# ANIMA

Aviation Noise Impact Management through Novel Approaches

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[1] Use one of the following codes: R=Document, report (excluding the periodic and final reports)
DEM=Demonstrator, pilot, prototype, plan designs
DEC=Websites, patents filing,press & media actions, videos, etc.
OTHER=Software, technical diagram, etc.

[2] Use one of the following codes: PU=Public, fully open, e.g. web
CO=Confidential, restricted under conditions set out in Model Grant Agreement
CI=Classified, information as referred to in Commission Decision 2001/844/EC.

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# 1 Executive Summary

This deliverable D2.4 is embedded in ANIMA work package WP2 – "Critical Review and Assessment of Noise Impact and Related Management Practices." It refers to subtask 2.2.2 and serves – in conjunction with deliverable D2.3 from subtask 2.2.1 – the **critical review of noise impact** (task 2.2).

This deliverable has three main topics. While deliverable D2.3 deals with aircraft noise-related health impacts in general, here **(1) annoyance as an outcome** is at the centre stage. Moreover, this deliverable **(2)** pursues a **holistic approach** to the emergence, maintenance and, especially, mitigation of aircraft noise annoyance. That is, **in addition to acoustic variables**, in particular **the range of non-acoustical contributors** is also examined, as well as the combined effects and interactions of acoustical and non-acoustical variables. Finally, based on the findings, **(3) implications and recommendations for noise management strategies** are derived and presented. The centrepieces to achieving these objectives are several systematic literature reviews.

The first systematic literature review addresses the question of how noise annoyance is defined in the relevant scientific literature. The results of this review are presented in Section 3 of this deliverable. It shows that in the vast majority of the studies providing a definition, a definition from a review and expert survey on the concept of noise annoyance (Guski et al., 1999) is cited and, in more recent publications, the updated version of that definition, given in the WHO review on environmental noise and annoyance (Guski et al., 2017). Accordingly, **environmental noise annoyance is understood as**:

"…a **retrospective judgment**, comprising past experiences with a noise source over a certain time period. The noise annoyance **response usually contains three elements:**

an **often repeated disturbance** due to noise (repeated disturbance of intended activities, e.g., communicating with other persons, listening to music or watching TV, reading, working, sleeping), and **often combined with behavioral responses in order to minimize disturbances**;

an **emotional/attitudinal response** (anger about the exposure and negative evaluation of the noise source); and

a **cognitive response** (e.g., the distressful insight that one cannot do much against this unwanted situation).

This multi-faceted response is seen by many researchers as a stress-reaction." (Guski et al., 2017, p. 2).

These topics are revisited in depth in Section 5, where a deeper understanding of the emergence and nature of noise annoyance is developed. Here it is worked out in more detail that – according to established theories and empirical findings – **annoyance can** indeed **be understood as a classical stress reaction** in terms of the standard and well-established "transactional model of stress and coping" (Lazarus & Folkman, 1984). Stress - likewise annoyance - is, therefore, **the result of an interaction between environmental and personal factors.** That is, the level of subjective stress or annoyance perception depends not only on the particular stressor or the specific level of exposure.

The relevance of the extent of exposure is illustrated in Section 6, in which both the different standardized acoustic metrics as well as the perceived noise level metrics are summarised. It becomes apparent that **there is a wide range of acoustic metrics, each of which is a summary of reality that inevitably involves some loss of information (no measure can fully map reality) and that is partially subject to certain more or less arbitrary weightings.** Also, there is a difference between the extent of objectively measurable sound and the extent of individually perceived - or interpreted - noise. Thus, the subjectivity of perception shows itself here, too.

This becomes all the more clearer if further contributors are taken into consideration. This takes place in Section 7, which deals with **non-acoustical factors**. For this purpose, another systematic review is carried out first. There are a number of studies on the influence of non-acoustical factors on the extent of aircraft noise annoyance. It turns out that **on the one hand, some non-changeable factors** play a role here **– like** the **age** of an affected person. Of particular importance to our deliverable are, **on the other hand**, however **those factors that are principally addressable within management strategy approaches and that at the same time also able to influence the extent of annoyance. These include, for example, trust, fairness, and attitudes towards the source of the noise.** In Section 7 it is pointed out that **these factors can best be addressed through measures of communication and engagement.**

**Noise management strategies** represent, as mentioned in the beginning, one of the focal points of this deliverable. In this regard, firstly the status quo is presented in Section 4. **State of the art is the "Balanced Approach to Noise Management" by the International Civil Aviation Organization** (**ICAO**, a United Nations specialized agency). These are **international guidelines for the reduction of noise problems around airports**, addressed to all aviation actors and binding on all signatory states. A revised version is published at several years intervals. The core of the "Balanced Approach" has always been **4 pillars**:

1. **Reduction of noise at source**

2. **Land-use planning and management policies**
3. **Noise abatement procedures**
4. **Operating restrictions**

It can be stated that most of the measures are **based on the assumption that a reduction of the exposure** to those affected **directly implies a reduction in negative effects**, such as adverse health outcomes and annoyance. **However, this is not consistent with the now widespread finding that, for example, annoyance does not necessarily decrease in proportion to exposure**. This, in turn, is in line with the realization that annoyance is not solely determined by mere acoustical factors, but also by various non-acoustical contributors. **In the latest version of the "Balanced Approach"** (ICAO, 2007), this is accounted for by the addition of **another pillar:**

5. **People issues**

This reflects a broader approach, **emphasizing**, in particular, **the importance of communication and engagement as well as information management.** This pillar can in a way be understood as **transversal to the other pillars**, as it can interact with each of the others and enhance the impact of the actions of every other pillar.

**This conclusion is also reached in the final Section 8, which summarizes the results of the previous explanations and derives recommendations for appropriate management measures and intervention options**. For this purpose, the literature and other sources were searched for already known, actual interventions. The result, based mainly on a systematic WHO review on the impact of transport noise interventions on health (Brown and van Kamp, 2017), shows that interventions utilizing communication and engagement measures are generally believed to have a relevant impact on the reduction of adverse health effects and the mitigation of annoyance. **However, it also becomes apparent that nearly all of the interventions actually carried out are exposure-related, that is, seeking to reduce the actual sound level by technical or other means. In the absence of actual communicative or educational interventions, there are no quantitative-empirical statements about their effectiveness possible**. The results of some qualitative studies, however, also presented in Section 8, suggest their effectiveness. The need for the implementation and evaluation of these types of interventions is all the greater as they also can add to the effectiveness of all other types (i.e., exposure-related) interventions. This – that is the implementation and evaluation of the effectiveness of a communication campaign to lower annoyance – is precisely what is part of the subtask 3.2.1 of WP3.

# 2 Introduction

In this report, we begin by providing an outline of the context of a review on aircraft noise annoyance, the acoustical and non-acoustical contributors, aircraft noise interventions and the implications for aircraft noise management. This is followed by a brief discussion of the approach taken, which includes the aim, guiding principles, and methods applied under them. It does so in a systematic, comprehensible, and – as far as possible – replicable way.

## 2.1 Context

This deliverable 'D2.4' is the result of subtask 2.2.2 of Work package (WP) 2 of the **ANIMA** project. As such, it has some connections to other sub/tasks and WPs. The aim in this context was to minimise overlaps between different reports, where possible, while at the same time ensuring that each report is entirely comprehensible by itself.

This report therefore is intended to complement and in parts build on D2.3, insomuch as, whilst both address the impacts of human response to aircraft noise, D2.3 focuses very much on short-term physiological responses and long-term health associations. D2.4 on the other hand, looks to a more psychological lens to discuss both acoustical and non-acoustical factors contributing to aircraft noise annoyance.

Suggestions for how this deliverable can be further utilised as an informative aid and contribution to future studies can be found in the final section.

## 2.2 Approach of the Report

The main aim of this work is to systematically derive scientifically well-founded and substantiated recommendations on practicable and actionable measures to reducing aircraft noise annoyance. With this in mind, the deliverable is guided by two core principles:

1. Firstly, a pathway is set, from the emergence of the need for industry actors to manage aircraft noise impacts, to the present day need for more novel approaches to do so. With this in mind, the deliverable provides an in-depth insight that allows for a deeper understanding of aircraft noise annoyance, encompassing a review of core literature around the causal factors and their implications in terms of health consequences from annoyance. Given that deliverable 2.3 gave more focus to acoustical factors, this deliverable, whilst acknowledging both, gives its focus to non-acoustical contributors, particularly in the context of working towards a novel approach to noise management.
2. Additionally, the deliverable sets to systematically develop and assess interventions of contributors or influences to aircraft noise annoyance. In doing so, theoretical and statistical models help us understand the impact

of these interventions and highlight the relevance of a more systematic approach if there is to be an effective response to annoyance.

Guided by these principles, we have taken a phased approach consisting of a literature review; a review of the implications for novel management strategies identified, and associated research gaps in preparation for WP3.

The literature review starts by scoping the definitions to aircraft noise annoyance (section 3) and providing an overview of Balanced Approach guidance of the International Civil Aviation Organization (ICAO) (section 4). To reach this definition comprehensively, we had to first look beyond the term as an umbrella concept and understand what is meant by the word 'noise', and moreover, the meaning of 'annoyance' in general. This is considered and discussed in Section 5.

Sections 6 and 7 then substantiate and follow a multi-dimensional approach, considering the combined effects and interactions of both acoustical (section 6) and non-acoustical contributors (section 7) to the formation and reduction of noise annoyance. Following this, section 8 shows how this multi-faceted approach to considering both acoustical and non-acoustical factors has yet to be taken into account in existing interventions and illustrate – based on our findings and conclusions – the needs of both further research and enhanced noise management. Finally, section 9 summarises and elaborates on implementing intervention measures of a noise management strategy process into communication campaigns.

It is important to note that some sections are more derivative and some more literature based. Sections, therefore that focus on efforts of the aviation industry to mitigate annoyance and the impacts of causal factors, are heavily founded in literature. The literature search process and list of core search engines can be found in Annex 1. Where however, the implications of suggested novel management strategies are considered, the deliverable takes the evidence presented and poses further questions about what the industry could do in light of a more systematic approach.

**Key messages**

- The key messages of the sections 3 to 7 are summarized in a box at the end of each chapter.

# 3 Definition of Noise Annoyance

In this Section, we specify the concept of noise annoyance. We discuss established theories and empirical findings that explain the physical and psychological processes leading to noise annoyance. Moreover, we broaden the view and illustrate the relations and interactions within the nomological network/within the context in which noise annoyance is located.

## 3.1 General Definitions

### 3.1.1 Noise

Noise is often defined as 'unwanted sound'. The Civil Aviation Authority (CAA, 2018) suggests that laws around noise make it clear that sound only becomes noise when it exists in the wrong place or at the wrong time. This indeed can cause annoyance, sleep disturbance or other effects. In the context of aviation, airports in more densely populated areas are therefore considered to have a greater noise impact, as a greater number of people are likely to be affected.

Noise is in general defined as a sound that is 'unpleasant' (Encyclopædia Britannica, 2010; Merriam-Webster, 2009; Oxford English Dictionary, 2012) and that is either 'intrinsically objectionable' (Encyclopædia Britannica) or 'causes disturbance' (Oxford English Dictionary) and 'interferes with other sounds that are being listened to' (Encyclopædia Britannica), respectively. Thus, noise is not the same as sound, which is a physical, quantifiable vibrating or oscillating variation of pressure that propagates in waves through air or another medium.

### 3.1.2 Annoyance

In everyday speech, annoyance is either understood solely as a feeling – accordingly, for example, Merriam-Webster (2009) defines it as a 'feeling of slight anger or irritation' – or as a 'feeling or state' of 'being irritated' or experiencing a 'nuisance or vexation' (Encyclopædia Britannica, 2010; Oxford English Dictionary, 2012).

A search in the relevant scientific psychological and medical databases suggests that in these disciplines annoyance is rarely studied by itself, but mainly in the context of *noise annoyance* (see Annex 1). This is further discussed in subsequent sections below.

## 3.2 Noise Annoyance

In order to capture and illustrate the various definitions of noise annoyance, a systematic literature review was carried out (see Annex 1), which shows that the largest proportion of scientific publications dealing with sound or noise annoyance is located in the area of traffic noise (29.7%; 585 out of 1973). This is closely followed by tinnitus (29.3%; 579 out of 1973) and then in the context of factories, open-plan offices, and other workplaces (10.2%; 201 out of 1973). In those publications dealing with noise annoyance from traffic noise, especially aviation as a source is represented in a large proportion. This could be due to several findings that aviation noise is perceived as more annoying than other road traffic noise, even at the same objective noise levels (see e.g. Miedema and Oudshoorn, 2001 or Guski et al., 2017).

Of the 289 publications dealing with aviation noise annoyance that have been compiled for this review according to the approach described in Section 3, more than half do not contain a definition of noise annoyance at all (179, 61.9%). Only 45 publications (15.6%) provide an explicit definition of noise annoyance.

In order to capture as complete a picture of the literature as possible, in categorizing the different types of definitions used in the publications, we also formed some categories that do not represent definitions in the strictest sense, but still convey to the readers at least an indirect sense of how noise annoyance is meant/understood. One example of these 'indirect definitions' is the category "Empirical definition through correlations," which covers publications explaining noise annoyance by naming correlated constructs. Other examples are the categories "Referring to the measurement item/scale" and "Definition by examples."

Taken together, among the 289 publications of our review there are 45 publications that contain at least one explicit definition of noise annoyance, as well as 65 publications with only one or more indirect definitions, and 179 publications without any definition of noise annoyance.

An overview of the different types of direct and indirect definitions and their frequency of occurrence in the 289 publications is given in Annex 1.

The most used type of a direct definition is citation, that is, the reference to an established definition. Among the citations, the definitions of Guski, Felscher-Suhr, and Schuemer (1999) and, although still rather novel, of Guski, Schreckenberg, and Schuemer (2017) are the most cited ones.

Guski et al (1999) have combined a review of existing definitions of noise annoyance with a comprehensive survey among international experts. As part of the review, various definitions are classified into the following categories:

- Noise annoyance as emotion
- Noise annoyance as a result of disturbance
- Noise annoyance as attitude
- Noise annoyance as knowledge
- Noise annoyance as a result of rational decisions

In addition to this review, international noise impact researchers were asked to conduct a survey on the definitions of noise annoyance. They used the method of similarity ratings in addition to a questionnaire survey. As a result, Guski et al

(1999) conclude that, "noise annoyance is a multi-faceted psychological concept, including , and evaluative aspects" (Guski et al., 1999: 513).

Finally, they develop/come to the following definition of noise annoyance: "Noise annoyance is a multifaceted concept, covering mainly (1) immediate behavioural noise effects aspects, like Disturbance and Interfering with intended activities, and (2) evaluative aspects like Nuisance, Unpleasantness, and Getting on one's nerves. (…) Noise annoyance is a psychological concept which describes a relation between an acoustic situation and a person who is forced by noise to do things he/she does not want to do, who cognitively and emotionally evaluates this situation and feels partly helpless." (Guski et al., 1999, p. 525)

In their WHO review on environmental noise and annoyance, Guski et al (2017:2) provide an updated and already often quoted definition of annoyance:

"Environmental noise annoyance as observed in surveys is a retrospective judgment, comprising past experiences with a noise source over a certain time period. The noise annoyance response usually contains three elements:

- An often-repeated disturbance due to noise (repeated disturbance of intended activities, e.g. communicating with other persons, listening to music or watching TV, reading, working, sleeping), and often combined with behavioural responses in order to minimise disturbances;
- An attitudinal response, for example, anger about the exposure and negative evaluation of the noise source; and
- A cognitive response e.g. the distressful insight that one cannot do much against this unwanted situation.

**Key messages of Section 3**

- Noise is unwanted sound and contains a conscious or unconscious evaluation of the sound source.

- Noise annoyance is a multifaceted concept, usually containing
    - often-repeated disturbances, often accompanied by behaviour aiming at a reduction of the disturbances,
    - an attitudinal response, and
    - a cognitive response.

# 4 Aircraft Noise Regulations and Management

There has been considerable effort to reduce the amount of noise per individual aircraft event quite significantly through advanced technologies and more stringent regulatory standards (National Research Council, 2002). Traded off by the increasing number of aircraft events at large airports in Europe [although this does not necessarily hold true for new airports] growing steadily, but not dramatically, there has been a marginal decrease in noise exposure on the ground overall as described by $L_{eq}$-type metrics (Horonjeff and Robert, 1997; Guski, 2005; Gelderblom et al., 2017). This has however, not been followed by corresponding reduction in annoyance, with public opinion becoming more, rather than less, of an obstruction to growth of the industry despite fewer people now exposed to high levels of aircraft noise compared to 50 years ago (National Research Council, 2002).

Several other studies have also focused on the disjunct between reduction in exposure and increase in annoyance; the exposure-response curve by Miedema and Oudshoorn (2001) for example, was recommended by the European Commission in 2002 as the standard and is based on data from 1965 to 1993. More recent data comparisons on annoyance obtained since 2000 (Babisch et al., 2009; Janssen et al., 2011; van Kempen and van Kamp, 2005), echo similar findings, which suggest an increase in the percentage of highly annoyed (%HA) residents with respect to a given exposure level. Variables for %HA have been considered however, and are found to significantly impact responses when considering location of an airport, both geographically and in relation to its surrounding community (Job, 1988; van Kempen and van Kamp, 2005; Janssen et al., 2011).

## 4.1 Guidance on the Balanced Approach to Noise Management

ICAO's Balanced Approach document is today a staple guidance for the introduction of noise management measures within the aviation industry, with increasing attention being given to community noise annoyance at each annual meeting of the its Assembly. The guide examines several practical tools for modelling noise around airports and sets out to offer a suite of priorities and guidance measures with its core goal of supporting all aviation actors to systematically respond to the management of noise (ICAO, 2004); this is achieved through four core approaches for managing noise: reducing noise at the source, land use planning, noise-reducing operational procedures, and operating restrictions. In order to utilise these guiding principles, there is a need to first understand each one and the sequential nature in which their implementation is intended.

### 4.1.1 Mitigation measures – the four pillars of the Balanced Approach

#### *4.1.1.1 Reduction of noise at source*

Efforts by the industry have focused on reducing noise exposure with the aim of reducing impact. Mandatory noise policies and "hardening of certification procedures" are all documented within Appendix 16 of ICAO's Chicago Convention, the Environmental Protection document; one of 19 technical annexes within the International Standards and Recommended Practices [SARPs] (Leylekian et al., 2014).

The updates and additions to this appendix are added as new chapters. Since the first Noise Standard of 1972, there have been numerous updates and amendments, the most recent to come in to force being Chapter 14, set at CAEP/10 in February 2013 (Roetger and Adam, 2016). Focusing on reducing noise exposure means that the primary focus has been on the physical reduction of sound generation through engine and airframe technology and mechanical adaptations to aircraft, and upgrades and modernisation to next generation aircraft fleet. The most recent certification standard applies to aircraft that had prototype approval after January 2006, and is being enforced in two stages: to high-weight aircraft in 2017 and to low-weight aircraft in 2020. The new standards aim to reduce Effective Perceived Noise Level (see -> EPNdB and $L_{EPN}$ in the glossary for a definition) by 7dB compared to that of existing Chapter 4 standards. The result of the reduction in sound generation is that the area of land in active noise zones should decrease by 2% by 2026, and by 4% by 2036 compared to that of 2000. This means that up to one million people will be moved out of active noise zones by 2036 (Roetger and Adam, 2016). The latest ICAO Noise Standards serve as a clear indication of how proactive the aviation industry has become in reducing noise exposure (ACI, 2013).

As well as these upgrades and adaptations being a function of technological advancements in general, increasing societal pressures on policy-makers meant additional legislation and enforcement of tighter regulations and recommendations at various levels and on a frequent basis (Leylekian et al., 2014), suggesting that although a response is indeed apparent, the pressure for further improvements remained. These policies and technologies are discussed in further detail in below.

##### 4.1.1.1.1 Engine technology

Essentially there are two core trajectories of technological improvement, engine and airframe. The aviation industry has previously focused on engine technology as the main source of aircraft noise. Aircraft are today 20-30dB quieter than the first generation of jet engine aircraft of the 1970s due to the turbo fan engine and the application of high bypass ducts and serrated nozzles (Clean Sky, 2018). This has seen a shift in focus from engine to airframe over the last 15 years with regard to noise output, particularly during landing when engines tend to operate at low power and high-lift devices and landing gear are deployed (Jaxa Aeronautics Magazine, 2013).

##### 4.1.1.1.2 Airframe technology

Contrarily to engine noise, the airframe remained poorly addressed in the past decades both because it was marginal compared to the engine noise and because it is quite difficult to treat: airframe noise appears mostly downstream of the aircraft and is generated by various protruding parts such as landing gears or high-lift devices. Recent efforts tend to reduce these various noise source either through smarter shape design or by active and passive noise reduction devices.

###### 4.1.1.1.3 Continued technological innovation

The roll-out of new fleet designs such as NEO [New Engine Option] and A350-XWB coincide well with the newly sanctioned SARPs, especially given the long life-cycle of the aviation industry's core technologies i.e. the aircraft, and shows that aircraft manufacturers are prioritising noise concerns in their designs more prevalently than has previously been seen (Roetger and Adam, 2016; ACI, 2013). In fact, it has been suggested that the manufacturing industry saw the new regulation enforcements as an opportunity for technological innovation. As a result, new aircraft types are being built to anticipate future stringencies (International Air Transport Association, IATA, 2016). A geared turbofan for example, will replace current designs to power the A320 NEO, allowing each part of the engine turbo machinery to rotate at individual optimal speed, reducing both noise and fuel burn. Whilst the A350-XWB, is said to be up to 16dB below the required standard of 2006's Chapter 4 due to such design modifications. Airbus also highlights the Automatic Noise Abatement Departure Procedure (NADP) as an example of the functionalities available on new aircraft (ACI, 2013). Equally, IATA's Assistant Director in Aviation Environmental Technology, Thomas Roetger, notes recently developed 'tweaks' to the nacelles of Boeing's 787 and 747-8 to optimise the way that engine airflow is mixed with ambient air to effectively reduce noise (Rivers, 2014).

###### 4.1.1.1.4 The role of engine and airframe technology within the Balanced Approach Goals

Aircraft noise certification as documented in the ICAO Appendix 16, discussed above, is based on an individual aircraft's performance with both the engine and airframe taken in to account. In line with the progressively stringent chapters of Appendix 16, ICAO recorded a reduction in aircraft noise of 75 per cent in the context of the ICAO Council's adoption of "Chapter 14", measuring noise reduction recommendations in EPNdB [Effective Perceived Noise decibel levels] (ICAO 2013a, ICAO 2013b; see Figure 1).

In the same year (2001) that the ICAO Balanced Approach was published as a means of disseminating sequential steps of SARPs [standards and recommended practices], ACARE (Advisory Council for Aeronautics Research in Europe) published somewhat more definitive, 'technical' wording: "to achieve between 2000 and 2020 a 10dB reduction in the noise perceived by the community per plane and per operation" (Leylekian et al., 2014:2). With 75 per cent of global fleet (currently in service and on order) due for replacement before 2050, the Clean Sky 2 program is aiming to see these replaced by the novel technologies currently being developed. If achieved, it is predicted that this could result in a further 65 per cent reduction in perceived noise by 2050 compared to performance in 2000 (Clean Sky, 2018). Figure 2 outlines the target path in both decibel level and means of reaching each stage of target using Noise Reduction

Technologies outlined in FlightPath2050 (Sustainable Aviation, 2011; Clean Sky, 2018).

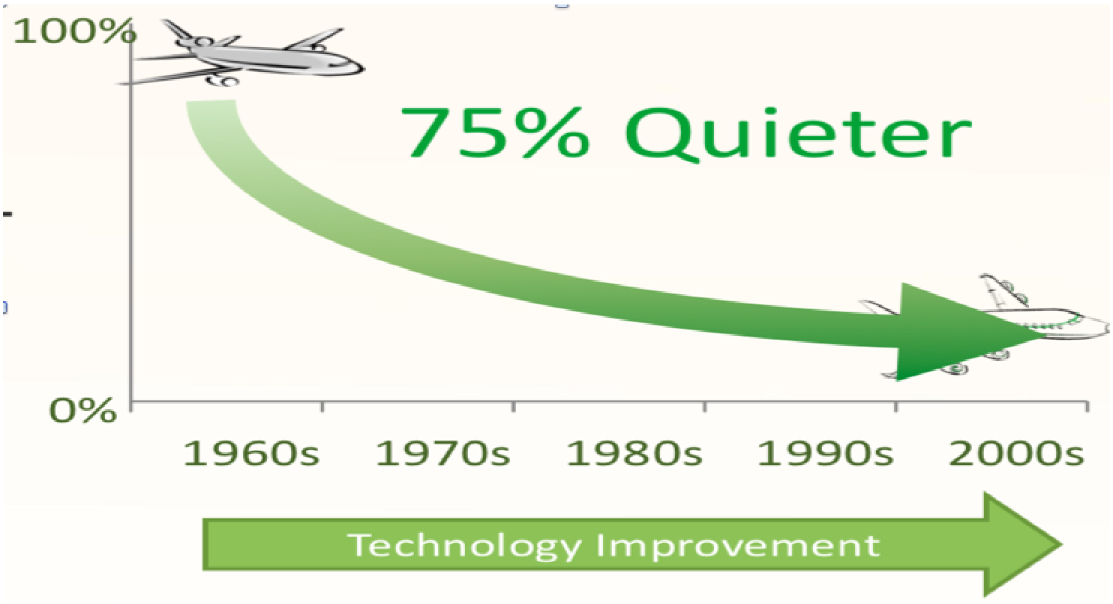


Figure 1: ‘Aircraft Noise Reduction Due to Technological Improvements’, ICAO, 2013a

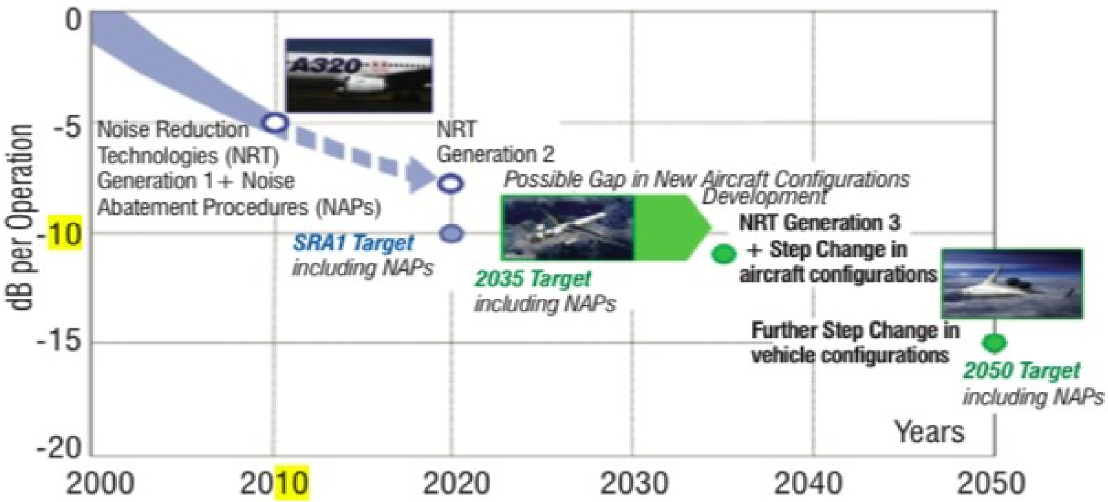


Figure 2: Pathway to FlightPath2050 Targets through Noise Reduction Technologies, Clean Sky, 2018

#### *4.1.1.2 Land-use planning and management policies*

Along side continued technological advancements, land use planning (LUP) has been a long-term strategy in attempts to reduce noise exposure on the ground.

ICAO set out their guidance on land-use planning and management in Annex 16, Volume I, Part IV and in the Airport Planning Manual, Part 2 — Land Use and Environmental Control (ICAO, 2014). This recognises that not only can aircraft exposure be reduced through technological improvements, but also that there was also scope to manage consequences of the noise on the ground. By managing noise exposure as well as its generation, the notion of LUP sets out means by which to ensure that activities around airports are harmonious with aviation activity with the main goal of minimising population affected by aircraft noise with the use of land-use zoning in airport-surrounding areas (Dickson, 2015). The ICAO guidance document outlines minimisation tools; control or prevention measures of the impact of aircraft noise and describes some practices already adopted by some states.

It should be recognised that land-use planning is considered a long-term strategy and should not be based on short-term or current contour maps. Thus, there is a continued need to take future levels of aircraft activity at an airport into account during any new land-use planning.

A summary of core land-use principles is outlined below in Table 1.

Table 1: Core Principles of Land-Use Planning (adapted from CANSO, 2015:17)

| **Core Principles of Land-Use Planning** |
|---|
| Noise sensitive areas such as residences, hospitals and schools, are avoided as much as possible by current and future aircraft operation |
| Local or municipal governments are usually responsible for land zoning |
| In high noise areas new activities incompatible with aircraft noise should not be permitted (or planned to be removed from those areas) |
| Air Navigation Service Providers [ANSPs] need to take land use considerations into account when contemplating the implementation of new airspace procedures. Sometimes a small change in a procedure design can avoid a locally sensitive area. The airport authority or ANSPs that fulfill both roles can help by ensuring awareness of local issues and the relative priority of each |
| Local developers will often resist proposals to limit residential development even in areas affected by noise |
| Airports and other aviation stakeholders, especially airlines and ANSPs, must work with local governments; requesting and recommending appropriate LUP rules to protect airport operations |
| Some national governments recognise the impact on airports of the encroachment of residential areas and have created national policy to restrict residential growth near airports |
| For some high noise areas, existing homes and schools may be retrofitted with improved sound insulation and alternative ventilation. In some cases, an airport operator may even purchase homes in very high noise areas |

#### *4.1.1.3 Noise abatement procedures*

Noise abatement procedures are specifically designed to avoid or reduce noise over populated areas through the operation of aircraft as summarised in Table 2 below.

Table 2: Noise Abatement Procedures (adapted from CANSO, 2015: 18)

| **Noise abatement procedures** |
|---|
| Noise preferred routes (NPR), preferential flight track or runway use |
| Concentrating flights over unpopulated areas or areas less sensitive to noise |
| Dispersion of flights over populated areas or noise sharing (flying over certain areas on some days and moving the flights to other areas on other days) |
| Noise abatement take-off procedures such as the management of engine power during departures [managing thrust] |
| Approach procedures such as continuous descent operations (CDO) and low power, low drag techniques |
| Moving the nominal takeoff (sic) or landing points on the runway |
| Restrictions on engine run-ups and/or ground equipment |

Noise abatement procedures [NAP] are not a one-size-fits-all problem solver however (CANSO, 2015). The appropriateness and effectiveness of any selected mitigation measure is dependent upon the physical and geographical location of the airport and its surroundings (Girvin, 2009). Moreover, in serving as one solution, such procedures pose operational problems in other areas. Noise abatement procedures will differ from aircraft to aircraft simply as a function of weight and size; the use/reduction of thrust will fluctuate meaning that the approach/departure for each will vary, for example. For the sake of safety, Air Traffic Control needs to maintain a strict minimal distance between aircraft, suggesting that the inevitable variation in aircraft speed due to thrust fluctuation dictates that ATC regulations will need to account for maximum distance scenarios, which consequently reduces operational capacity per airport in use of NAP (Clarke, 2003).

It must be highlighted that in designing such regulations, it is not only noise that requires consideration. Despite the notion of trade-offs being outside of the remit of this section’s focus, it must be recognised that as a procedure to address one issue is designed, there may indeed be consequences for another issue. In the context of environmental noise, a ‘trade-off’ with other environmental issues such as $CO_2$ emissions and other operating priorities i.e. safety or cost, may be created (Airports Commission, 2015).

#### *4.1.1.4 Operating restrictions on aircraft*

Where noise abatement and other mitigating operational procedures have not provided sufficient impact relief on community response to noise exposure, varying restrictions have been imposed; restrictions are usually based on the noise performance of the aircraft and are specific to the noise problem at an individual airport in line with the scheme ratified by the 38th ICAO Assembly meeting (ICAO, 2004).

The chapterisation of aircraft has ensured that a phase-out process of older and therefore noisier aircraft is introduced in such manner that makes use of the life of the aircraft but equally encourages engine and airframe technological improvement with each fleet renewal (Girvin, 2009). Other shorter-term restriction impositions however, are listed below in Table 3.

Table 3: Adapted from ICAO, 2004; Girvin, 2009

| **Short Term Noise Restrictions on Aircraft Operations** | |
|---|---|
| Curfews | Operational noise limits i.e. nighttime restrictions |
| Noise quotas/budgets/charges | Cap rules and non-additional rules |
| Preferential runways | Restrictions related to the use of ground infrastructure |

As noted above, noise problems are specific to individual airports (CANSO, 2015). As such, Europe’s larger airports tend to impose tailored “more mandatory restrictions and take more diverse approaches to noise mitigation because of varying degrees of local and national pressure” (Girvin, 2009:15). An outline of how restrictions vary in stringency and imposition is detailed below in Table 4.

A system similar to that of today’s quota count was predicated purely on the number of aircraft movements, however since the increased stringency of noise certification, evolution of engine and airframe technology has delivered increasingly quieter aircraft over time; this has meant that a classification system can now be used to assign values to aircraft based on take-off/landing and, more specifically, an individual aircraft’s noise certification to much more effect than the previous system. The varying value bands differ by 3dB steps with each value band depicting a quota (ICAO, 2014).

It should be however noted that operational restrictions is considered as a last-resort solution by the ICAO and by the industry when it is often deemed as a priority by airports’ surrounding communities.

Table 4: Operating Restrictions and their Conditions (adapted from ICAO, 2004)

| **Category of Restrictions** | **Conditions of Restriction** | | |
|---|---|---|---|
| Global | Apply to all traffic at an airport based on total fleet noise performance | | |
| Aircraft-specific | Apply to a specific aircraft or a group of aircraft based on individual noise performance | | |
| Partial | Apply for an identified time period during the day, on a specific days of the week, or only for certain runways at the airport | | |
| Progressive | Provide for a gradual decrease in the maximum level of traffic or noise energy used to define a limit over a period of time. This period is typically defined as a number of years before reaching a final level | | |
| **Ways In Which Restrictions Can Be Implemented** | | | |
| **Number of Move-ments:** | Per period of the day and/or year for the airport or per runway direction i.e. a maximum annual number of movements at the airport | **Quota Counts:** | Expressed as a combination of movements and aircraft acoustic characteristics or a fixed contour. Consequences of quotas may be a restriction on available slots or the closure of certain runway direction during a certain period |

The use of these sorts of restrictions, principally at night, is particular apparent within the UK as the result of power in the local authorities to impose planning related conditions (Antoine and Kroo, 2004); the UK offers a particularly robust example of this with London Heathrow, Gatwick and Stansted airports implementing night time operational restrictions through a quota count system (CAA, 2003; Antoine and Kroo, 2004; Roetger, 2014).

A set number of quota counts are allocated to each airport per year where airlines must submit requests for slots in line with the airport's allowance. Such a system dictates that the number of aircraft versus the noise level of aircraft is weighted, encouraging the use of quieter aircraft in order to maximise the amount of aircraft use within the given quota: "This system does not only reduce noise pollution during night-time hours but also drives home the operational benefits of the latest, quietest aircraft types to global operators" (Roetger, 2014).

The equipment and scheduling constraints from the pressure created by airports imposing such restrictions, results in a knock-on effect as airlines continually compel manufacturers to improve the performance of their aircraft. This encourages manufacturers to recognise the significance of such restrictions and adopt the 'London system' as a benchmark for the noise levels of their aircraft in efforts to continually improve noise performance (CAA, 2014). The report of the 7th Committee on Aviation Environmental Protection [CAEP] meeting summarises the relationship between all actors within the industry and how each one impacts the next for continual improvements: "The prime purpose of noise certification is to ensure that the latest available noise reduction technology is incorporated into aircraft design demonstrated by procedures which are relevant to day to day operations, to ensure that noise reduction offered by technology is reflected in reductions around airports." (ICAO/CAEP, 2007).

## 4.2 Recognising the need for an additional approach

The Balanced Approach can be viewed as a significant means by which to mitigate physical noise presence, restrict future habitable areas within maximum noise exposure areas and control physical exposure times and levels through operational means. The associated noise goal is to reduce perceived noise emissions of flying aircraft by 65%, which translates to a 15dB EPNL reduction in noise by 2050 relative to year 2000 technology; the equivalent of a 0.3dB improvement per aircraft operation per year (Sustainable Aviation, 2011). It is thought that through the continual implementation of a range of improvements in aircraft and airspace operational techniques, this is achievable. Despite this, however, measures to reduce the amount of noise per event have centred on the notion that if noise exposure on the ground is reduced, the cumulative $L_{eq}$'s are therefore lowering, thus, the problem is getting 'better'. In reality, this approach may actually increase annoyance as exposed communities are 'surprised' by changes and an overall average (i.e. $L_{eq}$) may disguise underlying changes inherent in the pattern of intended improvements, in other words, there may well be both winners and losers within an anticipated general improvement.

In line with the Miedema and Oushoorn (2001) curve and further associated exposure-response data comparisons, other variables impacting annoyance have also been considered, with Gelderblom et al (2017) for example, advocating that the nature of change in operational patterns has significant impact on a community's recognition of and therefore response to aircraft noise (Guski, 2017). In addition, Gelderblom et al (2017) introduce the notion that 'high rate change' (HRC) returns a higher annoyance percentage than 'low rate change' (LRC) airports, which see only gradual, or even no, change in operations over a similar time period (Bartels et al., 2018).

In their review, Bartels et al (2018) however, advise that this variance in annoyance cannot be sufficiently explained by noise exposure changes alone, and echo the industry wide acknowledgement (Fields, 1993; Guski, 1999; Lercher, 1996; Miedema and Vos, 1999; Stallen, 1999; Wirth et al., 2004; Kroesen et al., 2008; Schreckenberg et al., 2010) of the need to understand non-acoustical factors and their role within response to aircraft noise. Throughout the main literature these tend to be grouped as:

- Situational factors (e.g., the time of day when the noise occurs)
- Personal factors (e.g., individual attitudes or traits)
- Social factors (e.g., attitudes towards the noise sources which are shared by the community)

Fields (1993) and Miedema and Vos (1999) also consider:
- *Attitudes* and *expectations*
- A person's sensitivity to noise
- *Demographics* (e.g., age, gender, occupational status, educational level, homeownership, use of the noise source, length of residence, etc.)

The role of non-acoustical factors is outlined and discussed in detail in Section 7 of this deliverable.

The belief that multiple variables are contributing to the disjunct between reduction of aircraft noise exposure on the ground and increasing annoyance is one of the reasons that has motivated a consideration of a wider approach to noise management that places more emphasis on communication and engagement, recognising that these may be vehicles by which managing the impact of aircraft noise (namely, annoyance) can be better achieved.

Indeed, in 2007, ICAO recognised more needed to be done, and began to identify other interventions that might be useful, such as communication and engagement linked to a more proactive management of the response to noise exposure rather than simply the exposure itself.

The 2007 revisions to the Balanced Approach include the principal element of 'people issues' focusing on 'information dissemination' and 'information exchange'. This was seen as a significant step forward in addressing the need for interaction with stakeholders if attitudes towards airports and thus levels of tolerance were to be influenced. The rationale is that by better understanding how an individual becomes annoyed by aircraft noise, the improvements can be focused on how the industry responds and communicates. Sustainable Aviation (2011) believes that in turn this will reduce annoyance surrounding aircraft noise (and its 'source'). Further, it has been recognised that an effective engagement process cannot be designed to a 'one size fits all' approach and the CAA demonstrates recognition of this in the development of tailored mandates for each regulated airport within "a common set of principles…" in line with ICAO's Balanced Approach standards and recommended practices [SARPs] "…but with detailed arrangements according to the prevailing circumstances" (CAA, 2012:4).

In order to understand the issues that need to be considered to inform such tailoring requires a more detailed appreciation of the nature of noise annoyance (See Section 5) and the acoustic (Section 6) and non-acoustical contributions (Section 7).

## 4.3 Limitations to aircraft noise management

### 4.3.1 Limitations of relying solely on engine and airframe technology

Aircraft engine and airframe manufacturers continue to improve technology to lower aircraft noise and airlines continue to modernise fleets in line with long ranging targets for novel Noise Reduction Technologies to be rolled out in time for a 2050 target (Sustainable Aviation, 2011). Both however, can take several years to have significant impact on noise reduction on the ground (aircraft), particularly when taking in to consideration the upward trajectory of flight numbers; air traffic movements said to be doubling in the next 50 years (Sustainable Aviation, 2011).

It is for this reason that ICAO, and much of the industry has also recognised the need to tackle the noise problem through other means. Indeed, additional opportunities exist for further reducing noise impacts on the ground through better operational procedures and controls of land development around airports, for example (Sustainable Aviation, 2011).

Whilst technological strides have been made as a result of such standards and recommended practices [SARPs], to the tune of a 75% reduction in aircraft output sound level compared to 50 years ago (Rivers, 2014; Dickson, 2015), and noise standards adhered to, noise annoyance has not followed a similar pattern of improvement, and has actually increased at some locations that have 'benefited' from reduced noise exposure on the ground over the same period (as measured by $L_{eq}$) (Dickson, 2015).

### 4.3.2 Limitations to the four pillars of the Balanced Approach

When viewing each mitigation measure in summary, as outlined above, it is clear to see how each measure builds on the last to maximise effectiveness of reducing noise exposure on the ground. This is of particular importance to note, as the four Balanced Approach measures are not intended to be treated as equal, rather they represent a hierarchy of phases to reduce sound exposure on the ground and its consequences (ICAO, 2004).

These are positive steps in mitigation measures, however there are limitations to them. **For example, none of the steps are considered to require any input from community members; all are predicated on the fact that if less noise exposure is felt on the ground, it is improving the problem. This does not however capture what is impacting human perception of noise, and therefore response to it**.

## 4.4 Conclusion

There is evidence that today people are more sensitive towards aircraft noise as represented by long term average noise metrics, than they were decades ago (Guski, 2004). Despite the reduction in noise exposure (measured as a long term averaged aggregate e.g $L_{den}$, $LA_{eq}$,), expressed disturbance and annoyance has continued to increase over the 50-year period of technological enhancements, suggesting that measures designed to simply reduce long-term average noise exposure may not result in the desired outcome of reduced impact (Dickson, 2015).

This highlights a dichotomy between efforts being made to reduce the aircraft noise exposure, and the tolerance of local communities towards it, suggesting that negative human response to aircraft noise stems from perception and interpretation as well as the physical exposure. Indeed, such a claim cannot be made without an explorative look in to non-acoustical factors and their role in influencing human attitudes towards, and the perception and interpretation of, the source of noise.

Throughout this Section it has been made clear that communication and engagement should now be the focus at the heart of aircraft noise management. In order to gain a holistic understanding and outline what the target of that communication and engagement should be however, there is a need to first examine the annoyance response itself and the tenets of which we need to manage.

**Key messages of Section 4**

- When aviation noise exposure is reduced, aviation noise annoyance does not decrease to the extent that would be expected due to the well-known exposure-response curves.
- Thus, for aviation noise annoyance more than just exposure-related factors are relevant and influential – the so-called non-acoustic factors or contributors (see Section 7).
- This shows: To reduce aviation noise annoyance to a minimum, approaches that rely on a reduction of noise exposure alone are cannot be sufficient.
- The current state of the art regarding noise management strategies are the international guidelines called the “Balanced Approach to Noise Management” by the International Civil Aviation Organization (ICAO). They address all aviation actors, are binding on all signatory states, and are revised every few years.

**Key messages of Section 4 (continued)**

- Acknowledging the abovementioned findings, the centrepiece of the the "Balanced Approach" – the 4 pillars – was extended as part of the 2007 revision by a $5^{th}$ pillar as follows:
    1. Pillar: Reduction of noise at source
    2. Pillar: Land-use planning and management policies
    3. Pillar: Noise abatement procedures
    4. Pillar: Operating restrictions
    5. Pillar (added 2007): People issues

- The 5th pillar can enhance the impact of each of the other pillars.

- Altogether, a broader approach, focusing on communication and engagement, is of central importance for future noise management strategies (see next sections).

# 5 Understanding Annoyance

In this section, we specify the concept of noise annoyance. We discuss established theories and empirical findings that explain the physical and psychological processes leading to noise annoyance. Moreover, we broaden the view and illustrate the relations and interactions within the context of noise annoyance.

## 5.1 Theoretical models and explanations of causes

As shown in the previous subsection, noise annoyance is commonly understood as a complex, multifaceted response to noise (Guski et al., 2017) comprising:

a) Behavioural;
b) Attitudinal-affective-emotional; and
c) Cognitive elements.

In addition, many studies of noise annoyance are based on, or at least echo the transactional model of stress and coping, developed by Lazarus (Lazarus and Folkman, 1984). Such studies have identified certain precursors as well as implications and consequences, of noise annoyance models, all of which are integrated into a coherent model, which reflects both theoretical explanations and empirical findings of the Lazarus model.

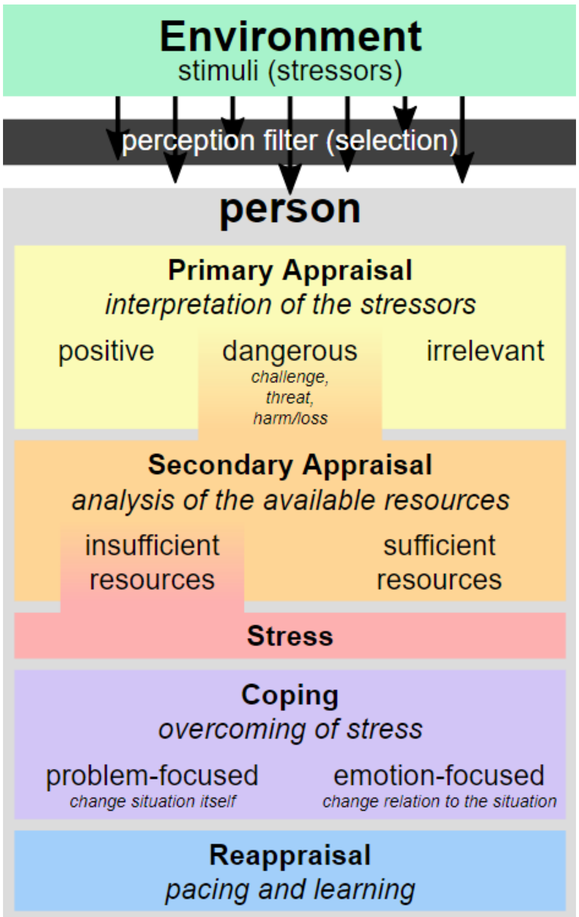


Figure 3: Transactional model of stress and coping according to Lazarus and Folkman, 1984 (Guttmann, 2016)

In the transactional model (Lazarus & Folkman, 1984) ***stress* is explained as the result of an interaction between environmental and personal factors. Special importance is attached to the subjective evaluation of both the stressor and a person‵s individual resources.** Lazarus describes stressors as, "demands made by the internal or external environment that upset balance, thus affecting physical and psychological well-being and action to restore balance" (Lazarus & Folkman, 1984).

When a person is exposed to a stressor, initially - consciously or unconsciously - an interpretation of the stressor takes place (*primary appraisal*). The model suggests that if this is judged as positive or irrelevant, no stress will occur. However, if the stressor is classified as dangerous, it is potentially stress inducing. It can then be:

A: a challenge, if the situation seems manageable,
B: a threat, if there is potential future harm or
C: harm/loss, when harm has already occurred

In all of these potentially stress-inducing situations, according to the model, there will be another - again conscious or unconscious - assessment of whether the situation can be overcome with available resources (*secondary appraisal*), that is, an assessment about the person’s controllability of the stressor. These evaluation processes do not necessarily have to happen consecutively; they can also take place simultaneously and interact with each other. The resources can be within the person (e.g. physical or mental) as well as externally available options (e.g. social or material).

**If the available resources are rated as insufficient for the given stressor, a stress response is triggered. Stress, in turn, provokes coping processes to reduce stress.**
**Depending on the person's feeling about controllability, these mechanisms can either address the *problem* or the *emotions*:**

- In the case of perceived control there will be problem-focused coping, aimed at reducing/changing the problem or the stressor itself, including strategies like generating alternative solutions or learning new skills to deal with the stressor.
- In the case of little or no perceived control there will be emotion-focused coping, aimed at reducing negative emotions, including strategies like avoiding, acceptance, selective attention, venting anger, and substance abuse.

After the coping attempts, a reappraisal of the stressor and the resources takes place. For example, after a reappraisal, a former threat might be rated as a non-stress-inducing challenge. After the reappraisal, if necessary, further efforts to cope take place.

Therefore, according to this model, decisive for the development of stress are the cognitive assessment processes and, in particular, the assessment of available resources. Stress, then, is the result of a complex interaction process between a person and the environment, with a perceived imbalance between the perceived threatening or dangerous requirement of the environment and the perceived resources.

### 5.1.1 Noise annoyance as a psychological stress response

As stated above, many models of noise annoyance are based on Lazarus' transactional model of stress and coping.

As one of the first, Stallen (1999) specified a corresponding specific noise annoyance model. Many of the models proposed later are essentially extensions or slight modifications from Stallen's model.

As an example, Figure 4 shows the central part of the model by Schreckenberg (2010; for the complete model, which also contains sleep, health, and environmental quality of life-factors, see ibid), which is the most recent model.

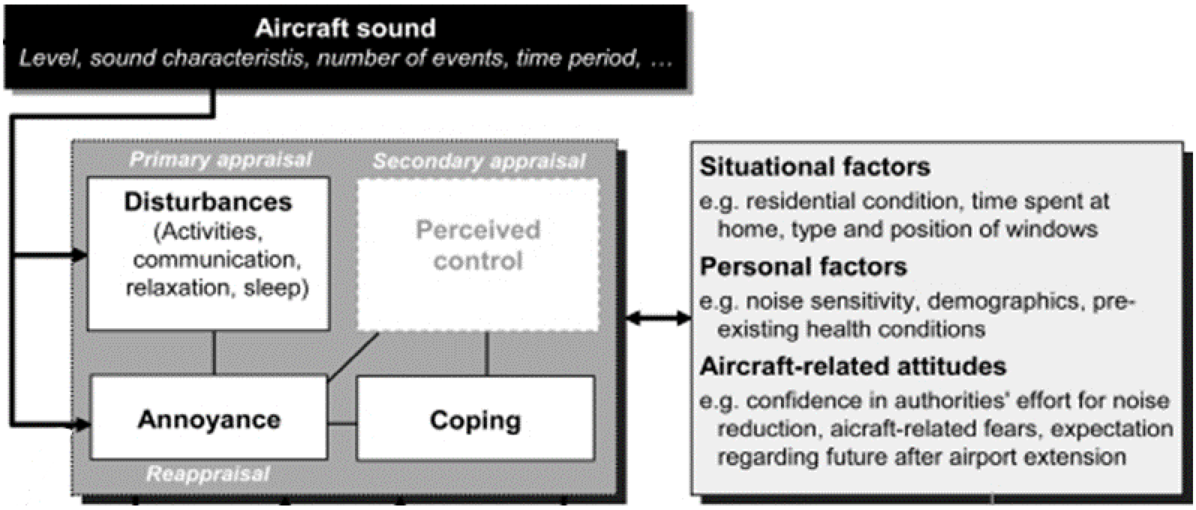


Figure 4: Model of noise annoyance according to Schreckenberg, 2010

In this model - just as in the other models to noise annoyance - the environmental *stressor* a person has to deal with is, of course, sound. The stress *response* is annoyance. It results, analogous to the model of Lazarus, from an interaction of the appraisal of the threat of the stressor (*primary appraisal*) and the appraisal of the resources to face or cope with the threat (*secondary appraisal*).

Stallen (1999) points out that in the context of noise annoyance primary appraisal can be understood as *perceived disturbance* and secondary appraisal as the extent of the *perceived control* of the sound or noise situation.

Perceived control plays a central role in the emergence of noise annoyance. It may have mental, that is cognitive and affective, components (e.g. the predictability of future sound exposure), as well as behavioural components (e.g. the ability to alter exposure).

The meaning and significance of perceived control applies equally to all models of noise annoyance found in our literature search, and has moreover also been underpinned by many empirical findings.

**Stallen (1999:77) emphasises that the various components of perceived control can never be completely subjective: "To a large extent *perceived control* is rooted in how noise is managed in practice by the source". Thus, he identifies the management of sound levels (in addition to the *actual* sound level) as an important determinant of noise annoyance.**

*Coping* has a dual meaning and function in the noise annoyance models based on Lazarus. On the one hand, it is to be understood as a ***strategy*** to deal with experienced stress. In this sense, coping can - analogous to Lazarus' original model - be both problem-focused (e.g. acquiring sound insulation measures to minimize the impact of the stressor on the person) and emotion-focused (e.g. mindfulness exercises to reduce perceived stress). On the other hand, the ***state*** of the successfully achieved overcoming of stress is called *coping*, too.

Coping is seen as a process of reappraisal of the person-environment situation, that is, in Stallen's words "a matter of mental (cognitive and/or emotional) change including the formation of new behavioural intentions and (…) the undertaking of correspondent actions" (Stallen, 1999:76). At this point, "non-noise related characteristics of the person or environment" become particularly relevant. These are presented and discussed in Section 7 on Non-acoustical factors below.

## 5.2 Noise annoyance and health

From a health perspective, noise annoyance can best be seen as a specifically noise-induced health outcome that is used to estimate the adverse impact of noise on human health, e.g. in the Environmental Noise Guidelines for the European Region (WHO, 2018).

To examine further consequences of environmental noise on population and update the existing guidelines, the WHO commissioned several reviews concerning the impact of noise from traffic sources aircraft, railway and road on different health outcomes including annoyance, cardiovascular symptoms, sleep, cognition, child development and mental health. **Based on these, further reviews were carried out in subtask 2.2.1 of the ANIMA project to include new findings after 2014 to the recently published evidence.**

Evidence for the impact of aircraft noise on general health (and as such physical health), mental health, and sleep, are more extensively discussed in D.2.3. Findings indicate that aircraft noise exposure increases the risk for cardiovascular diseases (D.2.3, Section 3.1), further it seems that aircraft noise negatively affects physiological and self-reported sleep indicators (D.2.3, Section 3.2). For mental health, findings are inconsistent suggesting aircraft noise to have only a marginal negative impact on quality of life and depression, but not on self-reported psychological symptoms (D.2.3, Section 3.5).

The appearance of annoyance with its emotional, cognitive and behavioural characteristics might contribute to further health effects. The WHO states that noise annoyance in general leads to anger, disappointment, dissatisfaction, withdrawal, helplessness, depression, anxiety, distraction, agitation/exhaustion, and sleep disturbance (WHO, 1999). Following the noise reaction schema by Babisch (2002) annoyance contributes to physiological stress reactions that might lead to more severe consequences. Also a reversed mechanism is possible and can be simultaneously discussed, i.e. that an impaired health condition affects vulnerability and could lead to stronger noise annoyance reactions.

In D.2.3 an additional review was performed to investigate the association between health outcomes and noise annoyance due to aircraft noise (see D.2.3 Section 3.8 for more details). It shows annoyance to be also directly associated with health outcomes. Moreover, for some health outcomes no direct association between the noise metric and the outcome was found, however associations between annoyance and health outcomes were.

Overall, only very few studies examine the link between health outcomes and aircraft noise annoyance. Annoyance thus is shown to be associated with physical health, i.e. cardiovascular symptoms. Several studies find a positive association between noise annoyance due to air traffic and cardiovascular functioning, particularly for atrial fibrillation (Hahad et al., 2018) and hypertension (Babisch et al., 2013; Eriksson et al., 2010), with the latter reporting higher relative risks for hypertension in subjects reporting annoyance in comparison to those not being annoyed. Regarding sleep, only two of the newer studies were found to examine the relationship between aircraft noise annoyance and sleep, confirming the well-known association of that self-reported sleep disturbances and sleep quality seemed to be associated with aircraft noise annoyance (Bartels, 2014; van den Berg et al., 2014). While most studies that examine mental health outcomes and noise metrics do not show associations, noise annoyance and mental health outcomes seem to be associated for mental health quality of life, psychological distress and manifest disorders (Baudin et al., 2018; Beutel et al., 2016; Dreger et al., 2015; Schreckenberg et al., 2017). One study even showed a reciprocal causal relationship between annoyance and mental quality of life (Schreckenberg et al., 2017) showing that annoyance mediates the effect of aircraft noise on mental quality of life but also that the mental quality of life co-determines the subsequent noise annoyance.

Overall, results of the literature reviewed in D2.3 indicate associations between noise annoyance and health outcomes. As most studies are cross-sectionally designed, the causal direction of the associations can only be interpreted by drawing on plausible theoretical-based assumptions. However, the varying measures used hamper the comparability of studies and due to the small number of studies it is not possible to draw significant general conclusions. **Thus, results indicate that annoyance seems to have a mediating role from noise on health outcomes, which is schematically depicted in** Erreur ! Source du renvoi introuvable.**.**

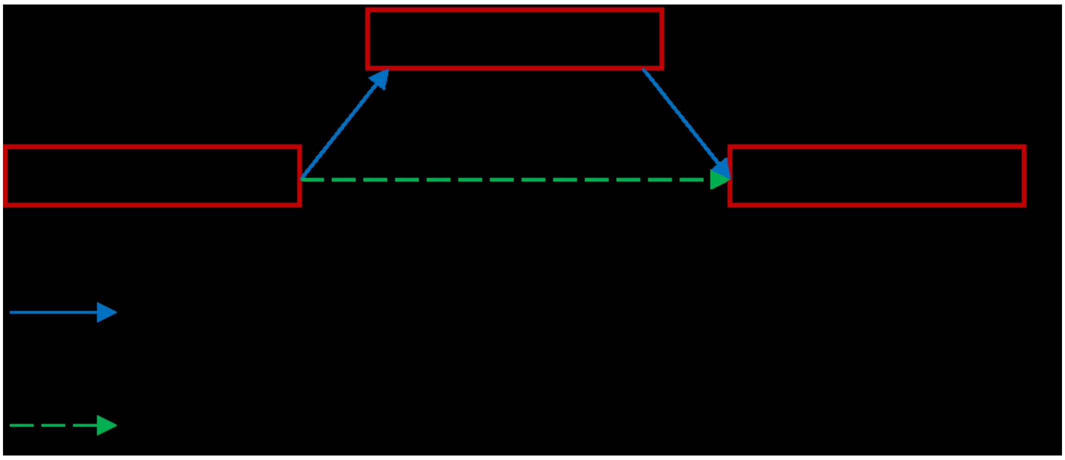

Figure 5: Schematic representation of the direct and indirect (annoyance mediated) effect of noise exposure on health outcomes

**Key messages of Section 5**

- Noise annoyance can be understood as a classical stress reaction.
- Therefore, it is a result of an interaction between environmental factors (the stressor; i.e., sound exposure, disturbances) and personal factors.
- Stress arises from an perceived imbalance between the environmental demands and the internal and external resources to deal with them. Both the demands/the stressor and the available resources are subject to subjective appraisal or evaluation.
- Mechanisms to cope and deal with stress can address both the stressor (or the problem) and the emotion (or the subjective evaluation). This depends substantially on the person’s perceived control.
- Perceived control has cognitive, affective, and behavioural components.
- Stallen (1999:77) emphasises that the various components of perceived control can never be completely subjective: "To a large extent *perceived control* is rooted in how noise is managed in practice by the source", thus enhancing the importance of the magagement of sound levels.
- Noise annoyance is also associated with different adverse physical and mental health outcomes.
- Only very few studies have investigated this association yet. However, results so far suggest that noise annoyance seems to mediate – in particular, increase – negative effects of noise exposure on health outcomes.

# 6 Acoustical Factors Associated with Aircraft Noise Annoyance

## 6.1 The Problem

Over the past 50 years and more, the main drivers for action to limit, minimise, and reduce aircraft noise has been ***noise complaints*** and ***reported noise annoyance***. Chronic annoyance may also contribute to stress-related health effects, as discussed in ANIMA D2.3. It is well known that the likelihood of making a complaint depends on many other factors additional to the noise itself. In addition, in most cases where the majority of complaints are submitted by only a small minority of the noise exposed population, the statistical representativeness of general attitudes in the population at large is unknown.

Much effort has therefore been expended on developing means of measuring, or at least estimating, average annoyance in the overall population. Self-reported or expressed noise annoyance is, of course, entirely ***subjective*** and can vary for many reasons additional to actual changes in noise exposure attributable to aircraft operations (see Section 5 above). For these reasons, it has long been standard practice to measure aircraft noise exposure in terms of ***basic standardised acoustic metrics***, with or without the use of ***supplementary*** and/or ***sound quality*** indicators, and/or ***weighting factors***; all of which are ***objectively*** defined. The general reasoning has been that standardised acoustic metrics are a means of avoiding subjectivity, which would otherwise compromise the accuracy and reliability of assessments based only on reported noise complaint statistics.

In addition to human variability, actual aircraft sound exposure can, and does, vary over a very wide range of different situations and contexts often leading to considerable differences in subjective outcome; this can prove difficult to represent by the use of just one specific metric. There is an underlying tension between the need to develop simple single number numeric metrics based on overall average quantities, and the need to properly reflect the full range of input variables which may need to be taken into account to properly reflect key input variables in specific situations.

This wide range of possible 'input variables' is reflected in the wide range of possible objective representations of aircraft noise exposure. Acoustic metrics vary in measurement, representation, form and description, meaning they can increase in complexity from a simple long term averaged indicators (specified in the European Environmental Noise Directive and the World Health Organisation Noise Guidelines) through various specifications for supplementary indicators (Airports Commission, 2015:170; SEFA, 2007; Bauer, 2013) to full acoustical demonstrations, some of which may be accompanied by visual aids (ISIS, 1997; Hooper et al., 2009).

Such varied use of metrics compromises the practicality of any regulatory application. On the other hand, this progression allows for more detailed representation of a given situation, which can significantly enhance public understanding when used in communication and consultation.

Many possibilities exist for adding weightings to metrics, which are applied to reflect given situations, for example time of day. The extent to which these specific weightings are 'correct' or not under particular situations is often unknown, and may well lead to inappropriate or misleading assessments, particularly when used for predictive purposes and without proper consideration.

It is not as widely known as it should be that the set of relative weightings for the different input variables that are combined by averaging into the current standard indicators specified in the European Environmental Noise Directive (Directive 2002/49/EC, 2002), and similar regulations and guidelines used elsewhere, are only one of a wide range of different possibilities, and may not be optimum for particular circumstances, some examples of which are given below.

## 6.2 Basic standard acoustic metrics

Two main issues have emerged throughout the search for the most useful and effective acoustic metrics over the past 50 years:

- ***Sound exposure varies*:** actual sound exposure varies over a wide range of situations and dimensions leading to a range of attempts to capture aspects of sound as explained in the remainder of this Section and Section 6.3
- ***Noise annoyance is difficult to relate to objective noise metrics*:** human auditory perception does not function in the same way as a calibrated sound level meter. This creates challenges when attempting to relate noise exposure to annoyance responses as discussed in Section 6.4.

Both issues arise because of the rich variation that can occur in the external soundscape and because of the different ways that human auditory perception has evolved, primarily to extract information from that environment. Music perception provides an interesting analogy. The long-time averaged A-frequency weighted sound level ($L_{Aeq}$) of a musical performance has very little meaning in terms of subjective appreciation of that performance other than any relevance it might have to hearing damage risk.

The main dimensions over which sound can vary are:

- ***Instantaneous sound quality***, represented by the short-time varying frequency spectrum;
- ***Longer time temporal distribution***, represented by the sound level time history; and
- ***Spatial distribution***, which can only be represented by the use of multiple measurement positions.

For example, even the supposedly constant sound level emitted by a heating and ventilating plant will vary in both sound quality and sound level at different distances and directions from the plant, and aircraft noise events certainly vary over all three main dimensions. The range of acoustic metrics and indicators that have been developed over the years to reflect these dimensions is vast. For a comprehensive listing and selected definitions of the most frequently encountered metrics and indicators (Appendix 3). For present purposes it will be sufficient to focus on the standard metrics and indicators currently used in most European countries for the measurement of aircraft noise; $L_{Amax}$, $L_{Aeq}$, $L_{den}$, and PNdB; these are explored below.

### 6.2.1 Standard metrics for single events

***LAmax*** is defined as the maximum A-frequency weighted sound level (see Appendix 1) during a specific sound event. The two words '***sound level***' imply the use of the logarithmic decibel scale of sound pressure (see Appendix 1). This is both important and unfortunate because decibel arithmetic requires the use of logarithms, and is consequently not widely understood except by a very small minority of the general public, and can even be misinterpreted by experts who should know better.

Originally developed for quantifying the magnitude of electrical signals in telephone circuits, the logarithmic decibel scale when applied to sound level is widely believed to reflect the assumed dependence of subjective loudness on the physical magnitude of the sound better than any alternative. As for many similar issues in acoustics, this is not entirely true; the decibel scale is simply an alternative way of representing physical quantities numerically that reduces the amount of arithmetical computation required for calculations of attenuation and amplification in telephone circuits. In addition, the decibel scale of sound level is a long-established custom and practice. Replacing decibel scales by much simpler linear scales of sound pressure would simplify most calculations and probably facilitate increased public understanding of acoustical issues. Any attempt to abandon the traditional decibel scale however, is likely to be too disruptive, in terms of having to rewrite existing standards and regulations, to be seriously contemplated.

The use of the ***A-frequency weighting*** in $L_{Amax}$ and other standardised acoustic metrics is similarly problematical. The A-frequency weighting was originally standardised in the 1930s as part of a more complex scheme to reflect the differing contributions made by audio frequency variations to overall subjective loudness. It is well known (Salt and Hullar, 2010) that human auditory perception is less sensitive to both very high frequency and low frequency sounds, than to medium frequency sounds. While numerous empirical measurements over the past 50 years have shown the A-frequency weighting to be generically representative of this differential frequency sensitivity, there are also many situations where different frequency weightings and/or so-called loudness weighting schemes (see for example, the Section on PNdB below) have performed better. A good example of this issue is the relative contribution made to overall disturbance or annoyance by the low frequency components in current aircraft flyover event sounds compared to typical aircraft flyover event sounds of 30 - 50 years ago. There is some evidence (Scannell, 2003) that the A-frequency weighting takes insufficient account of these low frequency components, which have become relatively more prominent (particularly when heard indoors). It is suggested that reasons for this are both physical and economic in nature, and associated with the long wavelengths being relatively harder to attenuate. Mid and higher frequency components however, have been reduced. Despite this, in the same vein as the arguments against changing from currently decibel scales discussed above, changing the current A-frequency weighting used in standardised acoustic metrics would be too disruptive to long established custom and practice.

Another feature that can have an impact on sound perception is the speed of instantaneous sound fluctuation. The 'F' (fast) time weighting is intended to respond to rapidly fluctuating changes in subjective loudness at about the same speed as human auditory perception and is defined as exponential averaging with a 125ms time constant. Any situation where the instantaneous sound level is fluctuating rapidly, the speed at which the sound level meter responds to these fluctuations can have a small but potentially significant effect on the results. The F sound level meter ***time weighting*** is used for the majority of environmental noise measurements (denoted by ***LAFmax***, and referenced in the glossary under "*Maximum time-weighted sound level*"). It should be noted, however, that for other aspects of human auditory perception, 125ms exponential averaging is a generic compromise solution and is not necessarily representative of any particular case.

Aircraft flyover noise is a specific case where the 'S' (slow) sound level meter time weighting, with a 1 second time constant, is customarily specified instead (denoted by ***LASmax***, and referenced in the glossary under "*Maximum time-weighted sound level*"). It is generally accepted that, for rapidly fluctuating sounds, damping down the sound level meter response in this way will lead to a marginally lower reading of $L_{Amax}$, with typical differences of the order of 1 or 2 decibels. The technical justification for this is an assumed requirement to discriminate between the relatively slowly changing onset, peak and decay during the aircraft flyover event sound level time history and the superimposed faster fluctuations in instantaneous sound level above and below the underlying aircraft flyover event sound level time history attributable to rapid variations in acoustic propagation conditions as the aircraft moves through different layers of air with constantly changing atmospheric conditions.

It should be recognised that, mainly because of the typically lower readings obtained by this means, the technical justification for using the S time weighting might not be as convincing to interested and partially informed members of the public as airport management might otherwise hope. Equally, the differences between F and S time weightings in the determination of $L_{Amax}$ values is irrelevant to long time averaged $L_{Aeq}$ type metrics and indicators. This is discussed below.

### 6.2.2 Standard long-term averaged metrics

When the maximum (or peak) sound levels reached during individual aircraft flyover events are measured using $L_{Amax}$, it will become immediately obvious that successive events can be subject to considerable variation; to the order of plus or minus 5dB, even for the same type of aircraft, under (at least nominally) the same operating conditions. This variability can be attributed to various factors, including the following; larger older aircraft types are likely to be considerably noisier than more modern, smaller aircraft types; the overall take-off weight depending on the aircraft loading and the weight of fuel carried to reach a specified range can be taken into account when selecting the take-off power setting and can affect the rate of climb subsequent to take-off; and the actual route flown; in addition to the often considerable variation in acoustic propagation conditions attributable to both macro and micro variation in atmospheric conditions.

It is not (usually) very helpful for overall and strategic assessment purposes to quote long lists of actual $L_{Amax}$ values for each individual aircraft flyover event at busy airports where the number of take-offs and landings on a given runway can exceed 500 per day, and considerable variation can occur from one over flight to the next. Instead, airport regulators and management have come to rely on long-time averaged metrics such as ***LAeq***, which (by definition – see Appendix 1) represents the A-frequency weighted continuous sound level that would result in the same amount of acoustic energy received at the defined receiver point as the time varying sound being measured, and over the same specified averaging time.

$L_{Aeq}$ is normally be measured over a defined 16-hour daytime period or a defined 8-hour night-time period and further averaged over an extended time period of months or even a whole year to take into account daily and seasonal variation.

***Lden*** is based on $L_{Aeq}$ with additional, and somewhat arbitrarily defined, time of day weightings of 5dB and 10dB added to events during defined 4-hour evening and 8-hour night-time periods. It is difficult or even impossible for members of the public to understand or relate to the long-time averaging process inherent in $L_{Aeq}$ type metrics and indicators because of the much shorter time focus of human auditory perception. **For example, using long-time averaged $L_{Aeq}$ to represent aircraft noise exposure at night can be particularly problematical for members of the public, who if they happen to be disturbed while asleep, are much more likely to understand the disturbance to be directly attributable to specific events (which could be represented by $L_{Amax}$) occurring at some stage during the night-time**

**period than by a numerically much lower $L_{Aeq}$ average.** The latter takes into account all those extended periods of time during which nothing happens in addition to the occasional and relatively infrequent disturbing event, and this rarely makes any sense to persons complaining of night-time sleep disturbance by aircraft noise events.

It should be noted that the concept of long time averaging can create difficulties where the $L_{Aeq}$ average attributable to noise sources other than aircraft events is equal to or exceeds contribution made to overall, or ambient, $L_{Aeq}$ made by specific aircraft events. These difficulties have contributed to the requirement for internationally standardised definitions of specific noise, ambient noise, residual, and background noise (see Appendix 1). **However, it seems unlikely that these definitions, whilst well intentioned, help public understanding. For example, there are many urban situations around busy airports where full compliance with the current WHO guidelines (Environmental Noise Guidelines, 2018) would require the aircraft noise contribution to the overall (or ambient) $L_{Aeq}$ to be mitigated down to sound levels below the thresholds of noticeability and certainly below levels which would be capable of verification by measurement.**

On the other hand, the long-term averaged measuring of acoustic energy at defined receiver points in the context of $L_{Aeq}$ type metrics, dictates that duration and number of all events happening during that time period are taken into account. This offers administrative advantages for regulatory and comparison purposes because many of the acoustic dimensions considered to be important for impact assessment are automatically taken into account in a single number indicator. Moreover, $L_{Aeq}$ type metrics are based on physical quantities, which can be *directly* measured or calculated using readily available aircraft noise contour calculation models.

As an indicator of the overall amount of sound energy received (technically, because of the time averaging, $L_{Aeq}$ is physically equivalent to the long-time averaged A-weighted sound intensity per unit area), $L_{Aeq}$ increases if the average $L_{Amax}$, number of separate events, or average durations of those events increase. It should be noted that alternative long-time averaged indicators can be applied which take proportionally greater (or lesser) account (than $L_{Aeq}$) of the number of events vs. the average sound levels of those events. As such, these alternatives should not be considered as derived physical quantities capable of being directly measured, because they can only be calculated from separately measured input variables. **However, there is by now both empirical and anecdotal evidence that taking greater (relative) account of the number of events within the determination of the indicator, than implicit in $L_{Aeq}$, can lead to higher correlations with averaged reported disturbance and annoyance.**

Based on observed correlations between average reported annoyance and measurements of aircraft noise levels around Heathrow in the early 1960’s, (Wilson Committee Report, 1963) the UK government adopted a non-physical indicator of aircraft noise exposure, the Noise and Number Index (NNI). When comparing this metric to the $L_{Aeq}$, it placed greater emphasis on the number of events within the determination of the indicator. After extended consultation in 1982, which included some empirical research (Brooker et al., 1985) the UK government adopted the 16-hour $L_{Aeq}$ as its preferred aircraft noise indicator for a 3-month period during the summer. During the same time period, a general international convergence was emerging towards the universal adoption of $L_{Aeq}$ and $L_{Aeq}$ type metrics for aircraft noise assessment and regulation. The UK government utilised the averaging nature of the new metric to demonstrate a more rapid reduction in the areas of annually produced aircraft noise contours around airports than would have otherwise been the case with NNI. This was achieved through the gradual replacement of older noisier aircraft types with quieter ones, which was more than enough to offset any increase in aircraft numbers during the period. During that same period however, increasing (but largely anecdotal) evidence suggested that reductions in aircraft noise contours were not leading to commensurate reductions in reported disturbance and annoyance around airports.

Increasing pressure from members of the public, and from local amenity groups led eventually to further research in 2005 and 2006 (Le Masurier et al., 2007). This research found higher overall correlations between noise and annoyance by taking greater account of the number of events within the determination of the indicator than implicit in $L_{Aeq}$.

At least partly due to limitations of experimental design which could not be changed retrospectively, statistical comparisons against the earlier research carried out in 1961 and 1982 were unable, however, to distinguish between the two main hypotheses to explain the data; these are:

- That the population had become increasingly sensitive to aircraft noise over the 23 years from 1982 to 2005, which had consequently cancelled out the recently achieved reductions in average aircraft noise event sound levels; OR,
- That the changeover from NNI to $L_{Aeq}$ following the 1982 research had not taken sufficient account of the significant increase in overall traffic that was occurring at that time.

Of course, by 2005, $L_{Aeq}$ had become sufficiently entrenched within the (by then) long established regulations and assessment procedures that any upheaval from further changes in preferred aircraft noise indicator would not have been welcomed.

It should be noted that the three main UK studies carried out in 1961, 1982 and 2005/6 were relatively unusual in that the experimental designs permitted at least partial breakdown of the relative contributions to overall reported disturbance and annoyance made by the average maximum sound level. This was due to data being available on separate consecutive aircraft flyover events and the average numbers of those events. The majority of similar studies carried out internationally over the past 60 years did not include this trade-off as experimental design priorities, which can add significantly to the overall cost, and even sometimes compromise feasibility if included. There is always a finite range of issues, which can meaningfully be investigated within any research study design; for example, it is not usually meaningful in even large-scale cross-sectional field studies to investigate alternative frequency and time weightings because of unavoidable correlations between these variables within the available ranges of observation points, even if unlimited resources were available.

These, and similar, issues have led to increasing pressure to adopt additional or supplementary indicators, and sound quality indicators to take into account acoustic input variables which are thought not to be properly accounted for within the standard formulation of $L_{Aeq}$ and $L_{Aeq}$ type metrics and indicators (see Appendix 1). It should be noted that using additional or supplementary indicators can highlight further procedural issues, and does not by itself solve the problem. If the supplementary indicators in effect tell the same story (i.e. they lead to exactly the same assessment of any proposed development or change) as the officially adopted $L_{Aeq}$ type metrics and indicators, then they have not really achieved anything significant other than possibly contributing to confusion and misunderstanding amongst the public at large. If however, the supplementary indicators tell a different '*story*' to the officially adopted $L_{Aeq}$ type metrics and indicators, then who is to say which story is correct. **For example, confusion and irritation could arise from changes to currently adopted indicators and metrics that have been used to define areas eligible for noise insulation and/or financial compensation where applying supplementary indicators change those areas deemed to qualify for support, which in turn would create considerable administrative difficulties.**

### 6.2.3 Weighted Leq type metrics

With weighted $L_{eq}$ metrics an attempt has been made to reflect assumed increases in community sensitive to noise at different times of the day. Such indicators include $L_{den}$ and the similar $L_{dn}$ indicator used in the USA. $L_{den}$ for example, applies the somewhat arbitrary addition of 5dB to evening and 10dB to night-time events and thus can become relatively more sensitive to small differences in the numbers of evening and night-time events than to similarly proportional differences in the numbers of day-time events. However, it should be noted that, due to the somewhat arbitrary application of weightings, these implied differences in relative sensitivity to small differences in the 24 hour operating pattern also depend on the relative overall amounts of daytime, evening and night-time traffic, and can sometimes lead to apparently counter-intuitive results. For example, at a location where the hourly $L_{Aeq}$ is 70dB throughout the day and evening but there is no noise at night (23.00 - 07.00), the $L_{den}$ aggregates to 69.9dB. In this situation, it could be argued that the 70 hourly $L_{Aeq}$ during the assumed-to-be-more-sensitive evening period (19.00 - 23.00) has not been well represented. Now consider the effect of relaxing the night time ban for the last two hours of the defined night time period (05.00 - 07.00) so that the hourly $L_{Aeq}$ during these two hours becomes 70dB; the $L_{den}$ increases to 72.7dB - an increase of less than 3dB. Numerical differences of less than 3dB are often considered to be 'insignificant', although many residents would probably consider the partial relaxation of the night time ban highly significant. Suppose then, that the airport makes a concession to the local residents by introducing a complete ban for 5 hours during the daytime period, from 11.00 to 18.00. The $L_{den}$ reduces to 70.6dB, again a hardly significant reduction in numerical terms. It seems clear in these examples that what would probably be considered by many residents to be significant changes to the pattern of aircraft operations over the 24 hour day might only lead to marginal differences in the overall value of aggregated $L_{den}$.

One of the main administrative benefits of long-time averaged acoustic metrics and indicators is that it then becomes conceptually simple (if, possibly, computationally intensive) to interpolate iso-contours and noise 'footprints' overlaid onto geographic maps of areas around an airport, to show areas and calculate overall numbers of residents exposed within defined bands of $L_{Amax}$, $L_{Aeq}$ or $L_{den}$. Airport managers, administrators and regulators can then compare contour plans with associated area and population counts for alternative scenarios as an overall decision-making tool based on the spatial distribution of aircraft noise.

None of these administrative benefits comes without cost. Noise contour plots using conceptually difficult metrics and indicators such as $L_{Aeq}$ and $L_{den}$ are poorly or not at all understood by the general public, who may often have little or no interest in seeing the wider picture of most use to strategic decision makers, being instead, much more interested (if at all) in seeing how any proposed developments will, or might, affect them individually. If members of the public take any interest in what are often perceived as being highly technical matters, many will then go on to suspect decision makers of attempting to '*prove*' whatever they want to 'prove', by '*blinding them with science*'. This situation is not helpful and can be further exacerbated by what are increasingly thought of as misguided attempts to explain noise contour plots calculated in $L_{Aeq}$ and similar metrics in terms of degrees of annoyance within each contour area. Few members of the public appreciate being told how 'annoyed' they are depending on where they live, and those people who are actually annoyed and who happen to live outside of the contour area defined as representing that degree of annoyance are even less likely to be appreciative.

#### 6.2.4 Perceived noise level metrics

The final acoustic metric, which aircraft noise regulators and administrators need to be most aware of is PNdB, or ***Perceived Noise Level*** (see Appendix 1). This is a relatively complex family of indicators defined in international agreements for the standardised measurement of aircraft take-off and landing noise during aircraft noise certification procedures. The PNdB procedures were devised in the late 1950s and early 1960s to achieve the highest possible correlation between objective measurements of frequency and time weighted sound levels and relative subjective judgments of the '***perceived noisiness***' of sequences of separate simulated aircraft flyover event sounds presented under carefully controlled laboratory conditions using loudspeakers. '***Perceived noisiness***' was defined at the time as being a specific subjective attribute of aircraft noise which falls somewhere between ***subjective loudness,*** which was considered to be essentially neutral (i.e. neither pleasant or unpleasant), and ***subjective annoyance***, which was considered to be essentially an attitude or response by the listener to the sound; this need not necessarily reflect any underlying physical properties *of* that sound. To present day readers, these distinctions may seem a bit obscure and academic. Participants in the original laboratory listening experiments may have had difficulty with these finer distinctions when faced with the practical reality of having to make numerous repeated pair-comparison judgments of relative noisiness between otherwise similar pairs of recorded aircraft flyover noise events. However, they draw attention to a fundamental aspect of human auditory perception; namely to what extent is perception focused on:

- Understanding the details of the distant external environment?
- How a sound might impinge upon or intrude into that person's individual space? OR
- The purely objective physical magnitudes of sensory inputs?

By referring to '***noisiness***' the researchers attempted to focus attention on the 'pleasant vs. unpleasant' dimensions of the supposedly distant aircraft sound itself, rather than on the perceived physical magnitude of the sound at the listener ***(loudness)***, or on the emotional (and proximal) response of the listener to that sound ***(annoyance)***, which might be expected to vary rather more than the noisiness per se. Under present-day circumstances, this distinction does not seem as clear-cut as it may have done to the original researchers.

As originally formulated, the measurement of perceived noise level required recordings of aircraft flyover noise events to be fed through a one-third octave band frequency analyser, the band levels are then aggregated together for every 0.5 seconds according to a defined frequency and time weighting, taking into account assumed masking of higher frequency bands by lower frequency bands. Further arithmetic procedures are, or can be, applied to account for tonal content and overall event duration under agreed standards and regulations to derive the final numerical value (for tone-corrected perceived noise level and effective perceived noise level, EPNdB, respectively [-> see EPNdB and $L_{EPN}$ in the glossary]). While it was (and remains) possible to calculate perceived noise levels from the specified one-third octave band levels manually, if somewhat tediously, modern digital techniques allow the determination of perceived noise levels automatically in real-time, and so the apparent complexity is no longer an obstacle to more widespread use. On the other hand, and viewed from a present day perspective, many of the laboratory methods and statistical techniques used to derive the required results may appear somewhat restricted compared to what is currently available under present day conditions, and indeed many similar style listening experiments have been carried out since the 1960s with, in most cases, either marginally or significantly different results. This might seem to provide a strong argument for review of current practice.

Nevertheless, aircraft manufacturers have invested considerable sums of money in noise control engineering to be able to achieve compliance with increasingly stringent noise certification requirements since that time, and any attempt to change the parameters of the specified noise metric to reflect increasing scientific knowledge accumulated since that time would be seen as '*moving the goal posts*' and could have unintended consequences. For example, some currently compliant aircraft types could be found to be no longer compliant if measured using an alternative or updated metric. It is entirely plausible that current aircraft types would not be rank ordered for 'perceived noisiness' in the same order as implied by their currently certificated sound levels measured in EPNdB, and that their actual subjective rank ordering could be better represented by some alternative acoustic metric or indicator yet to be devised. On the other hand, the current regulatory framework is what it is. Provided that the known limitations are clearly understood and taken into account, it is probably best to leave well alone, at least for the time being, or until some radically different technology such as electric power plants is introduced and which clearly requires radical changes to regulatory procedures to accommodate it.

## 6.3 Alternative acoustic metrics

As can be seen in Appendix 1, a considerable number of alternative acoustic metrics and indicators have been devised over the past 50 years and more, some of which have been proposed as direct alternatives to the four essential types described above. Others have been proposed as supplementary metrics intended to be used in addition to, rather than as alternatives to, the four key metrics (LAmax, LAeq, Ldn/Lden, PNdBs). The motivation for many of these developments has primarily been a widening appreciation of the limitations of current key metrics, and a desire to 'do better'. For example, the recent SEFA (2007) and COSMA (2013) European research projects found that a number of so-called '***sound quality***' indicators were capable of higher correlations observed between subjective judgments and objective measurement (as compared to standard metrics), but that the increases in correlation were a: not large enough to justify general adoption, and b: inconsistent under different situations.

None of the proposed alternatives have been found to offer sufficient benefits over the current key metrics for general applications that would justify replacing any of them, providing that the known limitations of the four key metrics are recognised and taken into account. It should be noted that there are often many situations and specific contexts in which the use of one or more of these supplementary metrics and indicators may be found to offer a better or easier to understand explanation and/or exposition of proposed changes when used for public engagement or similar purposes.

## 6.4 Predicting noise annoyance based on objective metrics

The second main issue noted in Section 6.2 is that human auditory perception does not operate in the same way as a calibrated sound level meter fitted with a precision grade microphone of the type normally used for objective measurement of sound levels according to standard procedures.

Irrespective of standardised acoustic metric being used, the difference between wanted or neutral ***sounds*** and unwanted ***noise*** is ultimately a matter for ***subjective interpretation***, depending mainly on the context in which the sound is heard. For example, it can be a topic for philosophical discussion to decide whether an unpleasant sound can, or should, be classified as a noise if there is nobody present to hear it. Just as individual preferences in music can vary, people differ in their interpretation of the sound that they can hear, or indeed *think* they can hear. A well-known example of this issue is helicopter noise in cities, where the majority of the population raise no objections to helicopters used for emergency medical purposes, but may nevertheless object strongly to the same sounds emitted by the same types of helicopters used by high net worth individuals to access city centre facilities at minimum inconvenience to themselves. As another example, whereas according to the EC recommended harmonised dose-response relationships for different types of environmental noise, aircraft noise is considered to be more annoying than road traffic noise.

Under controlled laboratory listening conditions however, many people have difficulty in distinguishing between and correctly identifying recordings of aircraft flyovers and heavy road vehicles driving past, provided that the relative durations and overall spectral content of each event are similar. Differentiating between the two types of sound can depend on context and experience as much as on acoustic sound quality per se.  For example, skilled musicians can often identify and discriminate between different musical sounds that less skilled audiences have no overt awareness of unless their attention is particularly drawn to the differences.

Most, if not all, current noise metrics and indicators originated either directly or indirectly from various kinds of research comparing defined output variables, such as reported disturbance and annoyance, against defined input variables, which historically included only acoustic variables, but in more recent years, have also included limited ranges of so-called *non-acoustical* variables (see Section 7). According to the standard methodology, various types of statistical analysis would then be applied to find the particular combinations of input and outcome variables giving the highest correlations. Thereby providing theoretical justification for adopting those variables in standards and regulations intended for the estimation of subjective disturbance and annoyance based outcomes from strictly objectively determined input variables.

Unfortunately most, if not all, of this research has been, and will continue to be, unavoidably constrained by resource and other limitations, such that if too many different sets of input and outcome variables are compared for the overall number of independent observations, it becomes statistically unreliable to discriminate between them. In many cases, available resources have constrained the number of variables that can actually be measured. This constraint can be particularly applicable to noise and health research where it has not generally been feasible to obtain independent measurement of all possible confounding variables to a sufficient degree of precision and accuracy. For example, supposing that a, possibly rather simplistic, study is intended to investigate the effect of aircraft noise on blood pressure. As an obvious minimum the study must measure both noise and blood pressure over a sufficiently large sample size to be able to a: cover a range of noise exposure (the input variable), and b: to obtain a sufficiently large sample of blood pressure observations (the output variable) to be able to derive statistically representative estimates of average blood pressure within each noise exposure category.

Complications then arise when other variables are considered, which are known to be associated with differences in blood pressure, such as age and general state of health. Each of the other variables must be independently measured to be able to statistically separate out their effects, requiring additional resources. Suppose then, that one or more of these other variables correlate with the degree of noise exposure, i.e. older people tend to live in the noisier areas. Depending on the degree of correlation, it could be impossible to statistically separate out the effects of age on blood pressure from the effects of noise on blood pressure, requiring the extension of the study to much larger sample sizes in the hope of finding locations where the correlation is less marked.

In many cases, while the overall size of a research project might not have been unduly constrained by available resources, it has still not been possible to obtain sufficient de-correlation between key input variables for reliable statistical discrimination. Typical examples might include trends for residents with particular socio-economic characteristics to congregate in specific districts with different degrees of noise exposure such that it is impossible to differentiate (in terms of hypothesised cause and effect) between statistical associations of reported disturbance and annoyance with socio-economic grouping, or with noise exposure.

Another common problem is that for uniform residential population densities, there is many fewer residents exposed to the higher aircraft noise sound levels close to the airport than residents exposed to lower aircraft noise sound levels at increasing distances from the airport. Depending on the objectives and design priorities for the research relative to the geographic distributions of populations around the airport, the resulting and unavoidable difficulties of obtaining sufficient numbers of survey responses to achieve adequate statistical power can, and often does, compromise the feasibility of being able to obtain statistically definitive results.

In theory, while it can be difficult or impossible to avoid these kinds of problems in the design of typical cross-sectional field research, such problems can be overcome by the use of a 'repeated measures' type experimental design in laboratory based research using controlled simulations of (pre-recorded) aircraft noise exposure. Unfortunately, however, laboratory based listening experiments are not real-life and the short time based relative comparisons carried out in laboratories are not necessarily representative of one-time subjective judgments carried out in the field. In all such cases, people are necessarily invited to report opinions or state preferences in situations that are of unknown representativeness of their everyday lives. In all subjective research, and particularly in listening laboratory situations, it is difficult or impossible to minimise or avoid the effect of research participants actively paying attention (***active listening***) to sounds which they might pay little or no attention to in a real-life situation ***(passive listening)*** where they might only consciously attend to or become consciously aware of particularly prominent or intrusive events.

## 6.5 Summary

Given these (and other) uncertainties, it may be considered surprising that any correlations can be found at all between acoustic and non-acoustical objective input variables, aggregated together according to defined specifications (metrics and indicators), and average outcome variables such as reported disturbance and annoyance. The research collected over the past 60 years shows general trends for reported disturbance and annoyance to increase with increasing degrees of noise exposure, however measured, but with sufficient uncertainty to justify considerable caution when attempting to extrapolate from any existing data sets or meta-analyses to derive any kind of general or universally applicable predictive relationships.

To take these uncertainties fully into account, each new situation should be considered individually, whereby existing objective metrics and indicators, standards and regulations can be applied within their known limitations; with all known possibly confounding factors taken under consideration, and clear justification provided for any expressed professional opinion. Additional, alternative, or supplementary indicators can and should be used wherever they can enhance public engagement through increased comprehension and resonance with individual experience, but not where additional and sometimes contradictory information simply adds to overall confusion. Inappropriate simplifications should be avoided wherever possible. This includes, for example, defining particular degrees of *objectively* measured noise exposure in terms of equivalent degrees of *subjective* outcome variables, as based on naive interpretations of selected previous research. The key issues to be identified in advance of any proposed development (or continuation without development) are the degree of understanding and misunderstanding likely to ensue in identifiably different sectors of the stakeholder community (e.g. members of the public, amenity groups, operators, local and national government regulators, airport and operator employees and shareholders, airport users).

Having identified likely misunderstandings, the next most important step in enhanced public engagement is remediation through measures that are likely to be most effective in a given situation. Properly and fully informed opinion can be managed and/or taken into account through reasoned and rationale debate, whereas uninformed opinion can only be dealt with on an emotional and often irrational basis.

The basic standardised metrics and indicators are useful for regulatory and strategic assessment purposes, BUT interpretation in terms of subjective outcome must always be considered subject to substantial uncertainty. Considerable caution should always be exercised when basic standardised metrics and indicators are misused for predictive purposes.

**Key messages of Section 6**

- A number of standardised acoustic metrics have been established to reflect aircraft noise.

- These are *objective* in the sense that they are objectively defined, measurable, and computable, but at the same time they are always *subjective* in the sense that they are subject to certain averaging, summaries, and weightings. A single numerical value can not reflect the entirety of the facets of a given sound or noise situation.

- Actual sound exposure varies over a wide range of situations and dimensions like
  a) instantaneous sound quality, represented by the short-time varying frequency spectrum,
  b) longer time temporal distribution, represented by the sound level time history, and
  c) spatial distribution, which can only be represented by the use of

multiple measurement positions.

- The **LAmax** is a classic standard metric for **single sound events** and is defined as the maximum A-frequency weighted sound level. It is measured on a logarithmic decibel scale of sound pressure which makes it not intuitively comprehensible.

- Standard **long-term averaged metrics** like **LAeq** represents the A-frequency weighted continuous sound level that would result in the same amount of acoustic energy received at the defined receiver point as the time varying sound being measured, and over the same specified averaging time. It is often reported separately for day and night hours.

**Key messages of Section 6 (continued)**

- One problem accompanied using long-term averaged metrics arises when the average value attributable to noise sources other than aircraft events is equal to or exceeds the contribution made to the overall, ambient value by specific aircraft events. This leads in some cases to situations where full compliance with the current WHO noise guidelines would require the aircraft noise contribution to the overall value needed to be mitigated down to sound levels below the thresholds of noticeability.

- **Weighted metrics** reflect assumed increases in community sensitive to noise at different times of the day. The **Lden** is a long-term averaged metric with additional time of day weightings of 5dB or 10dB added to events during defined day- or night-time periods to give, for example, nocturnal noise a stronger weight. Thus, the resulting value does not correspond to a pure physical quantity.

- When the number of events is entered into the indicator in addition to sound characteristics, the prediction accuracy and correlations with averaged reported disturbances and annoyance increases.

- To focus on the degree of pleasantness (vs. unpleasantness) of the sound, rather than on the physical magnitude of the sound at the listener (loudness), or on the emotional response of the listener to that sound (annoyance), **Perceived Noise Level metrics** were established. This is a relatively complex family of indicators defined in international agreements for the standardised measurement of aircraft take-off and landing noise during aircraft noise certification procedures. These metrics were devised to achieve the highest possible correlation between objective measurements of frequency and time weighted sound levels and relative subjective judgments of the ‘perceived noisiness’ of sequences of separate simulated aircraft flyover event sounds.

- Moreover, there is a number of alternative metrics beyond the key metrics (LAmax, LAeq, Ldn/Lden, Perceived Noise Level metrics). None of those has, however, been found to offer sufficient benefits over the current key metrics for general applications that would justify replacing any of them, providing that the known limitations of the key metrics are recognised and taken into account.

# 7 Non-Acoustical Factors Associated with Noise Annoyance

As was described in the previous Section 6, empirical findings show that the acoustical features of noise only explain part of the annoyance response to aviation noise, regardless of how noise annoyance is measured or operationalized.

Also, the theoretical model explaining noise annoyance in Section 5 implies that the "non-noise-related characteristics of the person or environment" play a crucial role in the formation and explanation of noise annoyance; particularly ‘perceived disturbances’ and ‘perceived control’.

Accordingly, in recent years those contributors to the noise annoyance response and ratings commonly referred to as “non-acoustical factors” in the literature and among experts have received increasing attention in aviation noise annoyance studies.

This Section consists of 2 major parts. In the first part, we will again be following a classic review process. We give an overview of the currrent state of research, including different categorizations of so-called non-acoustical factors. This is followed by a special consideration on the state of research of those non-acoustical factors, that are principally addressable/modifiable within the scope of interventions. In the second part of this section, links between these modifiable and influential non-acoustical factors and intervention options will be revealed and established. Particular attention is paid to the aspects of communication and engagement that are suitable to address the most promising variables; trust, fairness, and attitudes to the source of noise.

## 7.1 Types and categorization of non-acoustical factors

After several broader reviews and meta-analyses on the relevance of non-acoustical factors in (traffic) noise effects on health or annoyance had been published (Fields, 1993; Jones, 2010; Miedema & Vos, 1999; Smith, 1991; van Kamp & Davies, 2008), Asensio, Gasco, and Arcas (2017) recently presented a review specifically targeting non-acoustical measures pertaining to the effects of aircraft noise, whose most important findings we will review in the next subsections.

They define non-acoustical factors as those "which are not directly connected to the nature of the sound." (Asensio et al., 2017, p. 232)

In general, personal characteristics and traits, social factors, as well as environmental features – including situational factors – are counted among non-acoustical factors. This essentially corresponds to the categorization of some authors (Sánchez, Naumann, Porter, & Knowles, 2015).
In 2007, Vader provided a comprehensive review of non-acoustical noise annoyance mitigation measures (NANAMM) at airports.

Before giving an extensive overview of a variety of existing NANAMMs, he first collected a total of 31 non-acoustical factors known to affect noise annoyance. Then he arranged the non-acoustical factors along two dimensions:

1. their **strength** or importance as a factor, i.e., the magnitude of their influence on annoyance (using the categories *strong*, *intermediate*, and *weak*);

2. the extent of their **modifiability** by aviation authorities, which reflects their usability as an instrument (using the categories *modifiable*, *not modifiable*, and *unsure/need to be examined*).

This categorization results in the array depicted in Table 5. Many authors refer to this classification when dealing with non-acoustical factors (Asensio et al., 2017; Sánchez et al., 2015).

Table 5: Categorization of Non-acoustical factors according to Vader, 2007

| **Non Acoustical Factors** | **Strong** | **Intermediate** | **Weak** |
|---|---|---|---|
| **Modifyable** | Attitude towards the source<br>Choice in insulation<br>Choice in compensation (personal)<br>Influence, voice (the | Avoidability<br>Choice in compensation (societal)<br>Expectations regarding future of source | Media coverage and heightened awareness to noise<br>Social Status |

| | | | |
|---|---|---|---|
| | opportunity to exert influence on behaviour of source)<br>Perceived control<br>Recognition of concern<br>Trust | Information (accessibility and transparency )<br>Predictability of noise situation<br>Procedural fairness | |
| **Not modifyable** | Age (under 55)<br>Income<br>Individual sensitivity to noise<br>Past experience with source | Duration of residency near airport<br>Fear related to source of noise<br>Home ownership (fear of devaluation)<br>Use of airport services | Age (above 55)<br>Awareness of negative consequences (health, learning)<br>Children<br>Education |
| **Unsure/ need to be examined** | Conviction that noise could be reduced or avoided by others | Benefits from airport (personal, societal)<br>Cross cultural differences<br>Country of origin | |

## 7.2 Communication and Engagement

The previous Section identified the most significant of the non-acoustical contributors know to be associated with annoyance and concluded that those relating to attitude to the source, capacity to influence ('voice') perceived control and trust are most modifiable by potential action on the part of aviation actors. The implication being that a comprehensive response to ameliorate the health impacts associated with noise exposure should address both acoustical and non-acoustical contributions to annoyance. Given the nature of the modifiable non-acoustical factors it is hardly surprising that many aviation actors have identified communication and engagement as key elements in the management of noise impact - see for example: Federal Aviation Authority (FAA), 2011, 2016; Airport Cooperative Research Program (ACRP), 2009; Canadian Airports Council (CAC), 2015; European Economic and Social Committee (EESC), 2015; Eurocontrol, 2018; Sustainable Aviation, 2014; and Civil Air Navigation Service Organisation (CANSO), 2013, 2015. Illustrative of this shift in focus is the position taken by ICAO when re-visiting their 4 core principles of the Balanced Approach (2004) in 2007 and adding a '5th Pillar' – 'People issues'. This commitment was later developed further in Circular 351 – Community Engagement for Aviation Environmental Management (ICAO, 2017).

The continued and developing commitments and priorities of the aviation industry raise a series of important questions:

- What form should these communication and engagement efforts take?
- Are some forms of communication and engagement more effective than others?

- What should we expect form 'successful' communication and engagement actions?
- How might success be evaluated?

If the aviation sector is to address these questions and help establish the principles by which communication and engagement initiatives should be designed to have maximum effect on annoyance and more broadly the acceptability of airport/aviation decisions, it is important to reflect on the broader literature relating to public participation in decision-making.

### 7.2.1 Public Participation – Theory and Practice

Concepts of public participation can be traced back to the idea of the 'public sphere', which was first used by German philosopher Jürgen Habermas (1962) to indicate 'the area of public life where inter-subjective agreement on values can be reached in order to solve socio-political or practical questions' (Webler, 1995: 42). Habermas, in his book *The Structural Transformation of the Public Sphere* portrayed the appearance of the sphere as:

- The emergence of a normative ideal of a rational public discussion from within the distinctive social formation of the bourgeois civil society; and
- The realisation of this ideal within that society.

The concept of the sphere further developed in the 18th and 19th centuries when capitalist entrepreneurs achieved independence from the church and state, thereby stimulating calls for change and establishing a commitment to critique. It was 'during this time that rules were developed to regulate hearing processes and to resolve disagreements in open, impartial and rational ways' (Webler, 1995: 43). The sphere utilised 'critical scrutiny, full reportage, increased accessibility and independence of actors from economic interest and state control' (Webster, 2006: 165) to integrate society and engaged citizens in significant public debate. Indeed these are attributes of legitimate and fair public participation that we would recognise today when designing public communication and engagement activities such as focus groups, workshops, roundtables and the like.

Orr (2002) describes public participation as a 'generic term for any kind of involvement of the public in decision-making' (Woods, 2008: 259). Rowe and Frewer (2004) develop this definition, describing 'participation as a process where individuals, groups and organisations choose to take an active role in making decisions that affect them' (Reed, 2008: 2418). Whilst Petts (1999: 147) expands the definition further, describing public participation as 'a process of engagement, where people are enlisted into the decision process to contribute to it', thus requiring **'that those initiating the process are open to the potential need for change and are prepared to work with different interests to develop plans or amend or even drop existing proposals'**.

Figure 6 illustrates Hanchey's (1998) three central objectives of public participation, each of which is subdivided to form seven second-order objectives. The diagram outlines the different functions of public engagement, emphasising not only its importance for the distribution of information, but its role in promoting community acceptance and diffusing conflict.

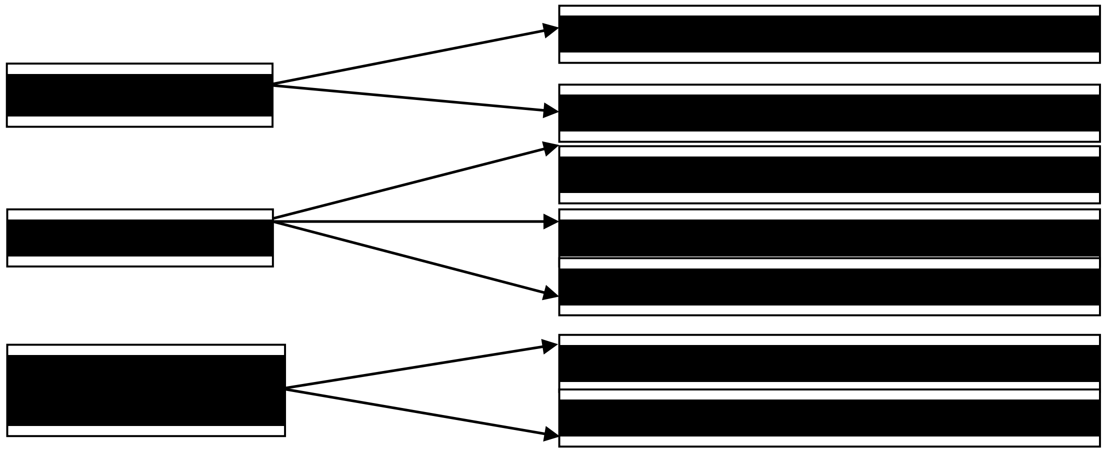

Figure 6: Objectives of Public Participation (Hanchey, 1998)

Participation in policymaking is 'designed to empower, enlighten, and engage the public in the process of self-government' (Smith & Ingram, 1993: 1). It facilitates greater organisational transparency, and develops community trust in and an understanding of an organisation's proposal, thereby reducing stakeholder business conflict. Participation can also 'increase the likelihood that environmental decisions are perceived to be holistic [i.e. embrace all perspectives] and fair, accounting for a diversity of values and needs and recognising the complexity of human-environmental interactions' (Richards et al., 2004 in Reed et al., 2008: 8). Roberts (1996: 230) states that organisations should consider the use of public participation when:

- Reaching a decision requires choosing between important social values;
- The results of a decision will significantly affect the environmental, economic, political, cultural or social interests of certain individuals and groups more than others;
- The public perceives that it has a lot to gain or lose by the decision;
- The issue to be decided is already a source of controversy;
- The organisation needs positive public support to implement a decision; or
- Considerable social or environmental impacts may be expected.

So these theoretical aspects of public participation speak directly to the non-acoustical aspect of annoyance where trust, legitimacy, empowerment, fairness and accountability feature predominantly in the justification for advocating communication and engagement, and indeed in the intended outcomes from these processes.

This however, raises further questions as to how these objectives/outcomes can best be achieved.

Barber (1984 in Webler et al., 1995: 444) believes that 'when citizens become involved in working out a mutually acceptable solution to a project or problem that affects their community and their personal lives; they mature into responsible democratic citizens and reaffirm democracy'. This is also known as social learning, a term Webler et al (1995) classify as the public uniting to solve a shared problem. This speaks directly to the issue of 'voice/influence', which is often cited as a key non-acoustical contributor to enhanced annoyance and can only be addressed if opportunities are provided to influence the behaviour of the source (airports), leading to decisions that are perceived to be fairer (Asensio et al., 2017).

There are two elements of social learning (see Table 6), cognitive enhancement and moral development. Cognitive enhancement is defined as 'the acquisition of knowledge', whilst moral development is 'the reservation of personal and selfish requests in favour of actions which benefit society as a whole; in public participation' (Webler et al., 1995: 446). **If participants do not develop morally or enhance their level of cognition and process of thought, the participation exercise will be based upon individual benefits and group preferences and will not proceed in a sustainable manner.** Participants must therefore be encouraged to concentrate on the process of social learning and cooperate during community involvement in order to achieve rational decisions that account for the values and beliefs of the community as a whole. A study by Webler et al (1995: 460) found that a number of features within the participatory process promoted the development of social learning, these included:

- Site visits;
- Face-to-face small group work;
- A democratic atmosphere;
- Repeated meetings over several months;
- Unrestricted opportunities to influence the process;
- Political support for the process;
- Direct links to formal decision-making machinery;
- Expert support during the process; and
- Responsibility to design and implement the impact assessment tool.

The study also adhered to the criteria identified in Table 6, ensuring that the principles of cognitive enhancement and moral development were followed and used to strengthen participatory decision-making. Following Webler et al's (1995) example, public participation should be a beneficial activity to both the proponent and stakeholders and seek to achieve a sustainable outcome through educated and ethical decisions.

Table 6: Key elements of cognitive enhancement and moral development (adapted from Webler et al., 1995: 446)

| Cognitive Enhancement | Moral Development |
|---|---|
| • learning about the state of the problem<br>• learning the possible solutions and the accompanying consequences<br>• learning other peoples' and groups' interests and values<br>• learning one's own personal interests<br>• learning methods, tools, and strategies to communicate well and reach agreement<br>• practicing holistic or integrative thinking | • developing a sense of self-respect and responsibility to oneself and others, regardless of how these may impact on one's own personal interests or values, and acting accordingly<br>• being able to take on the perspective of others<br>• developing skills for moral reasoning and problem solving that enables one to solve conflicts as they arise<br>• developing a sense of solidarity with the group<br>• learning how to integrate new cognitive knowledge into one's opinion<br>• learning how to cooperate with others in solving collective problems |

Thus, if aviation actors are seeking to achieve more socially acceptable outcomes in their development decisions that improve attitudes to the perceived source of the problem and thus potentially reduce associated annoyance, they must support participants in the 'acquisition of knowledge' (i.e. provide information on the noise situation in the form that is comprehensible and allows people to understand the situation fully). The latter is essential to facilitate the 'moral development' required to appreciate both sides of any argument and provide opportunities for engagement in decision-making that can help to build consensus on the most acceptable outcomes.

Webler has more to say on the effectiveness of such efforts to build consensus and thus trust in the decision-making process and its outcomes when describing the Normative Model of Public Participation. His analysis of stakeholder involvement requires those evaluating the process to answer a number of questions to determine the fairness and competence of the stakeholder engagement. Webler (1995: 38) states that 'a normative model of public participation is one that expresses and defends a vision about what public participation should accomplish and in what manner'. It conveys a 'vision about what participation should accomplish and in what manner', bringing together 'two central goals of fairness and competence' (Petts, 1999b: 159). Fairness creates an opportunity where 'equality and popular sovereignty can emerge and personal competence can develop' (Webler, 1995: 38). Competence, on the other hand, 'refers to the ability of the participation process to provide participants with the procedural tools and knowledge needed to make the best possible decisions' (Petts, 1999: 159). Table 7 is a selection of Weber's fairness and competence criteria and indicators, which were adapted by Petts (1999) to illustrate how the normative model could be applied to environmental decision making (specifically environmental impact assessment procedures). The original criteria included 34 titles and 86 indicators, each of which were designed to assist in evaluating either the fairness or competence of participatory processes. The criteria encourage two-way conversations between proponents, speakers, listeners and participants, facilitating a non-hierarchical and consensual participatory process (Petts, 1999). They can also be applied to all participatory processes and allow those evaluating the activity to select the relevant criteria, as each lettered Section can be seen either independently or as a collective system. This concept of soliciting values and opinions from stakeholders with fair and competent knowledge is one which was also advocated by Habermas (1962) in his reflections on the bourgeois public sphere. **Habermas believed participants should be educated individuals who were able to reach a decision in an impartial and rational manner in an ideal speech situation.**

Table 7: Examples of criteria and indicators of fairness and competence (Webler, 1995 in Petts, 1999: 160)

| | |
|---|---|
| **A: Fairness – Agenda** | |
| A-1 | Does the process provide an opportunity for everyone to suggest issues to be discussed? |
| A-2 | Does the process provide an opportunity for everyone to debate the agenda for discussion and the rules by which the discussion will be controlled and to suggest changes to these rules and discussion proceeds? |
| A-3 | Does the process provide a means by which disagreements over the rules and agenda can be resolved and a consensus reached? |
| **B: Fairness – facilitator and rule enforcement** | |
| B-1 | Does the process provide an opportunity for everyone to suggest a facilitator of the consultation and participation activities and the style in which this facilitation should be conducted? |
| B-2 | If there are conflicts about the facilitator or the facilitation process, are there opportunities for these disagreements to be discussed and resolved in a consensual manner? |
| **C: Fairness – discussion** | |
| C-1 | Does the process attempt to identify the individuals or groups that are potentially affected? |
| C-2 | Does the process provide all potentially affected people an equal chance to participate? |
| C-3 | Does the process provide equal opportunities to everyone to express views, information and claims (based on knowledge, standards, beliefs, values)? |
| C-4 | Does the process provide for disputes over information and claims to be resolved in a consensually based manner, using procedures agreed in advance? |
| **D: Competence – understanding of definitions** | |
| D-1 | Does the process provide for equal access to commonly agreed upon definitions of terms which are relevant to the discussion? |
| D-2 | Does the process ensure that all terms, definitions and concepts are made explicit and are open to debate? |
| **E: Competence – access to experts** | |
| E-1 | Does the process ensure that, where expert knowledge is brought to the discussion, there is opportunity to challenge this knowledge? |
| E-2 | Is the process flexible enough to allocate time to consult other experts and for further information to be collected? |
| E-3 | Does the process provide financial support for participants to engage other expertise? |
| **F: Competence – access to anecdotal intuitive knowledge** | |
| F-1 | Does the process promote the consideration of anecdotal evidence and intuitive knowledge? |
| F-2 | Does the process provide opportunities for individuals to improve their own intuitive knowledge through direct experience (such as site visits etc)? |
| **G: Competence – checking of factual evidence** | |
| G-1 | Does the process provide a means by which the uncertainty in relation to factual evidence and predictions can be considered and discussed? |
| G-2 | Are peer review and independent verification of data and knowledge provided for? |
| G-3 | Are there opportunities for participants to choose and use independent experts? |
| G-4 | Does the process ensure that the range of expert opinion and knowledge about particular issues is made known to the participants? |

Table *7* – continued

| | |
|---|---|
| **H: Competence – checking of normative claims** | |
| H-1 | Does the process try to ensure that representation from formal interest groups, ad hoc groups and individuals is achieved? |
| H-2 | Is there use of an objective method to determine the potentially affected and interested parties and individuals? |
| H-3 | Does the process attempt to inform the wider / general population so that they can make informed judgements as to whether they might be affected? |
| H-4 | Does the process promote the elicitation of values and interests and inform others of these? |
| H-5 | Does the process ensure that all participants understand the consequences of their preferences before a decision is made? |
| H-6 | Are both rational and formal procedures used to ensure the development of understanding of different values and to optimise compromise? |
| **I: Competence – checking authenticity of claims** | |
| I-1 | Does the process encourage personal reflection? |
| I-2 | Does the process ensure that organisational and individual limitations and capabilities which may impact on the project are revealed and discussed? |
| I-3 | Does the presenter encourage participants to emphasise with presenters? |
| I-4 | Does the process provide sufficient time for speakers/presenters to accurately state and defend their expressed claims? |
| **J: Competence – reducing misunderstandings** | |
| J-1 | Does the process encourage participants to reach a compromise? |
| J-2 | Are opportunities taken to ensure that any existing consensus is stated and understood? |
| J-3 | Is feedback of final statements and agreements provided to allow verification? |

The ideal speech situation was the concept devised by Habermas to describe the beliefs and ideals participants must have before they can effectively contribute to decision-making. There are four criteria for ideal speech which are divided into two categories, the first two are trivial and the second two non-trivial (Habermas, 1973 in Hemmati et al., 2002: 67), discriminating participants and speakers:

1. All **potential participants** of a discourse must have the same chance to employ communicative speech acts;
2. All **discourse participants** must have the same chance to interpret, claim or asset, recommend, explain and put forth justifications, and justify or refute any validity claim;
3. The only **speakers** permitted in the discourse are those who have the same chance to employ **representative** speech acts[3];
4. The only **speakers** permitted in the discourse are those who have the same chance to employ **regulative** speech acts.[4]

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[3] A representative speech act commits the speaker to the truth of an expressed proposition. It represents the speaker's belief of something that can be evaluated to be true or false.

[4] A regulative speech act is intended to provide some form of structure to the conversation of the conclusions being drawn from it.

Webler simplifies these conditions in Table 8 and applies the concepts of fairness and competence, which emerged from his normative model for participation, to Habermas's ideal speech situation. The table illustrates the links between the two central goals and utilises the theories of ideal speech to present the criteria required for the model participation process.

Table 8: Conditions for fair and competent ideal speech situation (Webler, 1995: 60)

| Fairness | Competence |
|---|---|
| Anyone may participate | Minimal standards for cognitive and lingual competence |
| Assert validity claims | Access the knowledge |
| Challenge validity claims | Consensually-approved translation scheme |
| Influence final determinations of validity | Most reliable methodological techniques available |

One issue which Webler's conditions for ideal speech fails to account for is the fairness and competence standards required by the organisation or proponent that initiates the stakeholder participation. Under the conditions for fairness, the criteria could include involving all participants from within the organisation (internal stakeholders) and providing clear unbiased information. The conditions for organisation competence could comprise of ensuring external stakeholders understand the relevant information and that the participatory process involves a number of different methods, which occur at different periods of the day, to suite the diverse range of stakeholder groups. In this way the organisation provides a wide range of possible opportunities for stakeholder engagement in an attempt to ensure participation that is fully representative of the stakeholder community .

### 7.2.2 Public consultation: alternative approaches for fairness and competence

Illingworth and Jack (2018) provide a cautionary reminder about the inequality of the usual relationship between organisation or internal stakeholders and external participants:

> Typically, science communication between scientists (experts) and members of the public (non-experts) is rarely two-directional. A one-directional approach to communicating science and engaging an audience often leaves communities voiceless, disinterested, and discouraged (Fogg-Rogers and Hickman, 2014). For truly two-way dialogue to be established, the experts need to also listen to the non-experts, and to be willing to modify their approaches accordingly. Such an approach has been utilised with great success in communicating and developing medical research through the use of Community-Based Participatory Research (CBPR), which is defined by Green et al. (1995, pp. 4) as an "inquiry with the participation of those

affected by an issue for the purpose of education and action for effecting change." This approach presents experts (in this case health professionals and academics) and non-experts (community groups) with the opportunity to generate meaningful dialogue, and has been shown to give underserved and disadvantaged communities a discernible voice, thereby helping to increase the success of any potential intervention (Wallerstein and Duran, 2010).

Thus, a CBPR approach to aircraft noise exposure might then yield positive results amongst different community groups. However, the adaptation of such an approach is problematic, as despite the best intentions of researchers, a hierarchy of intellect is often established when people are encouraged to converse on a topic in which there is a perception that one of the parties is an expert and the other is not, as is the case with aircraft noise. **What is needed therefore, is the creation of an environment in which these hierarchies can be levelled, allowing non-experts (particularly underserved community groups) and experts to take part in meaningful dialogue about aircraft noise, and through which the understanding and opinions of the non-experts can be fully expressed, an initial step that should ideally be taken before the design and delivery of any potential interventions**. Such a step would then help to ensure that those affected were drivers of change rather than recipients of actions to which they had no ownership. Previous research has utilised techniques such as deliberative mapping (Bellamy et al., 2016) and the use of competency groups (Landström et al., 2011) to try to establish such two-way dialogues.

**Another suggestion for avoiding the traditional deficit model is the use of Q methodology** which should enable information about all stakeholders' viewpoints to be gathered in an unbiased way. The technique offers a way of revealing patterns and connections in opinions that cannot be revealed by non-statistical techniques. It establishes systematic patterns by identifying individuals who share attitudes, gives a structure to subjective opinion and has the potential to uncover insights into major social groupings' construction, in this case of aircraft noise, in terms of behaviour responses rather than the more traditional approach which uses social–demographic categories. Steelman and Maguire (1999, p. 2) describe Q-methodology as a tool for facilitating public involvement and understanding participant perspectives. They emphasise Q's ability to convey rigorous and systematic insight into the values and preferences of the public (Rajé, 2007).

There have been a few applications of the technique in aviation. For example, a Q study of the environmental discourses related to the expansion of Amsterdam's Schiphol Airport (van Eeten, 2000) investigated policy controversy surrounding the future of civil aviation at Schiphol Airport in the Netherlands. Amongst the factors revealed by this study's Q analysis were concerns about the problem of societal integration of the airport, the problem of the conditions needed to move civil aviation towards more sustainable development and the need to deal with the problems arising from the growing demand for mobility (Addams and Proops, 2000; van Eeten, 2000).

More recently, Q methodology was used to identify the frames of references held by those participating in the Australian aviation stakeholder arena to develop a better understanding of the context in which existing federal policy sits and to allow airport planners to navigate their way through the views of relevant stakeholders. The identification of these frames of reference across three Australian capital city airports revealed two underlying nation-wide discourses of ‘power’ and ‘functionality’ pertaining to utilization of the airport space, and aviation in general. These outcomes, though not providing a solution to existing controversies relating to airport expansion, nevertheless concretize the prevailing discourses that should be addressed when formulating and enacting aviation planning policy across the nation (Kivits and Charles, 2015, 102).

With respect to aircraft noise, Kroesen and Bröer (2009) adopted a social approach to investigating annoyance using Q methodology. The idea that aircraft noise is meaningful to people within a socially produced discourse was assumed and tested. In particular, the researchers expected that the noise policy discourse influences people’s assessment of aircraft noise. They used factor analysis and revealed five distinct frames as a result: “Long live aviation!”, “aviation: an ecological threat,” “aviation and the environment: a solvable problem,” “aircraft noise: not a problem,” and “aviation: a local problem.” It was shown that the former three frames were clearly related to the policy discourse. Based on this observation it was argued that policy making is a possible mechanism through which the sound of aircraft is turned into annoyance. In addition, the authors concluded that the experience of aircraft noise and, in particular, noise annoyance is part of coherent frames of mind, which consist of mutually reinforcing positions and include non-acoustical factors.

Effective public participation is very hard to do: genuine engagement should try to avoid anything that falls back in to using the deficit model. The use of alternative approaches which help close the distance between organisation and consultee to yield communities of common interest and understanding, made up of experts/internal stakeholders and non-experts/external stakeholders, can only benefit communication effectiveness and, thereby, influence non-acoustical factors contributing to aircraft noise annoyance. In an attempt to identify those attributes of engagement opportunities that could positively impact upon the annoyance generated by aircraft noise Maris et al (2007a,b) conducted laboratory experiments in which participants were exposed to noise in different social contexts. This helped them identify the attributes of ‘fair conditions’ for an initiative designed to reduce the annoyance generated by aircraft noise. These are listed as:

1. opportunities to participate in the decision-making process
2. taking into account the opinions of all parties
3. absence of bias in authorities (motivations trusted)
4. treating people with dignity and respect
5. access to relevant and accurate information
6. clear and appropriate information about the process and decision-making
7. consistent application of procedures across people and time

The resonance of these attributes with the priorities for engagement emerging from the preceding discussion are self-evident.

#### 7.2.3 Implications for Airport/Aviation Actors' Communication and Engagement Activities

These latter points are crucial to understanding how aviation actors should design communication and engagement processes that are likely to influence the non-acoustical factors contributing to noise annoyance. They imply that:

- Communication should be underpinned by a 'common language' that is comprehensible to all
- Access to expertise should be available to all
- Decision-making processes are inclusive, transparent and allow the validity of claims to be challenged

These points are emphasized using slightly different language in an adaptation to Davidson's Wheel of Participation made by Asensio et al (2017) (see Figure 7), which highlights that airports must shift from information provision and limited consultation to participation and empowerment if community engagement is to be genuine and influence the non-acoustical factors know to exacerbate annoyance responses.

A further is that if participation is to be secured and meaningful (and thus likely to influence attributes like attitudes and perceptions of fairness and trust) then communication and engagement should relate to issues that affect the participants i.e. relate to noise management or wider QoL issues directly impacting on communities close to airports.

Practically this means that airports need to:

- Communicate with local communities using noise descriptors that are easily understood and address the concerns of individuals (i.e. answer the - what does this mean for me? question). Earlier comments, and research indicating that current noise communication tends to be overly technical and does not address users needs (Gasco et al., 2017; Hooper & Flindell, 2013), suggest that this might best be achieved through metrics that disaggregate elements contributing to noise exposure such as through location-specific information on the loudness, number and timing of aircraft noise events

- Engage with affected communities from the outset of a Balanced Approach intervention from the design (e.g. location of a new noise preferred route), option selection (highlighting the strengths and weaknesses of each option including identifying potential 'winners' and 'losers'), implementation (including any trials) and evaluation (advanced agreement on monitoring regimes and expected outcomes should enable consensus on the success, or otherwise, of any intervention)

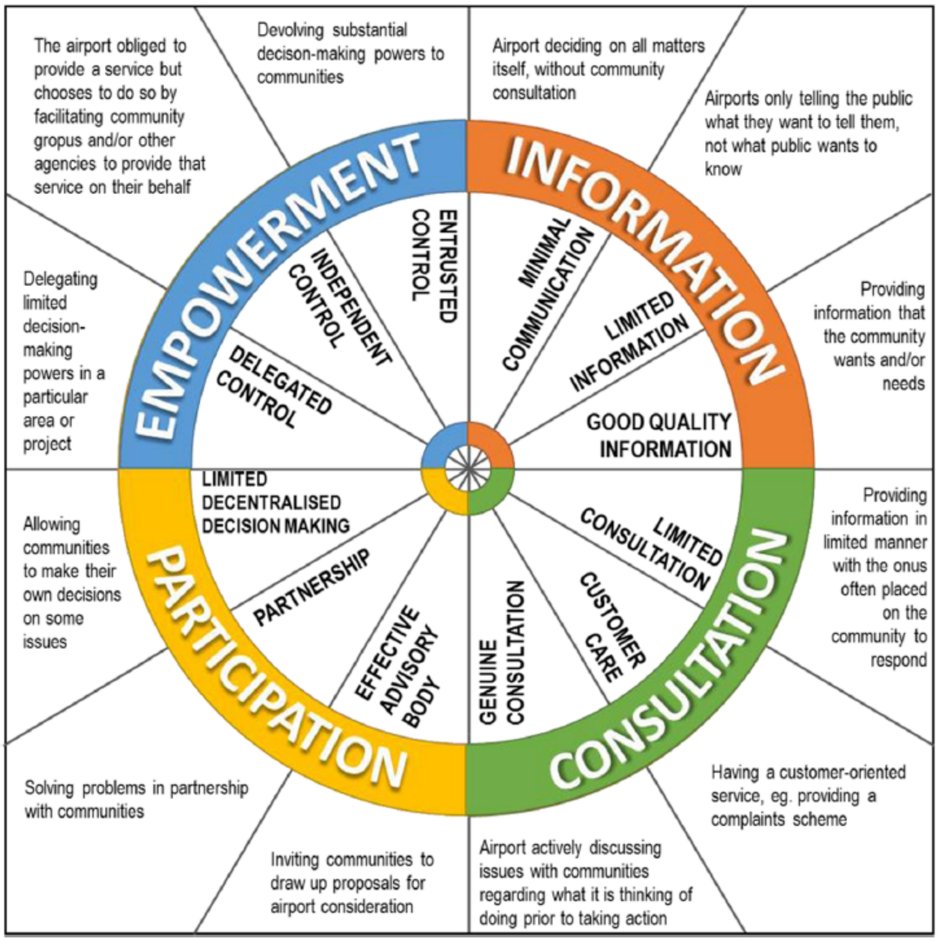


Figure 7: The Wheel of Participation as amended by Asensio et al (2017) for airports

This is not to say that realising such comprehensive communication and engagement processes is straightforward. Indeed, anecdotal evidence points to the need for intensive investment by airports in the **independent** 'education' of participants if they are to appreciate the operational causes of noise exposure, the technologically and economically feasible options for mitigation and the implications for communities on the ground and thereby be fully empowered to contribute to decision-making relating to potential noise management actions.

Such interventions are in their infancy, and some early examples are discussed below. Nevertheless these require more systematic evaluation – some of which will be attempted in WP 3 – if the aviation community is to optimise the impact communication and engagement on those non-acoustical factors known to exacerbate annoyance responses to aircraft noise exposure.

**Key messages of Section 7**

- Non-acoustical factors have received increasing attention in aviation noise annoyance studies in recent years.

- Non-acoustical factors refer to all non-sound-related factors that are known to affect annoyance and health responses to noise and include personal, social, environmental, and situational factors.

- Non-acoustical factors are typically arranged along two dimensions according to Vader (2007): 1) their **strength**, i.e., the magnitude of their influence (*strong*, *intermediate*, and *weak*), and 2) their **modifiability** by aviation authorities, i.e., their usability as an instrument (*modifiable*, *not modifiable*, and *unsure/need to be examined*).

- For management strategy approaches, those non-acoustical factors are crucial that are both known to yield strong impacts on the annoyance responses and that are modifiable. This applies particularly to ‘perceived disturbances’ and ‘perceived control’.

- These strong and modifiable non-acoustical factors can best be addressed through measures of communication and engagement (see section 8).

# 8 Interventions and Their Impact on Noise Annoyance and Quality of Life

Noise annoyance has – as described in the previous sections – many subjective aspects and is not only determined by mere acoustical impact, but also affected by non-acoustical influences. It follows, then, that seeking to address non-acoustical contributors can provide opportunities, beyond the established focus on mediating acoustic elements, to develop interventions aimed at reducing the annoyance related to noise.

In this section, we start by reviewing known findings on the influence of interventions on noise annoyance, health, and quality of life. Results from both quantitative and qualitative studies are discussed with a particular focus on the WHO review of Brown and van Kamp (2017) This systematic review of transport noise interventions and their health impacts is supplemented by information from other sources about noise interventions aimed at reducing annoyance. Although largely anecdotal in nature, these additional qualitative studies provide a richness to the understanding of the role that non-acoustical interventions can play in reducing noise annoyance. The value of qualitative approaches is to provide a more-nuanced insight into lived experience around airports, which is not captured in quantitative analysis and assessment.

Finally, referring back to Section 5 (*Understanding Annoyance),* and Section 7 (*Non-acoustical factors)*, we identify research gaps and needs, resulting in recommendations for further investigation.

## 8.1 Categorization of Noise Interventions

In 2017, Brown and van Kamp presented a systematic review of transport noise interventions for the WHO, covering interventions related to road traffic, railways, and air traffic, each aiming to reduce the negative health impacts of noise from the different sources.

In order to facilitate the comparison between and the evaluation of noise interventions, Brown and van Kamp (2017) developed a systematic and comprehensive categorisation for interventions, which is applicable to any noise source.

First, they distinguish "exposure-related actions", that "aim to change the level of noise exposure of people" (p. 873), from "non-exposure-related actions", that "are directed at changing health outcomes but do not include changing people’s exposure" (p. 873). These are further divided into altogether five categories of transport noise interventions:

A) source interventions,
B) path interventions,
C) new/closed infrastructure,
D) other physical interventions, and
E) education/ communication interventions.

Obviously, only interventions of category type 'E' belong to the "non-exposure-related actions" as described above. Table 9 contains further sub-categories as well as examples for illustration.

Table 9: Categorisation of noise interventions (taken from Brown and van Kamp, 2017)

| Type | Intervention Category | Intervention Sub-Category | Examples |
|---|---|---|---|
| A | Source Interventions | change in emission levels of sources | motor vehicle emission regulation; rail grinding; road surface change; change in traffic flow on existing roadways/ railways; change in number of aircraft flights |
| | | time restrictions on source operations | airport curfew, heavy vehicle curfew |
| B | Path Interventions | change in path between source and receiver | noise barrier |
| | | path control through insulation of receiver's dwelling | insulation of building envelope |
| C | New/ closed Infrastructure | opening of a new infrastructure noise source, or closure of an existing one | new flight path; new railway line; new road bypass; or closure of any of these |
| | | planning controls between (new) receivers and sources | urban planning control; "buffer" requirements |
| D | Other physical Interventions | change in other physical dimensions of dwelling/ neighbourhood | availability of a quiet side; appearance of the neighbourhood; availability of green space |
| E | Education/ communication interventions | change in behaviour to reduce exposures; avoidance or duration of exposure | Educating people on how to change their exposure |
| | | community education, communication | Informing people to influence their perceptions regarding sources, or explaining reason for noise changes |

Figure 8 shows where these different categories are located on a path ranging from noise sources to human outcomes.

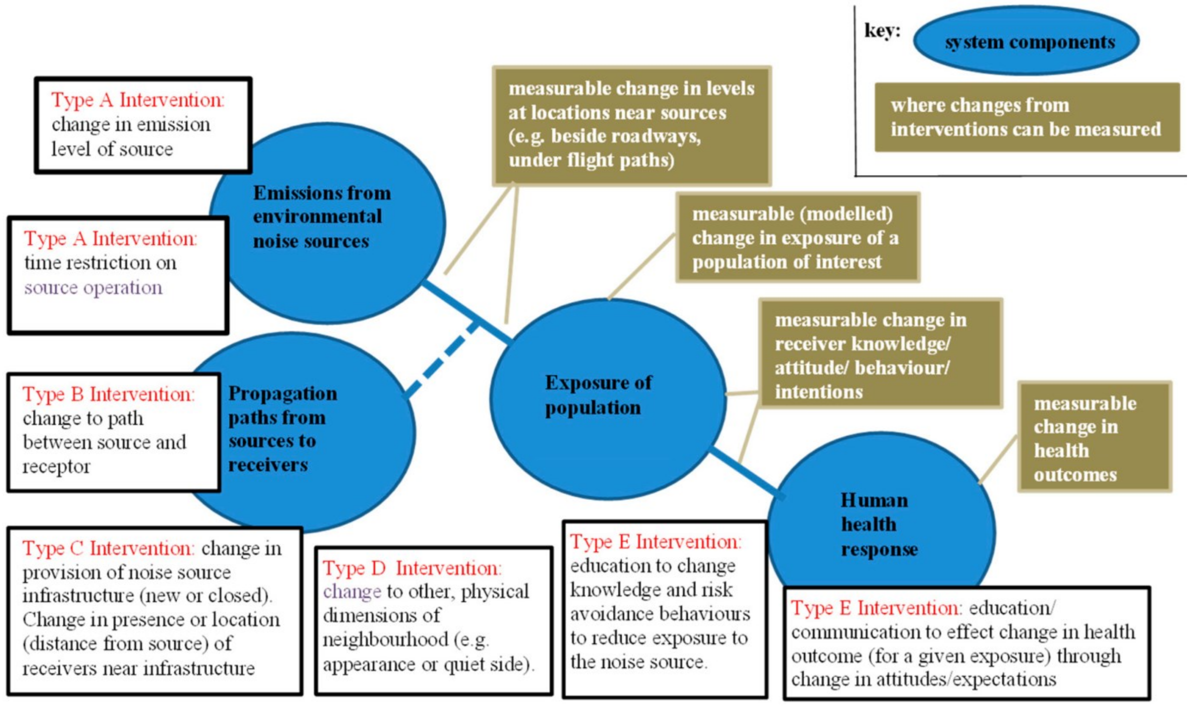


Figure 8: Intervention framework. Source: Brown & van Kamp (2017)

Noticeably, there is some overlap between the different intervention categories depicted in Table 9 and Figure 8 and Figure 9 and the pillars of the ICAO-Balanced Approach (BA) present in Section 4 and mentioned again in Section 7.2.

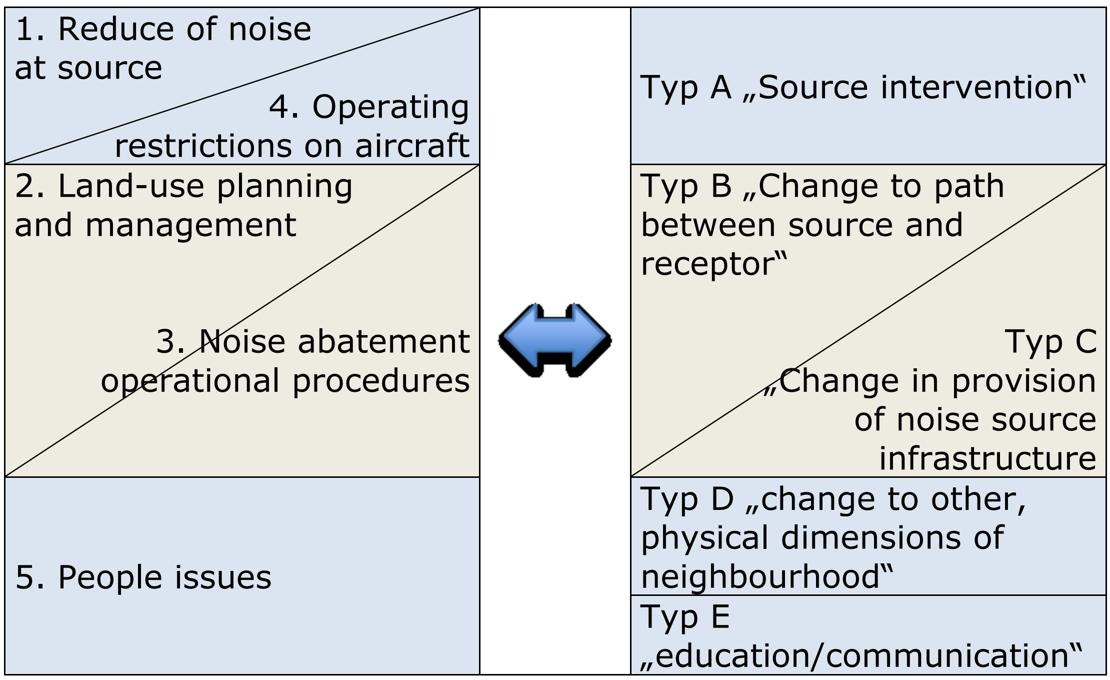


Figure 9: Overlap between BA pillars and types of interventions according to Brown and van Kamp (2017)

Type A interventions – "Source interventions" – refer on the one hand to a change in emission levels of the sources, thus clearly corresponding to the 1st BA pillar, "Reduction of noise at source". On the other hand, Type A interventions also apply to time restrictions on source operations, in this way also covering the 4th BA pillar, "Operating restrictions on aircraft", as summarized in Table 3 in Section 4.

Type B interventions – "*Path interventions*" – are concerned with changing the path between source and receiver as well as controlling the path through insulation of the receiver's dwelling. In the first sense, they refer both to the 3rd BA pillar, "Noise abatement procedures" as shown in Table 2 in Section 4, as well as to the 2nd BA pillar, "Land-use planning and management policies".

The 2nd BA pillar fits at the same time to type C interventions – "*New/closed infrastructure*", which refer to opening a new infrastructure noise source or closing an existing infrastructure and planning controls between the (new) receivers and the sources.

Type D interventions – "other physical interventions" – describe changes in other physical dimensions of the dwelling or neighborhood and do not directly match any of the BA pillars. Indirectly this intervention type aims at improving residential quality of life and thus is part of the broader approach of noise management which can be linked to the 5th BA pillar 'People issues'.

The intervention categories presented so far – A to D – and the related BA pillars 1 to 4 are all exposure-related. Remaining are the Type E interventions – "Education/communication interventions" as well as the 5th BA pillar presented in Section 7.2, "people issues". Both are non-exposure related and are very similar overall. They both focus on communication and engagement efforts, including aims to change behaviour to reduce exposures, or the avoidance/duration of exposure as well as community education and communication. For example, providing people with information in order to influence their perceptions regarding noise sources or explaining the reasons for noise changes has been shown to mitigate noise annoyance.

## 8.2 Review of Noise Interventions

Among the health effects considered in the review of noise interventions by Brown and van Kamp (2017), annoyance played a central role, next to sleep disturbances, cognitive impairment of children, and cardiovascular diseases.

Included in the review were all relevant intervention studies from 1980 to 2014 – altogether 43, 7 of which deal with air traffic noise interventions.

The authors differentiate the studies examined as to how the change intended by an intervention is measured. They make the following grading:

1. direct change in health outcomes,
2. intermediate change in exposure outcomes, and
3. change in knowledge/attitude outcomes.

Their main objective was to compile and analyze studies in which the intervention effects are directly measured in terms of health outcomes (1). However, acknowledging the well-known association between noise exposure and health outcomes, they also consider evaluations by the intermediate outcome in exposure measures to be appropriate and meaningful and accordingly also include studies of this kind (2). In addition, they also consider intervention studies that aim to change knowledge, perception or behavior (3). Thus, they are in line and reinforce the rationale that health outcomes, for example annoyance, are not soley dependent on a certain 'dose' of noise exposure: "Interventions (…) directed at changing knowledge or perceptions (…) may result directly in changes in health outcomes – as where a group may report lower annoyance scores from a transport source if authorities have under-taken a program of communication and explanation regarding the noise" (p. 873).

Brown and van Kamp (2017) describe in detail their systematic literature search for suitable intervention studies in various literature databases. They found that the number of such studies is very limited. Of originally 545 potential studies, only 43 eventually meet the criteria that they were intervention studies, that they dealt with transport noise, and that health outcomes were reported. As one of the main exclusionary reasons for studies, they state that oftentimes the effect of an intervention is reported solely as a change in the noise level at locations near the noise source, neglecting changes in the actual exposure of people, which would be required to assess the impact of an intervention on health outcomes.

Table 10 gives an overview of the distribution of studies regarding aircraft noise on the various outcome measures and intervention types according to their categorization described above.

Table 10: Included papers in the review of Brown and van Kamp (2017)

| | **Number of Peer Reviewed Papers** | **Number of Non-Peer Reviewed Papers** | **Total Papers per Group** |
|---|---|---|---|
| **Outcome: Annoyance** | | | |
| B Path Intervention | 1 | - | 1 |
| C New/ Closed Infrastructure | 2 | 1 | 3 |
| **Outcome: Sleep Disturbance** | | | |
| C New/ Closed Infrastructure | 1 | 1 | 2 |
| **Outcome: Cognitive Development in Children** | | | |
| C New/ Closed Infrastructure | 1 | - | 1 |
| **Outcome Modelled Change on Exposure/ Effect** | | | |
| A Source Intervention | 1 | - | 1 |

A total of 8 of the studies deal with aircraft noise sources, one of them only modelling a hypothetical intervention. Due to the overall small number of studies - and partly also due to restricted comparability because of diverse study designs, methods, and exposure levels - a systematic, statistical comparison of the studies was not possible. Instead, the authors described the results of their analyses in the style of a narrative review.

The path intervention study was around five Spanish airports (Asensio et. al, 2014). A noise insulation program (NIP) in Spain retrofitted dwellings near airports with acoustic insulation. The study looked primarily at the effectiveness of this program, namely in residents' satisfaction with the management of the process and the installation activities. It, also, assessed whether there had been a change in the annoyance (and sleep disturbance) as a result of the NIP. The study demonstrated a fall in annoyance following the insulation intervention. However, no statistical tests were reported on the change in annoyance, and comparisons with other studies, and with any ERF, were not appropriate as the study used retrospective assessment by participants as the before-intervention baseline against which to compare post-intervention annoyance scores.

All the studies in the new/closed infrastructure interventions group were associated with opening of new runways, closure of others, or flight path rearrangements (Brink et. al, 2008; Breugelmans et. al, 2007; Fidell et. al, 2002). Two were in Europe (Amsterdam and Zurich) and one in Canada (Vancouver). The interventions were the introduction, or removal, of overflights, as a step change, over certain areas near the respective airports—as distinct from increases or decreases of air traffic flow along existing flight paths. Two were before and after studies, and one a panel study with four waves of survey. The changes in exposure over the areas studied were highly variable, with only relatively small numbers of participants experiencing the larger changes in noise level (7, 12, and 14 dB: Lden or similar).

Nevertheless, for the majority of participants the change was much smaller, perhaps 1 to 2 dB. Changes in two of the studies included increased exposure as well as decreased exposure. In all three studies, there was evidence that the changes in noise exposure, as a consequence of the flight path changes, resulted in change in annoyance outcomes and that these observed changes were statistically significant.

In terms of sleep disturbance, in both studies (Breugelmans et. al, 2007; Fidell et. al, 2002), there was evidence that the changes in noise exposure as a consequence of flight path changes resulted in a change in sleep disturbance outcomes. In the Amsterdam study, it was also demonstrated that response was in the same direction, and of a magnitude, as estimated by a steady-state ERF for sleep disturbance for Amsterdam derived from before-intervention responses.

Finally, turning to cognitive development in children, the intervention in this study (Hygge et.al, 2002) involved relocation of flight paths resulting from the opening of a new airport and closure of another. The study found various cognitive effects on children (for both the reduction in exposure, and the increase in exposure), e.g. reading errors in lists of difficult words. That is, cognitive performance was impaired in children around the old airport before its closing. The cognitive performance improved again after the old airport was closed.

Instead, a deterioration of children's cognitive performance occurred around the new airport after its opening.

One of Brown and van Kamp’s key findings with regard to aircraft noise sources is that in many studies they observe a so-called ‚excess response‘, which „occurs when the magnitude of the observed change in outcomes is greater than that ‘predicted’ by the exposure-response function“ (p. 38). **This applies only to aircraft noise studies, not to studies of other transport noise sources, and, therefore, clearly indicates an impact of non-acoustical factors in this domain**.

Another thing that is striking with regard to Table 10 is that there is only one study of intervention type across all categories.

Overall the WHO review reveals a lack of studies on aviation interventions designed to address annoyance through non-acoustical means such as communication and engagement. However, there is some evidence that communication can have a positive impact on annoyance from a non-aviation study; namely the German Railway Grinding Study (Liepert et al., 2013; Schreckenberg et al., 2013), which points to the potential value of effective communication in having a positive impact on attitudes and thus on the acceptability of noise management interventions.
The authors studied the impact of rail grinding on noise annoyance and disturbance responses in communities along a railway line in South Germany between Munich/Augsburg (south-east) and Stuttgart (south-west). In the south-west (Stuttgart region) information was disseminated in communities about the rail grinding intervention and its (expected) sound level reducing impact. Information was distributed via mailings, leaflets, local radio news, press releases and press conferences with local majors, and representatives of German Railway (Deutsche Bahn) and the research team. In south-east (Munich/Augsburg region) no information was given prior to the rail grinding. About 3 months before and 1-2 months after the rail grinding railway sound levels were estimated for the home address of each of 340 residents participating in the study twice, before and after the grinding.

As expected, noise reductions were best for disc-braked trains (e.g. passenger trains about 5 to 7 dB) and less effective for freight trains (about 1 dB; see Liepert et al., 2013:1). Due to the failure of the rail grinding vehicle the noise reduction in the informed communities in the Stuttgart region was less than in the uninformed areas in the Munich/Augsburg region. However, it turned out that only residents from the informed communities showed a significant decrease in judgments of annoyance and disturbances of sleep, speech, recreation, and psycho-vegetative responses after the rail grinding, whereas changes in the noise responses of participants from the uninformed region did not reach statistical significance. Furthermore, when asked for perceived changes in disturbances due to railway noises at day and night-time after the rail grinding more participants from the informed communities reported a decrease in disturbances than did those from the uninformed communities.
As the authors of the railway grinding study stated, “it is likely that information about planned abatement measures given to exposed residents and transparency of implementation considerably support the impact of the technical/acoustical noise abatement measures on residents' noise responses and, thus, should

become common practice in noise control" (Schreckenberg et al., 2013:7). However, they also sounded a note of caution that the results do not mean "that for minimizing noise annoyance and disturbances leaflets and press releases can replace technical noise abatement measures." (Schreckenberg et al., 2013:7). This is line with the idea of regarding communication/engagement of communities being implemented as an integrated element of the four technical/acoustical BA pillars, not only as add-on separate aspect to them.

In a study that was reported after the Brown and van Kamp review period, Schreckenberg et al. (2016) presented results of an operational noise respite project at Frankfurt Airport (called '*Laermpausen*' = noise break) which includes as a one year trial the attempt to bring forward the night cut-off time (11pm to 5am) by one hour in the late evening period in certain areas around the airport, and by one hour in the early morning period in other areas to provide a seven hours night-time operations. This was achieved by re-distributing the shoulder hours approaching traffic between three of the four runways. A study with residents living in affected and areas not affected by the *Laermpausen* operation was conducted including a telephone survey and focus groups. All in all, respite from the *Laermpausen* operation was hardly if not at all perceived by the participants and annoyance judgements were not lower in areas that benefited from a decrease in sound levels during the hours of the *Laermpausen* operation compared to areas that suffered from an increase in sound levels or were not affected by the *Laermpausen* operation. One of the findings of the focus groups, also supported by results of the telephone survey, was that only a few were informed about the *Laermpausen* operation and that this noise respite project did not meet the perception and expectations of the residents. The term '*Laermpause*' was understood as a break in air traffic, i.e. that in the hours of *Laermpausen* operation no flight movements were expected. This was in contrast to the perception of flights in the hours of *Laermpausen* operation, that actually still occur. The focus group participants' impression was that this noise intervention would not work because airlines/the airport would not comply with it. This was in line with the survey findings that the mostly low to moderate trust in authorities' attempting to improve the noise situation for and quality of life of residents was strongly correlated with the annoyance judgment and the perception of the *Laermpausen* operation. The results of this study again indicate that at least informing about technical or operational noise management interventions if not engaging communities in the planning of it is essential for the efficacy of these measures in terms of reducing residents' aversive responses and attitudes to aircraft noise and aviation and for improving residents' quality of life.

The 'potential' of communication and engagement is reinforced by anecdotal evidence from a series of unpublished research projects at Heathrow airport that have focused on:

- **Evaluation of the sound insulation programme** - Considerable investments have been made over many years in providing noise insulation for houses and other buildings around the airport. Qualitative research carried out amongst recent recipients of financial contributions towards replacement windows fitted with high performance double glazing suggested that **personal contact by project management could be as**

**or more important in achieving satisfactory outcomes than simply making a financial investment**, which could be perceived (by some residents) simply as an obligation imposed on the airport by government regulations, and often thereby providing little or no public relations benefit. **Subjective impressions of the acoustic benefit appeared to be highly correlated with overall impressions of the project management process**, whether by the installer or the airport. Many residents perceived only limited, if any, objective benefit from the actual reductions in sound levels indoors before and after installation.

- **Impact of runway alternation** - Westerly landings at Heathrow are alternated between the north and south runways according to a long established pattern to provide a degree of noise respite on either mornings or afternoons, with a changeover at around 1500 hrs. It should be noted that runway alternation under less frequent easterly conditions does not occur at present due to long-standing commitments and infrastructure limits, meaning that the current respite pattern is incomplete. Recent research to investigate the perceived benefit of the current respite pattern discovered that while many otherwise uninformed residents are vaguely aware that the pattern of aircraft noise at Heathrow can vary considerably from one day to the next, they are not particularly aware that this variation follows a scheduled pattern, or of any particular benefit from it. However, after having been given detailed information about the current respite pattern, the majority of residents considered it to be of significant value to them. This research illustrated the significant effect of information and understanding on subjective perceptions of the airport and its mitigation strategies.

- **Public understanding of airport operations** - As part of the noise respite research, it was discovered that very few residents had much understanding of operations at the airport, and did not appreciate, for example, that there are only two runways. Most residents, when asked, assumed there must be at least five runways pointing in different directions and some suggested there could be as many as fifteen. It is easy to see that it would be impossible to understand the current runway alternation pattern without understanding that there are only two runways, which can be alternated between. A further discovery was that very few residents (without further information) could distinguish between landings and take-offs over their houses, or in which direction relative to the airport they were flying.

A key point arises from these combined experiences. **Communication efforts utilising extensive leaflet drops appeared to have had very little if any effect, most having been treated simply as junk mail**, to be disposed of as quickly as possible. Similarly, considerable investments in website and social media by the airport had achieved very little, **whereas individual contacts, in this case by researchers actually visiting residents in the own homes, could be highly effective in increasing understanding and thereby changing attitudes**. Important principles appeared to be; information must be individually tailored to individual levels of prior-knowledge and interest; anything that appeared overly technical, such as complicated sets of noise contours based on largely incomprehensible standard acoustic metrics, was unlikely to be effective and could even have negative effects on attitudes; information must be completely truthful and without 'spin' otherwise it risks being completely discounted; and finally, many residents are more likely to view sympathetically information provided by airport objector groups than information provided by the airport which may often appear counter-intuitive even if it is truthful. At Heathrow, in particular, there is a considerable backlog of negative controversy and disagreement, which cannot be overcome overnight and could justify considerable investment in alternative approaches to public engagement.

Overall this research, whilst anecdotal in nature has demonstrated the value of:

- Supplementary noise descriptors that appear to align with the perceptions of local residents and thus offer a 'common language' for describing noise exposure and thus any changes to noise that may result from a proposed intervention
- Use of this common language to describe airport operations and their noise consequences (e.g. with respect to respite)
- The development of 'educational' steps in the engagement process (using enhanced communication tools) to empower stakeholders to offer informed opinions about noise management interventions (indeed community participants have often been seen to be more accommodating of the airport as a result of the engagement process – which can be regarded as representative of an improved attitude to the airport and thus a feature that **may** ultimately reduce annoyance)

A key feature of this work has been working intensively with small groups/individuals. **Thus, whilst highlighting the potential of this type of communication and engagement exercise there are questions about the scalability of the approach.**

Overall the message is clear, enhanced communication and engagement provides an opportunity to address annoyance directly through affecting non-acoustical contributions to the annoyance response. However, whilst some airports at the lead-edge have been experimenting with such approaches there has been little/no systematic evaluation of these efforts nor indeed the wider consequences for more traditional exposure-reduction interventions (e.g. for impact on QoL for example). Further, research on the efficacy of certain forms of communication and engagement is so limited as to be of little use to airports when designing noise management interventions or more general community outreach programmes. This may explain why in many cases airport community engagement efforts do not yield the intended benefits for airports and communities alike.

## 8.3 Research and Management Needs

The previous remarks lead to the conclusion that there is obviously a research gap and even research (and noise management) needs.

Brown and van Kamp (2017) stress that in many studies they observe/determine a so-called 'excess response', which „occurs when the magnitude of the observed change in outcomes is greater than that 'predicted' by the exposure-response function" (p. 38), which indicates an impact of non-acoustical factors.
Moreover, a need for research can be derived from the combination of our previous sections on the definition of annoyance (in particular the reference to control, etc, section 5) with the non-acoustical factors (section 7).

We presented a theory for (the causes) of noise annoyance. Indicating key elements in the emergence/formation of noise annoyance are a number of features including perceived control, etc. Also, we showed that these factors could be influenced by non-acoustical contributors (we also provided some empirical evidence supporting the relevance of non-acoustical contributors to noise annoyance). These non-acoustical contributors can be addressed directly through enhanced noise interventions and noise management approaches.

Thus at the heart of effective noise management has to be a comprehensive response that addresses both the acoustical and non-acoustical contributors to annoyance. To date much of the industry focus has been on noise reduction at source complemented by exposure reduction/management through application of the 4 pillars of the Balanced Approach. Whilst this is entirely appropriate, if the societal benefit of these initiatives is to be optimised, these efforts should be underpinned by communication and engagement activities designed to involve exposed communities in decisions that affect them. In so doing airports can help address the perceived lack of control that can alienate communities and lead to poor attitudes to airports with consequent negative implications of annoyance responses. In other words, by focusing on the **process** by which change is designed, decisions are made on options, procedures are implemented and appropriate monitoring regimes determined, more socially acceptable outcomes should arise that may have beneficial impacts on tolerance/annoyance levels.

Such an approach requires evaluation of the outcomes of interventions that extends beyond the objective assessment of changes to noise exposure to embrace wider impacts such as that on annoyance, acceptability of management outcomes, attitudes to the source (airports) and QoL more generally. This in turn demands new approaches to research into the efficacy of balanced approach interventions which in part will be addressed in WP 3 where:

- ST3.1.2 – seeks to develop methodology for the assessment of BA interventions on attitudes and QoL
- ST3.2.1 – seeks to understand which communication and engagement tools have traction in terms of their capacity to facilitate engagement and thereby influence attitudes and potentially ultimately tolerance/annoyance

- ST3.3.2 – seeks a broader appreciation of the impact of noise and other aspects of living near airports on day-today activities and QoL

**Key messages of Section 8**

- To date, both management interventions and intervention studies have focused largely on acoustical factors and the mere reduction of noise exposure.
- To achieve optimal results and to reduce noise annoyance to a minimum, it is indispensable to implement a more comprehensive approach, addressing the totality of (known and potentially) contributing factors to noise annoyance, both acoustical and non-acoustical.
- Central to the success of such measures is the participation and engagement of the affected communities; both in their development and their realization, as well as their evaluation.
- For this it is important that hierarchies of intellect/knowledge and power are levelled as much as possible. This implies that a) a 'common language' should be established that is comprehensive to all, b) access to expertise should be available to all, and c) decision-making processes are inclusive, transparent and allow the validity of claims to be challenged.
- Practical implications for this approach include a) the use of noise descriptors that are easily understood, b) the engagement of airports and aviation authorities with affected communities from the outset of a Balanced Approach intervention from the design, implementation, and evaluation, and c) investments in the independent 'education' of participants.
- To date, few such interventions exist and more systematic evaluation is needed.

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# 10 Annex

## Ad Section 3 – Approach Systematic Literature Review on the Definition of Annoyance

The following section describes the systematic procedures for the preparation and conduct of the reviews on the definition of "aircraft noise annoyance."
The following 26 literature databases were used to conduct a literature search for scientific publications[5]: Applied Science & Technology Source, Applied Social Sciences Index and Abstracts (ASSIA), Bielefeld Academic Search Engine BASE, Digital National Security Archive, DIMDI, Environment Complete, GreenFILE, IngentaConnect, INSPEC, Library, Information Science & Technology Abstracts, Medline/Pubmed, OpenDissertations, Political Science Complete, ProQuest Social Science, PsycARTICLES, Psychology and Behavioral Sciences Collection, PsycINFO, Psyndex: Literature and Audiovisual Media with PSYNDEX Tests, Sage Journals Online, ScienceDirect, Scopus, Social Services Abstracts, SocINDEX with Full Text, Sociological Abstracts (CSA), SpringerLink, and Web of science.

In addition, we performed literature searches in the databases of the following conferences to find relevant conference papers: Euronoise (European Congress and Exposition on Noise Control Engineering; 1992-2018), Internoise and Noise-Con (International Congress and Exposition on Noise Control Engineering and Noise and Vibration Conference & Exhibition; 1971-2018), and ICBEN (International Commission on Biological Effects of Noise; 1973-2018).

The search in the databases mentioned above was specified as follows: The term 'annoyance' had to appear either in the title, in the abstract or as a keyword of a publication, as well as one of the terms 'noise' or 'sound'[6].
The search was not limited to aviation or aircraft noise annoyance at this point since there might exist explanatory models for the generation, maintenance or

[5] *Initially, the psychological and medical databases (i.e., Medline/Pubmed, PsycARTICLES, Psychology and Behavioral Sciences Collection, PsycINFO, Psyndex, Sage Journals Online, ScienceDirect, Scopus, and SpringerLink) were also searched through only with the search term 'annoyance', in order to find general determinants, explanatory models and consequences of annoyance. It turns out, however, that annoyance is almost exclusively investigated either 1) in the context of 'noise annoyance', which is already covered by the present search, or 2) in the context of aggressive behavior or 3) in a pathological manner (ICD10 diagnosis R45.4, "Irritability and anger"). These articles were therefore not included in the review/not considered any further for the review.*

[6] *A preliminary test had revealed that relevant articles were missing when the compound terms 'noise annoyance' and 'sound annoyance' were used.*

reduction of noise annoyance in related entities that might be transferable or modifiable for aircraft noise annoyance.

This way, a total of 7329 hits was obtained; after the removal of duplicates, 1973 hits remained.

Of these, 21 articles were denoted as reviews in the databases. These were considered separately at first. Seven of these articles explicitly deal with aircraft or aviation noise annoyance; these were used as starting point for the later analysis.
Of the remaining 1952 hits, those who exclusively dealt with children as a research or sample group were excluded.

This way, 1277 hits remained, which were then examined in a first step to check whether they address noise annoyance by civil aviation (not or not only by military aviation). This resulted in 259 publications that were retained for the final analysis (for the vast majority, the topic of the excluded articles was 1. tinnitus with 579 hits, followed by 2. road traffic noise with 302 hits).
In addition, however, the 1277 hits were also looked through to see if they offered a definition or an explanatory model for noise annoyance. This was true for a total of 16 hits that did not address civil aviation noise annoyance and were therefore not among the 259 articles already selected. These were also included in the final selection.
Finally, the reference lists of the seven reviews identified earlier were evaluated to see if they contained more pertinent literature. This resulted in 12 more relevant publications which were taken into account, all of which are technical reports or internet publications.
Thus, the contentual analysis is finally based on 289 articles.

For a categorization of the 289 articles, each was examined to see if it contained a definition of 'annoyance' or 'noise annoyance' anywhere in the text. Next, the various definitions have been classified by formal criteria and, according to the type of definition, been assigned to one of the following categories:

- Operational/validational psychological definition
- Def. via a theoretical framework
- Empirical definition via self-report measurement
- Empirical definition. via correlates/via high or low correlating other constructs
- Def. via examples
- Procedural def.
- Definition via precedents/causes
- Definition. via responses/consequences
- Notional/conceptual definition
- Lexical definition

For the content work, the seven available reviews on aircraft noise annoyance were used as a starting point. Besides, a synopsis was created across all articles for each of the types mentioned above of definitions. Additional aspects have been included in this review only to the extent that they have not been treated in any of the seven reviews already available; that is, where available or where possible, the findings of existing reviews have been supplemented or updated.

## Ad Section 4 – Approach Systematic Literature Review on Aircraft Noise Regulations and Management

| | | |
|---|---|---|
| **Step 1** | **Search Criteria** | - **The terms 'aircraft'/'aviation' with 'noise'/'sound' had to appear in the title, abstract/key word**<br>- **Not limited to aviation/aircraft industry organisation/organization** |
| | **Returned: 13,600** | |
| **Step 2** | Removal of duplicates/overlaps and organisational documents specifically identified as:<br>- airlines<br>- manufacturer<br>- government only bodies<br>- outside of Europe<br>- not specific to civil aviation | |
| | **Remaining: 1698** | |
| **Step 3** | **Identification of:** | - 60 relevant in accordance with criteria<br>- 6* of which specific to industry research *where available/possible, the findings of existing reviews have been supplemented or updated |
| | **Literature Review based on 66 articles** | |

## 11 Glossary

# A

### A-Weighted Noise Exposure Level Normalized to a Nominal 8h Working Day ($L_{EX,8h}$)

*Definition:* "level, in decibels, given by the formula

$$L_{EX,8h} = L_{pAeq,Te} + 10\lg(T_e / T_0)\,dB$$

where

$L_{pAeq,Te}$ is the A-weighted equivalent continuous sound pressure level for $T_e$;

$T_e$ is the effective duration of the working day in hours;

$T_0$ is the reference duration ($T_0$=8h).

Note 1 to entry: The quantity "noise exposure level normalized to a nominal 8 h working day" may also be called "daily noise exposure level".

Note 2 to entry: If the exposure averaged over n days is desired, for example if noise exposure levels normalized to a nominal 8 h working day for weekly exposures are considered, the average value of $L_{EX,8h}$, in decibels, over the whole period may be determined from the values of $(L_{EX,8h})_i$ for each day using the following formula:

$$\overline{L_{EX,8h}} = 10\lg\left[\frac{1}{c}\sum_{i=1}^{n} 10^{0,1(L_{EX,8h})_i}\right] dB$$

The value of c is chosen according to the purpose of the averaging process: it will be equal to n if an average value is desired; it will be a conventional fixed number if the exposure is to be normalized to a nominal number of days (for example, when n = 7, c = 5 will lead to a daily noise exposure level normalized to a nominal week of 5 eight-hour working days). For consideration of irregular exposures over an extended time period, see ISO 9612."

*Source:* ISO 1999:2013 ("Acoustics-Estimation of noise-induced hearing loss")

### Absorption

*Definition:* "The conversion of sound energy into another form of energy, usually heat, when passing through an acoustical medium."

*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Absorption Coefficient

*Definition:* "Ratio of sound absorbing effectiveness, at a specific frequency, of a unit area of acoustical absorbent to a unit area of perfectly absorptive material."

*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

**Acoustics**

*Definition:* "The science of the production, control, transmission, reception and effects of sound and of the phenomenon of hearing."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

**Active Sound Field**

*Definition:* "A sound field in which the particle velocity is in phase with the sound pressure. All acoustic energy is transmitted, none is stored. A plane wave propagating in free field is an example of a purely active sound field and constitutes the real part of complex sound field."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("SOUND INTENSITY", pg. 28-29)

**Adjustment**

*Definition:* "quantity, positive or negative, constant or variable, that is added to a predicted or measured acoustical level to account for some sound character, the time of day, or the source type"
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

**Aircraft Operation**

*Definition:* "<acoustics> movement (apart from taxiing) of an aircraft over or near to a sound monitor that can result in detection of the sound as an aircraft sound event"
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

**Aircraft Sound Event**

*Definition:* "data set of acoustical descriptors adequately describing a sound event produced by a single aircraft operation
Note 1 to entry: Depending on the context, the words, "aircraft event" and "single event" mean an aircraft sound event."
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

**Aliasing Error**

*Definition:* "An error in digital sampling in which two frequencies cannot be distinguished. Caused by sampling at less than twice the maximum frequency in the signal."

*Source: „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)*

**Ambient Noise**
*Definition:* "All-pervasive noise associated with a given environment."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

**Amplitude Distribution**
*Definition:* "A method of representing time-varying noise by indicating the percentage of time that the noise level is present in a series of amplitude intervals."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

**Anechoic Room**
*Definition:* "A room whose boundaries effectively absorb all incident sound over the frequency range of interest, thereby creating essentially free field conditions."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

**Approach**
*Definition:* "<aircraft acoustics> movement of an aircraft from when the sound can be distinguished above the residual sound to the exist from the runway after landing or to the moment when the sound becomes indistinguishable above the residual sound (whichever is the first to occur)"
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

**AS-weighted sound pressure level $L_{p,AS}(t)$**
*Definition:* "ten times the logarithm to the base 10 of the ratio of the square of the sound pressure, $p$, to the square of a reference value, $p_0$, expressed in decibels and measured with the frequency weighting A and time weighting S (slow) where the reference value, $p_0$, is 20 µPa
Note 1 to entry: For details see IEC 61672-1.
Note 2 to entry: Adapted from ISO/TR 25417:2007[1], 2.2."
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

**Audibility Threshold**
*Definition:* "The sound pressure level, for a specified frequency, at which persons with normal hearing begin to respond."

*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Automated Sound Monitoring System
*Definition:* "entire automated continuous sound monitoring system including all monitors […], the base or central data collection position (host station) and all software and hardware involved in its operation"
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

## B

### Background Noise
*Definition:* "The ambient noise level above which signals must be presented or noise sources measured."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Background Sound ($L_{p,AS,res,T}$)
*Definition:* "indicator of residual sound
Note 1 to entry: Background sound may be estimated by the 95 % exceedance level of total sound ($L_{p,\mathrm{AS},95}$) .
Note 2 to entry: Some countries use $L_{p,\mathrm{AS},90}$ or $L_{p,\mathrm{AS},99}$ instead of $L_{p,\mathrm{AS},95}$ as the indicator of background sound."
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

### Band Pressure Level
*Definition:* "Sound pressure level corresponding to the part of the spectrum (octave) under measurement."
*Source:* ISO 532:1975 ("Acoustics-Method for calculating loudness level")

### Band Pressure Level
*Definition:* "Sound pressure level corresponding to the part of the spectrum under measurement. Symbols $L_{GF}$, $L_{GD}$ signify band pressure levels in a critical band (Frequenzgruppen), for frontal sound F and diffuse field D respectively."
*Source:* ISO 532:1975 ("Acoustics-Method for calculating loudness level")

### Bandwidth (-3 dB)
*Definition:* "The spacing between the frequencies at which a filter attenuates by 3 dB. Normally expressed as frequency difference for constant bandwidth filters and as percent of center frequency for constant percentage filters."

*Source: „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)*

### Bandwidth (Effective Noise)
*Definition:* "The bandwidth of an ideal filter that would pass the same amount of power from a white noise source as the filter described. Used to define bandwidth of third-octave and octave filters."
*Source: „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)*

## C

### Calculated Loudness Level
*Definition:* "Calculated loudness level expressed in phons (GF) or phons (GD) […]. The abbreviations GF and GD signify that the calculation is based on critical bands and refer to frontal sound and a diffuse field respectively. […]
Note 1 to entry: The term phon, without a qualifying abbreviation, should be reserved for the expression of loudness levels determined by direct subjective measurement."
*Source:* ISO 532:1975 ("Acoustics-Method for calculating loudness level")

### Calculation Method
*Definition:* "set of algorithms to calculate the sound pressure level at a specified **receiver location** […] from measured or predicted sound power levels and sound attenuation data"
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

### Calibration Check Frequency
*Definition:* Nominal frequency, in the range from 160 Hz to 1250 Hz, of the sinusoidal sound pressure produced by a sound calibrator that is used in checking and adjusting a sound level meter.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

### Centre frequency
*Definition:* "The arithmetic centre of a constant bandwidth filter, or the geometric centre (midpoint on a logarithmic scale) of a constant percentage filter."
*Source: „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)*

## Community Tolerance Level ($L_{ct}$)

*Definition:* "day-night sound level at which 50 % of the people in a particular community are predicted to be highly annoyed by noise exposure

Note 1 to entry: $L_{ct}$ is used as a parameter that accounts for differences between sources and/or communities when predicting the percentage highly annoyed by noise exposure."

*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Complex Intensity

*Definition:* "Complex intensity is the combined intensity and imaginary intensity."

*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("SOUND INTENSITY", pg. 28-29)

## Constant Bandwidth Filter

*Definition:* "A filter which has fixed frequency bandwidth, regardless of center frequency."

*Source: „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)*

## Constant Percentage Filter

*Definition:* "A filter whose bandwidth is a fixed percentage of centre frequency."

*Source: „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)*

## Continuous Sound Measurement

*Definition:* "uninterrupted measurement of a sound level meter (or equivalent instrument)

Note 1 to entry: This measurement provides the continuous time-varying sound pressure level, $L_p(t)$."

*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

## Critical Bands (Frequenzgruppen)

*Definition:* "Critical bands approximated by bands one third-octave wide above 280 Hz and by groups of one-third octave bands for lower frequencies."

*Source:* ISO 532:1975 ("Acoustics-Method for calculating loudness level")

## Cumulative Distribution

*Definition:* "A method of representing time-varying noise by indicating the percentage of time that the noise level is present above (or below) a series of amplitude levels."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

# D

## Damping

*Definition:* (1) "The action of frictional or dissipative forces on a dynamic system causing the system to lose energy and reduce the amplitude of movement."
(2) "Removal of echoes and reverberation by the use of sound-absorbing materials" (also: sound proofing)
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Day-Evening-Night Sound Level

*Definition:* "day-evening-night-weighted sound pressure level is defined by

$$L_{den} = 10\lg\left[\frac{1}{24h}\left(t_{day}\cdot 10^{0,1L_{day,12}} + t_{evening}\cdot 10^{0,1\left(L_{evening,4}+5dB\right)} + t_{night}\cdot 10^{0,1\left(L_{night,8}+10dB\right)}\right)\right]dB$$

where $t_{day}$, $t_{evening}$, and $t_{night}$ are expressed in hours and $t_{day} + t_{evening} + t_{night} = 24$ h.
Note 1 to entry: The default values for $t_{day}$, $t_{evening}$, and $t_{night}$ are 12 h, 4 h, and 8 h, respectively, but individual countries, e.g. EU member states, reduce the evening period."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Day-Night Sound Level ($L_{dn}$)

*Definition:* "day-night-weighted sound pressure level is defined by

$$L_{dn} = 10\lg\left[\frac{1}{24h}\left(t_{day}\cdot 10^{0,1L_{day,15}} + t_{night}\cdot 10^{0,1\left(L_{night,9}+10dB\right)}\right)\right]dB$$

where $t_{day}$ and $t_{night}$ are expressed in hours and $t_{day} + t_{night} = 24$ h.
Note 1 to entry: The default values for $t_{day}$ and $t_{night}$ are 15 h and 9 h, respectively."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Day Sound Level ($L_{day,h}$)

*Definition:* "equivalent continuous sound pressure level when the reference time interval is the day
Note 1 to entry: Subscript h indicates the number of hours, e.g. $L_{day,12}$.
Note 2 to entry: A day is normally the 12 h between 7 h and 19 h or the 15 h between 7 h and 22 h. However, individual countries define day differently, e.g. 6 h to 18 h or 6 h to 22 h."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Decibel Scale

*Definition:* "A linear numbering scale used to define logarithmic amplitude scale, thereby compressing a wide range of amplitude values to a small set of numbers."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Degrees of Freedom, Statistical

*Definition:* "A measure of the statistical reliability of random signal data."
*Source: „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)*

## Departure

*Definition:* "<aircraft acoustics> movement of an aircraft from the start of roll on take-off or from the moment when the sound can be distinguished above the residual sound (whichever is the last to occur) to when the sound becomes indistinguishable above the residual sound"
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

## Diffraction

*Definition:* "The scattering of radiation at an object smaller than one wavelength and the subsequent interference of the scattered wavefronts."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Diffuse Field

*Definition:* "A sound field in which the sound pressure level is the same everywhere and the flow of energy is equally probable in all directions."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Diffuse Sound

*Definition:* "Sound that is completely random in phase; sound which appears to have no single source."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Directivity Factor

*Definition:* "The ratio of the mean-square pressure (or intensity) on the axis of a transducer at a certain distance to the mean-square pressure (or intensity) which a spherical source radiating the same power would produce at that point"
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Discrete Fourier Transform

*Definition:* "A version of the Fourier Transform applicable to a finite number of discrete samples."
*Source: „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)*

## E

### Emission Window

*Definition:* "set of emission conditions during which measurements can be performed with limited variation in measurement results due to variations in operating conditions"
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

### EPNdB

*Definition:* "Is a measure of Effective Perceived Noise Level (EPNL) which is a single number evaluator of the subjective effects of aircraft noise on human beings. EPNL is adjusted for the spectral irregularities and the duration of noise."
*Source:* ICAO ENVIRONMENTAL REPORT 2013. AVIATION AND CLIMATE CHANGE https://www.icao.int/environmental-protection/pages/envreport13.aspx

### Equal-Loudness-Level Contour

*Definition:* "equal-loudness-level contour that represents the average judgment of otologically normal persons within the age limits from 18 years to 25 years inclusive"
*Source:* ISO 226:2003 ("Acoustics-Normal equal-loudness-level contours")

## Equal-Loudness Relationship

*Definition:* "curve or function expressing, for a pure tone of a given frequency, the relationship between its loudness level and its sound pressure level"
*Source:* ISO 226:2003 ("Acoustics-Normal equal-loudness-level contours")

## Equivalent Continuous Sound Pressure Level ($L_{eq,T}$)

*Definition:* "ten times the logarithm to the base 10 of the ratio of the time-average of the square of the sound pressure, p, during a stated time interval of duration, T (starting at $t_1$ and ending $t_2$), to the square of the reference sound pressure, $p_0$
Note 1 to entry: The A-weighted equivalent continuous sound pressure level is

$$L_{Aeq,T} = 10\lg \frac{\frac{1}{T}\int_{t_1}^{t_2} p_A^2(t)dt}{p_0^2} dB$$

where
$p_A(t)$ is the A-weighted instantaneous sound pressure at running time t; $p_0$ is equal to 20 µPa.
Note 2 to entry: The equivalent continuous sound pressure level is also termed "time-averaged sound pressure level". It is expressed in decibels (dB)."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Equivalent Continuous Sound Pressure Level (Time-Averaged Sound Pressure Level) $L_{p,eq,T}$

*Definition: Definition:* „ten times the logarithm to the base 10 of the ratio of the time average of the square of the sound pressure, *p*, during a stated time interval of duration, *T* (starting at $t_1$ and ending at $t_2$), to the square of a reference value, $p_0$, expressed in decibels

$$L_{p,eq,T} = 10\lg \left[ \frac{\frac{1}{T}\int_{t_1}^{t_2} p^2(t)dt}{p_0^2} \right] dB$$

where the reference value, $p_0$, is 20 µPa
Note 1 to entry: Because of practical limitations of the measuring instruments, $p^2$ is always understood to denote the square of a frequency-weighted and frequency-band-limited sound pressure. If a specific frequency weighting as specified in IEC 61672-1 and/or specific frequency bands are applied, this should be indicated by appropriate subscripts, e.g. $L_{p,\mathrm{A,oct,10\,s}}$ denotes the A-weighted time-averaged octave-band sound pressure level over 10 s.

Note 2 to entry: $L_{p,\text{eq},T}$ can be interpreted as the sound pressure level of a stable and permanent sound that has the same average energy as the sound under study.
Note 3 to entry: Adapted from ISO/TR 25417:2007[1], 2.3.
Note 4 to entry: $L_{p,\text{eq},T}$ is mostly used in the following two applications: a) a series of $L_{p,\text{eq},T}$, each averaged over a short time interval (typically 1 s, then called "one second equivalent continuous sound pressure level, $L_{p,\text{eq},1\,\text{s}}$", often abbreviated as "short $L_{\text{eq}}$") to describe the level-time history of time-varying sound, and b) single $L_{p,\text{eq},T}$, averaged over long times (e.g. 1 h or longer) to describe the overall (average) sound situation."
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

### Evening Sound Level ($L_{evening,h}$)

*Definition:* "equivalent continuous sound pressure level when the reference time interval is the evening
Note 1 to entry: Subscript h indicates the number of hours, e.g. $L_{evening,4}$.
Note 2 to entry: An evening is normally the 4 h between 19 h and 23 h. However, individual countries define evening differently, e.g. 18 h to 22 h."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

### Event Classification

*Definition:* "classification of sound events based primarily on acoustical knowledge
Note 1 to entry: Sound events can be classified into "aircraft sound events" or a "non-aircraft sound events".
Note 2 to entry: Depending on the implementation, event detection and event classification can be combined in one stage."
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

### Event detection

*Definition:* "extraction of discrete sound events based on acoustical criteria"
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

### Event identification

*Definition:* "procedure for use of non-acoustical data to confirm the probable relationship of a sound event to a specific aircraft operation"
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

# F

## Far Field

*Definition:* "Distribution of acoustic energy at a very much greater distance from a source than the linear dimensions of the source itself; the region of acoustic radiation used to the source and in which the sound waves can be considered planar. *See also:* diffraction"
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Fast Fourier Transform (FFT)

*Definition:* "A rapid method for computing the Discrete Fourier Transform."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49)

## Fence

*Definition:* "hearing threshold level above which degrees of hearing disability are deemed to exist"
*Source:* ISO 1999:2013 ("Acoustics-Estimation of noise-induced hearing loss")

## Fluctuating Sound

*Definition:* "continuous sound whose sound pressure level varies significantly, but not in an impulsive manner, during the observation period"
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Fourier Transform

*Definition:* "A mathematical operation for decomposing a time function into its frequency components (amplitude and phase). The process is reversible, and the signal can be reconstructed from its Fourier components."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)

## Free field

*Definition:* "An environment in which there are no reflective surfaces within the frequency region of interest."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Free Sound Field
*Definition:* "sound field where the boundaries of the room exert a negligible effect on the sound waves"
*Source:* ISO 226:2003 ("Acoustics-Normal equal-loudness-level contours")

### Frequency weighting
*Definition:* For a sound level meter, the difference between the level of the signal indicated on the display device and the corresponding level of a constant-amplitude steady-state sinusoidal input signal, specified in this standard as a function of frequency.
NOTE: The difference in level is expressed in decibels (dB).
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## H

### Hanning Weighting
*Definition:* "An amplitude weighting of the time signal. Used with gated continuous signals to give them a slow onset and cutoff in order to reduce the generation of side lobes in their frequency spectrum."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)

### Hearing Disability
*Definition:* "effect of hearing loss on activities in daily living
Note 1 to entry: This is sometimes called "activity limitation" (WHO)."
*Source:* ISO 1999:2013 ("Acoustics-Estimation of noise-induced hearing loss")

### Hearing Loss
*Definition:* "An increase in the threshold of audibility due to disease, injury, age or exposure to intense noise."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Hearing Loss
*Definition:* "deviation or a change for the worse of the threshold of hearing from normal
Note 1 to entry: The term hearing loss may sometimes only refer to a change."
*Source:* ISO 1999:2013 ("Acoustics-Estimation of noise-induced hearing loss")

## Hearing Threshold Level associated with Age (HTLA/H)

*Definition:* "for a specified fraction of a population, the hearing threshold level observed as a function of age without any exposure to occupational noise
Note 1 to entry: HTLA can be directly observed only in the absence of other causes of hearing impairment, for example, pathological conditions or noise exposure."
*Source:* ISO 1999:2013 ("Acoustics-Estimation of noise-induced hearing loss")

## Hearing Threshold Level associated with Age and Noise (HTLAN/H')

*Definition:* "permanent hearing threshold level for a specified fraction of a population
Note 1 to entry: Hearing threshold levels (HTL), as defined in ISO 389, are expressed in decibels.
Note 2 to entry: The value HTLAN is a combination of the components associated with noise (NIPTS […]) and with age (HTLA […]) […]"
*Source:* ISO 1999:2013 ("Acoustics-Estimation of noise-induced hearing loss")

## Hertz

*Definition:* "The unit of frequency measurement, representing cycles per second."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## High-Energy Impulsive Sound Source

*Definition:* "explosive source where the equivalent mass of TNT exceeds 50 g, or sources with comparable characteristics and degree of intrusiveness
Note 1 to entry: Sources of sonic booms include such items as aircraft, rockets, artillery projectiles, armour projectiles, and other similar sources. This category does not include the short duration sonic booms generated by small arms fire and other similar sources.
EXAMPLE: Quarry and mining explosions, sonic booms, demolition, or industrial processes that use high explosives, explosive industrial circuit breakers, and military ordnance (e.g. armour, artillery, mortar fire, bombs, explosive ignition of rockets, and missiles)."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Highly Impulsive Sound Source

*Definition:* "source with highly impulsive characteristics and a high degree of intrusiveness

EXAMPLE: Small arms fire, hammering on metal or wood, nail guns, drop-hammer, pile driver, drop forging, punch presses, pneumatic hammering, pavement breaking, or metal impacts in rail-yard shunting operations."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

# I

### Ideal Filter

*Definition:* "A filter having a rectangularly shaped characteristic, unity amplitude transfer within its passband and zero transfer outside its passband."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)

### Identified Aircraft Sound Event

*Definition:* "aircraft sound event that is positively related to a specific aircraft operation
Note 1 to entry: The data set of the identified aircraft sound event can include operational information like aircraft type, runway, and route."
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

### Imaginary Intensity

*Definition:* "Imaginary intensity is the non-propagating part of the sound field (sometimes called the reactive part)."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("SOUND INTENSITY", pg. 28-29)

### Impedance, Specific Acoustic

*Definition:* "The complex ratio of dynamic pressure to particle velocity at a point in an acoustic medium, measured in rayls (1 rayl = 1 N · sec/m$^3$)."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Impulsive Sound

*Definition:* "sound characterized by brief bursts of sound pressure
Note 1 to entry: The duration of a single impulsive sound is usually less than 1 s."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Independent Measurement

*Definition:* "consecutive measurements carried out with a time space long enough to make both source operating conditions and sound propagation conditions statistically independent of the same conditions of other measurements in the series
Note 1 to entry: In order to achieve independent conditions for meteorological conditions, a time space of several days is normally required."
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

## Infrasound

*Definition:* "Sound at frequencies below the audible range, i.e. below about 16 Hz"
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Initial Sound

*Definition:* "total sound present in an initial situation before any change to the existing situation occurs"
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Intensity

*Definition:* "Intensity is the real part of the complex intensity and is the propagating part of the sound field (sometimes called the active part)."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("SOUND INTENSITY", pg. 28-29)

## Intermittent Sound

*Definition:* "sound that is present at the observer only during certain time periods that occur at regular or irregular time intervals and is such that the duration of each such occurrence is more than about 5 s
EXAMPLE: Motor vehicle noise under conditions of small traffic volume, train noise, aircraft noise, and air-compressor noise."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Isolation

*Definition:* "Resistance to the transmission of sound by materials and structures."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

# L

### $L_{AeqT}$

*Definition:* "Equivalent continuous sound level. The steady dB(A) level which would produce the same A-weighted sound energy over a stated period of time as a specified time-varying sound."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Community Noise Criteria", pg. 16)

### $L_{dn}$

*Definition:* "A 24-hour $L_{AeqT}$, except 10 dB is added to all levels measured between 2200 and 0700 hrs."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Community Noise Criteria", pg. 16)

### $L_{EPN}$

*Definition:* "Effective Perceived Noise Level. A complex rating used to certify aircraft types for flyover noise. Includes corrections for pure tones and for duration of the noise."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Community Noise Criteria", pg. 16)

### $L_I$

*Definition:* "Sound Intensity Level of the sound field"
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Dynamic Capability", pg. 29)

### $L_{I,R}$

*Definition:* "Sound Intensity Level measured with an intensity measuring system during calibration"
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Dynamic Capability", pg. 29)

### $L_K$

*Definition:* "Reactivity Index for the sound field"
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Dynamic Capability", pg. 29)

### $L_{K,O}$

*Definition:* "Residual Intensity Index for the measuring system"
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Dynamic Capability", pg. 29)

**$L_N$**

*Definition:* "The dB(A) level exceeded N% of the time, e.g. $L_{90}$, the dB(A) level exceeded 90% of the time, is commonly used to estimate ambient noise level."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Community Noise Criteria", pg. 16)

**$L_{NP}$**

*Definition:* "Noise Pollution Level. A variation of $L_{AeqT}$ which accounts for short-term variability in noise level. For a Gaussian distribution of dB(A) level, it is defined as:

$$L_{NP} = L_{eq} + \left(L_{10} - L_{90}\right) \text{ "}$$

*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Community Noise Criteria", pg. 16)

**$L_P$**

*Definition:* "Sound Pressure Level of the sound field"
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Dynamic Capability", pg. 29)

**$L_{P,R}$**

*Definition:* "Sound Pressure Level measured with an intensity measuring system during calibration"
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Dynamic Capability", pg. 29)

**Level Linearity Error**

*Definition:* At a stated frequency, an indicated signal level minus the anticipated signal level.
NOTE: Level linearity error is expressed in decibels (dB).
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

**Level Range**

*Definition:* Range of nominal sound levels measured with a particular setting of the controls of a sound level meter.
NOTE: Level range is expressed in decibels (dB).
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

**Linear Operating Range**

*Definition:* On any level range and at a stated frequency, the range of sound levels over which level linearity errors are within the tolerance limits specified in this standard.
NOTE: Linear operating range is expressed in decibels (dB).

*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

**Long-Term Measurement**

*Definition:* "measurement sufficiently long to encompass all emission situations and meteorological conditions which are needed to obtain a representative average"
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

**Long-Term Time Interval**

*Definition:* "specified time interval over which the sound of a series of reference time intervals is averaged or assessed
Note 1 to entry: The long-term time interval is determined for the purpose of describing environmental noise as it is generally designated by responsible authorities.
Note 2 to entry: For long-term assessments and land-use planning, long-term time intervals that represent some significant fraction of a year should be used (e.g. 3 months, 6 months, and 1 year)."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

**Loudness**

*Definition:* "Subjective impression of the intensity of a sound"
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

**Loudness (S) in Sones**

*Definition:* "Numerical designation of the strength of a sound which is proportional to its subjective magnitude as estimated by normal observers. One sone is the loudness of a sound whose loudness level is 40 phons."
*Source:* ISO 532:1975 ("Acoustics-Method for calculating loudness level")

**Loudness Index**

*Definition:* "Number determined by the geometric mean frequency and the band pressure level of the octave band [...]"
*Source:* ISO 532:1975 ("Acoustics-Method for calculating loudness level")

**Loudness Level**

*Definition:* "value in phons that has the same numerical value as the sound pressure level in decibels of a reference sound, consisting of a frontally incident, sinusoidal plane progressive wave at a frequency of 1 000 Hz, which is judged as loud as the given sound"
*Source:* ISO 226:2003 ("Acoustics-Normal equal-loudness-level contours")

### Loudness-Loudness Level Relation

*Definition:* "Loudness level P in phons of a sound is related to the loudness S in sones by the relation:

$$S = 2^{(P-40)/10}$$

Note 1 to entry: When loudness levels are computed from calculated loudness values, the results may differ from those obtained by direct subjective judgement. It is important, therefore, to state whether the values have been calculated or have been measured by other means."
*Source:* ISO 532:1975 ("Acoustics-Method for calculating loudness level")

### Low-Frequency Sound

*Definition:* "sound containing frequency components of interest within the range covering the one-third octave bands 16 Hz to 200 Hz
Note 1 to entry: This definition is specific for this document. Other definitions can apply in different national regulations."
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

## M

### Masking

*Definition:* "The process by which threshold of audibility of one sound is raised by the presence of another (masking) sound."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Maximum AS-weighted sound pressure level $L_{p,AS,max}$

*Definition:* "maximum of the AS-weighted sound pressure level within a stated time interval"
*Source*: ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

### Maximum one second equivalent continuous sound pressure level $L_{p,eq,1\,s,max,T}$

*Definition:* "maximum of the equivalent continuous sound pressure level averaged over the time interval of 1 s within a stated time interval *T*"
*Source*: ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

### Maximum Time-Weighted and Frequency-Weighted Sound Pressure Level

*Definition:* "greatest time-weighted and frequency-weighted sound pressure level within a stated time interval
Note 1 to entry: Maximum time-weighted and frequency-weighted sound pressure level is expressed in decibels (dB)."

*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Maximum time-weighted sound level

*Definition:* Greatest time-weighted sound level within a stated time interval.
NOTE 1: Maximum time-weighted sound level expressed in decibels (dB).
NOTE 2: For a maximum time-weighted sound level, example letter symbols are $L_{AFmax}$, $L_{ASmax}$, $L_{CFmax}$ and $L_{CSmax}$ for frequency weightings A and C and time weightings F and S.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Measurement Time Interval

*Definition:* "time interval during which measurements are conducted
Note 1 to entry: For measurements of sound exposure level or equivalent-continuous sound pressure level, the measurement time interval is the time period of integration.
Note 2 to entry: For measurements of maximum sound pressure level or percent exceedance level, etc., the measurement time interval is the **observation time interval** […]."
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

## Meteorological Window

*Definition:* "set of weather conditions during which measurements can be performed with limited and known variation in measurement results due to weather variation"
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

## Microphone reference point

*Definition:* Point specified on, or close to, the microphone to describe the position of the microphone.
NOTE: The microphone reference point may be at the centre of the diaphragm of the microphone.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Monitor

*Definition:* "instrumentation used for a single automated continuous sound monitoring terminal which monitors the A-weighted sound pressure levels, their spectra and all relevant meteorological quantities such as wind speed, wind direction, rain, humidity, atmospheric stability, etc.

Note 1 to entry: Meteorological measurements need not be taken at each monitor provided such measurements are taken within an appropriate distance from the monitors and such distance is given in the report."
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

# N

### N% exceedance level $L_{p,AS,N,T}$

*Definition:* "AS-weighted sound pressure level that is exceeded for *N* % of the time interval, *T*, considered
EXAMPLE:
$L_{p,\mathrm{AS},95,1\ \mathrm{h}}$ is the AS-weighted sound pressure level exceeded for 95 % of 1 h.
Note 1 to entry: Adapted from ISO 1996-1:2003, 3.1.3."
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

### N Percentage Exceedance Level

*Definition:* "time-weighted and frequency-weighted sound pressure level that is exceeded for N % of the time interval considered
Note 1 to entry: N percentage exceedance level is expressed in decibels (dB).
EXAMPLE: $L_{AF95,1h}$ is the A-frequency-weighted, F-time-weighted sound pressure level exceeded for 95 % of 1 h."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

### Near Field

*Definition:* "That part of a sound field, usually within about two wavelengths from a noise source, where there is no simple relationship between sound level and distance."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### NEF

*Definition:* "Noise Exposure Forecast. A complex criterion for predicting future noise impact of airports. The computation considers Effective Perceived Noise Level of each type of aircraft, flight profile, number of flights, time of day, etc. Generally used in plots of equal NEF contours for zoning control around airports."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Community Noise Criteria", pg. 16)

### Newton

*Definition:* "The force required to accelerate a 1 kg mass at 1 $m/s^2$. Approximately equal to the gravitational force on a 100 g mass."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Night Sound Level ($L_{night,h}$)

*Definition:* "equivalent continuous sound pressure level when the reference time interval is the night
Note 1 to entry: Subscript h indicates the number of hours, e.g. $L_{night,8}$.
Note 2 to entry: A night is normally the 8 h between 23 h and 7 h or the 9 h between 22 h and 7 h. However, individual countries define night differently, e.g. 22 h to 6 h."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

### Noise Emission Level

*Definition:* "The dB(A) level measured at a specified distance and direction from a noise source, in an open environment, above a specified type of surface. Generally follows the recommendation of a national or industry standard."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Noise-Induced Permanent Threshold Shift (NIPTS/N)

*Definition:* "for a specified fraction of a population, the permanent shift, actual or potential, in decibels, of the hearing threshold level estimated to be caused solely by exposure to noise, in the absence of other causes"
*Source:* ISO 1999:2013 ("Acoustics-Estimation of noise-induced hearing loss")

### Noise Reduction Coefficient, NRC

*Definition:* "The arithmetic average of the sound absorption coefficients of a material at 250, 500, 1000 and 2000 Hz."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Non-acoustical Data

*Definition:* "<acoustics> additional information on aircraft movements
EXAMPLE:
Operational information from the airport or information from systems that report aircraft position."

*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

### Noy
*Definition:* "A linear unit of noisiness or annoyance."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## O

### Observation Time Interval
*Definition:* "time interval during which a series of measurements is conducted"
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

### Octave Filter
*Definition:* "A filter whose upper-to-lower passband limits bear a ratio of 2. Is preferably centered at one of the preferred frequencies given in ISO R266 and should meet the attenuation characteristic of IEC R255 and ANSI S1.11-1966 Class II."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)

### Order Analysis
*Definition:* "A form of frequency analysis, used with rotating machines where the amplitude of signal frequency components is plotted as a function of multiples of the rotating frequency."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)

### Otologically Normal Person
*Definition:* "person in a normal state of health who is free from all signs or symptoms of ear disease and from obstructing wax in the ear canals, and who has no history of undue exposure to noise, exposure to potentially ototoxic drugs or familial hearing loss"
*Source:* ISO 226:2003 ("Acoustics-Normal equal-loudness-level contours")

## P

### Particle Velocity
*Definition:* "The velocity of air molecules about their rest position due to a sound wave."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Pascal, Pa

*Definition:* "A unit of pressure corresponding to a force of 1 newton acting uniformly upon an area of 1 square metre. Hence 1 Pa = 1 N/m$^2$."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Passband

*Definition:* "The range of frequencies between the filter cutoff frequencies."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)

### Peak Sound Level

*Definition:* Twenty times the logarithm to the base ten of the ratio of a peak sound pressure to the reference sound pressure, peak sound pressure being obtained with a standard frequency weighting.
NOTE 1: Peak sound level is expressed in decibels (dB).
NOTE 2: This standard provides specifications for measurement of peak C sound level; symbol $L_{Cpeak}$.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

### Peak Sound Pressure

*Definition:* Greatest absolute instantaneous sound pressure during a stated time interval.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

### Peak Sound Pressure Level

*Definition:* "ten times the logarithm to the base 10 of the ratio of the square of the peak sound pressure to the square of the reference value
Note 1 to entry: The reference value is 20 μPa.
Note 2 to entry: Peak sound pressure level is expressed in decibels (dB).
Note 3 to entry: Peak sound pressure should be determined with a detector as defined in IEC 61672-1. IEC 61672-1 only specifies the accuracy of a detector using C-weighting.
Note 4 to entry: The peak sound pressure is the maximum absolute value of the instantaneous sound pressure during a stated time interval."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

### Phase Mis-match

*Definition:* "The relative phase mis-match between the two channels in an Intensity Measuring System."

*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("SOUND INTENSITY", pg. 28-29)

### Phon

*Definition:* "The loudness level of a sound. It is numerically equal to the sound pressure level of a 1 kHz free progressive wave which is judged by reliable listeners to be as loud as the unknown sound."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Pink Noise

*Definition:* "Broadband noise whose energy content is inversely proportional to frequency (-3 dB per octave or -10 dB per decade)."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Power Spectrum Level

*Definition:* "The level of the power in a band one hertz wide referred to a given reference power."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Prediction Method

*Definition:* "subset of a **calculation method** […], intended for the calculation of future noise levels"
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

### Prediction Time Interval

*Definition:* "time interval over which levels are predicted
Note 1 to entry: It is now perhaps more common to predict sound levels using computers than to measure them for some sources such as transportation noise sources. The prediction time interval corresponds to the **measurement time interval** […] except, for the former, the levels are predicted, and for the latter, the levels are measured."
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

### Preferred frequencies

*Definition:* "A set of standardized octave and third-octave center frequencies defined by ISO R266, DIN 45 401 and ANSI S1.6-1967."

*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)

# R

### Random Noise

*Definition:* "Noise whose instantaneous amplitude is not specified at any instant of time. Instantaneous amplitude can only be defined statistically by an amplitude distribution function."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Rating Level

*Definition:* "predicted or measured acoustic level to which an adjustment has been added
Note 1 to entry: Measurements such as day/night sound pressure level or day/evening/night sound pressure level are examples of rating levels because they are calculated from sound measured or predicted over different reference time periods, and adjustments are added to the reference time interval equivalent continuous sound pressure levels based on the time of day.
Note 2 to entry: A rating level may be created by adding adjustments to a measured or predicted level(s) to account for some character of the sound such as tonality or impulsiveness.
Note 3 to entry: A rating level may be created by adding adjustments to a measured or predicted level(s) to account for differences between source types. For example, using road traffic as the base sound source, adjustments may be applied to the levels for aircraft or railway sources."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

### Reactive Sound Field

*Definition:* "A sound field in which the particle velocity is 90$^{o}$ out of phase with the pressure. An ideal standing wave is an example of this type of field, where there is no net flow of energy and constitutes the imaginary part of a complex sound field."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("SOUND INTENSITY", pg. 28-29)

### Reactivity Index, $L_K$

*Definition:* "The reactivity index in a given direction at a point is defined as the difference between the sound intensity level and the sound pressure level measured in the given direction at that point. In practice $L_K$ is normally negative.

Note: The reactivity index indicates an important character of the sound field as it is measured and is not a direct measure of how reactive the sound field is.”
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort”, Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl (“SOUND INTENSITY”, pg. 28-29)

**Receiver Location**
*Definition:* “location at which the noise is assessed”
*Source:* ISO 1996-2:2017 (“Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels”)

**Reference Condition**
*Definition:* “condition to which the measurement results are to be referred (corrected)
Note 1 to entry: Examples of reference conditions are atmospheric sound absorption at yearly average temperature and humidity and yearly average traffic flows for day, evening and night, respectively.”
*Source:* ISO 1996-2:2017 (“Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels”)

**Reference Direction**
*Definition:* Inward direction toward the microphone reference point and specified for determining the acoustical response, directional response, and frequency weighting of a sound level meter.
NOTE: The reference direction may be specified with respect to an axis of symmetry.
*Source:* CEI 61672-1:2002 – Part 1 (“Electroacoustics – Sound level meters Part 1: Specifications”)

**Reference Level Range**
*Definition:* Level range specified for testing the electroacoustical characteristics of a sound level meter and containing the reference sound pressure level.
NOTE: Reference level range is expressed in decibels (dB).
*Source:* CEI 61672-1:2002 – Part 1 (“Electroacoustics – Sound level meters Part 1: Specifications”)

**Reference Orientation**
*Definition:* Orientation of a sound level meter for tests to demonstrate conformance to the specifications of this standard for emissions of, and susceptibility to, radio frequency fields.
*Source:* CEI 61672-1:2002 – Part 1 (“Electroacoustics – Sound level meters Part 1: Specifications”)

## Reference Sound Pressure

*Definition:* Reference quantity conventionally chosen equal to 20 μPa for airborne sound.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Reference Sound Pressure Level

*Definition:* Sound pressure level specified for testing the electroacoustical performance of a sound level meter.
NOTE: Reference sound pressure level is expressed in decibels (dB).
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Reference Time Interval

*Definition:* "time interval to which the rating of the sound is referred
Note 1 to entry: The reference time interval may be specified in national or international standards or by local authorities to cover typical human activities and variations in the operation of sound sources. Reference time intervals can be, for example, part of a day, the full day, or a full week. Some countries define even longer reference time intervals.
Note 2 to entry: Different levels or sets of levels may be specified for different reference time intervals."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Regular Impulsive Sound Source

*Definition:* "impulsive sound source that is neither highly impulsive nor high-energy impulsive sound source
Note 1 to entry: This category includes sounds that are sometimes described as impulsive, but are not normally judged to be as intrusive as highly impulsive sounds.
EXAMPLE: Slamming of car door, outdoor ball games, such as football (soccer) or basketball, and church bells. Very fast pass-bys of low-flying military aircraft can also fall into this category."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Residual Intensity, $L_{I,R}$

*Definition:* "The sound intensity measured when the same signal is fed to both channels of a sound intensity measuring system, or it is exposed to a pure reactive field."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("SOUND INTENSITY", pg. 28-29)

## Residual Intensity Index, $L_{K,O}$

*Definition:* "The residual intensity index for a given measurement system is defined as the difference between the indicated intensity level and the measured sound pressure level when exactly the same signal is fed into the two channels of an intensity analysing system. This index will normally be negative."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("SOUND INTENSITY", pg. 28-29)

## Residual Sound

*Definition:* "total sound remaining at a given position in a given situation when the specific sounds under consideration are suppressed
[SOURCE: ISO 1996-1:2003, 3.4.3]"
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

## Residual Sound

*Definition:* "total sound remaining at a given position in a given situation when the specific sounds under consideration are suppressed"
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Reverberation

*Definition:* "The persistence of sound in an enclosure after a sound source has been stopped. Reverberation time is the time, in seconds required for sound pressure at a specific frequency to decay 60 dB after a sound source is stopped."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Risk of Hearing Disability

*Definition:* "percentage of a population sustaining hearing disability"
*Source:* ISO 1999:2013 ("Acoustics-Estimation of noise-induced hearing loss")

## Risk of Hearing Disability due to Noise

*Definition:* "risk of hearing disability in a noise-exposed population minus the risk of hearing disability in a population not exposed to noise but otherwise equivalent to the noise-exposed population"
*Source:* ISO 1999:2013 ("Acoustics-Estimation of noise-induced hearing loss")

## Root Mean Square (RMS)

*Definition:* "The square root of the arithmetic average of a set of squared instantaneous values."

*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

# S

## Sabine

*Definition:* "A measure of sound absorption of a surface. One metric sabine is equivalent to 1 sq. metre of perfectly absorptive surface."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Sampling Theorem

*Definition:* "A theorem which states that a signal is completely described if it is sampled at a rate twice its highest frequency component."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("GLOSSARY OF FREQUENCY ANALYSIS TERMS", pg. 49-50)

## SEL

*Definition:* "Single Event Noise Exposure Level. The dB(A) level which, if it lasted for one second, would produce the same A-weighted sound energy as the actual event."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl ("Community Noise Criteria", pg. 16)

## Semianechoic Field

*Definition:* "A free field above a reflective plane."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Short-Term Measurement

*Definition:* "measurement during **measurement time intervals** […] with well-defined emission and meteorological conditions"
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

## Sone

*Definition:* "A linear unit of loudness. The ration of loudness of a sound to that of a 1 kHz tone 40 dB above the threshold of hearing."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Sound

*Definition:* "Energy that is transmitted by pressure waves in air or other materials and is the objective cause of the sensation of hearing. Commonly called noise if it is unwanted."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Sound Emergence

*Definition:* "increase in the total sound in a given situation that results from the introduction of some specific sound"
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Sound Exposure

*Definition:* Time integral of the square of sound pressure over a stated time interval or event.
NOTE 1: Duration of integration is included implicitly in the time integral and need not be reported explicitly, although the nature of the event should be stated. For measurements of sound exposure over a specified time interval such as 1 h, duration of integration should be reported.
NOTE 2: In symbols, A-weighted sound exposure $E_A$ of a specified event is represented by

$$E_A = \int_{t_1}^{t_2} p_A^2(t)dt$$

where $p_A^2(t)$ is the square of the A-weighted instantaneous sound pressure during an integration time starting at $t_1$ and ending at $t_2$.
The unit of A-weighted sound exposure is pascal-squared seconds if A-weighted sound pressure is in pascals and running time is in seconds.
NOTE 3: Sound exposure in Pascal-squared hours is more convenient for applications such as measurement of exposure to noise in the workplace.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Sound Exposure ($E_T$)

*Definition:* "integral of the square of the sound pressure, *p*, over a stated time interval or event of duration *T* (starting at $t_1$ and ending at $t_2$)

$$E_T = \int_{t_1}^{t_2} p^2(t)dt$$

Note 1 to entry: The sound exposure is expressed in pascal squared seconds.
Note 2 to entry: Because of practical limitations of the measuring instruments, $p^2$ is always understood to denote the square of a frequency-weighted and frequency-band-limited sound pressure. If a specific frequency weighting as specified in IEC 61672-1 is applied, this is

indicated by an appropriate subscript, e.g. $E_{A,1\,h}$ denotes the A-weighted sound exposure over 1 h.
Note 3 to entry: When applied to a single event, the quantity is called "single event sound exposure" and the symbol $E$ is used without subscript.
[SOURCE: ISO/TR 25417:2007 [1], 2.6]"
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

## Sound Exposure Level

*Definition:* Ten times the logarithm to the base ten of the ratio of a sound exposure to the reference sound exposure, reference sound exposure being the product of the square of the reference sound pressure and the reference time interval of 1 s.
NOTE 1: Sound exposure level is expressed in decibels (dB).
NOTE 2: In symbols, A-weighted sound exposure level, $L_{AE}$, is related to a corresponding measurement of time-average, A-weighted sound level, $L_{AT}$ or $L_{AeqT}$, by

$$L_{AE} = 10\lg\left\{\left[\int_{t_1}^{t_2} p_A^2(t)dt / (p_0^2 T_0)\right]\right\} = 10\lg\left(E_A / E_0\right) = L_{AT} + 10\lg\left(T / T_0\right)$$

Where

$E_A$ is the A-weighted sound exposure in Pascal-squared seconds;

$E_0$ is the reference sound exposure of $\left(20\mu Pa\right)^2 \times (1s) = 400\times10^{-12}\,Pa^2 s$;

$T_0 = 1s$;

$T = t_2 - t_1$ is the time interval for measurement, in seconds, for sound exposure level and time-average sound level.

NOTE 3: Time-average, A-weighted sound level $L_{AT}$ or $L_{AeqT}$ during time interval T is related to the total A-weighted sound exposure $E_A$ occurring within that interval by

$$E_A = \left(p_0^2 T\right)\left(10^{0{,}1 L_{AT}}\right)$$

$$L_{AT} = 10\lg\left[E_A / \left(p_0^2 T\right)\right] = L_{AE} - 10\lg\left(T / T_0\right)$$

*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Sound Exposure Level ($L_E$)

*Definition:* "ten times the logarithm to the base 10 of the ratio of the sound exposure, E, being the integral of the square of the sound pressure, p, over a stated time interval or event of duration, T (starting at $t_1$ and ending at $t_2$), to a reference value, $E_0$

$$L_E = 10\lg\frac{E}{E_0}\,dB$$

where

$$E = \int_{t_1}^{t_2} p^2(t)dt;$$

$$E_0 = 400 \mu Pa^2 s$$

Note 1 to entry: Sound exposure is expressed in pascal-squared seconds. Sound exposure level is expressed in decibels (dB).
Note 2 to entry: Because of practical limitations of the measuring instruments, $p^2$ is always understood to denote the square of a frequency-weighted and frequency band-limited sound pressure. If a specific frequency weighting as specified in IEC 61672-1 is applied, this should be indicated by appropriate subscripts; e.g. $E_{A,1\ h}$ denotes the A-weighted sound exposure over 1 h.
Note 3 to entry: The duration, T, of the integration is included implicitly in the time integral and need not to be reported explicitly. For measurements of sound exposure over a specified time interval, the duration of integration should be reported and the notation should be $L_{E,T}$.
Note 4 to entry: For sound exposure levels of an event, the nature of the event should be stated.
Note 5 to entry: When applied to a single event, the sound exposure level is called "single-event sound exposure level"."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Sound Exposure Level ($L_{E,T}$)

*Definition:* "ten times the logarithm to the base 10 of the ratio of the sound exposure, $E_T$, to a reference value, $E_0$, expressed in decibels

$$L_{E,T} = 10 \lg \frac{E_T}{E_0} dB$$

where the reference value, $E_0$, is $(20\ \mu Pa)^2\ s = 4 \times 10^{-10}\ Pa^2\ s$
Note 1 to entry: If a specific frequency weighting as specified in IEC 61672-1 is applied, this is indicated by appropriate subscripts, e.g. $L_{E,A,,1\ h}$ denotes the A-weighted sound exposure level over 1 h.
Note 2 to entry: When applied to a single event, the quantity is called "single event sound exposure level" and the symbol $L_E$ is used without further subscript.
[SOURCE: ISO/TR 25417:2007 [1], 2.7]"
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

## Sound-Incidence Angle

*Definition:* Angle between the reference direction and a line between the acoustic centre of a sound source and the microphone reference point.
NOTE: Sound-incidence angle is expressed in degrees.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Sound Intensity

*Definition:* "The rate of sound energy transmission per unit area in a specified direction."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Sound Level

*Definition:* "The level of sound measured with a sound level meter and one of its weighting networks. When A-weighting is used, the sound level is given in dB(A)."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Sound Level Meter

*Definition:* "An electronic instrument for measuring the RMS level of sound in accordance with an accepted national or international standard."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Sound Monitor

*Definition:* "<acoustics> instruments and sound measuring equipment installed at a specified site for automatic and continuous measurements of the sound produced by aircraft flying over or near the microphone"
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

## Sound-Monitoring System

*Definition:* "entire automatic continuously operating system deployed in the vicinity of an airport, including all sound monitors, the central station and all software and hardware involved in its operation"
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

## Sound Path Radius of Curvature ($R_{cur}$)

*Definition:* "radius approximating the curvature of the sound paths due to atmospheric refraction
Note 1 to entry: $R_{cur}$ is given in metres.
Note 2 to entry: Often, the parameter used is $1/R_{cur}$ to avoid infinitely large values during straight ray propagation."
*Source:* ISO 1996-2:2017 ("Acoustics-Description, measurement and assessment of environmental noise – Part 2: Determination of sound pressure levels")

## Sound Power

*Definition:* "The total sound energy radiated by a source per unit time."

*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Sound Power Level

*Definition:* "The fundamental measure of sound power. Defined as

$$L_W = 10\log\frac{P}{P_0}dB$$

where P is the RMS value of sound power in watts, and $P_0$ is 1 pW. "
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Sound Pressure

*Definition:* "A dynamic variation in atmospheric pressure. The pressure at a point in space minus the static pressure at that point."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Sound Pressure Level

*Definition:* "The fundamental measure of sound pressure. Defined as:

$$L_p = 20\log\frac{p}{p_0}dB$$

where p is the RMS value (unless otherwise stated) of sound pressure in pascals, and $p_0$ is 20μPa for measurements in air. "
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## Sound Pressure Level

*Definition:* Twenty times the logarithm to the base ten of the ratio of the root-mean-square of a given sound pressure to the reference sound pressure.
NOTE: Sound pressure level is expressed in decibels (dB); symbol $L_p$
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Sound Pressure Level (L)

*Definition:* "Sound pressure level in decibels is $20\log_{10}(p/p_0)$ dB, where p is the measured sound pressure and $p_0$ is a reference sound pressure having the value
$2\times10^{-5} N/m^2 = 2\times10^{-4} dyn/cm^2$ (see ISO/R 131)."
*Source:* ISO 532:1975 ("Acoustics-Method for calculating loudness level")

## Sound Transmission Class, STC

*Definition:* "A single-number rating for describing sound transmission loss of a wall or partition"

*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort”, Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS”, pg. 11-15)

### Sound Transmission Loss

*Definition:* “Ratio of the sound energy emitted by an acoustical material or structure to the energy incident upon the opposite side.”
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort”, Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS”, pg. 11-15)

### Specific Sound

*Definition:* “component of the total sound that can be specifically identified and which is associated with a specific source
[SOURCE: ISO 1996-1:2003, 3.4.2]”
*Source:* ISO 20906:2009 (“Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports”)

### Specific Sound

*Definition:* “component of the total sound that can be specifically identified and which is associated with a specific source”
*Source:* ISO 1996-1:2016 (“Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures”)

### Standing Wave

*Definition:* “A periodic wave having a fixed distribution in space which is the result of interference of progressive waves of the same frequency and kind. Characterized by the existence of maxima and minima amplitudes that are fixed in space.”
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort”, Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS”, pg. 11-15)

## T

### Third-Octave Filter

*Definition:* “A filter whose upper-to-lower passband limits bear a ratio of $2^{1/3}$. Is preferably centered at one of the preferred frequencies in ISO R266. Should meet the attenuation characteristics of IEC R266. Should meet the attenuation characteristics of IEC R255 and ANSI S1.11-1966 Class III.”
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort”, Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl (“GLOSSARY OF FREQUENCY ANALYSIS TERMS”, pg. 49-50)

## Threshold Level ($L_{threshold}$)

*Definition:* "any suitable user-defined sound pressure level used to optimize reliable event detection
Note 1 to entry: This threshold level is different from the term to be used for calculating the exposure level."
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

## Threshold of Hearing

*Definition:* "level of a sound at which, under specified conditions, a person gives 50 % of correct detection responses on repeated trials"
*Source:* ISO 226:2003 ("Acoustics-Normal equal-loudness-level contours")

## Time-Average Sound Level (equivalent continuous sound level)

*Definition:* Twenty times the logarithm to the base ten of the ratio of a root-mean-square sound pressure during a stated time interval to the reference sound pressure, sound pressure being obtained with a standard frequency weighting.
NOTE 1: Time-average or equivalent continuous sound level is expressed in decibels (dB).
NOTE 2: In symbols, time-average, A-weighted sound level, $L_{AT}$ or $L_{AeqT}$, is given by

$$L_{AT} = L_{AeqT} = 20\lg\left\{\left[\left(1/T\right)\int_{t-T}^{t} p_A^2(\xi)d\xi\right]^{1/2} / p_0\right\}$$

Where

$\xi$ is a dummy variable of time integration over the averaging time interval ending at the time of observation t;
T is the averaging time interval;
$p_A(\xi)$ is the A-weighted instantaneous sound pressure;
$p_0$ is the reference sound pressure.

In this equation, the numerator of the argument of the logarithm is the root-mean-square, frequency-weighted sound pressure over averaging time interval T.
NOTE 3: In principle, time weighting in not involved in a determination of time-average sound level.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Time-Weighted and Frequency-Weighted Sound Pressure Level

*Definition:* "ten times the logarithm to the base 10 of the ratio of the time-mean-square of the sound pressure to the square of a reference value, being obtained with a standard frequency weighting and standard time weighting
Note 1 to entry: Sound pressure is expressed in pascal (Pa).
Note 2 to entry: The reference value is 20 μPa.

Note 3 to entry: Time-weighted and frequency-weighted sound pressure level is expressed in decibels (dB).
Note 4 to entry: The standard frequency weightings are A-weighting and C-weighting as specified in IEC 61672-1, and the standard time weightings are F-weighting and S-weighting as specified in IEC 61672-1."
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Time-Weighted Sound Level

*Definition:* Twenty times the logarithm to the base ten of the ratio of a given root-mean-square sound pressure to the reference sound pressure, root-mean-square sound pressure being obtained with a standard frequency weighting and standard time weighting.
NOTE 1: Time-weighted sound level is expressed in decibels (dB).
NOTE 2: For time-weighted sound level, example letter symbols are $L_{AF}$, $L_{AS}$, $L_{CF}$ and $L_{CS}$ for frequency weightings A and C and time weightings F and S.
NOTE 3: In symbols, A-weighted and time-weighted sound level, $L_{A\tau}(t)$, at any instant of time *t* is represented by:

$$L_{A\tau}(t) = 20\lg\left\{\left[\left(1/\tau\right)\int_{-\infty}^{t} p_A^2(\xi)e^{-(t-\xi)/\tau}d\xi\right]^{1/2}/\,p_0\right\}$$

where

$\tau$ is the exponential time constant in seconds for time weighting F or S;

$\xi$ is a dummy variable of time integration from some time in the past, as indicated by -∞ for the lower limit of the integral, to the time of observation *t*;

$p_A(\xi)$ is the A-weighted instantaneous sound pressure; and

$p_0$ is the reference sound pressure.

In the above equation, the numerator of the argument of the logarithm is the exponential-time-weighted, root-mean-square, frequency-weighted sound pressure at observation time *t*.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Time Weighting

*Definition:* Exponential function of a time, of a specified time constant, that weights the square of the instantaneous sound pressure.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Tonal Sound

*Definition:* "sound characterized by a single-frequency component or narrow-band components that emerge audibly from the total sound"

*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## Toneburst

*Definition:* One or more complete cycles of a sinusoidal signal starting and stopping at a zero crossing of the waveform.
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Toneburst Response

*Definition:* Maximum time-weighted sound level, time-average sound level, or sound exposure level, measured in response to a sinusoidal electrical toneburst minus the corresponding measured sound level of the steady sinusoidal input signal from which the toneburst was extracted.
NOTE: Toneburst response is expressed in decibels (dB).
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Total Range

*Definition:* Range of A-weighted sound levels, in response to sinusoidal signals, from the smallest sound level, on the most-sensitive level range, to the highest sound level, on the least-sensitive level range, that can be measured without indication of overload or under-range and within the tolerance limits specified in this standard for level linearity error.
NOTE: Total range is expressed in decibels (dB).
*Source:* CEI 61672-1:2002 – Part 1 ("Electroacoustics – Sound level meters Part 1: Specifications")

## Total Sound

*Definition:* "totally encompassing sound in a given situation at a given position and at a given time, usually composed of sound from many sources near and far
Note 1 to entry: Adapted from ISO 1996-1:2003, 3.4.1."
*Source:* ISO 20906:2009 ("Acoustics-Unattended monitoring of aircraft sound in the vicinity of airports")

## Total Sound

*Definition:* "totally encompassing sound in a given situation at a given time, usually composed of sound from many sources near and far"
*Source:* ISO 1996-1:2016 ("Acoustics-Description, measurement and assessment of environmental noise – Part 1: Basic quantities and assessment procedures")

## U

### Ultrasound

*Definition:* "Sound at frequencies above the audible range, i.e. above about 20 kHz."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

## W

### Wavelength

*Definition:* "The distance measured perpendicular to the wavefront in the direction of propagation between two successive points in the wave, which are separated by one period. Equals the ratio of the speed of sound in the medium to the fundamental frequency."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### Weighting Network

*Definition:* "An electronic filter in a sound level meter which approximates under defined conditions the frequency response of the human ear. The A-weighting network is most commonly used."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)

### White Noise

*Definition:* "Broadband noise having constant energy per unit of frequency."
*Source:* „Pocket Handbook Noise, Vibration, Light Thermal Comfort", Brüel & Kjær, September 1986, Printed in Denmark by Rosendahl („GLOSSARY OF ACOUSTICAL TERMS", pg. 11-15)