ANIMA

Aviation Noise Impact Management through Novel Approaches

D2.6 – Overview of the use of noise footprints for different operational, planning and communication purposes

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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.

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1. Executive Summary

This ANIMA Deliverable sets out to review available noise metrics and tools to help identify effective and ineffective practice with the aim of informing the development of a Best Practice portal designed to assist airports to make the best use of noise modelling tools and their outputs.

The review acknowledges the growth in the range of noise indicators now in use, often developed in an attempt to address specific stakeholder requirements. Whilst on the one hand the enhanced capability to 'capture' different aspects of the noise environment, on the other the picture can be seen as overly complex and confusing.

In an attempt to provide some structure to the noise information now available and the modelling tools used to arrive at many of these outputs Sections 3 and 4 of this Deliverable develop frameworks for their categorisation.

Section 3 acknowledges that if users are to identify and utilise the most appropriate noise descriptors they must first be clear about the purpose for which the information is being provided. These purposed as grouped into four main categories:

- Defining and testing ***specifications for engineering design***
- Setting ***criteria and targets*** for regulatory purposes
- Comparing alternative ***what-if scenarios***
- ***Communicating aircraft noise issues*** to different stakeholder groups

Once the purpose for particular information provision has been established users are then in a position to select from the range of indicators those that best suit the intended outcomes. Such indicators are classified by function as:

- **Operational indicators** – including:
    - Lists of aircraft operations;
    - Cross-sectional charts; and
    - Flight tracks
- **Acoustic metrics** - - including:
    - Single events at defined receiver points
    - Time-average metrics at defined receiver points; and
    - Spatially averaged and aggregated metrics

Section 4 highlights the acoustic metrics defined above are often outputs from two different types of noise models, whilst the operational data are used as inputs to the models. Such models can be broadly divided into two types:

- **Best Practice models** – or integrated models used to provide overviews of the noise environment at airports, usually over extended periods such as a year
- **Scientific models** – used to accurately simulate specific flight characteristics and thus provide accurate single-event noise data

The information from airport Balanced Approach case studies summarised in **Section 5** demonstrates that airports are providing a range of operational indicators and utilising modelling tools to generate a range of acoustic metrics in an attempt to communicate the nature and potential impact of specific interventions. However, whilst there appear to be some attempts to tailor information provision to particular purposes there is no systematic evaluation of the efficacy of such information provision, nor more broadly of the wider consequences (impact on attitudes, well-being and quality of life) of the interventions themselves.

Consequently, the Deliverable concludes that it is impossible to define best practice noise metrics on the basis of evidence from systematic assessments. Thus, given the absence of the latter it is **only possible to define the principles of best practice in the selection and use of noise information**. These are that when establishing how best to communicate noise, **airports and others with authority over noise management should engage with stakeholders throughout the process of Balanced Approach interventions.** This should facilitate focused use of noise information that:

- Enhances comprehension of key issues
- Illustrates the nature of any proposed change to operational practice and thus the potential consequences for individual stakeholders
- Enables stakeholders to reach decisions on their noise management priorities informed by insights into operational limitations and opportunities
- Can track (model and monitor) implementation of any actions/interventions
- Provide information to assess the efficacy (against agreed objectives) of the changes/actions and thus feedback to stakeholders about the outcomes and evidence to improve practice going forward

Thus the steps to attaining improved outcomes from integrating enhanced utilisation of noise information into noise management processes are as follows:

- Step 1 – **decide objectives/purpose** of the intervention or strategy
- Step 2 – **review options** for noise footprint methodologies (tools and outputs) and **select** those that best suit the objectives
- Step 3 - **continuously evaluate** the contribution of the noise metrics to achieving the desired objectives
- Step 4 - **review mitigation options** in the light of feedback received structured using the agreed noise tools and metrics
- Step 5 – continue the **cycle of improvement**

These targeted outcomes and steps to achieving them will be used to inform the Best Practice portal in WP5, with the aim of allowing users to tailor noise information provision to the requirements of specific management interventions. Further, mechanisms for addressing the absence of effective evaluation of both communication tools and Balanced Approach intervention outcomes will be explored in WP3, sub-tasks 3.2.1 and 3.1.2 respectively.

2. Introduction

ANIMA Task ST2.3.2 – Noise Footprints – has two main parts as follows:

'*Review **noise metrics** and **modelling tools** used to monitor performance and communicate/inform noise reduction strategies*'.

'*Summarise **best and ineffective practice** in terms of the metrics most appropriate for different purposes'.*

Noise metrics describe or indicate different aspects of the physical characteristics of aircraft noise. Various ***effects metrics*** can also be used to describe the effects of aircraft noise. Numerous ***modelling tools*** have been developed to estimate or predict the values of many noise metrics and a wide range of ***exposure-response relationships*** have also been developed to estimate or predict effects from measurements or modelled estimates of the physical characteristics. In this field, ***uncertainties of measurement and prediction*** can be significant and depend on:

- The accuracy and precision of measuring instruments;

- Inherent variability within successive sample measurements;

- The extent to which any defined metric actually represents the desired quantity;

- The degree of correlation between different variables; and

- To whatever extent variation in the exposure variable actually ***causes*** variation in the response variable.

With respect to ***summarising best and ineffective practice***, the extent to which different metrics and their associated modelling tools have been found useful or not, depends not only on the extent to which they actually represent the desired quantity, but also on their relative effectiveness in meeting wider purposes or functions relevant to the planning or development of continuing airport operations. For example, it is possible to measure instantaneous sound levels at defined points in time and space to a high degree of precision, but the measurement of consequent human effects, such as ***annoyance***, is subject to many possible forms of bias and uncertainty. The measurement of sound levels, while accurate and precise, may only be relevant to an assessment in relation to the extent of statistical representativeness in a given situation; whereas the measurement of annoyance, while of obvious relevance, may nevertheless be too uncertain to be useful.

There is only ***limited empirical information*** available surrounding the extent to which existing metrics and modelling tools actually deliver their wider purpose and functions. However, it has been possible to list most of these wider purposes and functions based largely on theoretical and anecdotal considerations, and to consider the defined technical specifications of current noise metrics and modelling tools in this light (see Section 2 below).

The primary function of civil aviation is transportation, and while the economic and social benefits are widely (if somewhat unevenly) spread across the entire population, the environmental costs in terms of aircraft noise and pollution tend to fall disproportionately upon the airports' nearest residents; notwithstanding the extent to which they might also benefit from employment, social, and/or travel opportunities.

These environmental costs have led to increasing demands for noise control action, supported by the results of research showing generally higher levels of ***average reported annoyance***, as well as other effects in areas of higher outdoor measured objective sound levels, around busy airports (see D2.3 and D2.4 for a detailed review of noise and health associations). Unfortunately, noise control action is rarely cost free and may require significant financial investment and/or the imposition of constraints (e.g. noise preferred routes) or other restrictions on normal activities. Rational decision-making requires meaningful cost-benefit analysis, which in turn requires meaningful estimates, or predictions, of the likely effects of any decisions made.

The historical records show numerous attempts to devise reliable ***exposure-response relationships*** capable of accurately predicting average reported annoyance and effects such as sleep disturbance from simple combinations of objectively quantifiable input variables. However, the historical records also demonstrate considerable variation between different studies, with much anecdotal evidence of uncertainty whenever these exposure-response relationships have been used for predictive purposes. Amongst the chief causes of exposure-response relationship uncertainties are; the large number of different ways in which both sound levels and human response can be measured; and the consequential statistical constraints on being able to differentiate (based on empirical evidence with only finite numbers of observations) between all potentially relevant combinations of input and output variables. Not surprisingly, qualified opinions vary regarding the best metrics and combinations of metrics for different purposes. It therefore seems likely that different metrics and combinations of metrics for different applications and purposes - and furthermore, that rational selection between them - should be based on the specific requirements of each application, rather than placing undue reliance on any single solution devised by a committee or politicians. In this field, uniformity and consistency can be the enemy of good practice.

The following review is offered in anticipation that it may be found helpful in resolving much of this current uncertainty.

3. Review of purpose and function of noise information provision

3.1 The purpose of noise information provision

The primary function of aircraft noise metrics is the quantification of aircraft noise. The selection of any particular metric should depend on **the purpose for which the aircraft noise is being quantified**, which may include:

- Defining and testing ***specifications for engineering design***
- Setting ***criteria and targets*** for regulatory purposes
- Comparing alternative ***what-if scenarios***
- ***Communicating aircraft noise issues*** to different stakeholder groups

For taxonomic classification purposes, each of these main categories could be divided into sub-categories, for example; engineering design could have a wide range of different priorities and objectives, many of which will be dependent on financial cost, but will also interact with economic and social priorities such as efficiency, convenience, and customer preference. Another example is that stakeholder groups can have many different priorities depending on whether they represent individual residents near airports, commercial interests, and/or political groups.

In an ideal world, metrics should be selected to meet the specific requirements of a particular purpose. However, current practice tends towards selecting metrics largely on the basis of administrative convenience and/or historical precedent; this can lead to misunderstanding and less than optimum decision-making. A good example of this situation is the current practice by the UK Department for Transport (DfT) to specify a long time averaged 16 hour daytime and evening L_{Aeq} for monitoring aircraft noise around major airports in the UK. For public engagement purposes it became standard procedure for the UK DfT to equate 57 L_{Aeq}16hour, with firstly, ***the onset of low annoyance***, and more recently, with ***the onset of significant annoyance***.[3] This was done for two main reasons. First, as an engineering metric based on decibels, L_{Aeq} is very poorly understood by the general public, thus interpreting L_{eq} in terms of equivalent annoyance represents an attempt to increase understanding. Secondly, because defined criterion values are necessary for strategic comparisons, it is not entirely clear that these successive interpretations have been as helpful as intended, particularly in respect of the considerable numbers of residents who live in areas with lower L_{Aeq} values and still find aircraft noise to be annoying and vice versa.

While there is nothing philosophically wrong with interpreting a metric in one modality as a proxy for something else (such as interpreting any particular value of L_{Aeq} in terms of annoyance), the technical validity depends entirely on the strength of any statistical relationship observed between the two types of

[3] More recently still, the UK DfT have begun to refer to 54 L_{Aeq},16hour as representing the onset of annoyance, with the CAA describing levels of more that 57 L_{Aeq},16hour as 'significantly annoying' (https://www.caa.co.uk/Consumers/Environment/Noise/Noise)

quantity, particularly when used for extrapolation to future scenarios for this example. This has been shown elsewhere in ANIMA deliverables and in many other documents and reports. Such a relationship however, has never been shown to be a particularly strong one (e.g. Job, 1988 and Guski, 1999).

3.1.1 Specifications for engineering design

It seems reasonably clear that for the purpose of defining specifications for ***engineering design*** involving complex technology, the deployment of appropriate objective physical metrics such as conventional measurements of sound levels using decibels, is required. Subjective judgement (e.g. subjective ratings of relative loudness and/or annoyance) cannot be relied upon for contractual purposes, not least because of the possibility of bias, which can of course be unintentional and unrecognised. Examples of objective metrics used for engineering design purposes include; EPNdB (Effective perceived noise level) which is a complex objective metric used for aircraft noise certification purposes to avoid the considerable uncertainty that would arise if noise certification were carried out on the basis of subjective tests; and the time varying frequency spectrum, which is used by engineers to isolate specific noise sources that contribute to overall aircraft sound, and which may need to be addressed separately in any engineering noise control programme.

3.1.2 Setting criteria and targets for regulatory purposes

Similarly, ***criteria and targets*** for regulatory purposes require appropriate objective physical metrics, such as conventional measurements of sound levels using decibels. However, in the aircraft noise field, it could be argued that setting criteria and targets without regard to subjective objectives and priorities could be ineffective or even counter-productive. This is because the demand for aircraft noise control action comes mainly from people who regard the current aircraft fleet as imposing too much noise on affected communities. Practical experience suggests that meeting even technically stringent noise control action targets defined in objective terms might not achieve widespread public acceptance if subjective objectives and priorities have not been satisfied. Historically, there has been tension between what has been achievable with available technology and what might have been necessary to achieve more universal public acceptance. Further progress may require careful consideration tailored specifically to each individual case and it seems unlikely that any one-size-fits-all solutions will be entirely satisfactory.

3.1.3 Comparing alternative what-if scenarios

Arguably, comparisons between alternative ***what-if scenarios*** are the most important aspect of informed decision making. Different scenarios can be compared using objective physical metrics, but any resulting decision-making should also take into account likely community response as far as it is practicable and feasible to do so. Unfortunately, for decision-making, the likely community response cannot usually be predicted to within any degree of certainty on the basis of objective physical metrics alone, and may require the measurement, testing and assessment of many other situational and contextual factors. Only through involving communities in decisions over how best to manage the noise environment to which they are exposed can we expect to arrive at outcomes that are more acceptable to those communities. This requires that the noise environment and any change to it from proposed interventions, such as those envisaged under the Balanced Approach is described in ways that are comprehensible to those same communities if attempts to involve them in decision-making are to be successful. On the other hand, it should be noted that increasing community understanding of proposed changes will not necessarily increase community acceptance of those changes and could indeed have the opposite effect, depending on the actual changes proposed.

3.1.4 Communicating aircraft noise issues to different stakeholder groups

Measurement, testing and assessment of community attitudes and opinions may require extensive public engagement and consultation, in turn requiring effective ***communication of aircraft noise issues***. The presentation of different issues to different stakeholder groups may require a wide range of different tools carefully adapted to each stakeholder and stakeholder groups' level of interest, motivation and understanding. For some tasks and stakeholders, detailed technical presentations involving relatively complex objective physical metrics and engineering concepts may be entirely appropriate. But for many other tasks and stakeholders, something much less technical may be required, depending on the ultimate purpose of the communication exercise. The same problem of interpreting objective physical metrics in terms of equivalent subjective effects arises in this purpose category as in many of the other purpose categories, and may need to be dealt with sensitively and creatively. Indeed attempts by airports to address such purposes may well explain the huge increase in the range of noise descriptors and metrics being used by airports to communicate with affected communities (some of these have been captured in our Balanced Approach intervention case studies – see D2.5 – and are reviewed in Section 4 to this report). By way of providing a framework to help organise this expanding range of indicators the following sections classify indicators by the features they aim to capture, namely operational and acoustical aspects that define the noise environment.

3.2 Classifying indicators by function

3.2.1 Operational indicators

Human perception is primarily addressed to collecting sensory information about the outside world of relevance to biological survival. While in modern industrial society, biological survival is less of an issue than it may have been 10,000 years ago, the perceptual systems which had evolved over millions of years before then are still of relevance today. Human auditory perception is primarily concerned with assisting the organism to form perceptual constructs of whatever is going on externally, and with the possible exception of acoustic specialists, not so much interested in judging long-time average sound levels. This is probably the main reason why members of the public resident around airports, if they have any interest at all, are generally much more interested in presentational materials showing the types and numbers of aircraft and the routes which they fly to get to and from the airport (i.e. ***operational indicators***) than in presentational materials showing so-called acoustic metrics, except perhaps for special cases where eligibility (or otherwise) for noise insulation and other forms of compensation is shown on a sound level contour map.

In this field and from the human perception point of view, the most important difference between operational indicators and acoustic metrics is that operational indicators are largely concerned with the aircraft and what they are doing relative to any defined observer, whereas acoustic metrics (those that are generally applied in the field of aircraft noise regulation and assessment) are largely concerned with the exposure effects of aircraft events at defined receiver positions, proximal to the observer and distant from the source. For example, a noisy aircraft that is distant from an observer could generate similar sound exposure levels to a quieter aircraft which is much nearer to the observer, but which could nevertheless be perceived completely differently. In such cases, operational indicators showing the type, operating configuration, and changing position of the aircraft relative to an observer during the flyover could be more relevant to human subjective perception than any indicators of sound levels adjacent to the observer during the same flyover.

There are three main types of operational indicator that are deployed by airports and other stakeholders under present-day conditions; these are (see **Figure 1**):

- Lists of aircraft operations, compiled by, for example, time of day, type of aircraft, distance to/from destination, aircraft weight;

- ***Cross-sectional charts*** showing aircraft height and track when passing a defined observer point – known as gate analyses;

- Maps showing individual ***flight tracks*** and the distributions of multiple flight tracks across the ground in relation to defined observer points on the ground.

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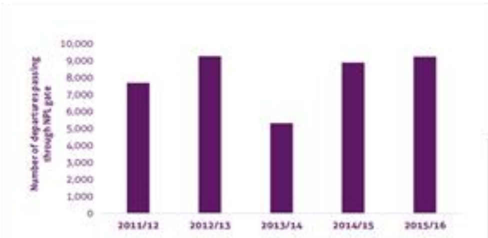
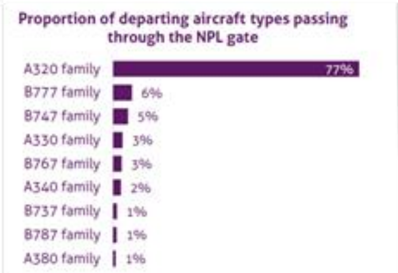
***Figure 1**: Examples of Operational Indicators taken from the Heathrow Case Study in D2.5*

1) Lists of aircraft operations

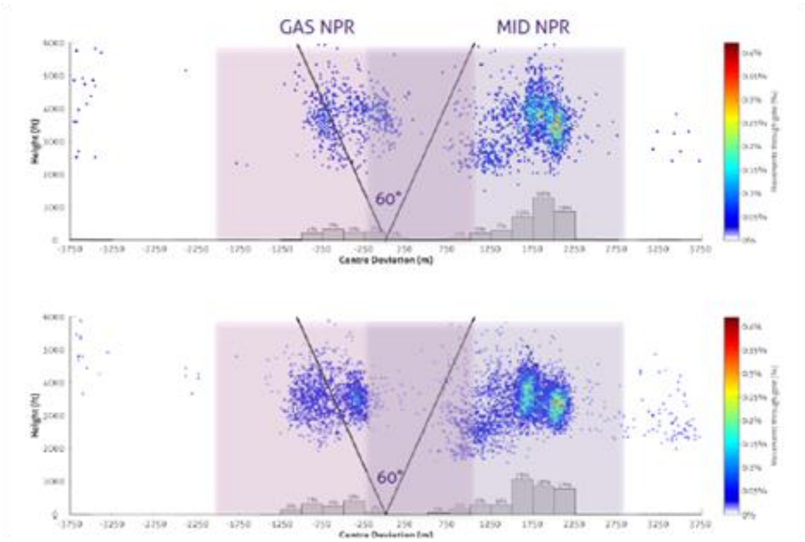


	2011/12	2015/16	Diff	% change
Proportion of easterly operations (all Heathrow flights)	24%	31%	+7%	N/A
Proportion of easterly departures passing through the NPL gate*	22%	21%	-1%	N/A
Average number of easterly departures passing through the NPL gate per day	142	136	-6	-4%



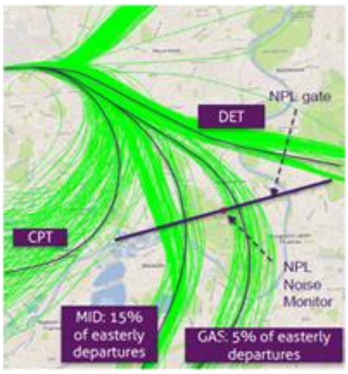
Numbers of departures on a given route and proportion of different aircraft types

2) Cross-sectional charts



Heat maps showing concentration of aircraft as they pass through a gate

3) Flight tracks



Radar flight tracks on specific routes

Notes: NPR – refers to the noise-preferred route for south/east bound Easterly departures from Heathrow Airport. These are shared between the CPT NPR, GAS NPR, MID NPR and the DET NPR. NPL – refers to the location of a temporary noise monitor in the grounds of the National Physics Laboratory

In addition to these operational indicators, it is also possible to apply various quantitative metrics to each type of indicator, by for example; counting the total number of aircraft movements following any route per hour or per day, and then breaking the totals down into the percentages of different aircraft types; or by counting the number of aircraft movements above or below a specified height at a specified distance along the flight tracks; or by counting the total numbers meeting (or not as the case may be) some industry target or noise limit. Appropriate presentations of one or more of these types of operational indicators are far more likely to provide a reasonable overall impression of how an airport is operated, and coincidentally, how 'noisy' it might be perceived to be compared to other airports (when compared using similar operational indicators), than any acoustic metrics.

3.2.2 Acoustic metrics

Single event metrics at defined receiver points

At any defined receiver point on the ground, the physical amount of aircraft noise is determined by the type of aircraft (i.e. the engineering design) and how the aircraft is operated, particularly in relation to the time varying distance from the aircraft to the receiver point while the aircraft is flying overhead or nearby. There are many different variables involved, including the atmospheric/meteorological conditions at the time of operation, which can significantly affect the acoustic propagation of sound waves from the aircraft down to the ground. Any and all of these variables can be reflected in variations in the overall sound level time history, both in terms of the overall duration of the flyover event, and in terms of changes in sound quality during the flyover event. Particular acoustic features such as the Doppler effects and the relative balance between high and low frequency components at different times during the flyover event can be interpreted or perceived by listeners in terms of differences in the type of aircraft and the type of operation being performed.

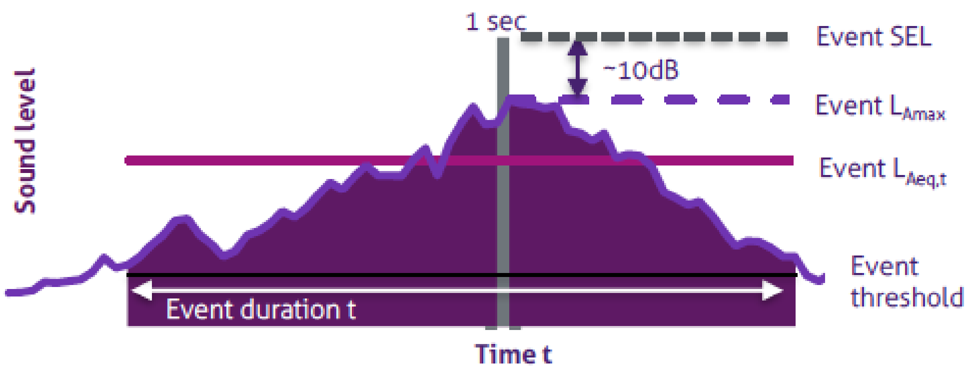
Sound level event metrics, such as L_{Amax}[4], which quantify the short time maximum A-frequency weighted sound level of individual aircraft flyover events at defined points on the ground, are of interest for scientific and engineering purposes, but may be of limited interest to members of the public except to whatever extent they can be associated with particularly noticeable events (see **Figure 2** for an illustration of different metrics used to describe the maximum - or peak - loudness of a single flyover event).

A major difficulty with L_{Amax} values is the generally rather weak correlation with subjective loudness. Unfortunately, none of the many more sophisticated sound quality metrics that have been developed over the past 50 years can be recommended as a panacea for this problem. This is largely a consequence of human '**selective attention**' which, and perhaps perversely from an

[4]In this context, LAmax is the maximum A-weighted sound pressure level of an aircraft noise event (aircraft pass-by)

engineering point of view, can focus on different features of different sounds at different times. These features may or may not be particularly well represented by any particular metric used at the time. The historic record shows that attempts to take into account, for example, event duration (SEL[5]); low frequency content (the C-frequency weighting[6]); or specific features assumed or defined to contribute to ***subjective noisiness*** (EPNL[7]) instead of ***subjective loudness*** can achieve higher correlations with subjective loudness (than L_{Amax}) under limited ranges of specific circumstances, but not in the general (SEFA, 2007).

Figure 2*: Example from the Heathrow case study showing different flyover sound measures*



Of course even weak correlations are better than none, particularly where the purpose or function of measurement is to inform noise control engineering decisions or resolve contractual or regulatory disputes. Long experience has shown that it is unwise to rely on subjective judgement alone when measuring the effects of engineering noise control, and this is where objective acoustic metrics have been found to offer the most value. Precision grade sound level meters and similar instruments deployed to measure L_{Amax} and similar quantities have very much narrower tolerances on measurement results than subjective judgements which (as stated above) can be subject to considerable uncertainty and even unknown bias. On the other hand, it should be noted that just because a small reduction in L_{Amax} (or any similar flyover event metric) might be measurable using precision grade instrumentation, and could even be sufficient to turn a fail into a pass when tested against some defined sound level criterion

[5]Sound exposure level (SEL) or acoustic exposure level is a logarithmic measure of the sound exposure of a sound relative to a reference value. It stands for the traditional noise level expressed in decibels (dB)

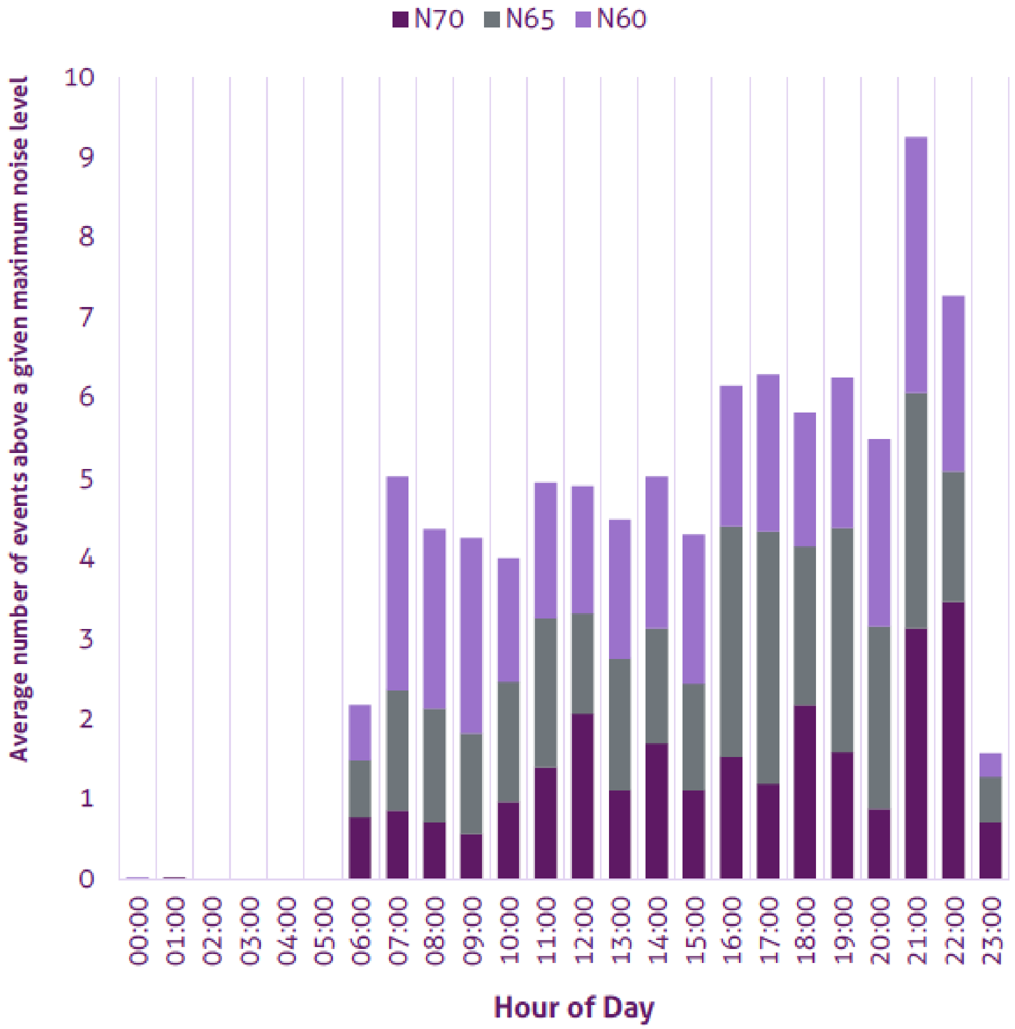
[6] C' Weighting is a standard weighting of the audible frequencies commonly used for the measurement of Peak Sound Pressure level. Measurements made using 'C' weighting are usually shown with dB(C)

[7]Effective perceived noise in decibels (EPNdB) is a measure of the relative loudness of an individual aircraft pass-by event. Separate ratings are stated for takeoff, overflight and landing phases, and represent the integrated sum of loudness over the period within which the noise from the aircraft is within 10 dB of the maximum noise (usually at the point of closest approach.) It is defined in Annex 16[1][2] of the Convention on International Civil Aviation and in Part 36 of the US Federal Aviation Regulations.[3]

or noise limit, this does not necessarily mean that any human listener would automatically be able to perceive the difference, or be impressed by it.

A key point here is that small objective changes to the acoustic environment that can nevertheless be reliably represented by an appropriate objective metric might not necessarily be sufficiently large to be noticed by the population in receipt of this ‘benefit’. This may explain why residents are often unaware of noise control efforts applied ostensibly on their behalf. Indeed such changes may be small in comparison to the variation in noise events, which occurs anyway from one aircraft flyover the next as a result of changing operational and atmospheric conditions. Thus single event metrics alone may be insufficient to highlight the potential impact of noise management interventions on affected communities. Both qualitative and anecdotal evidence suggests that many residents are far more interested in, and likely to be convinced by, easily observable differences in aircraft operations, than by much more perceptually ambiguous differences in aircraft flyover event sound levels. Nevertheless, a sense of the range of flyover events over time can be achieved using simple event histograms for a single location as illustrated in **Figure 3**.

***Figure 3**: Heathrow case study histogram showing change over the day of number of events of over L_{Amax} 60, 65 and 70 for a specific location*



Time-averaged metrics at defined receiver points

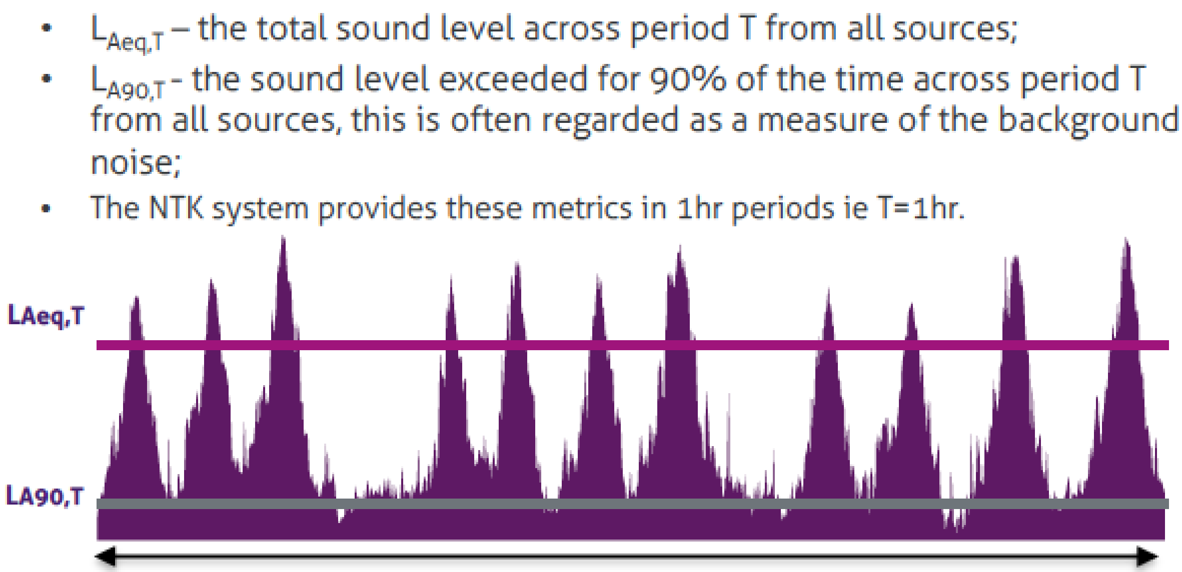
Time-averaged metrics seek to build on single event data by capturing the totality of noise exposure over a given time frame. Community perceptions of aircraft noise are affected by the totality of individual experience and not just by individual isolated events, important though these may be. Both qualitative and anecdotal evidence suggests that while particularly noisy or disturbing separate aircraft flyover events may act as triggers for noise complaints and other forms of objector behaviour, it is the perceived totality of individual experience in the light of contextual and situational factors that determines overall attitudes and opinions for or against an airport.

Regulators and assessors have attempted to describe this overall exposure using long time average metrics such as L_{Aeq}[8], L_{dn}[9], and L_{den}[10]. The simplest type of

[8]Basically, the $L_{Aeq,T}$ is the continuous noise level in dB(A) with the same energy that a fluctuating noise level also in dB(A) over the considered T period. The $L_{A90,T}$ is the

long-time average metric, L_{Aeq}, is in fact representative of a fundamental or basic physical quantity: the long time average acoustic intensity at the defined receiver position (see **Figure 4**).

***Figure 4**: Heathrow case study example demonstrating calculation of L_{eq} from aggregation of flyover events*



L_{Aeq} is capable of being measured and/or modelled to within much narrower limits of physical uncertainty than is required for correlation with reported annoyance. Problems arise because L_{Aeq} has no higher correlation with individual reported long-term annoyance than has L_{Amax} with individual reported short-term loudness or noisiness. The main reason for the low correlation is that the aetiologies of individual human attitudes and opinions are complex and as such can be influenced by many other variables not taken into account by simple long time average physical measures (the role of non-acoustic factors and their influence on expressed annoyance are discussed in some depth in D2.4). Further, it is likely that for different respondents, responses to standardised noise annoyance questions are differently influenced by different features within the overall noise environment, such as the relative amounts of night-time and day-time traffic. Some survey respondents may be more or less sensitive to night-time traffic than others, or may spend different amounts of time outdoors or away from home than others.

Variations on the simplest type of long-time average metric, L_{Aeq}, have been devised and adopted as attempts to reflect some of these possibly differing

continuous noise level in dB(A) over which the considered fluctuating noise level is superior 90% of the time of the considered period.

[9] L_{dn} is the average noise level L_{Aeq} over a 24-hour period. The noise level measurements between the hours of 10pm and 7am are artificially increased by 10 dB before averaging

[10] L_{den} is basically the same than L_{dn} but with a different ponderation: a penalty of 5 dB added for the evening hours or 19:00 to 22:00, and a penalty of 10 dB added for the nighttime hours of 22:00 to 07:00.

sensitivities, such as L_{dn} and L_{den} with different day, evening and night-time weighting factors applied. The problem with any weighting scheme is that it is essentially arbitrary. The bottom line here is that long time averaged metrics such as L_{Aeq}, L_{dn}, and L_{den}, have been found useful for regulatory assessment purposes, notwithstanding that their correlation with individual attitudes and opinions is uncertain for predictive purposes. It should also be noted that notwithstanding the application of considerable ingenuity within the scientific community in recent years, it seems unlikely that any alternative long time average metric could be devised that would overcome this problem, particularly as any alternative to L_{Aeq} type metrics would not be as closely representative of physical reality.

Spatial averaging and aggregation

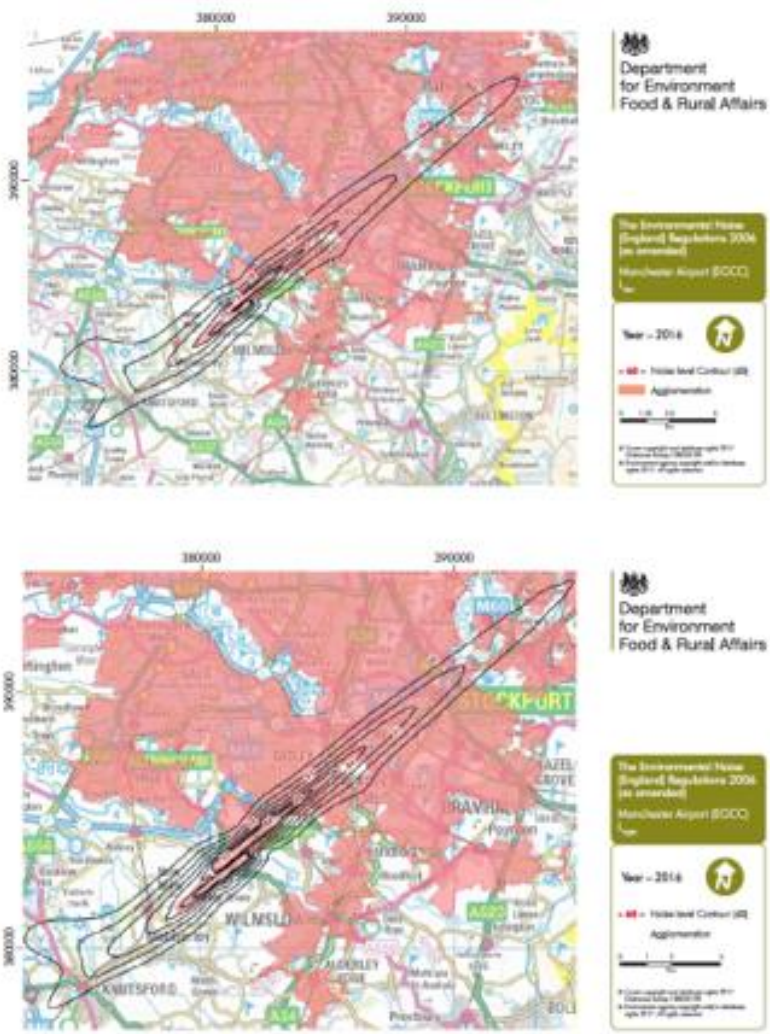
Community response to aircraft noise is an aggregate of many different individual subjective responses, which can vary from almost complete lack of awareness to unhealthy obsession. The concept of average community response may therefore be of limited relevance to individual residents, the most 'annoyed' of whom could well believe that the average is simply a statistical concept designed specifically as a means of discounting their individual and strongly held opinion from regulatory attention. Other residents might take an opposing view, that discounting the more extreme opinions from regulatory consideration is a good thing. Regulators and administrators are likely to welcome the concept of spatial averaging as applied to objective metrics and modelling tools, if for no other reason than averages can be assumed to represent mass exposure, and to whatever extent that may or not correlate with aggregate subjective opinion will determine the usefulness of that assumption for predictive purposes. If, for example, average opinion is either mildly indifferent or even marginally supportive of an airport, then regulators and decision-makers might feel justified in paying less attention to airport objectors than might otherwise be the case. On the other hand, paying less attention to those with more strongly held opinions might encourage sympathy with the airport objectors and have otherwise unforeseen consequences.

So far we have concerned ourselves with the illustration of noise exposure at specific locations acknowledging the role of single events and the totality of exposure over a given time as influential in the individual perception of, and response to, noise. Another key aspect of noise management however, is the implication of changes at multiple locations as this often associated with procedural fairness and equity. In order to capture the spatial implications of airport operations and thereby inform management interventions such as those associated with land-use planning, airports and regulators commonly use contour maps to summarise the spatial distribution of noise. Indeed, the EU Environmental Noise Directives places a requirement on all airports with more than 50,000 ATMs (air traffic movements) per annum to produce L_{den} and L_{night}

noise maps to highlight the geographical extent of noise exposure around Europe's largest airports (see **Figure 5** for examples).

Aircraft noise contour maps can be used to calculate the total areas, residential populations affected, numbers of schools and hospitals, or other potentially noise sensitive locations, geographically located within defined aircraft noise contour bands, and then used to compare between, for example, different runway locations and orientations. It should be noted that this type of comparison is only useful for high-level strategic assessment and is essentially meaningless in respect of individual and potentially affected residents. Regulators and administrators may wish to publish the results of this type of strategic comparison in order to justify any resulting decisions made, but practical experience shows that this does not necessarily lead to increased acceptance of those decisions by individual residents likely to be adversely affected by those decisions. On the other hand, if those residents can also be convinced that any decisions made, while having adverse effects on them as individuals, have nevertheless been made with the greater good of the whole community in mind, this may lead to increased understanding and a possibly increased degree of individual acceptance. This is an important application area for effective public engagement which may fail if presentation materials are overly technical or complicated, or fail to take into account the individual objectives and priorities of target audiences.

Figure 5: *Examples of Noise contours required for large airports under the EU ENDS Directive*



3.3 Conclusion

Section 3 has demonstrated that whilst numeric quantification is often essential for regulatory and administrative purposes, providing that the chosen metric is properly specified and appropriate for any bureaucratic task, no great degree of understanding is required. However, depending on the target audience, for public engagement purposes the degree of understanding required may be greater than that required for bureaucratic purposes. In essence, regulatory procedures deal with the '***what***' of any issue while public engagement can be more concerned with the '***why***'. In this field, one of the greatest obstacles to increased public understanding is not the accuracy and precision of statistical enumerations of noise contour areas and such like, it is instead the generic lack of understanding of why noise assessments are carried out in that way at all. So **the challenge of airport operators and others charged with enhancing noise management is to select noise metrics that address the purpose**

identified directly in a way that is comprehensible to the target audience(s).

4. Review of Modelling Tools

4.1 Classification of noise models

Many organisations (authorities, aircraft manufacturers, research establishments, consultants, etc.) have developed aircraft noise models for different purposes. Although each of these models has its specific characteristics and functionalities, in general they can be classified in two broad groups:

- **Best Practice** or Integrated models
- **Scientific** or Simulation models

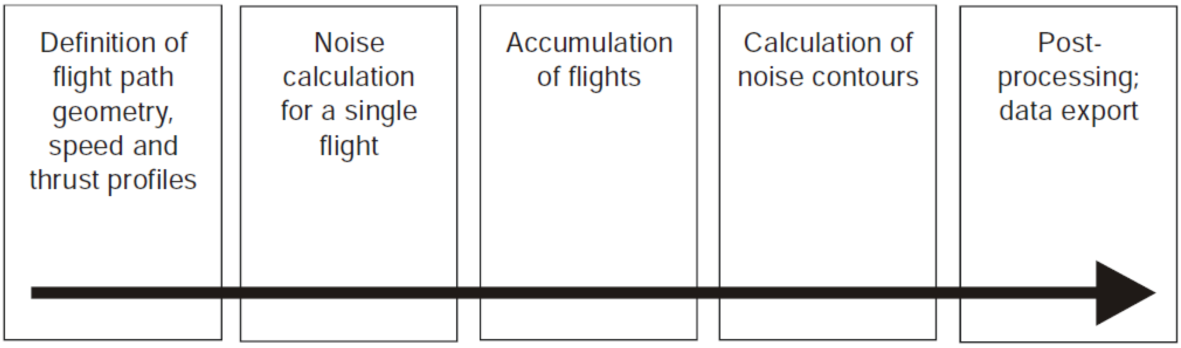
Both types differ significantly in the required input data, the modelling principles, the generated output and the purposes they are used for. These differences must be taken into account when selecting an aircraft noise model for a specific task. Certainly, **there does not exist a "one-size-fits-all" model**.

4.1.1 Best Practice models

Best Practice models estimate the noise around airports, for determined air traffic scenarios and usually for relatively long periods of time (typically up to a year).

The first Best Practice aircraft noise models were developed decades ago. The computation power available in those times was such that a practical approach to the modelling methodology had to be taken. Over the years this methodology has proven reliable for the purpose it was designed for. Therefore, even current Best Practice models are still using basically the same underlying principles (see **Figure 6**).

Figure 6*: Noise contour generation process (source : ICAO Doc 9911)*



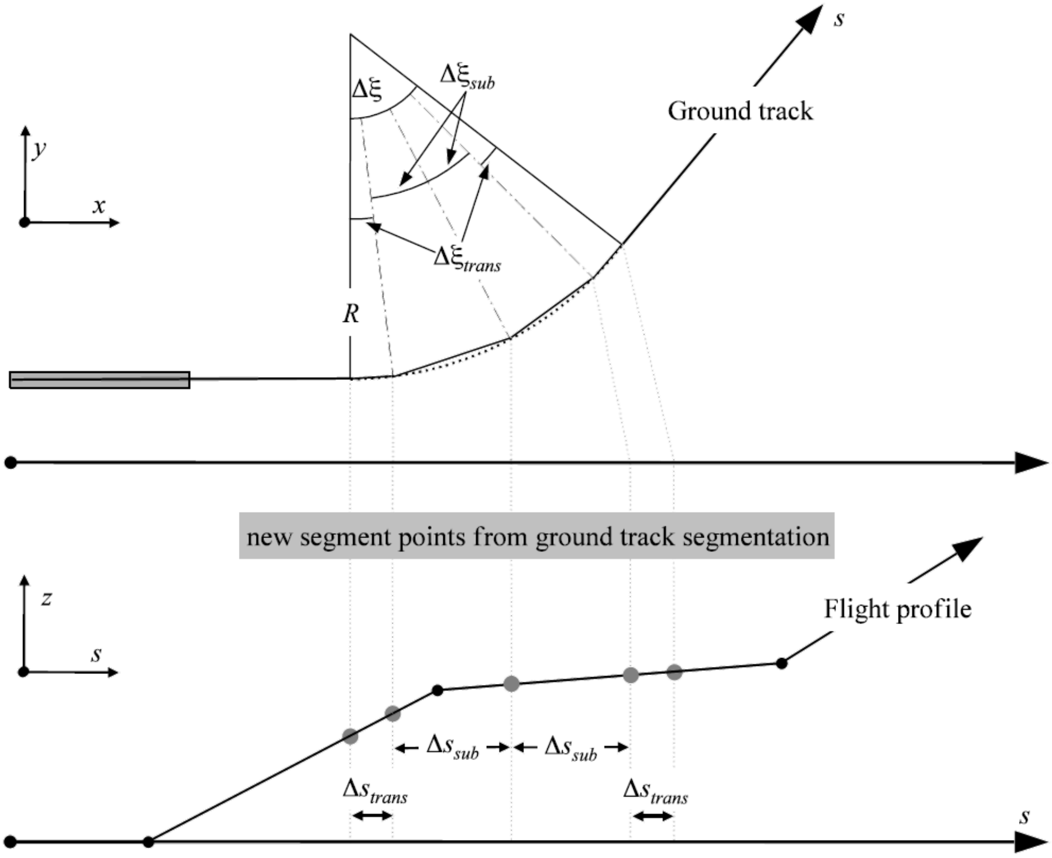
In the last decade harmonisation has been achieved between the various methodology descriptions used worldwide (e.g. ICAO Doc 9911, ECAC Doc29). Models based on these documents (e.g. INM/AEDT, STAPES, ANCON, SONDEO, etc.) will give equivalent results for the same input. The main differences between these models can be found in their user interfaces and some specific functionalities.

A major component of Best Practice aircraft noise models is the database containing noise and performance data for the various aircraft types of the current aircraft fleet. At present, the Aircraft Noise and Performance (ANP) database, hosted by Eurocontrol[11], is used worldwide. This database contains so-called Noise-Power-Distance (NPD) tables, usually derived by the aircraft manufacturers from data obtained during the noise certification process. For aircraft for which no data are available in the ANP, proxies are defined that may be used to represent them. One of the main characteristics of a NPD is that the noise source data and propagation effects are integrated into a single database (hence the name "integrated noise models").

Most Best Practice models use the so-called segmentation technique, in which the 3D flight trajectory is split in a horizontal part ("ground track") and a vertical part ("flight profile"). For a specific airport noise study this information may be derived from e.g. the AIP (prescribed Standard Instrument Departures and Approaches) or from actual radar tracks. The ground track is then subdivided into a number of straight segments. The flight profile represents the actual flight conditions of the aircraft (thrust, speed, aircraft configuration, etc.) and can be estimated by using standard profiles, usually available in the model's database (see hereafter), or by defining procedural profiles, that can be used to customise the profiles to the actual ones. These profiles are subdivided into segments of constant conditions. The 3D flight path is then constructed by combining the segments of both ground track and flight profile, as presented in **Figure 7**.

[11] https://aircraftnoisemodel.org/

***Figure 7**: Construction of flight path segments (source : ECAC Doc29)*



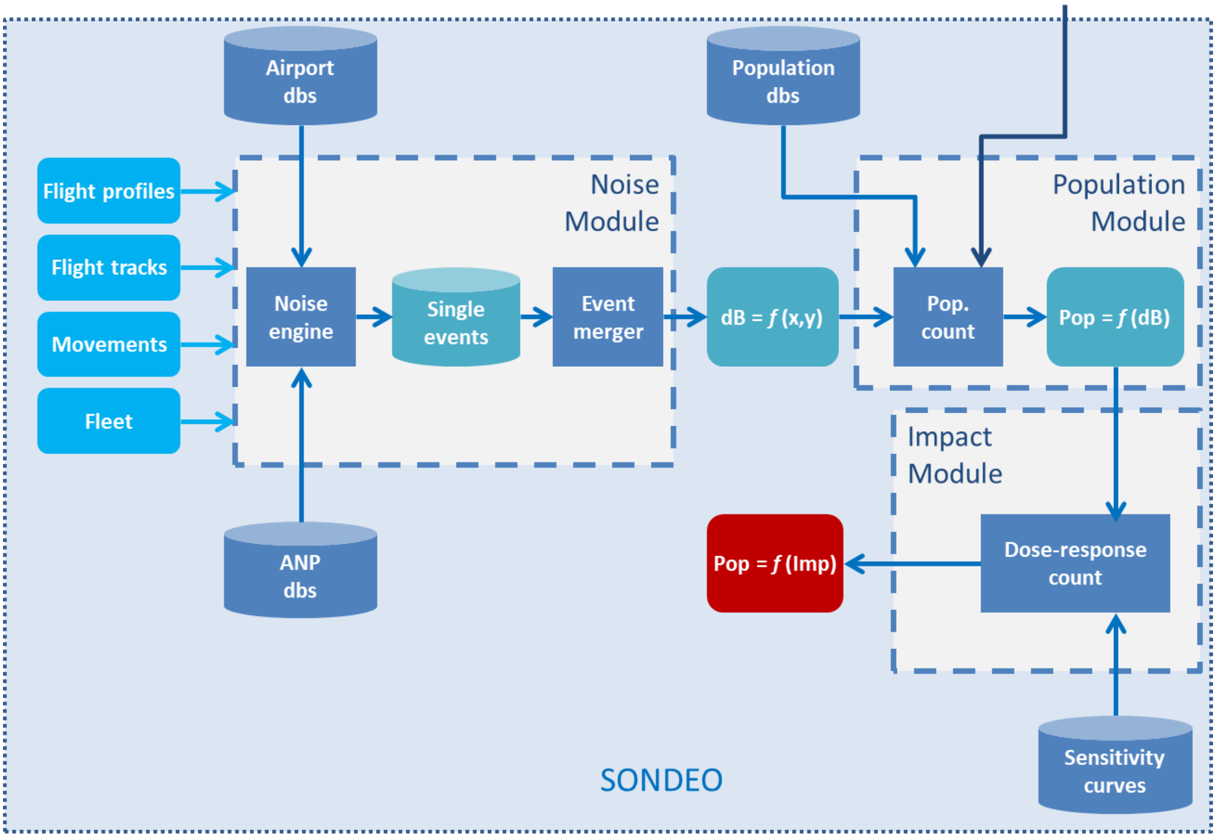
To account for the deviation of actual tracks from the standard routes (lateral dispersion), sub-tracks may be defined that are treated in the same manner as those described above.

For a certain observer point on the ground at which the noise level from the aircraft pass-by is to be determined, the distance to each segment is calculated. This distance and the power setting (usually thrust) corresponding to each segment are used to interpolate in the NPD table to yield the corresponding noise level. The final noise level at the observer location is then calculated by summing the contribution of each individual segment. This process is repeated for each observer location in a grid of points. Then the whole process is repeated for each aircraft operation after which the total noise at each grid point can be determined and expressed in a variety of metrics, as defined in section 3.

The outcome of the noise calculations can be used in a post-processor to derive e.g. number of people exposed to certain noise levels, or more sophisticated impact metrics.

Figure 8 provides the above described process for the SONDEO model, implemented in the Noise Management Tool chain, developed in ANIMA WP4.

Figure 8: *Airport noise calculation process used in SONDEO*



Best Practice models have demonstrated their value in airport noise studies with a fleet of aircraft and a longer term scope. Due to the specific methodology followed they are less appropriate for accurate single event assessments.

4.1.2 Scientific models

The main difference between scientific models and the Best Practice models described in the previous section, is the way that noise sources and propagation effects are treated. Whereas in Best Practice models both are integrated in a single database (NPD), in scientific models they are separated. This separation has several advantages:

- Calculation of individual noise sources (engine, airframe, etc)
- Calculation of installation effects (e.g. wing shielding)
- Calculation of atmospheric propagation effects (e.g. refraction, ground reflection, shielding by barriers)

However, this comes at the cost of a need for significantly more input data (e.g. engine working conditions, detailed geometrical information of the engine/aircraft, detailed atmospheric data, etc.). In many cases this information is not (publicly) available, which limits their application to organisations like manufacturers and research institutes. To determine the engine parameters engine models like GasTurb[12] or GSP[13] may be used if no engine deck is available from the manufacturer.

ANOPP (NASA), PANAM (DLR), CARMEN/IESTA (ONERA) and SOPRANO (Anotec) are examples of scientific models.

The prediction models used for the noise sources may be semi-empirical or more sophisticated physics-based models and usually provide at least 1/3 octave band resolution. Models like SOPRANO can use multi-dimensional tables as a source noise description, which have been generated previously by more sophisticated external Computational Aero-Acoustic (CAA) tools.

Another characteristic of scientific models is the use of a 4D discretisation of the flight trajectory (3D position + time). For each discrete point all required parameters (engine working conditions, flight conditions, aircraft configuration, etc.) are known and used to predict the noise of all sources considered. For each observer position the propagation path to this point is determined and the corresponding propagation effects calculated. This is repeated for each point of the flight trajectory. As a result, a noise-time history at the observer position is obtained. This then allows for the calculation of all kinds of noise metrics. This process can be repeated for all points on an observer grid and hence noise contours can be derived for the simulated event.

Due to their characteristics, scientific models are especially appropriate for e.g. optimisation of flight profiles (noise abatement procedures), assessment of noise reduction technologies and in general those cases where accurate single event noise levels are required.

In the Noise Management Tool chain, developed in ANIMA WP4, such modelling capability (offered by SOPRANO) is used to generate single event noise data for aircraft with new noise reduction technologies, which can be used by SONDEO to simulate insertion of these aircraft in an existing fleet at an airport.

Figure 9 presents the generic structure of SOPRANO, in which the division between source noise and propagation can clearly be observed.

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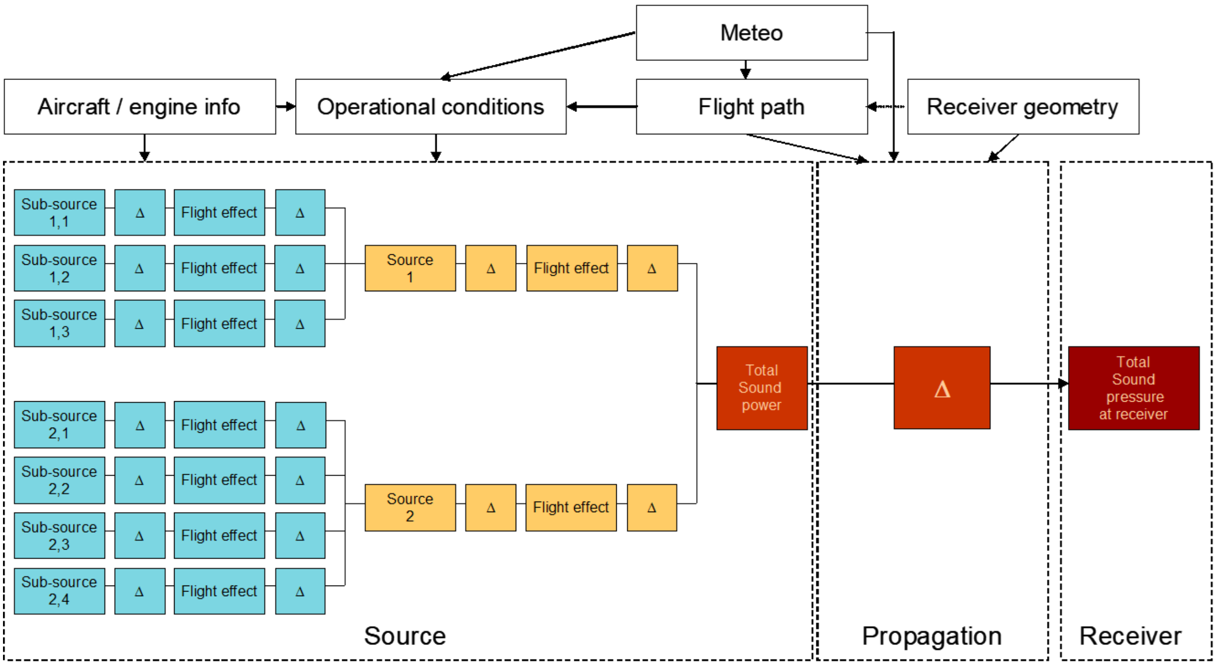
[12] http://www.gasturb.de
[13] https://www.gspteam.com/

***Figure 9**: Generic programme structure of SOPRANO*



4.2 Application of noise models

As already mentioned earlier, there is no single noise model that will be able to address all needs for modelling. To provide some guidance in selecting the best model for each purpose, the various elements of the ICAO Balanced Approach can be considered.

4.2.1 Noise reduction at source

Studies for noise reduction at source are usually performed by manufacturers and/or research establishments. For this purpose, noise of the individual sources and their contribution to the total noise, is obviously paramount. For this reason, each manufacturer usually has its own in-house scientific model, calibrated for its own products. The required input is not an issue, since these organisations have at their disposal detailed information on the aircraft and engine in their different operating regimes.

For new concept aircraft like e.g. flying wing bodies, no detailed information is available, so more generic flight mechanics tools and engine models are used to provide the required information to feed the noise models. Obviously also **for this purpose a scientific model will be necessary.**

4.2.2 Noise abatement procedures

For the design of noise abatement procedures (NAPs), a distinction must be made between NAPs for departure and NAPS for approach. Best Practice models usually have the capability to define procedural profiles, based on a set of coefficients (in the ANP database) that describe with sufficient accuracy the aerodynamics and flight mechanics of the aircraft. Since the noise in departure is mainly generated by the engines and the corresponding NPD already takes variations in engine power setting into account, the noise of non-standard departure flight profiles can be estimated with reasonable accuracy.

However, in approach the airframe noise is of similar importance as engine noise. Airframe noise is strongly influenced by the configuration of high-lift devices and landing gear position and the aircraft speed. Also the engine thrust required to maintain a certain glide slope angle will depend on the aircraft configuration. However, the NPD data provided in the ANP, is only valid for a certain fixed aircraft configuration (usually full flaps and landing gear are down). Designing an alternative approach procedure, which allows for e.g. low drag would require multi-configuration NPDs, which are not available in the ANP database. Therefore **NAPs for approach have to be modelled with scientific models**.

4.2.3 Land Use Planning

Policy makers and spatial planners are mainly interested in airport scenarios with a longer term perspective. Therefore **Best Practice model are the most appropriate for these applications**.

A distinction should be made between noise predictions for past and future situations, especially with respect to the available information (input data). Whereas for past situations (e.g. in the frame of the Environmental Noise Directive) actual traffic data (aircraft movements per type) and in many cases also radar tracks are available, for future scenarios this information is not available and thus forecasts will have to be made about aircraft movements, types and routes followed. In the first case the noise modelling is rather straightforward. However, for the future case, the result will strongly influenced by the assumptions made. Experience from the existing situation (e.g. flight profiles used) may help to make reasonable assumptions for the future. Usually several potential scenarios need to be defined to obtain an indication of the range of noise levels that may be expected.

4.2.4 Airport Noise Management

For overall planning purposes and e.g. the assessment of expansion plans, which have a similar scope as Land Use Planning, the **Best Practice models will be the most appropriate to use.** With these models it is possible to identify potential problematic areas around the airport that should be addressed in an action plan for noise mitigation.

For the detailed design of the specific actions to be taken, the use of Best Practice models is usually adequate, but **in certain cases a more detailed study might be necessary that will require support of a scientific model**.

4.2.5 Operational restrictions

Operational restrictions may limit or ban the use of certain aircraft types, define curfews or in any other way limit certain aircraft operations at certain times and/or at certain routes. These restrictions are to be considered as a last resort, when all other solutions are found to be economically or technically unviable. These **restrictions can be simulated adequately by means of Best Practice models.**

4.3 Verification and validation of noise models

For a Best Practice noise model, to accurately calculate the noise around an airport, it should:

- Correctly implement the prescribed noise modelling methodology
- Correctly apply the model

4.3.1 Correct implementation of methodology in a noise model

The description of the methodology (e.g. ECAC Doc29) is elaborated by a working group, consisting of experienced noise model specialists (for ECAC Doc29: AIRMOD). The methodology can be considered state-of-the-art and is updated whenever new evidence for improvements becomes available. However, the description always has some room for interpretation, which during the implementation of the methodology in software (the "noise model") will oblige the developer to make some decisions that may influence the final results. This fact was recognised by the AIRMOD group and this resulted in Volume 3 Part 1 of the 4th edition of ECAC Doc29. This document provides several reference cases and their results. Model developers should use these reference cases to validate their model. In this manner it can be ensured that a noise model is compliant with the prescribed methodology.

Obviously this exercise is mainly of interest to the software developer and once compliance is shown, the model may be used for actual airport noise modelling studies.

4.3.2 Correct application of the model

Even if a noise model is used that has been validated as described in the previous section, the user must apply the model in an appropriate manner to obtain the correct results. Especially the use of correct input data is of utmost importance. The manner in which ground tracks and flight profiles are modelled will have a significant influence on the final results.

The only feasible manner in which the adequate use of the model can be verified is by means of comparison with measured data. At many airports a permanent noise and track monitoring system is installed that provides the required information for this. The noise at the monitoring locations can be predicted and compared with the measured noise levels at the same station. Since Best Practice models are not designed for accurate single event predictions, but rather for long-term noise level predictions, the validation should be performed by using relevant noise metrics (like L_{den}). It should be noted that measurements also have their inaccuracy and thus should not be considered the "gold standard".

ECAC Doc29 Volume 3 Part2 (still in elaboration) will address this topic in detail.

5. Review of Noise Communication Metrics

5.1 Conventional Noise Metrics

All EU airports over 50,000 ATMs per annum are required to produce noise maps indicating the geographical extent of noise exposure using L_{den} and L_{night} contour maps. Examples of these were given in Section 2.1.4 (**Figure 5**) and traditionally are used to demonstrate the spatial extent of current and historic noise exposure around airports[14]. These maps are an example of **a spatially aggregated and averaged acoustic metric** (as define in Section 2.1.4) and are usually based on modelled data; but can be validated against sound recordings from monitoring stations. They are an objective indication of noise exposure that combine the number and loudness of individual noise events into an overall decibel level-equivalent of sound energy over a given period, which can be represented in the form of contours to highlight the spatial extent of exposure. As such they are an objective representation of total sound energy around an airport and provide the basis of policy and regulatory decisions such as those associated with zoning for land-use planning purposes and thresholds for the application of compensation and insulation mitigation measures.
Unfortunately, however for many lay people these metrics have proven difficult to understand as some:

- have difficulties in the interpretation of contour representations overlaid on maps (Hooper et al, 2009); and
- others believe that long time average aggregated metrics average out across indicators of more direct relevance to the public such as the numbers and times of day at which aircraft noise events of different relative magnitudes actually occur (Hooper and Flindell, 2013).

Indeed it has been argued that the shortcomings of conventional acoustic metrics and their relative insensitivity to changes in the number and loudness of events has fuelled general dissatisfaction, and indeed mistrust in some cases among members of the public of the noise information provided by airports (Hooper et al, 2011).

It is for this reason that many airports have sought to extend the range of noise information routinely made available to the public to include other supplementary acoustic and operational data. Furthermore, airports are embracing a wider range of metrics when communicating on specific topics such new balanced approach interventions and the implications of new infrastructure/airspace changes. These are reviewed in the following sections.

[14]They can be used to predict future changes to noise exposure (such as in the case of the Australian Noise Exposure Forecasts), but often obscure important differences in the composition of the sound environment as they combine the impact of technological change (e.g. quieter aircraft) with that of fleet changes (i.e. Increases in the number of aircraft)

5.2 'WebTrak' and 'WebTrak MyNeighbourhood'

The use of supplementary metrics to enhance noise communication to the general public by airports has resulted in increasingly sophisticated web-based interfaces to allow individuals to interrogate aspects of airport activity giving rise to noise exposure. Two examples that have been adopted by a number of airports worldwide are WebTrak and WebTrak MyNeighbourhood. These are tracking software platforms that can be linked to via the airports' websites or through direct interface with the software developer's website[15].

The developer of the two web-based tools, EMS Brüel & Kjær, describes them as, focused on "shar[ing] noise and flight track data to improve airport community engagement and increase the public's trust to build tolerance for airspace activity and grow [an airport's] social license to operate". The developer goes on to suggest that they "avert airport noise complaints by enabling people to investigate noise disturbance in near real-time" (EMS Brüel & Kjær, 2019)

WebTrak can be used for tracking recent flight activity in and out of an airport and provides information about each aircraft and noise levels (in dB) at monitoring stations in the surrounding area. WebTrak MyNeighbourhood provides historical traffic patterns and trends and facilities for the user to interrogate the database; these WebTrak systems are currently offered by 74 airport operators and transport authorities worldwide, in various combinations (see Annex 1). The following section looks at the usability and practicality of the WebTrak programmes. The final section discusses the effectiveness of the tools for engagement and communication.

5.2.1 Functionality

This review assumes that an interested resident or other user is aware that WebTrak is available for their airport. If they have been informed that it is by the airport operator, it is possible that they may also have been told how they can access the flight-tracking site and may even have received training on its use.

However, visiting individual airport websites and searching for a link to their WebTrak site can prove challenging. A random visual search of a selection of airports' websites found that it is often difficult, if not impossible, to find a reference or a link to this resource. For example, even using the search facility on such websites, say at Oakland and Stockholm Arlanda, yields a nil response. At other airports, the official website link to WebTrak is located under

[15] There are other examples of similar web-platforms such as FANMOS used at Vienna https://flugspuren.at/jart/prj3/flugspuren/main.jart and NOMOS used at Schiphol https://noiselab.casper.aero/ams/#page=actual

'Environment' or a related section, though it may require considerable delving through several layers of information to access the actual link required (e.g. Barcelona).

As one enters the system, there is a clock on the top right of the screen, which displays a different time than the current time. Looking at Heathrow's WebTrak, there is around a half hour delay between the time of viewing and the tracks shown on screen. This lapse varies by airport (e.g. at Bournemouth, it is 24 hours; at Eindhoven, the gap is much smaller - of the order of 11 minutes). These delays are apparently required for security reasons but could confuse any lay member of the public coming to the screen for information, in the absence of any training on how to use the website and how to interpret its content, particularly if they wish to look up some aircraft that has immediately overflown and motivated their enquiry. Although the delay for security reasons may have been valid years ago, more recent public websites like Flightradar24, showing flight tracks in real-time, have made this need for a delay obsolete.

On WebTrak, the flight tracks are based on air traffic control radar data. Aircraft information on altitude, operator and aircraft type is available by clicking on an aircraft to open a text box. The user can define the historic period they wish to view. Weather information is available in a box that can be minimised, if required. The default map view overlays aircraft and noise data on a road map. Two other layers can be selected: aerial or terrain view. To help illustrate, an opening image of a WebTrak screen for Heathrow Airport is available at **Figure 10**.

Figure 10: Heathrow Airport WebTrak Image

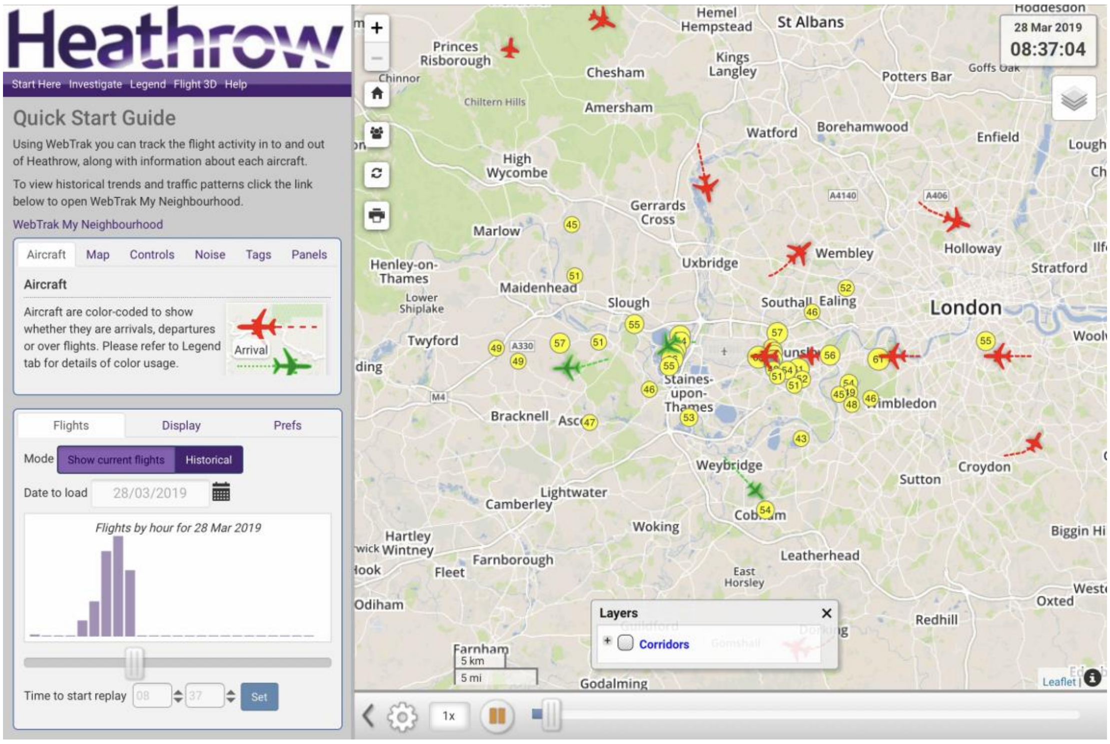
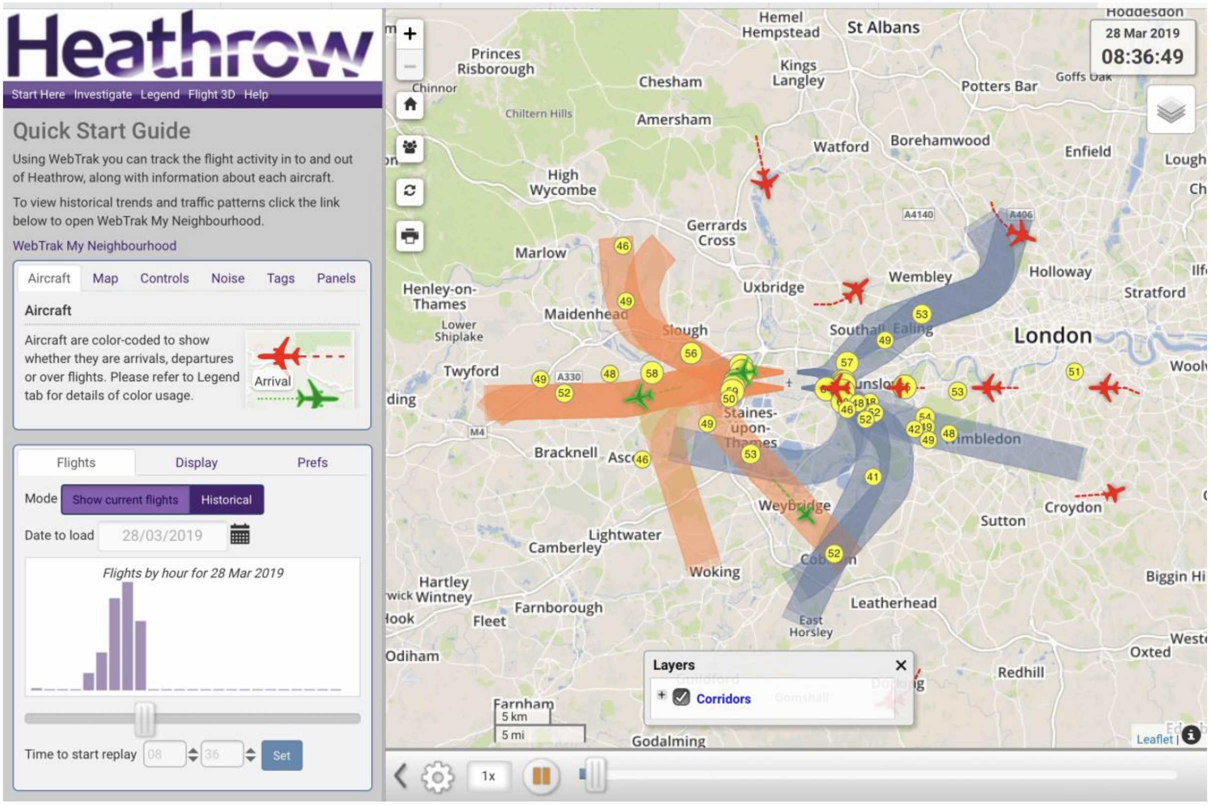


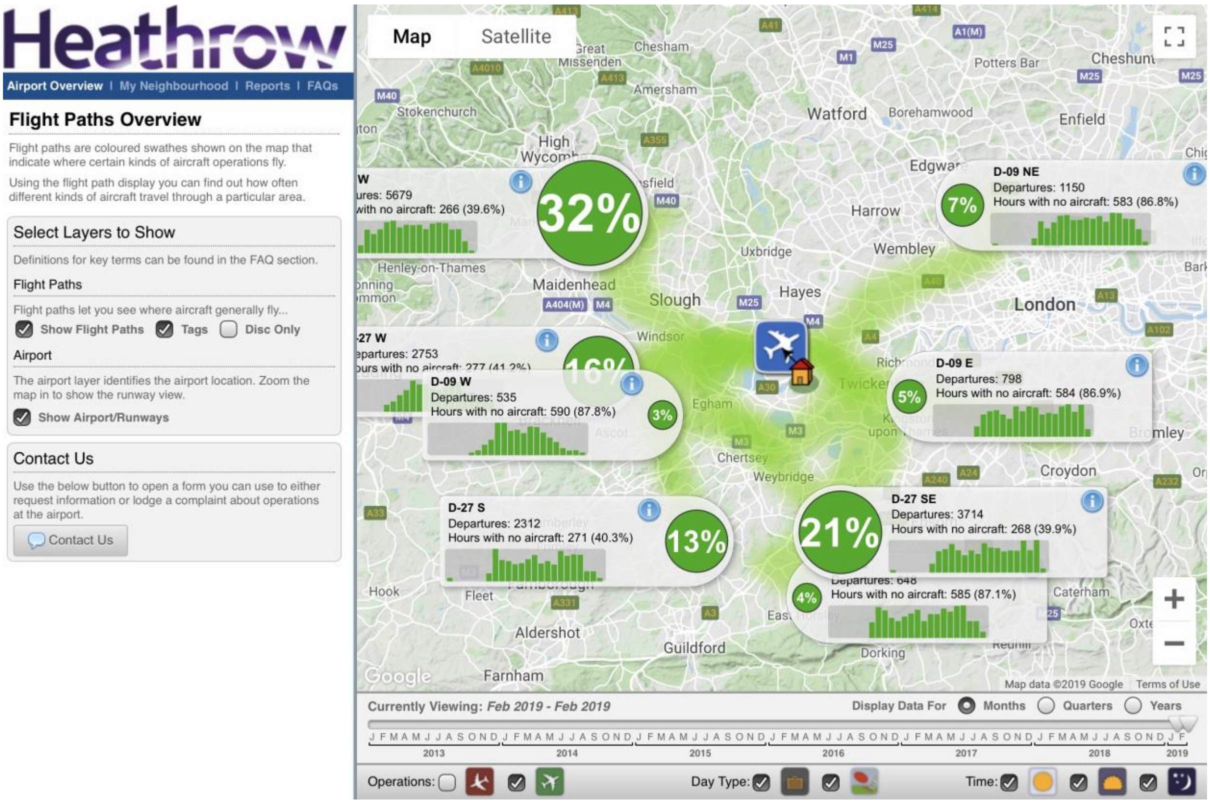
Figure 11: Heathrow Airport WebTrak (corridors option selected)



In **Figure 11**, an image of the screen above is provided with the corridors option selected. This illustrates the types of information the user has available and may need to interpret.

On WebTrak MyNeighbourhood, aggregated historic data on flight paths is illustrated on either the default road map view (on which terrain can also be overlaid) or satellite imagery. Day, evening and night data can be selected, as well as weekday or weekend period information; furthermore, the user can change the settings to define varying periods of interest. **Figure 12** demonstrates an initial screen from WebTrak MyNeighbourhood for Heathrow.

***Figure 12**: Heathrow Airport WebTrak MyNeighbourhood Image*



5.2.2 Effectiveness for communication and engagement

WebTrak and WebTrak MyNeighbourhood can help provide evidence for people and communities who are concerned about aircraft noise at their local airport. The strength of such information provision is that it does not require a mediator, for example, the airport's environment department, to satisfy data requests. It also enables multiple and varied inquiries to be carried out to develop a portfolio of information which may be helpful to residents seeking more information on airport operations and how these influence the noise environment. For example, Heathrow's version of WebTrak My Neighbourhood can:

- Provide a comprehensive overview of aggregate flight track densities for all arrival and departure routes, including number of flights, distribution of flights over a selected time period (in a pop-up histogram for each route with event numbers in hourly segments), hours with no flights, and proportion of flights on each arrival or departure route, pattern of hourly movements over a selected time period for each route and average total movements in each hour in for a selected time period;

- Tailor the aggregation of information by time of year, duration (in months), arrivals and/or departures, time of day (specified in day (d), evening (e) and night (n)), weekdays and/or weekends
- Offer an option to zoom in and select a very specific geographical point of reference. It must be noted here however, that no location specific information is provided. This particular example instead provides an opportunity for the public to establish where flight track densities are relative to a selected location;
- Provide a relatively complex overview of over flight patterns. No explanation is given however, of operational procedures (i.e. three ops modes are not illustrated and thus variation in movement patterns is not explained).

It should be noted that the Heathrow version of Webtrak MyNeighbourhood does not provide any noise data. These web-based resources clearly provide access to a range of operational information not previously available in a form that can be interrogated by users and thus offer the capacity to address residents' questions and concerns. Nevertheless, their provisions by airports raise a number of questions. While the trained and/or motivated user who dedicates time to understand the systems may gain substantial insight into noise and aircraft activity at their airport of concern, simple provision of such tools may exclude vulnerable social groups or those for whom such technology is not familiar. If the intention, as stated by the developer, EMS Brüel & Kjær, is to build trust and tolerance, it is difficult to see how this is achieved for all noise-affected people around airports. The exercise of releasing WebTrak to community users to make data more readily available needs to be revisited if it is simply a standalone practice. If it is augmented by online tutorials, training and readily available helplines then it can start to become a means of communication. However, provision of a web-based tool and its associated data is not true engagement. Arguably, this type of approach to information availability barely climbs Arnstein's Ladder of Citizen Participation (see D2.4 and D3.3) into the early rungs of tokenism. If augmented by other forms of engagement and, alongside user education, the airport operator may move towards more participative approaches and genuine partnership working nearing the higher levels of the Ladder.

The developer asserts that the tools avert noise complaints, although there is no quantitative evidence of this. It is difficult to find evidence to justify this assumption. It appears that there is some notion that greater public availability of information about aircraft movements and noise may reduce the need for some individuals to lodge complaints. It may be that the developer carried out user testing in the development of WebTrak tools and this was found to be the case. However, no reports of such testing have been found. It also seems to be a rather large leap to move from having a tool to understanding its ability to avert complaints.

As a corollary, it would have been helpful to know whether, during development and testing, anyone asked the public/affected communities how they would like noise data presented. Were user tests carried out with real people in development of the tools? Is there tailoring to meet individual community needs? In the absence of such information, there is a danger that tools may have been created around data availability and not necessarily user needs and functionality. The danger therein is, as Heylighen (2002: 1) highlights, writing on information overload in society, that communications technology has brought additional complexity. He asserts that "[p]eople find it ever more difficult to cope with all the new information they receive…" and that this leads to "growing stress and anxiety".

In terms of WebTrak, the presentation of data can seem more complex than necessary, potentially conveying the idea that this is 'expert' material and rather impenetrable for the average user. Perhaps a simple example/dummy airport scenario could be provided with WebTrak tools as a resource to help people gain understanding of the way data is being presented and how it may be interrogated. The use of active, 'live' data could then be less challenging once some familiarity with the system has been developed. In addition, there is always the point that WebTrak type tools only provide information that is already available to residents simply by going outside to take a look, and does not, of itself, provide any information about what the airport is actually doing about noise, and possibly of even greater interest to residents, what it might be doing in the future to meet public concerns.

In short, while the benefits of WebTrak tools are in information provision, some understanding of how they are used by communities and individuals would be beneficial to ensure that the objective of credible data delivery is being achieved. Complementary research to understand the WebTrak development and the updating thereof would also be helpful to confirm that the least complicated tools have been created with a firm focus on end user needs rather than airport authorities and operators desire to appear that they are truly engaging with their affected audiences by providing these tools.

5.3 Noise information provision in Balanced Approach airport case studies (see D2.5)

The case studies presented in D2.5 relate to specific airport Balanced Approach (BA) interventions and, from the perspective of this sub-task, provide insights into the purpose and nature of noise information provision to support the design, decision-making, implementation and evaluation of measures designed to reduce noise exposure. These case studies demonstrate a range of purposes for which noise information was prepared and disseminated that reflect the categories outlined in Section 2.1 above excepting the 'specifications for engineering design' category which is associated with reduction of noise at source and thus beyond the remit of WP2. How the provision of noise information in the Balanced Approach case studies aligns with different purposes is summarised below[16]:

- Setting ***criteria and targets*** for regulatory purposes, the **Frankfurt** case study examples how acoustic metrics have informed a complex set of operating restrictions and compensation plans designed to manage the impact of airport expansion. In a similar fashion the **Barcelona** case study highlights the challenges of managing the impact of airport expansion. The **Catania** case study used aggregate metrics to justify zoning for land-use planning and compensation.
- Comparing alternative ***what-if scenarios*** arose in a number of case studies examining possible enhanced operating procedures such as those at **Helsinki** (alternative departure procedures), **Arlanda** (steeper arrival glide slopes), **Vienna** (design of a new curved approach) and **Schiphol** (amendments to NADPs to protect targeted communities).
- ***Communicating aircraft noise issues*** to different stakeholder groups. This was at the heart of the **Heathrow** response to concerns raised by the Teddington Action Group about changes in departure profiles and was also central to **Vienna's** work with their Dialogue Forums.

It is hardly surprising that the range of purposes served by the information provision within specific case studies is also reflected in the breadth of noise indicators used to describe the noise context and any proposed changes to it to different stakeholder groups. This is summarised in Table 1 using the noise information categories described in Section 3.2 above.

[16]It should be noted that a range of less experienced airports were subject to case studies (e.g. Iasi, Kiev, Cluj and Ljubljana). The purpose here was to understand the situation of airports that in the future might be recipients of best practice, rather than to provide insights into specific Balanced Approach interventions

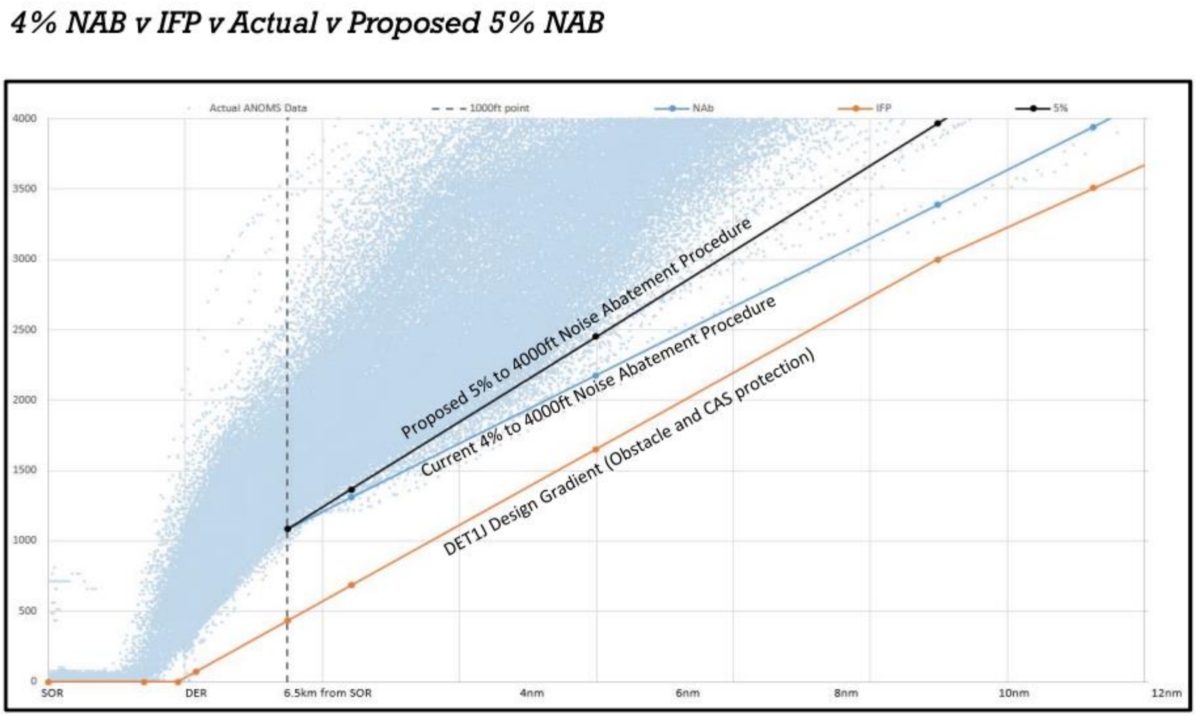
Table 1: Noise information matrix – airport case study use of different noise indicators by type

Airport Case Study	**Operational Indicators**			**Acoustic Metrics**		
	Lists of operations	Cross-sectional charts	Flight tracks	Single Event (at defined receiver points)	Time Averaged (at defined receiver points)	Spatial Averaging and Aggregation
ACNUSA	On request	On request	On-line flight track visualisation tools	LAmax – Number above event profiles over time periods and by aircraft groups	Laeq, Lden, Lday, evening, night. For arrival, departures and total movements	Lden contours for noise exposure plan
Arlanda	None listed	None Listed	None listed	None listed	Lden/Lnight	Lden noise contour maps
Barcelona	Per use of each runway and overall number of movements	Only on request	Number of infringements per track under 6000 ft	Lmax events from noise monitoring stations in 5dB bands for town councils	Lday, evening, night. Plus averaged indicators for monitoring stations	Lday, evening, night noise contours
Catania	% movements by different aircraft on different flight tracks	None listed	Flight tracks	None listed	Lden /Lnight	Lden and Lnight contours
Cluj	Lists of operations	NADP1 and NADP2 published information (AIP)	Flight paths and online tools (e.g. flightradar24)	$L_{E,A}$ sound exposure level; $L_{p,AS,max}$ or $L_{p,A,eq,1s,max}$ maximum sound pressure levels	Lden / Lnight	Lden and Lnight contours
Frankfurt	On request	On request	On-line flight track visualisation tools Environmental/neighbourhood Agency: INAA, FRAPORT: FRANOM German Air Traffic Control: Stanley track	Continuous SPL, L_{Amax_events} from noise monitoring stations	Measured data for every : $Leq_{Aircraft}$,Leq_{total}, $L_{DEN\_Aircraft}$, L_{DEN_total}, L_{DEN}, Maximum level distribution, L_{night}	Contour maps calculation Leq_{Day}, Leq_{Day}, $Leq_{Night50}$+6x68
Heathrow	% movements by operational mode Proportion of	Deviation from centre of gate chart	For particular departure routes	Single event noise profile	Leq for specific location	LAeq dB noise contours

	departing aircraft by type					
Helsinki	On request	None listed	Departure profile comparisons to show NADP1 and NADP2 altitudes on climb	LAmax used to identify changes to the routes	None listed	None listed
Iasi	Lists of operations	NADP1 and NADP2 published information (AIP)	Flight paths and online tools (e.g. flightradar24)	$L_{E,A}$ sound exposure level; $L_{p,AS,max}$ or $L_{p,A,eq,1s,max}$ maximum sound pressure levels	Lden / Lnight	Lden and Lnight contours
Kiev	None listed	None listed	None listed	LAmax	LAeq day, evening and night	LAeq day, evening and night contours
Ljubljana	None listed	None listed	None listed	EPNL for loudest aircraft	Lday, Levening, Lnight and Lden	Lden and Lnight contours
Schiphol	Lists of trial and reference flights	NAPD 1 and 2 profiles compared	Flight paths highlighting runway usage	Lmax used to record measurements from monitoring stations	Lden	Grid analysis of contours
Vienna	Flugspuren.at has specific data relating to all routes from all runways at any point in time.	Flight profiles	Full information of flight tracks provided on flugspuren.at	LAmax profiles	Leq	N65 contours (As per mediation contract).

Table 1 demonstrates the wide range of noise information provided by airports as part of specific BA interventions[17] and highlights that information provision has been tailored to individual purposes. For example, in the case of Heathrow the airport was responding to concerns about lower and noisier aircraft on a particular departure routes over Teddington. Thus their approach was to interrogate the flight track data to establish whether this was indeed the case. The use of flight track vertical profiles and gate analysis presented extensively in literature prepared for the communities demonstrated that all departures were compliant with the original 4 degree climb-out trajectory, however a very small number of aircraft (0.72%) failed to achieve a 5 degree trajectory (see Figure 13). However, those that did fail were usually A380s, which being the largest aircraft operating at Heathrow, appear to have had a disproportionate impact on perceptions. Thus the airport set a new minimum trajectory of 5 degrees and has been able to monitor performance against this using the same illustrate operational data. Interim results show an improvement in compliance with the new 5 degrees threshold with only 0.52% of aircraft departures failing to achieve the performance standard.

Figure 13*; Illustrating the results of the analysis, showing how the vast majority of flights were well in exceedance of the 4% and 5% departure gradients (source : ANIMA report D2.5).*



[17]The matrix is intended as a summary of noise information provided as part of the BA intervention and not intended as an exhaustive overview of all noise information provided by the case study airports

This example, and the range of information provision illustrated by the matrix, highlights the **need for airports to consider carefully the purpose for which noise information is being prepared and disseminated and to choose the most appropriate noise measures accordingly**. As highlighted in the previous section 5.2, care must be taken not to overload target recipients with too much information as this may lead to confusion and thus inhibit engagement in any participatory decision-making processes that may be in place. Nevertheless, disaggregated metrics that provide insight to the operational practices explaining noise exposure do seem to be increasingly prevalent, despite the risk of needing to provide a wide range of illustrative metrics.

Unfortunately, whilst we can distil the principles for better use of noise information from this review of noise communication tools, the case studies and other sources highlight an almost complete absence of systematic evaluation of the effectiveness of noise communication tools and outputs. There are no examples of attempting to understand how stakeholder groups received noise information, or the extent to which it provided insights into the specific noise management challenges being addressed.

6. Exposure to Impact

This section builds on previous sections by reviewing attempts to extrapolate from noise exposure to impact, driven by a desire to establish the significance of given noise exposure to human health and well-being. If robust, such evidence can help inform noise management decision-making; however, as will be demonstrated, where these efforts to capture effect are based on uncertain evidence they can lead to more controversy and arguably undermine attempts to build consensus with communities over how best to manage noise effects in given circumstances. This review addresses the following effect metrics:

- Exposure-response functions for annoyance
- Exposure-response functions for noise-induced awakening reactions
- Aircraft noise indices at Zurich and Frankfurt Airport
- Quantification of possible noise hazards on health - DALYS

6.1 Exposure-response functions for annoyance

Twenty years ago, 68 international noise experts were asked what in their opinion was the main noise effect. 51% answered “annoyance” (Guski, 1999). Nowadays, ‘annoyance’ is the most obvious and immediate impact reaction from transport noise and according to the World Health Organization (WHO) causes (after Sleep disturbances) the second biggest loss of healthy life years (DALYs lost) due to Environmental Noise in the European Union (see Section 6.4). This is due to the link between transport noise, persistent annoyance reactions and sleep disturbances, and the implications for stress mechanisms and consequent adverse health effects (Babisch, 2003).

In 1999 Guski et al (1999) listed several theoretical constructs of noise annoyance that they found in earlier publications:
- 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 their 2017-Review for the "WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Annoyance" the authors Guski, Schreckenberg and Schuemer sum it up giving the following definition:

"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 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 multifaceted response is seen by many researchers as a stress-reaction."

Before 2001 plenty of inconsistent, non-standardised questionnaires had been used in order to quantify annoyance judgements. This led to the fact that the comparability of these studies had been limited if not impossible (Janssen et al, 2011). Therefore the *International Commission on Biological Effects of Noise* (ICBEN) developed a standard question for the assessment of noise-induced annoyance, available in 9 languages in the original version (Fields et al, 2001), since 2017 in 17 languages (Gjestland, 2017):

1) A 5-point verbal scale, recommended for contexts of communication with policy makers:

"Thinking about the last (… 12 months or so…), when you are here at home, how much does noise from (… noise source…) bother, disturb, or annoy you?"
"extremely", "very", "moderately", "slightly", and "not at all"

2) An 11-point numeric scale, recommended for research purposes, as it is suitable for multivariate statistical methods:

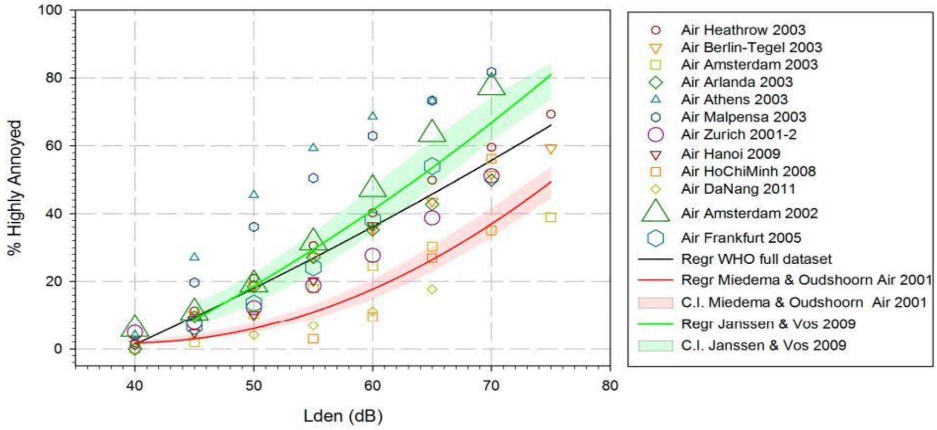
"Next is a zero to ten opinion scale for how much (…source...) noise bothers, disturbs or annoys you when you are here at home. If you are not at all annoyed choose zero, if you are extremely annoyed choose ten, if you are somewhere in between choose a number between zero and ten. Thinking about the last (...12 months or so...), what number from zero to ten best shows how much you are bothered, disturbed, or annoyed by (...source...) noise?"

Brink et al (2016) found that the standardized average annoyance scores were slightly higher using the 11-point numerical scale whereas the percentage of highly annoyed respondents was higher based on the 5-point scale, using conventional cut-off criteria.

Following methodology first developed in the U.S. (Schultz, 1978), meta-analyses of exposure-response curves for aircraft noise annoyance in the European Union were established by Miedema and Vos (1998), then refined in 2001 by Miedema and Oudshoorn (2001). In the later publication the authors defined the measure "Percentage Highly Annoyed (%HA)" as the percentage of annoyance ratings exceeding the upper limit of 72% on a transformed scale from 0 (not annoyed at all) to 100 (extremely annoyed) and correlate them to the day-night level L_{dn} and the day-evening-night level L_{den}. The latter curves are the so-called "European standard curves" to assess the harmful effects of environmental noise according to the Directive 2002/49/EC of 25 June 2002 (**Figure 14**; see red curve). These curves are not officially part of Annex 3 of this Directive but the result of a working group of noise experts set up by the European Commission in order to provide guidance on the dose-effect relations to be used for the assessment of numbers of people annoyed by noise ("Position paper on dose response relationships between transportation noise and annoyance", 2002). Therefore these curves are always used then when no local exposure-response functions are available.

As for this meta-analysis 20 aircraft noise studies from 1965 to 1992 were considered. However, today's aircraft noise has changed dramatically since those years. Nowadays single noise events are on average 30 dB quieter than in the 1960s, but on the other hand the number of movements has increased considerably. So in 2015 the World Health Organization (WHO) financed a new meta-analysis, in which "*Data from 15 aircraft noise annoyance surveys around national and international airports were collected from publications and the completed authors' questionnaires. The surveys took place from 2001 to 2014, encompassed a total of 18,947 respondents, and a noise level range from 11 to 74 dB $L_{Aeq,24h}$, corresponding to 12 to 78 dB L_{den} and 11 to 77 dB L_{dn}, i.e., from small airports with 34 regular flights per day to large international airports with more than 1200 movements per day*" [1.3], see **Figure 14**.

Figure 144*:Scatterplot and quadratic regression of the relation between L_{den} and the calculated %HA for 12 aircraft noise studies, together with Exposure-Response Functions from meta-analysis by Miedema and Oudshoorn (2001) shown in red, and Janssen and Vos (2011)*



Adapted from Guski et al (2017)

In **Figure 14**, it can clearly be seen that the median exposure response curve for the newer studies (black) is much higher than the old one (red). It seems that airport residents with today's aircraft noise and the exposure as measured by L_{den} are clearly more annoyed than residents were decades ago.

Another key point is that the annoyance ratings between the individual studies differ significantly. This was also the case in the previous meta-analysis from Miedema and Oudshoorn (2011). Reasons for this can be manifold. As in the previous meta-analysis the annoyance assessment had not been standardised by then, this is not the case any more for the WHO-analysis. The acoustical logarithmic average levels L_{eq}, L_{dn}, L_{den}, however, do not consider other (psycho-) acoustical features like the event-related maximum sound level, number and distribution or intermittency of noise events, sound characteristics such as sharpness, roughness, etc. which presumably might add to the explanation of annoyance as well. Besides, there are several noise calculation software on the market (e.g. INM, AzB, FLULA2, NORTIM). To date, no perfect agreement could have been reached between the different aircraft noise exposure calculation models used in these software. The considered studies used different software; the quality of input data might have been diverse as well. All these arguments might be reasons for the different results at the study airports but which cannot really be tested for retrospectively.

But not just acoustical factors contribute to the aircraft noise annoyance. Guski (1999) stated in that, *"at best, about one third of the variance of annoyance reactions can be "explained" by the variance of acoustic features, another third by the variance of personal or social variables*", so-called non-acoustical factors. Newer studies, for example have found that L_{dn} explains just 17% of the variance in the annoyance ratings, whereas non-acoustical factors explain 55% of the ratings (Bartels et al, 2018). **Table 2** shows the possible non-acoustic factors contributing to aircraft noise annoyance, their assumed general effect strength and an assessment as to whether they are modifiable or not. This table must be taken as a rough approximation of effect as the importance of these non-acoustical factors can vary from airport to airport as well as over time.

Table 2: *Categorization of Non-acoustical factors*

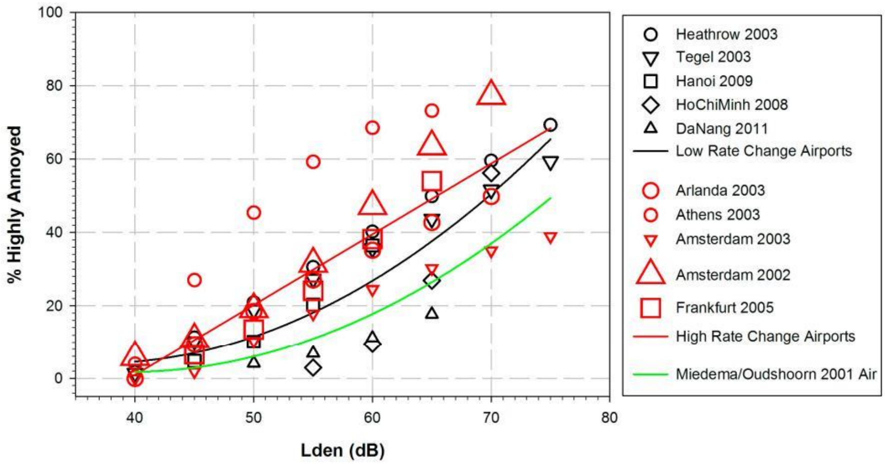
Non-acoustical Factors	**Strong**	**Intermediate**	**Weak**
Modifiable	Attitude towards the source Choice in insulation Choice in compensation (personal) Influence, voice (the opportunity to exert influence on behaviour of source) Perceived control Recognition of concern Trust	Availability Choice in compensation (societal) Expectations regarding future of source Information (accessibility and transparency) Predictability of noise situation Procedural fairness	Media coverage and heightened awareness to noise Social Status
Not modifiable	Age (under 55) Income Individual sensitivity to noise Past experience with source	Duration of residency near airport Fear related to source of noise Home ownership (fear of devaluation) Use of airport services	Age (above 55) Awareness of negative consequences (health, learning) Children Education
Unsure/need to be examined	Conviction that noise could be reduced or avoided by others	Benefits from airport (personal, societal) Cross cultural differences Country of origin	

Adapted from Vader, 2007, from ANIMA-Deliverable 2.4

In the WHO-review Guski et al (2017) also tested one hypothesis that came up when trying to explain the really big difference between the old and new meta-analysis curves:

"It is sometimes stated that recent airport noise annoyance surveys are often done in the context of abrupt change, i.e., before and/or after a step change of airport traffic (e.g., by implementing a new runway, changing flight routes, and/or an abrupt increase of the number of aircraft movements). Janssen and Guski (2017) call airports "low-rate change airports" as long as there is no indication of a sustained abrupt change of aircraft movements, or the published intention of the airport to change the number of movements within three years before and after the study. "An abrupt change is defined here as a significant deviation in the trend of aircraft movements from the trend typical for the airport. If the typical trend is disrupted significantly and permanent, we call this a 'high-rate change airport'. We also classify this airport in the latter category if there has been public discussion about operational plans within [three] years before and after the study" (2017, p.8). This definition might be somewhat arbitrary and far from perfect. For instance, it does not cover changes in the composition of aircraft fleets or tragic aircraft crashes. Irrespective of its shortcomings, the definition has been used already by [24], and we explored the influence of high-rate airport changes on our dataset with respect to this definition as far as possible."

***Figure 15**: Scatterplot and regression lines of the relation between L_{den} and the calculated %HA for five "high-rate change" (red curve) and five "low-rate change" (black curve) airport noise studies, together with exposure-response function by Miedema and Oudshoo (2011), shown as the green curve*



Adapted from Guski et al (2017)

Figure 15 shows that the two curves for High Rate Change Airports (red) and Low Rate Change Airports (black) from the WHO review are both above the old curve (green), although, however, the Low Rate Change curve is significantly closer to the old one. So these two-factors alone do not explain the differences in the results of the two meta-analyses. Therefore, there seems to be a clear trend that aircraft noise annoyance for the same L_{den} has increased over the years.

In summary, it is undisputed that exposure-response curves for annoyance provide some insight into the significance of aircraft noise impact around an airport that may not be captured by simple L_{eq}-based noise exposure maps. This can be useful for politicians and decision-makers when developing noise mitigation strategies. Due to the fact, however, that the importance of the non-acoustical factors might differ from airport to airport and also vary over time, this demands local-specific annoyance studies, considering a wide range of possible effective non-acoustic factors at those specific airports. Unfortunately, this has not stopped some organisations from applying universal exposure-response functions in an attempt to predict impacts at specific locations/airports. This form of impact prediction we would argue can create more problems than it solves as outputs can be misleading and certainly the means of arriving at impact values are open to debate that can often create and atmosphere of mistrust with communities.

This point is illustrated by the following phenomenon. Generally, people highly annoyed by airport noise can be found in every given noise contour around an airport. Annoyance maps (the intersection of noise contour maps with the exposure response curves), however, would imply that only residents in the highest contours are highly annoyed. This can be extremely counterproductive to communication efforts as the implication is that people in lower noise contours cannot be legitimately highly annoyed. Such messaging, explicit or implied can strengthen the impression that such residents are not fairly treated in the noise management process.

A more detailed description of the psychological construct “Annoyance” and its implications on health and possible mitigation strategies can be found in ANIMA-Deliverables D2.3 “Recommendations on noise and health” and D2.4 “Recommendations on annoyance mitigation and implications for communication and engagement”.

6.2 Exposure-response functions for noise-induced awakening reactions

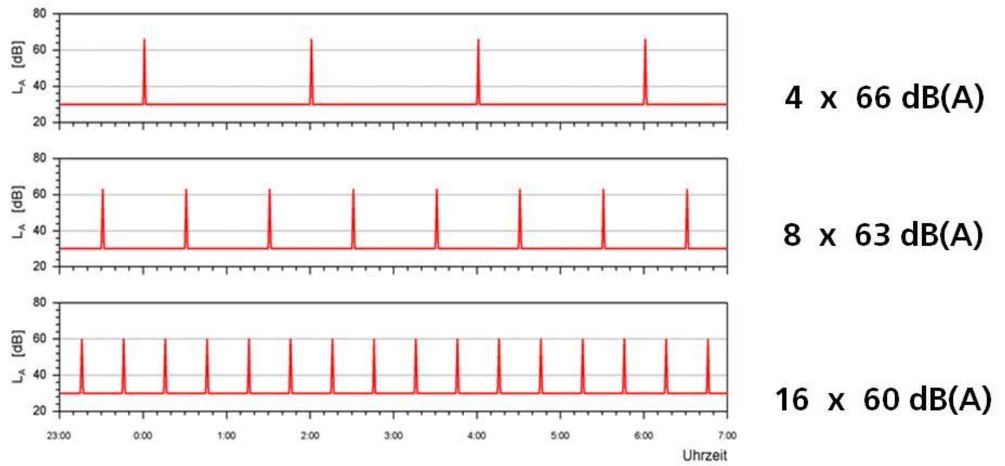
Undisturbed sleep of sufficient length is a vital process for human beings providing the necessary daytime alertness, performance ability and health. Therefore it is very important for the general quality of life (Watson et al, 2015) and hence the night should be especially protected against sleep disturbing influences.

During sleep time human beings are usually unconscious. The ear, however, has a alerting function to prevent harm from possible ambient threats and therefore continually inspects the environment acoustically whilst sleeping. Within the last decades the growing need for mobility and transport of goods has led to increasing night noise which is potentially identified as such a threat by some individuals and can lead, amongst other outcomes, to disturbed sleep. The consequences of such interrupted sleep from transport noise can be classified as follows:

- immediate reactions can be additional awakenings, palpitations and reduced deep and Rapid Eye Movement (REM or 'dream') sleep during the night;
- short-term reactions the following day can be fatigue, lack of concentration and therefore a higher risk of accidents and a reduced quality of life perception;
- long-term consequences after years of permanent night traffic noise can be increased risks e.g. of high blood pressure, ischaemic heart diseases, dysfunction of blood vessels (END, 2018).

As described in Section 6.1, in order to report transport-noise induced annoyance the habitually employed acoustical metric is the energy equivalent noise level L_{eq} or its derivatives L_{dn} or L_{den}. **Figure 16** highlights why this might not be optimal for describing single event-noise effects on sleep. In this figure three different aircraft night noise scenarios are illustrated which have the same indoor energy equivalent level $L_{AS,eq}$ = 38.3dB, measured at the sleeper's ear. Reducing the maximum level of each aircraft noise event by 3dB(A) (which is half of the physical sound energy but normally a much greater reduction of up to 10 dB(A) or more would be required to be perceived as half as loud by the human ear) permits a doubling of the number of aircraft noise events at the same $L_{AS,eq}$. It is obvious that the human sleep response on these dissimilar aircraft sound scenarios will be different. Therefore, in order to adequately describe transport noise effects on sleep, a maximum sound level distribution of all noise events during the night should be at least available.

Figure 16: *shows 3 different aircraft night noise scenarios with the same indoor energy equivalent continuous sound level $L_{AS,eq}$ = 38.3dB at the sleeper's ear. Reducing the maximum level of the aircraft noise events by 3 dB(A) leads to a doubling of the number at the same $L_{AS,eq}$*



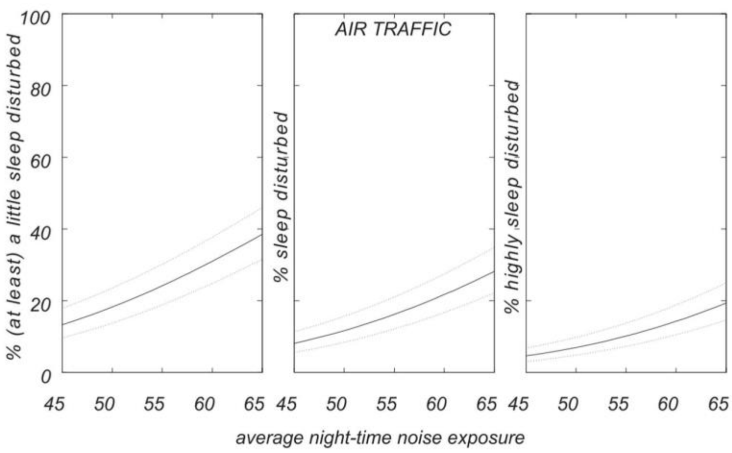
Source: Müller et al, 2015

A comprehensive sleep survey does not just include the measurement of physiological body functions, but also the subjective perception of sleep. An optimal sleep quality implies both, an objectively measured undisturbed sleep of sufficient length and positive subjective sleep ratings.

Due to the fact that humans are mostly unconscious during sleep, subjective sleep assessments do not necessarily agree with the objective measurements. The subjective assessment usually includes questionnaires about number of (noise-induced) awakenings, time to fall asleep, general sleep quality etc. As for the annoyance survey (see Section 6.1), these assessments can be confounded by non-acoustical factors, for example, attitude towards the noise source, procedural fairness in processes relating to the noise source, or simply to make a political statement. This also means that the results of such studies can vary from airport to airport and might presumably also fluctuate over time.

Since assessments using questionnaires are relatively cheap and easy to implement, there are numerous published examples which have been used for calculating 'mean' exposure response curves of 'at least a little sleep disturbed', 'sleep disturbed' and 'highly sleep disturbed' people over an energy equivalent noise level $L_{eqNight}$ (Jarup et al, 2008) neglecting the problem that those 'mean' levels, if not unrealistically low, are not really suitable for communication or protection purposes for noise effects on sleep as many different noise situations lead to the same L_{eq} but have different effects on sleep. The World Health Organization recommends in its 2018 "Environmental Noise Guidelines for the European Region" an L_{Night} of 40dB(A) for aircraft due to the number of 'Highly Sleep Disturbed people' (HSD), assessed by questionnaires (END, 2018). In reality a Boeing 747 on take-off with a distance of 10km from the runway, 600m height, one movement per 8 hours would lead to a L_{Night} of 51dB(A), or for an Airbus 320, 10km distance from the runway on take-off, 770m height, eight movements per 8 hours would lead to a L_{Night} of 50 dB(A).

***Figure 17**: The functions specify three sleep disturbance measures (solid lines) in relation to the average night-time exposure outside at most exposed façade, and their 95% confidence intervals (broken lines) for air traffic.*

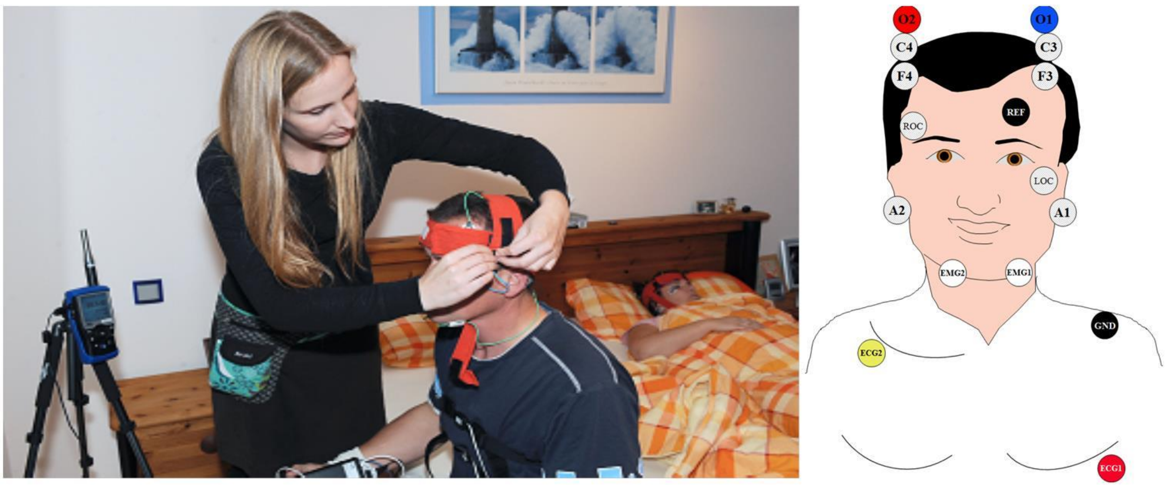


Source: Jarup et al, 2008

With this information in mind therefore, it seems very advisable to revert to objective sleep assessment techniques that mainly depend on acoustical factors, consider the single noise events during sleep time and avoid the influence of potential non-acoustic influences over months or years. Measuring the 'objective' physiological body reactions could do that although the assessment is much more complex and laborious.

The 'gold standard' in clinical research for studying sleep is the multi-parametric polysomnography technique (Perron et al, 2012). It consists of a continuous monitoring of the Electroencephalography (EEG, electrical activity of the brain), Electrocardiography (ECG, electrical activity of the heart), Electrooculography (EOG, eye movements) and Electromyography (EMG, electrical activity by skeletal muscles) (Iber et al, 2004).

Figure 18: Left: *A subject of a field sleep study on the effect of aircraft noise on sleep is being prepared for polysomnography recording.* ***Right:*** *Electrode positions needed for that recording.*



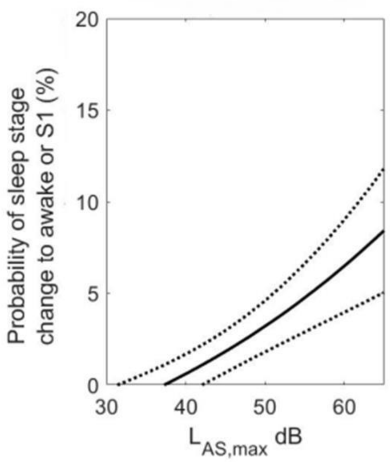
Source: Müller et al, 2015

Preparing subjects for the measurements before going to sleep takes nearly an hour by trained personnel, detaching the electrodes after awaking takes around 25 min. The method is slightly invasive and subjects on the first night might sleep a bit worse than usual. Therefore the first night should serve as an adaption night and not be used for analysis. The evaluation of the polysomnographic data has to be visually rated by trained personnel and default in 30s - epochs (Rechtschaffen et al, 1968), which can lead to a certain inter-rater variability (Danker-Hopfe et al, 2009).

Thus, if the sound pressure level and the sound itself are continuously recorded at the same time as the sleep data, these controlled experimental studies allow a very exact event-related evaluation at any time during the night. Then it is possible to build up an optimal statistical model, sorting out all relevant acoustical measures (e.g. L_{ASmax}, SEL, level rise time, noise length), sleep measures (e.g. previously passed sleep duration, sleep stage before noise event, time spent in sleep stage before noise event) and personal parameters (age, gender), providing an exposure-response function that delivers the probability to awake for every noise event dependent on its maximum sound pressure level (Basner and McGuire, 2018). The summation of all awakening probabilities, subtracting the spontaneous probability to awake (a healthy adult briefly awakens around 20 times in an 8-hour-bed time (Bonnet and Arand, 2007) but most of these awakenings are too short to remember the next morning), results in the additional noise-induced awakening reactions. It must be remembered here that the spontaneous awakening reactions occur at the time scheduled by the body and are physiologically meaningful. The awakening reactions caused by aircraft noise usually occurs at times when they prematurely interrupt sleep cycles and are thus detrimental to sleep quality. Thus, a 1:1 comparison of the number of spontaneous and noise-induced additional awakening reactions is not admissible.

These additional noise-induced awakenings per night can be calculated for every household around an airport and are easy to understand by laypersons like e.g. residents. They are currently used in the Zurich Aircraft noise ZFI and Frankfurt night noise index FNI since 2006 and 2007 respectively; in order to communicate the nocturnal aircraft noise impact over the years (see Section 6.3) and for the development of night noise protection concepts (Basner et al, 2006).

Figure19: *Probability of additional sleep stage changes to awake or S1 in a 90s time window following noise event onset depending on the maximum indoor sound pressure level ($L_{AS,max}$) for aircraft (STRAIN study, N = 61) 95% confidence intervals (dashed lines). Results are for the unadjusted model.*



Source: Basner and McGuire, 2018

The investigation methodology demands that only subjects without any inherent sleep disorders and without any diseases, which have side effects on sleep are examined. Otherwise any sleep effects during an aircraft noise event and total sleep quality parameters could not be unambiguously inferred. The high time and cost of these kinds of experimental studies also limits the examination of subjects in the two- to lower three-digit number range of subjects per study. These limitations should be kept in mind.

Therefore, especially when developing night noise protection concepts, additional assumptions must be made in order to protect also vulnerable groups of residents. Ecologically valid data for such night noise protection concepts also require that they have been collected in field studies within the residents' home environment.

Additional attempts have been made to increase the number of subjects in those field studies by simplifying the methods to detect awakenings. Awakenings often go along with a heart rate increase and body movements. These measures have been validated in the NORAH sleep study around Frankfurt Airport 2011-2015 with polysomnography data. Then this simplified method has been used in a pilot study around Philadelphia airport (McGuire et al, 2014; Muller et al, 2015; Basner et al, 2017). Further studies are envisaged.

A more detailed description of the consequences of aircraft noise induced sleep disturbances and the derivation of exposure-response functions will be made available in ANIMA-Deliverable 3.2.

6.3 Aircraft noise indices at Zurich and Frankfurt airports

Noise contours based on annual average logarithmic noise levels like the L_{eq} and its derivatives L_{dn} and L_{den} with weightings for the evening and night time period are still the most common metrics communicated by almost all airports and often are still the only ones. They are not easily understood by lay people, do not reflect the total noise impact that an airport generates and imply that there is no aircraft noise outside the contours. Whereas aircraft noise impact depends, for example, on the flight routes and number of people overflown under these routes, on number and type of aircraft, time of operations (especially differentiation between day and night), possible respite times, noise insulation schemes etc.

Planners, decision-makers, residents and aircraft manufacturers, however, often desire a more complete picture of the aircraft noise impact. The aim here is to move from noise exposure to an appreciation of impacts, and thus an understanding of the significance of a given exposure to annoyance and health outcomes. In turn this can help inform appropriate management interventions, such as when to apply sound insulation, for example.

In Europe, Zurich Airport was one of the first airports to derive and apply such a *noise effect index* after the German government restricted approaching flights to Zurich in southern German airspace in 2001. Zurich airport authorities were forced to install a quite complex flight regime that puts the noise strain on different communities around the airport at different times of day. Especially dense populated areas in the south and east of the airport were affected in critical shoulder hours. Massive protests by residents meant that the canton government of Zurich had to develop a more transparent noise monitoring, which in particular adequately reflected the noise effects at individual times of the day in the various regions around the airport. The aims of the Zurich noise index were specifically that it should be able to:

- Calculate the noise impact development on the population in different regions around the airport in a transparent and understandable way;
- Allow an effect-oriented assessment of different operating plans (e.g. changing of flight routes) and their comparisons in regard on overall impact as well as on effects on single communities;
- Inform active noise abatement measures like steeper approaches, changes in aircraft fleet were adequately visible using prediction methods of sufficient precision.

After a feasibility study (Brink et al, 2010) the Züricher Fluglärmindex (ZFI) emerged in 2006 and was soon afterwards, officially acknowledged by authorities as a Noise Impact tool for Zurich Airport.

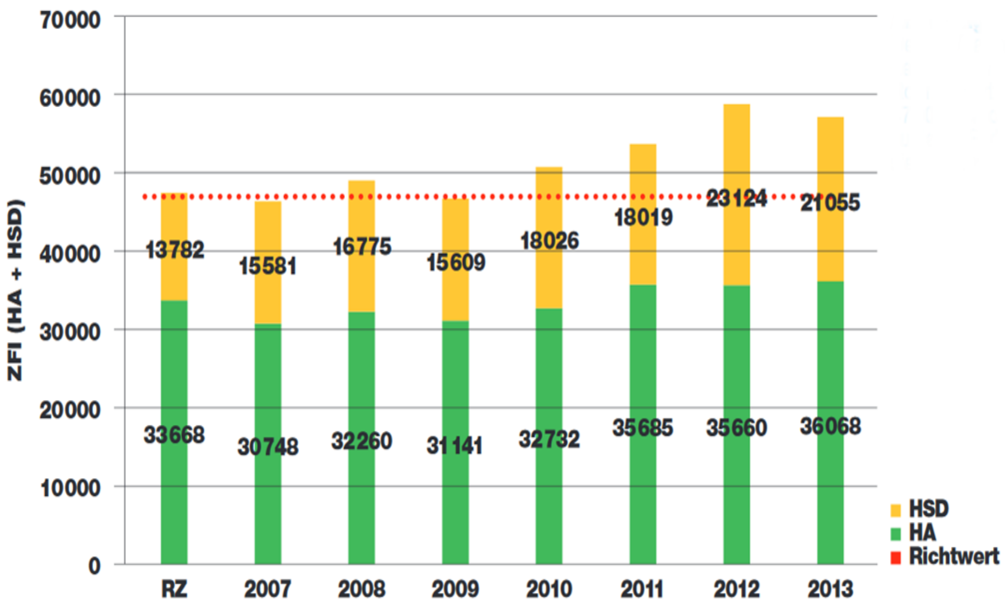
The ZFI unit is "Number of persons". The more people are affected by aircraft noise, the higher is the ZFI. It can be calculated for a larger area around the airport (perimeter) but also for every single hectare within this perimeter. It consists of two components: a prediction of the number of persons highly annoyed by aircraft noise during day (Highly Annoyed: HA derived from the Miedema et al, 2006 mean annoyance curve, see Section 6) and a forecast of the number of persons highly sleep disturbed by aircraft noise during night (Highly Sleep Disturbed: HSD derived from the Basner et al (2006) awakening probability curve, see Section 6). The two ZFI components are calculated based on the actual aircraft noise exposure in each hectare square of the perimeter. For each hectare grid the percentage HA and HSD are determined and then the resulting percentage is multiplied with the number of residents within the hectare and the results are summed up for the total perimeter.

The ZFI at Zurich Airport now depends on the population density, the actual flown arrival and departure routes, the duration and period of the night flight ban as well as the aircraft fleet mix, as capture by L_{den} and L_{night}. If, for example, densely populated areas are overflown on a large scale, this will lead to an increase of the ZFI presuming the other basic parameters remain unchanged. If the airlines operate less noisy aircraft, the ZFI will decrease which might open the door for authorities to handle additional flight movements. A significant influx of people into the airport region will also cause the ZFI to increase.

In order to demarcate the perimeter and thus whether an area is still used to calculate the index or not, an abort criterion was fixed by means of the HA and the HSD. The demarcation criterion for HA is set at a daily noise load of L_{den} 47dB(A), for HSD at a night noise load of L_{night} 37dB(A). The setting of the demarcation criterion is not trivial. A too large perimeter would include a very high number of residents that are relatively low aircraft noise loaded, but due to their high number would dominate the index. A too small perimeter, on the other hand, would just consider the highest aircraft noise burdened areas and effects in lower loaded areas could not be inferred from the index. For a detailed overview of the ZFI and the deduction of the demarcation criterion see Brink et al (2010).

As part of the agreement of all local stakeholders it has been stipulated that the authorities of the Canton of Zurich aim to ensure that the critical limit value "Richtwert" of the ZFI is not exceeded by 47,000 HA or HSD. In order to guarantee this agreement, they must take the necessary measures in good time and influence the airport operator and the federal government. **Figure 20** shows the trend of the ZFI from 2007 to 2013.

Figure 20: *Zurich Aircraft noise index ZFI; Trend of number of people HA (green) or HSD (red). The dotted line (red) represents the critical value limit "Richtwert".*



Source: Kanton Zürich, 2013

In a similar fashion, a further aircraft noise index was developed as part of the planning of the 4th runway at Frankfurt airport and the associated mediation process, which led to a so-called Anti-Noise Pact (ANP). Within that framework in the early 2000s it was decided also to develop an index of impact that would communicate the consequences of noise exposure in a more transparent fashion, because significant protests of airport residents were expected. The development of the ZFI and the Frankfurt noise index were independent from each other and, in contrast to the one-value approach in Zurich, two indices were planned for Frankfurt: The "Frankfurt Aircraft Noise Index" (FFI) for the day (6am to 10pm) and the "Frankfurt Night Index" (FNI) (10pm to 6am), which have been implemented in 2007. The 4^{th} runway is being operated since October 2011.

The principle ideas on what the index(ces) should do and how they are structured are quite similar to those described above. **However, one decisive difference to the ZFI is that for the FFI a regional exposure-response curve for annoyance has was used which has been determined in a field study in communities around Frankfurt airport in 2005 (Schreckenberg and Meis, 2006).** This allows a more realistic calculation of the HA than just the usage of a meta-analysis of studies at different airports and times as it was implemented in the ZFI. The exposure response functions for the awakening probabilities of over flights were the same (Basner et al, 2006).

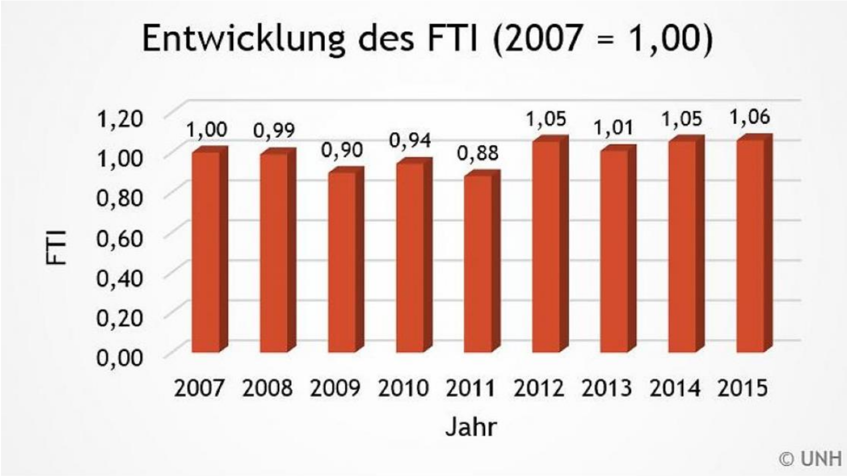
In mid 2019 the FFI and FNI will be updated with regional exposure response functions for annoyance and probability to awake from the NORAH study (2011-2015) around Frankfurt airport (Guski et al, 2016).

A second important difference of the indices at the two airports is the demarcation criterion of the perimeter. For the FFI the L_{dn} contour of 55dB(A) was chosen which corresponds to the 'Daytime protection zone 2' in the German Act for Protection against Aircraft Noise, whereas for the FNI all regions were included where more than 0.75 additional aircraft noise induced awakenings per night are expected. Also there is a plan to change the demarcation criteria in mid 2019. Changing exposure response curves or demarcation criteria of an index has to go along with a recalculation of the indices of the previous years considering these new parameters; otherwise comparability over the years is no longer possible.

A third difference of the indices is that the ZFI is part of the cantonal public law and therefore has legal force. This is not the case for the FFI and FNI.

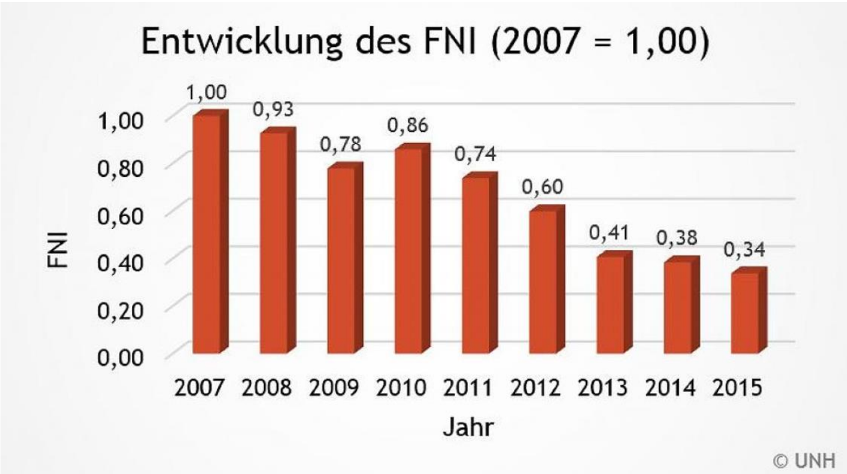
A more detailed description of the Frankfurt Aircraft Noise Indices can be found in Brink et al (2010).

Figure 21: *Trend of the Frankfurt Day Time Index FTI. Since the first calculation in 2007, the FTI has been subject to upward and downward fluctuations*



Source: Forum Flughafen und Region, 2019

Figure 22: *Trend of the Frankfurt Night Time Index FNI. The FNI has fallen to one third of the baseline since 2007 as in October 2011 a night flight ban between 11pm and 5am was implemented*



Source: Forum Flughafen und Region, 2019

Figure 21 to **Figure 22** show the overall trend of the respective indices in the whole perimeter around the airport. These developments can be calculated down to one-hectare grids as well so that they can be used for communicating changes in noise impact at a local level as well. However, these figures demonstrate the difficulty with the indices. The theory behind their calculations and the interpretation of the results is hard to understand for lay residents or local policy makers. This leads to suspicion by residents that something is being hidden by these indices. Given that it seems that the total number of affected people in the ZFI can be more easily understood than the Frankfurt Indices. On the other hand, the ZFI tries to combine several impact effects in just one single value, which makes the interpretation quite difficult especially when attempting to establish the individual contribution of several separate interventions that may occur in a given year. So probably it would be better to calculate an own single noise index for every measure.

It must be noted that exposure response curves, especially for annoyance, have to be airport specific to lead to realistic values. They have to be updated from time to time, as well as population maps. Input flight data for the calculations should be real measured radar data and there are still significant variances in different noise calculation software, which should be adjusted (EMPA, 2006).

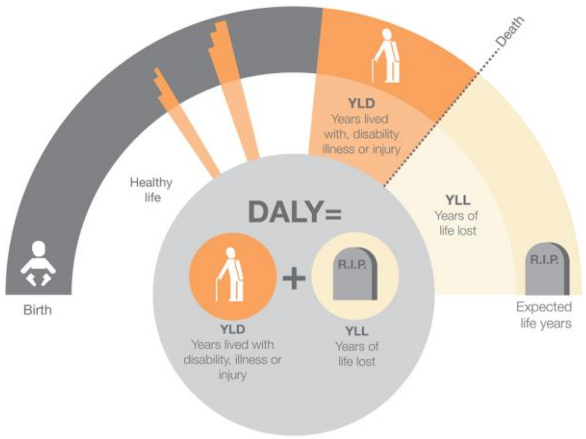
To conclude, these aircraft noise indices are an attempt to illustrate the aircraft noise impact for both the whole airport region and as well certain areas within this region. The prerequisite is that, in particular, the exposure-response curves for annoyance are up-to-date and airport-specific. The indices are a good tool for planners/decision makers who understand the data and calculations behind and can use them for surveying of legal noise limits or to derive new noise-mitigation strategies. For lay residents, the original intent was to provide greater transparency surrounding the impact of given noise exposure levels; unfortunately however, they appear to be over complex and incorporate potentially contentious/uncertain evidence (i.e. exposure response relationships) and thus do not address the need for more transparent information on noise that can be achieved with some of the more simple metrics described in Section 5.

6.4 Quantification of possible noise hazards on health - DALYS

Another way to describe noise impacts is to monetise possible health risks caused by transport noise. As a first step to assess those risks it is necessary to determine appropriate exposure-response relationships from noise exposure and health outcome after years of exposure, which is usually done by means of epidemiological studies.

In 1993 the *World Development Report,* published by the United Nations UN-World Bank, introduced a new concept called DALY (*disability-adjusted life years* or also *disease-adjusted life years*). The DALY should not only measure the mortality, but also the impairment of the normal, symptom-free life by an illness and being summed up in a measure number. The DALY combines the number of lost life years due to premature death YLL (Years of Life Lost, essentially the number of deaths multiplied by the remaining life expectancy at the age at which death occurs prematurely) with the years lived with a noise-induced disability, illness or injury YLD (Years lived with Disability, see **Figure 23**). The YLD are also calculated as lost years of life, multiplied by a certain factor depending on the level of disability, illness or injury.

Figure 23: *The 'noise burden' is measured by combining two indicators; the number of years of life lost due to disease and the number of years lived with disability as a result of disease. The concept is called DALY - Disability-Adjusted Life Years.*



Source: Public Health England, 2015

In principle, epidemiological studies are the appropriate tool to investigate the influence of long-term noise exposure on possible pathogenesis. Usually, the following disease endpoints are most looked upon as potential consequences of long-term noise exposure: cardiovascular disease hospitalizations and mortality, hypertension, cardiovascular risk factors, birth outcomes, psychological health, e.g. depression (Basner et al, 2017). These types of studies face the great challenge of obtaining valid data on long-term perceived noise exposure as well as on clearly diagnosed diseases and possible other causes for these diseases.

The World Health Organization (WHO) states in their publication 'Burden of disease from environmental noise: Quantification of healthy life years lost in Europe': *"The validity of any exposure–response relationship depends on the quality of the studies used to derive it, the choice of studies used and the modelling process used to pool the results. It is therefore very important that the process to derive the exposure–response relationships is well defined."* (WHO, 2011).

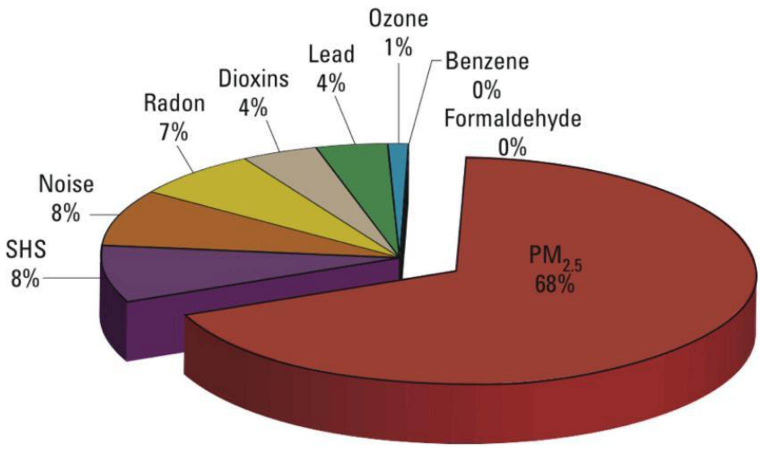
In these studies, often just annual average logarithmic noise levels can be taken from official noise mappings. This usually does not include location specific topology or shielding/reflection effects of the housing. More accurate studies make address-related calculations. So far, however, only calculated external sound levels can be used because in practice there is generally no information on the location of the noise sources towards rooms or the usual window position. Most of the people do not spend their daytime at home, but have their workplace in areas with different noise situations. So the noise values that can be used in these epidemiological studies might be just very rough and inaccurate estimates for the perceived noise.

The outcome 'disease', on the other hand, is also prone to inaccuracies. Some studies just use self-reported diagnoses, others data from health insurance classified by the valid ICD system (International Classification of Diseases and Related Health Problems). However, the reasons for the genesis of disease are generally multifaceted and noise is just one factor amongst others. If for example, cardiovascular diseases are considered as a possible endpoint after many years of exposure to noise then possible important confounders like 'number of cigarettes smoked per day' or the 'body mass index' must be considered as well. However, often these data are not available in epidemiological studies. This means that the estimates usually suffer from a considerable degree of uncertainty. This uncertainty is very difficult to quantify, although it is sometimes possible to provide low and high limits using sensitivity analyses.

Nevertheless, there have been some epidemiological studies investigating the effects of transport noise on health in the past. Basner et al (2017) come to the conclusion that "*there is a good biological plausibility by which noise may affect health in terms of impacts on the autonomic system, annoyance and sleep disturbance. Studies are suggestive of impacts on cardiovascular health especially hypertension, but limited and inconclusive with respect to quantification of these, with a relatively small number of studies conducted to date. More studies are needed to better define exposure–response relationships, the relative importance of night versus daytime noise and the best noise metrics for health studies (e.g., number of aircraft noise events versus average noise level)*" (Basner et al, 2017).

The 2018 published WHO "Environmental noise guidelines for the European Region" (2017) report for example the relative risk for the incidence of an ischaemic heart disease due to aircraft noise as a result of the meta-analysis of available studies of 1.09 per 10dB, however they rate the evidence quality as "very low". They could not report a significant increase of risk for hypertension in the one study that met their quality criteria. For the prevalence of highly annoyed population they found an absolute risk of 10% at a noise exposure level of 45.4dB L_{den}.

Figure 24: Relative contributions of nine targeted risk factors (SHS = second hand smoke, Noise = Traffic Noise) to the estimated burden of disease attributed to these risk factors, averaged over the six participating countries.



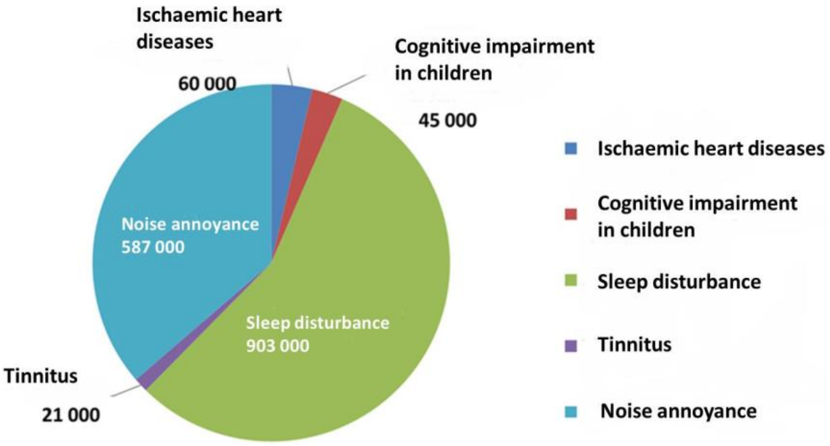
Source: WHO, 2011

In order to get an idea how significant the risk factor "noise" is compared to other environmental stressors, Hänninen et al (2014) analysed available data of nine risk factors in six European countries. Due to the fact that there are more data available for traffic noise than for other transport modes, **Figure 24** on the results of traffic noise studies only. There the traffic noise ranks on number two together with second hand smoke and far after $PM_{2.5}$[18] air pollution.

Based on these health outcomes from epidemiological studies, in principle the disability-adjusted life years *DALYs* or the loss of healthy life years *DALYs lost* can be calculated. As so far no DALY calculations based on the 2018 WHO report (END, 2018) and no data just based on aircraft noise are available, in **Figure 25** an example of DALYs lost calculations for Environmental Noise is given. Regarding the restrictions mentioned above it clearly shows that Sleep disturbance and Noise annoyance are the main factors that contribute to the DALYs lost.

[18] Particulate Matter of diameter less than 2.5µm

Figure 25: *WHO-Calculation, Loss of healthy life years (DALYs lost) due to Environmental Noise in the European Union.*



Source: WHO, 2011

To conclude, the concept of monetising health hazards due to noise is certainly a very helpful tool for politicians and other decision-makers in assessing the main hazards of transportation noise compared to other environmental risk factors and for taking countermeasures. However, the explanations above have shown that due to the inaccurate input data, the results can only be very rough estimates and must always be seen in comparison to other environmental risk factors to allow at least to some degree a classification of the risk size.

At the current stage of accuracy and complexity this metric is unsuitable for being communicated to lay residents. For example, if DALYs were communicated without appropriate contextual information (e.g. comparisons to other risk factors), this could lead to entirely inappropriate conclusions and the potential to unnecessarily heighten public concerns over the impact of aircraft noise.

Section 6 has demonstrated that any attempt to extrapolate from noise exposure to a given impact is fraught with challenges. These relate to the confidence in the exposure-response relationships, means of measuring/representing noise, presence of confounding factors, lack of precision over noise exposure and so on. Indeed as one moves from the more immediate physiological responses to noise (e.g. sleep disturbance) to longer-term effects (annoyance) and potential health outcomes these uncertainties increase. As a consequence, such impact indicators should be treated with caution and only used with careful contextual consideration and ideally only as part of a wider input into decision-making processes.

7. Recommendations and Gaps – MMU developing first draft for discussion

The case studies outlined in section 4 (above) illustrate a wide range of different practices and procedures regarding noise metrics applied by different airports under different circumstances. It should be noted that these metrics are often outputs from a range of different modelling tools and that these should be chosen depending on the degree of resolution required on the noise exposure (i.e. for overview long-term aggregate indicators integrate modelling tools can be used, whereas for detailed appreciation of subtle changes in flight operations scientific simulation tools may be necessary (see section 4).

Whilst the case studies highlight that there is a considerable amount of commonality regarding the use of standard noise metrics such as L_{Amax}, L_{Aeq}, and L_{den}, there is also evidence of much originality and creativity in various attempts to solve particular problems by using a wide range of different methodologies. Unfortunately however, there is **very little evidence of any systematic approach to the design of noise footprint methodologies to meet clearly defined objectives and assessed against the extent to which those objectives have been achieved**, or not, as the case may be. Instead, it appears that most individual airport management and regulatory bodies have simply and uncritically adopted what they perceive as being standard procedures, without necessarily carrying out any preliminary assessment of fitness-for-purpose for their particular application and unfortunately leading to in some cases at least, expensive failures to achieve consensus solutions to airport development proposals. (see for example, the 50 plus year history of trying and failing to achieve a consensus for the development of a new runway, or new runways, to serve the South-East of England and the Greater London area, with the result that Heathrow Airport in particular is effectively full-up with traffic and has been full-up for some time).

Consensus building requires effective two-way exchange of information between relevant parties where each stakeholder has at least a rudimentary appreciation of the requirements and aspirations of other stakeholders in any debate. This cannot be achieved where one party presents overly technical information, which is outside the capacity of other stakeholders to fully appreciate, and neither can it be achieved where necessary information is withheld. Instead **it is recommended that users first establish precise and detailed objectives in terms of what kind of consensus is being sought, and then select noise metrics and other types of information provision that can best meet (or seems most likely to meet) those objectives**.

Regarding noise indicators, users must decide between relatively complex aggregated metrics, which are capable (in theory) of discriminating between complex alternative operating and/or development proposals and simple disaggregated metrics, which can describe only single features of operating or development proposals. Aggregated metrics (such as L_{Aeq} and L_{den}) depend (unavoidably) on implied weightings or priorities on the extent to which different factors are taken into account, and can generally support clear-cut decision making which has the appearance of transparency, even though the implied weightings might not be particularly understandable, transparent or even justified by available scientific evidence. A good example of this problem is the L_{den}, or day, evening, and night indicator adopted by the European Union for the 2002 Environmental Noise Directive, where the specified evening (5 dB per event) and night (10 dB) weightings are essentially arbitrary, and not actually based on any 'scientific' evidence whatsoever. Disaggregated metrics need not depend on any arbitrary weightings; but must be used in multiple when applied to complex scenarios and situations and do not, therefore, facilitate clear-cut decision making. There is tension between the conflicting requirements of clear-cut decision making (procedural efficiency), which normally requires aggregated numeric indicators and metrics that are unavoidably dependent on implied arbitrary weightings, and scientific legitimacy and stakeholder understanding which both require disaggregation and by definition more time and effort to reach decisions based on consensus. The latter, it is argued by proponents of pluralistic decision-making (see ANIMA Deliverable 2.4), should result in more acceptable outcomes but is certainly more demanding procedurally (i.e. requirements for effective communication, opportunities for engagement and transparency of processes used to reach decisions).

When faced with this kind of complexity, **users are cautioned against deploying different types of noise indicators in multiple all at the same time simply to avoid potential criticism about withholding information**, because this approach can overload stakeholder understanding and generally cause more confusion than it solves. Instead, **users are recommended to first carry out a careful evaluation of their precise objectives and then produce only those types of noise indicators that best meet those specific needs.** Often, different stakeholders will have different interests, priorities, and consequently, different requirements for different types of information. Some **process of continuous evaluation may then be required to assess fitness for purpose in achieving (or not) the defined objectives in the light of feedback received through continuing stakeholder engagement**. It may be important to distinguish between the business objectives of commercial organisations, which may simply be trying to persuade stakeholders to accept their commercially motivated plans and proposals, and objectives based on corporate responsibility where those same organisations will be interested in consensus decision making where other stakeholders achieve benefits outside of purely commercial motivation. For example, agreement on an appropriate and balanced approach to mitigation can only be achieved where all parties have a full understanding of the relative advantages and disadvantages of each option considered

Thus overall, this Deliverable has established that there is **insufficient systematic evaluation of the efficacy of noise communication tools** to conclude as to what should be best practice in a given situation. Rather what can be distilled from experience are the **principles of best practice**, which are that **airports and others with authority over noise management should engage with stakeholders throughout the process of Balanced Approach**

interventions and indeed more broadly over the development of strategic approaches to noise mitigation through a series of steps designed to ensure focused use of noise information that:

- Enhances comprehension of key issues
- Illustrates the nature of any proposed change to operational practice and thus the potential consequences for individual stakeholders
- Enables stakeholders to reach decisions on their noise management priorities informed by insights into operational limitations and opportunities
- Can track (model and monitor) implementation of any actions/interventions
- Provide information to assess the efficacy (against agreed objectives) of the changes/actions and thus feedback to stakeholders about the outcomes and evidence to improve practice going forward

These steps to attaining improved outcomes from integrating enhanced utilisation of noise information into noise management processes are as follows:

- Step 1 – **decide objectives/purpose** of the intervention or strategy
- Step 2 – **review options** for noise footprint methodologies (tools and outputs) and **select** those that best suit the objectives
- Step 3 - **continuously evaluate** the contribution of the noise metrics to achieving the desired objectives
- Step 4 - **review mitigation options** in the light of feedback received structured using the agreed noise tools and metrics
- Step 5 – continue the **cycle of improvement**

These targeted outcomes and steps to achieving them will be used to inform the Best Practice portal in WP5, with the aim of allowing users to tailor noise information provision to the requirements of specific management interventions. Further, mechanisms for addressing the absence of effective evaluation of both communication tools and Balanced Approach intervention outcomes will be explored in WP3, sub-tasks 3.2.1 and 3.1.2 respectively.

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9. Annexes

Annex 1: Current WebTrak Users (as at 27.03.2019)

Country	Operator
Australia	Adelaide International Airport
	Brisbane International Airport
	Cairns International Airport
	Canberra Airport
	Coolangatta Airport
	Melbourne International Airport
	Perth International Airport
	Sunshine Coast Airport
	Sydney International Airport
Canada	Toronto City Airport
	Toronto Pearson International Airport
	Vancouver International Airport
Denmark	Copenhagen Airport
Finland	Helsinki-Vantaa Airport
Iceland	Keflavik International Airport
New Zealand	Wellington International Airport
South Africa	Cape Town International Airport
	King Shaka International Airport
	O. R. Tambo International Airport
Spain	Aeropuerto de Alicante
	Aeropuerto de Bilbao
	Aeropuerto de Málaga
	Barcelona Airport
	Gran Canaria Airport
	Madrid Airport
	Palma de Mallorca Airport
	Valencia International Airport
Sweden	Angelholm Airport

	Are Ostersund Airport
	Gothenburg-Lanvetter Airport
	Jonkoping Airport
	Karlstad Airport
	Kiruna Airport
	Malmo-Sturup Airport
	Ronneby Airport
	Skelleftea Airport
	Stockholm Arlanda Airport
	Sundsval/Harnosand Airport
	Umea Airport
	Visby Airport
The Netherlands	Eindhoven Airport
UK	Bournemouth International Airport
	East Midlands Airport
	Glasgow Airport
	Heathrow Airport
	London Biggin Hill Airport
	Manchester International Airport
	Stansted Airport
USA	Bob Hope Airport
	Centennial Airport
	Chicago Dept. of Aviation
	FAA – LA Basin
	Fort Lauderdale Executive Airport
	Honolulu International Airport
	Long Beach International Airport
	Los Angeles International Airport
	McClellan-Palomar Airport
	Oakland International Airport
	Ontario International Airport
	Palm Beach International Airport
	PANYNJ (New York & New Jersey Port Authority)

	Port Columbus International Airport
	Portland International Airport
	Reno-Tahoe International Airport
	Ronald Reagan Washington National International Airport
	Sacremento International Airport
	San Diego International Airport
	San Jose International Airport
	Santa Monica Airport
	Southwest Florida International Airport
	Torrance Municipal Airport – Zamperini Field
	Van Nuys Airport
	Washington Dulles International Airport
	Westchester County Airport