AIRCRAFT NOISE AND PUBLIC UNDERSTANDING: HOW TO IMPROVE ENVIRONMENTAL COMMUNICATIONS

REBECCA ELIZABETH DIANE HUDSON

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Abstract

Airports are often the single largest generators of economic activity and social development in the regions they serve, and so their continued growth is seen by many as critical. The social and economic adverse impacts that arise from the growth in air transport are equally significant; at a local level these manifest themselves primarily in terms of the disturbance caused by aircraft noise to communities surrounding airports and along flight routes. Community opposition to aircraft noise can result in operational constraints or failure to secure planning approval for growth, thereby limiting the social and economic benefits, with the perception of aircraft noise disturbance being a highly subjective issue. In response to this challenge, the air transport industry has implemented a wide variety of technological and operational measures designed to reduce the noise generated by aircraft, but these improvements have been offset by changes in perception of 'acceptable' disturbance levels. Previous studies have lacked in identifying and exploring issues that influence perception.

Through a series of case studies exploring auralisation and visualisation as a communication tool, this thesis focuses on public attitudes thereby looking to improve environmental communications between airports and their local communities. The case studies use document analysis, observations, and semi-structured interviews, to chart the evolution of an auralisation and visualisation tool, under the guise of Arup's SoundLab technology, in enhancing public understanding of technical information being provided, and the success (or otherwise) of such use. The exploration of case studies culminates in the design and execution of an experiment based upon this technology to explore the impact of visual stimuli on human perception of a sound source.

Principle findings suggested that the use of auralisation and visualisation effectively facilitates research into understanding the point (decibel level) at which the human ear discerns a change in sound level; this is the case when testing mostly audio stimuli. Further experimentation however saw visual stimuli having considerable influence on human perception of the sound stimuli, raising the question of the extent of influence of other stimuli (non-acoustic factors). Findings also suggest that auralisation and visualisation has the potential to yield meaningful communications between airports and their local communities. This potential of such a communication tool, however, has limitations when compromising between utilising the sophistication of Arup's SoundLab technology conducive to a small number of people, and a simplified mobile version accessible to a far larger number of people. Moreover, restrictions surrounding 2D visualisation become more pronounced when applying the technology to direct overhead aircraft demonstrations. It is recommended for future use that more recent developments of 3D technology be explored.

The contribution of this study lies in better understanding the role of auralisation and visualisation as a communication and engagement tool; by using findings from this thesis, industry should be able to focus time, effort and money on the most effective channels for improving environmental communications, and acoustic consultant companies such as Arup are better placed to utilise their tool based on the systematic evaluation of past experiences, which through this thesis has revealed key strengths and weaknesses of such technology.

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List of Abbreviations and Acronyms

ACARE	Advisory Council for Aviation Research and Innovation in Europe
ANSP	Air Navigation Service Provider

ATC	Air Traffic Control
ATM	Air Traffic Movement
BA	British Airways
CAA	Civil Aviation Authority
CAEP	Committee on Aviation Environmental Protection
CANSO	Civil Aviation Navigation Services Organisation
DEFRA	Department for Environment, Food and Rural Affairs
DfT	Department for Transport
EMR	Environmental Minimum Requirements
HCNF	Heathrow Community Noise Forum
IATA	International Air Transport Authority
ICAO	International Civil Aviation Organization
LAMP	London Air Management Programme
NADP	Noise Abatement Departure Procedure
NAP	Noise Abatement Procedures
NATS	National Air Traffic Services
NIS	Noise Insulation Scheme
NNI	Noise and Number Index
NRT	Noise Reduction Technology
PBN	Precision Based Navigation
QC	Quota Count
RWG	Respite Working Group
SARP	Standards and Recommended Practices
TRL	Technological Readiness Level
UN	United Nations

Chapter 1 Introduction

The air transport industry has played an increasingly significant role in the global socio-economy over the past 50 years (Sustainable Aviation, 2005). Demand for growth of the industry is strong, and meeting that demand brings benefits, but also adverse environmental impacts; one of the most significant of which is aircraft noise (Thomas and Lever, 2003). It is for this reason that considerable effort has been expended by the industry, designed to reduce key environmental outputs and thus the negative impacts of the sector. The continual advancements of airframe and engine technology and operational changes over the last 50 years have resulted in substantial, measurable reductions in aircraft noise exposure in terms of overall noise levels and areas affected (ACI, 2015). These advancements have helped reduce human exposure to aircraft noise in many locations despite a considerable increase in numbers of aircraft flown over the same period (Hooper et al, 2003).

Progress in improving aircraft noise output has been supported and encouraged by the International Civil Aviation Organization (ICAO), the world body for aviation, as it sets noise performance targets for the certification of future aircraft types and implements programmes for the phase-out of old aircraft as a part of its 'Balanced Approach' (ICAO, 2008).

Unfortunately, however, despite the reduction in noise exposure (measured as a long term averaged aggregate e.g, L_{den}, L_{Aeq},)[1] that these initiatives have achieved around many airports, perceived annoyance and expressed disturbance has continued to increase, suggesting that measures designed to simply reduce long-term averaged noise exposure may not result in the desired outcome of reduced impact (MMU, 2010) and therefore reduced opposition to growth.

This phenomenon highlights a disjoint between efforts being made to reduce the aircraft noise exposure, and the tolerance of local communities towards it, suggesting that negative human response to aircraft noise stems from perception

[1] Equivalent sound level of aircraft noise, often called equivalent continuous sound level. L_{eq} is most often measured on the A-weighted scale, giving the abbreviation LA_{eq}

and interpretation *as well as* the physical exposure. It is for this reason that the importance of non-acoustic factors and their role in influencing human attitudes towards the source of noise annoyance must be explored. Research has indicated that a wide variety of non-acoustic factors linked to affluence, fear[2], expectation of quality of live as well as individual variation, influence attitudes to noise.

Efforts to reduce the noise of individual aircraft movements are becoming more and more difficult and expensive to deliver and now are failing to keep up with the rate of growth of the industry at some airports. This, coupled with changing attitudes to the environment, quality of life and industry suggests that a technological solution to the noise problem will not be sufficient and that there is a need to give more attention to influencing or informing attitudes.

To provide context, this chapter outlines the concept of sustainable development. In doing so there is a need to highlight the cost and benefit to society borne out of the search for an equitable 'human-environmental system' (Turner, 2010: 570). Further, the chapter discusses sustainable development in the context of aviation, and how sustainable development as a phenomenon impacts the growth of the industry, and indeed the way in which it is managed. This indelibly puts emphasis on the social and environmental responsibilities of key industry actors and organisations. Core responsibilities specific, in this case, to the aviation industry, increasingly dictate the need for organisations to explore engagement with their stakeholders, and more specifically, create a platform to allow their local communities to participate in decision-making processes. Each of these aspects is explored as principles of sustainability in this chapter before being looked at in more detail later in the thesis.

In view of this contextual information, the chapter introduces the aim of research and objectives set to reach this aim. The structure of the thesis is also outlined.

[2] Fear of diminished house prices, crashing, pollution

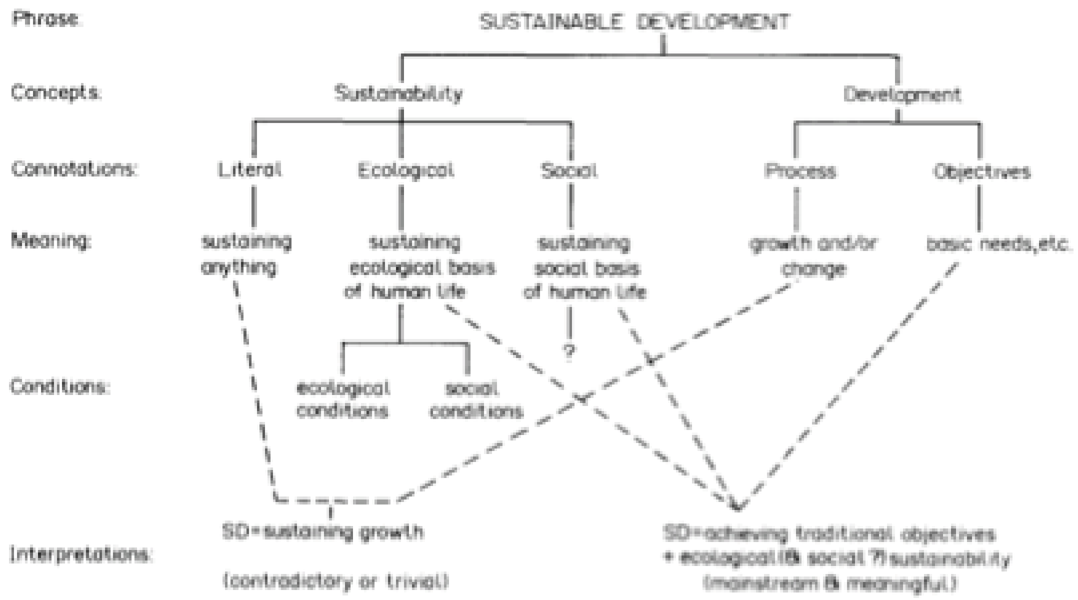
1.1 Sustainable Development

The Brundtland Commission, formed by the United Nations in 1983, defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland, 1987). While this is a general aspiration that few could disagree with, it does little to explain what it means for a single industry or actor within it (for example an airport operator or an airline). There are suggested to be more than 70 different definitions of sustainable development proposed, in varying contexts and approaches (Sharpley, 2000). Whilst the roots of sustainable development can be traced back to 1974 under the concept of Sustainable Societies (Lozano, 2008:1838), it was the Brundtland Commission’s 1987 *Our Common Future* report that called for sustainable development to become “a new mental model” as a policy guide, combining environmental, societal and economic issues, which has since informed its application as an “environmental management concept” (Hunter, 1995:850, Baker, 2006:19; McCool, 2013:214). The notion of sustainable development is a function of three key elements: protection of the environment, economic growth, and societal development; defined in crude terms as the ‘triple bottom line’ or ‘dimensions’ of sustainability in business management and reporting processes (Jordao, 2009); each maintaining equitable levels of importance, functionality and accessibility, working together to aid each other and survive as an output of one another in equal measures (Koc and Durmaz, 2015).

Equity, as noted by Lozano (2008), implies an attempt to meet all basic human needs, and, ‘perhaps the satisfaction of human want’, both now and in the future (intra, and inter-generational, respectively). In the context of quality of life, or ‘human well-being’, this means the avoidance of developments that maintain, create, or widen spatial or temporal differences (Lozano, 2008). In the context of aviation noise this means, simultaneously delivering the social and economic benefits of airport and airline growth without adversely affecting the quality of life and health of those impacted by aircraft noise events.

Our Common Future (1987) suggests that the only way to adapt to increasing environmental problems and their impacts is to construct a link between environmental improvement and economic development; this would ensure global development that is sustainable (Baker, 2006). Satterfield et al (2009:206) advocate viewing the concept of sustainable development as a business opportunity, 'an investment for a future and pathway for innovation and creative thinking'. For airports, the business opportunity of avoiding operational and growth constraints arising from noise issues. Turner (2010:570) shares this idea; noting sustainable development as an 'intellectual umbrella' formed of 'several collaborative pathways […] associated with research development on global climate and environmental change and its human dimensions'. The acknowledgement of the 'human-environmental' problems, and practice arising from researching development of these collaborative pathways, Turner (2010:570) believes, has led to the 'formal development' of sustainability as an 'interdisciplinary science'. A sustainable human-environmental system is described as 'provisioning humankind without threatening nature's support system' (2010:572).

Baker (2006) discusses the differentiation of sustainability from sustainable development and depicts the two terms as non-interlinking. Baker advocates that the term *sustainability* belongs to ecology, and by adding the notion of development the term *sustainable development* shifts focus from ecology to that of society, "The chief focus of sustainable development is on society, and its aim to include environmental considerations in the steering of societal change, especially through changes to the way in which the economy functions" (Baker, 2006:7). An earlier depiction by Lele (1991) helps to visually track Baker's theorising, in a consideration of semantics and origin of the term, sustainable development (see Figure 1.1).



Furthering the discussion of sustainable development as a paradoxical theory, several authors have laid out their argument suggesting similar conclusions. O'Riordan (1985:609), for example, suggests sustainable development to be a 'contradiction in terms' because *development* itself is a 'process of directed change'. Furthermore, it has been suggested that traditionally, societal development in its own right has been achieved through economic growth, with development and economic growth being 'widely considered' synonymous. This indeed contradicts the notion of sustainable development, as the emphasis on economic growth unbalances the triple bottom line (Goulet, 1992). Furthermore, this undermines the fundamentals of sustainable development because the 'value of the environment cannot be expressed in monetary terms' (Lozano, 2008:1839), suggesting that a focus on the pillar (economy) intended as a *means to* sustainably developing environmental and societal needs, would actually negate the holistic ethos of the concept; essentially becoming a victim of it's own success. It could be argued here that in the context of aviation noise, adverse health impacts, house price impacts, operational constraints, i.e. night flight restriction systems, and refusal of planning permission, can all be given an economic value. Whilst this may be true in a tangible sense, there is no *direct* means of monetarily valuing the environment in its totality.

Sharpley (2000:306) acknowledges the out-dated viewpoint of development as a concept according to 'strict economic criteria', and suggests that it has evolved in to a 'continual, global process of human development guided by the principle of self-reliance'. The notion of human development here is particularly prevalent with the suggestion that development can only be assessed through the 'advancements perceived by the very societies undergoing change' (Sharpley, 2000:306); enforcing the point that economic growth must indeed remain an equal pillar of the triple bottom line sustainable development has become synonymous with. The challenge here, however was noted in DEFRA's (2005:12) report on the UK government's updated sustainable development strategy: *"While increasing wealth is most often associated with depletion of environmental resources, extreme poverty can also leave people with no option but to deplete their local environment – so sustainable poverty eradication depends on the poor having access to adequate natural resources and a healthy environment."* This is a core example of unsustainable living and arguably even stronger evidence for the need to work towards effective 'sustainable development' strategies.

1.2 Sustainable Development in the UK

The UK was one of the first nations to address sustainable development directly through policy commitments, producing the first national sustainability strategy in 1994 following the Earth summit in Rio de Janeiro of 1992 (DEFRA, 2005). Early initiatives worked towards the production of the 1999 strategy, '*A Better Quality of Life'.* This was illustrative of the core message that developed nations took from *Our Common Futures* – namely the triple bottom line agenda and the need to guard against the negative social and environmental impacts of economic growth (the latter was not questioned). The report focused on the widely used 1987 Bruntland Report definition of sustainable development, and from this built their own four core aims for their strategic framework to reflect what they believed were the 'simple priority areas at the heart of sustainable development':

- social progress which recognises the needs of everyone
- effective protection of the environment
- prudent use of natural resources, and

- maintenance of high and stable levels of economic growth and employment

By 2005 some acknowledgement can be seen, of compromises that may be needed if the social and economic goals are to be met. It was here that the first use of the term ‘limits’ was introduced. The term was not seen as limiting economic growth per se, rather that the capacity of technology to reconcile economic, social and environmental priorities might be limiting. With this, the UK government produced a report, ‘*Securing the future: UK Government strategy for sustainable development’* that built on the originally produced ‘*A Better Quality of Life’* (1999). Whilst the initial report presented these core aims, urging they be used in parallel, many ‘agencies’ indicated that they had focused on the most relevant one or two to them, only. The updated report (2005) therefore, integrated these core aims in to an ‘evolved sustainable development policy’ and presented a new definition of sustainable development, ‘*to enable all people throughout the world to satisfy their basic needs and enjoy a better quality of life, without compromising the quality of life of future generations’* (DEFRA, 2005:16) with a new set of guiding principles:

- Living within environmental limits
- Ensuring a strong, healthy and just society
- Achieving a sustainable economy
- Promoting good governance
- Using sound science responsibility

Once again however, the report dictated use of all five guiding principles be used in alignment, in order to build and maintain sustainable policy. Nevertheless, the government used the newly developed strategic framework to conceive ‘priority areas for immediate action’:

- Sustainable consumption and production
- Climate change and energy
- Natural resource protection and environmental enhancement
- Sustainable communities

These priority areas are a positive acknowledgement that sustainable development is not solely about protecting the environment, but balancing that with societal quality of life in 'sustainable communities', echoing the recognition in 1999 of the lesser-developed countries being a product of their own natural resource depletion and environmental degradation that the 1987 Brundtland Commission sought to combat. This further emphasises that the economic aspect of the triple bottom line has seemingly always dominated and continues to do so. As one of global aviation's largest and most competitive markets, UK aviation is a clear key source to economic growth, on both a national and global scale (British Aviation Group, 2017). With UK aviation businesses providing goods and services to the world's largest 50 airports (Sustainable Aviation, 2017), aviation is a vast economic contributor from both an operational and manufacturing standpoint. It is however, also one of the top polluting industries, impacting the environment through emissions, but also impacting societal quality of life through noise pollution. The impact of aircraft noise becoming increasingly prevalent in recent years provides further rationale for this study. The tenets of sustainable development in the context of aviation are discussed further in the next section.

1.3 Sustainable Aviation

At the heart of this research is sustainable development: the faster the growth, the greater the challenge of reconciling economic outcomes with the desire to manage down negative environmental and social impacts. More specifically, as a result of its accelerated growth in further developed countries, capacity constraints within the aviation industry have developed resulting in greater challenges, balancing the global economic need of a licence to grow in order for airports to operate, with the environmental cost borne locally by communities surrounding airports, specifically with reference to aircraft noise. This is a particular challenge when looking at noise impacts, because over time noise *exposure* has actually reduced whilst noise disturbance appears to have increased (Hooper et al, 2015).

Whilst the already existing problem of aviation noise does not appear to be getting any better, and growth of air traffic demand over the next 30 years is estimated to continually outstrip technological advancements in aircraft noise reduction (Upham et al, 2003), there is pressure by various stakeholders for airports worldwide to be managed within the framework of sustainable development (Jordao, 2009 in Koc and Durmaz, 2015). To fully understand how this challenge can be addressed, the fundamental cause of the disturbance needs to be identified and understood, i.e. not just managing exposure issues; rather, a challenge of managing *impact*.

The nature of reported rapid growth in commercial aviation is such that segments of the community have been 'brought within earshot of modern airports' (Ollerhead, 1995). In a bid to protect people from noise associated 'health hazards' of significant socio-economic and environmental impacts inherent to their operations, airports over time have built noise management strategies. Furthermore, the need for airport noise management is enhanced by political as well as local pressure, urging a better understanding of the extent of aircraft noise effects and the role it plays within a sustainable aviation policy (Sanchez and Berry, 2015; Sanchez et al, 2015). This is explored throughout the coming chapters.

1.3.1 Quality of Life

Indeed there has been an increasing movement throughout recent years, within the aviation industry, to not only understand airports' impact on quality of life, but to proactively map out how to assess the impacts and measure the effectiveness of intervention measures set by airports to "reduce and mitigate their impacts on the environment and neighbouring communities". (Porter and Norman, 2018:1).

Quality of Life as a concept, is often used to describe an individual's well-being (Toscano, 2020), and furthermore, seen as an individual's perception of their position in life (WHO, 2021). The World Health Organization's Quality of Life Group suggests that this is perceived by the individual in the context of the culture and value systems in which they live, and in relation to their goals, expectations, standards and concerns (WHO, 2021); all suggested as social indicators by which to measure well-being (OECD, 2005), and all subjective and intangible. Other, impacts however, are measured through quantitative channels, such as income and production (OECD, 2005), providing more tangible, objective and recognisable results. This may go some way to explaining why the aviation industry and associated organisations to date have often focused aircraft noise impact management efforts on the reduction in noise exposure levels rather than reductions in adverse community reactions (Porter and Norman, 2018).

With such growing importance being placed on the role of airports in conversations surrounding quality of life, many across Europe in particular, are working with research organisations and initiatives to consider how best to proactively contribute to the international agenda. Porter and Norman (2018) produced a roadmap scorecard (Figure 1.2) as a means of working towards a better understanding of airport impacts on quality of life by assessing the positive and negative impacts of aviation on local communities, and identifying the impacts that the airport is able to influence.

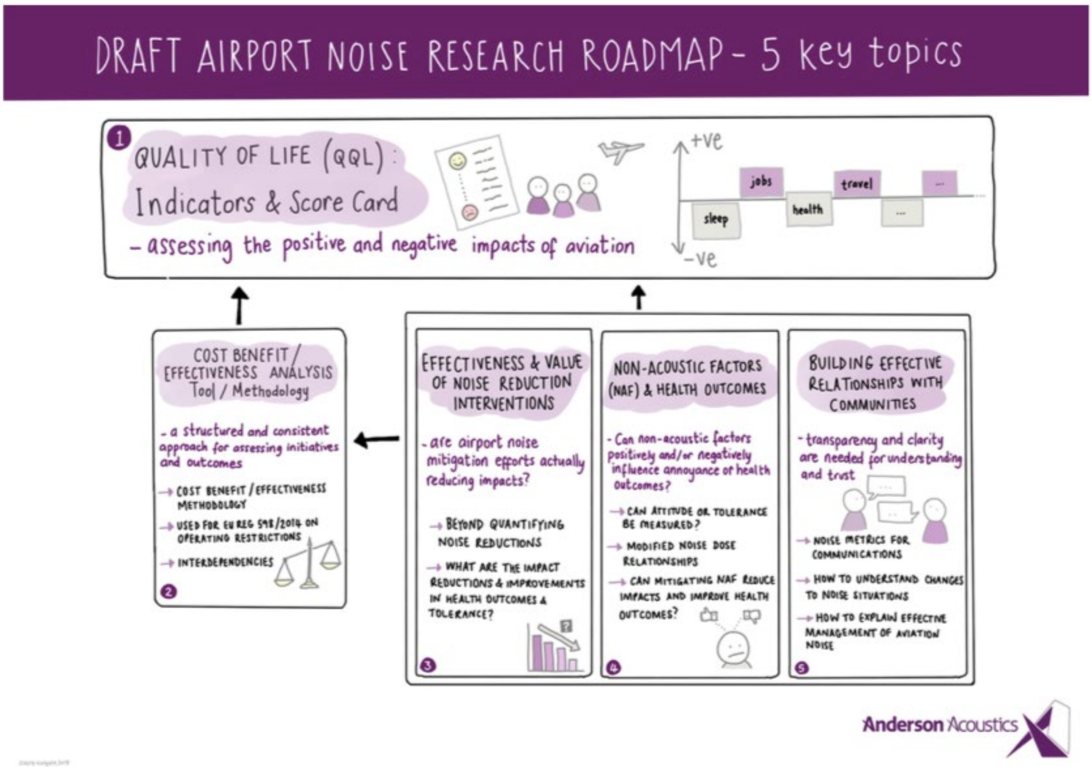


Figure 1.2 Airport Noise Research Roadmap (Porter and Norman, 2018)

Allied to this, the most recently published World Health Organization (WHO) Environmental Noise Guidelines (Brown and van Kamp, 2017) advocates a more proactive contribution to research surrounding aviation noise impact management;

giving further vigour to the need for this research study. With this in mind, the following sections to this Chapter set out the aim and objectives that will subsequently be addressed throughout the following chapters.

1.3.2 Limits to Growth

At the heart of the sustainability challenge, in the context of aircraft noise, is the negative human response (annoyance) to noise and the resistance this creates to expansion of the industry and airports in particular. As it has already been highlighted, sustainable development within the aviation industry is about balancing the need for growth with the need to avoid environmental impact increase. The core environmental impacts at the forefront of concern are climate change, noise and local air quality emissions; with renewed focus on the impacts of aircraft noise on those living beneath flight paths in recent years, partially fuelled in the UK at least by the proposals for airport expansion in the South East of England (House of Commons Library, 2017), this study focuses specifically on the impacts of noise from aircraft.

In line with this notion, when seeking to find balance between an environmental impact and societal well-being, there are inevitably going to be winners and losers along the process (Sustainable Aviation, 2017), reinforcing the need for reconciliation of competing interests if a more acceptable and sustainable outcome is to be achieved (DEFRA, 2011). This is made all the more challenging as satisfying the demand for more air transport services requires expansion of specific infrastructure, the negative impact of which is borne disproportionally by those living nearby; more simply put, the cost and benefit of airport expansion are inequitably distributed. Given that engine and airframe technology has achieved acoustically quieter aircraft over the last 50 years, whilst annoyance appears to have continually increased (CAA, 2014), there’s wide acceptance of the need to do more than simply drive down noise through existing measures in a move towards a more sustainable aviation sector.

In order to achieve the most effective (sustainable) balance between social, economic and environmental needs, in the context of aircraft noise, there is demand for a systematic response (Turner, 2010). This has been achieved to a certain extent by the leadership of ICAO, having sought to develop aviation management through adding three additional pillars to the original guidance of reducing noise at source. The fundamental driving objective of the 4 pillars was to work towards environmental goals whilst minimising restrictions to aviation operations; delivering the most growth in the industry with the least environmental and social impact. Unfortunately (as will be reported in the following chapter) whilst these efforts have seen a fall in noise exposure around many large, mature airports, this has not been associated with a reduction in the human impact, i.e. annoyance and disturbance, implying that there are contributors to annoyance other than the noise itself (non-acoustical factors).

Non-acoustical contributors, for example, mistrust of (airport) authorities, personal and social factors i.e. quality of life, economic benefit from the source (airport), have been increasingly recognised, and explain why there is increasing demand for better communication and engagement with affected communities. The sustainable development challenge of the aviation industry (airports and airlines) is to tackle noise impact more effectively through such communications and engagement in order to increase transparency and reduce mistrust, and look to de-couple growth of the industry from environmental and social impacts through working more closely with the communities to address such factors.

The aim of this relationship building then, must be to ultimately enable the dissemination of aircraft noise information in a way that is meaningful to local, affected communities, in order that they might feel more empowered in decision-making processes, thereby engendering greater tolerance and enabling the industry to develop control and mitigation measures that are more meaningful. It is widely understood in the present day that many aviation regulatory bodies – such as the CAA in the UK, for example – are now increasingly emphasising the role of communication and public engagement as key elements in the management of noise impact.

Indeed, ICAO recognised in the updated Balanced Approach document (2007), more attention must now be focused on non-acoustic factors to address the disjunct between physical measures to mitigate noise and increasing reports of annoyance. The motivation and rationale for involving the public in decision-making is set in the tenets of sustainable development; public participation today is becoming increasingly regarded as a normative, democratic right in decision-making processes, particularly within environmental agendas, from local to international scales. This reinforces this need to acknowledge the very people affected, and raises important questions; namely, what are the non-acoustic factors (in detail), and how amenable to influence might they be as part of a noise management protocol? In investigating this, the question arises of what might the role of more sophisticated auralisation and visualisation techniques be in supporting/facilitating the required enhancements in communications and engagement?

Exploring auralisation and visualisation as a communication tool, seeks to address a gap in knowledge through introducing a novel approach to improving communications and engagement between airports and their surrounding communities, and thereby facilitating a new means by which to tackle the sustainable development challenge.

The following chapters address this in further detail.

1.4 Aim

To critically investigate the potential contribution of a combined audio and visual engagement tool to enhance environmental communications relating to aircraft noise, specifically the impact visualisation has on stakeholder perception of audio stimuli.

1.5 Objectives

1. To critically analyse the causal link between the acoustic and non-acoustic factors that form the psychological interpretation of and subsequent response to sound.
2. To explore evidence pointing to a link between the importance of stakeholder engagement in influencing the attitudinal factors central to the

non-acoustic determinants of the human response to noise, and how this impacts on the understanding of information dissemination.

3. To review the current and consequent supplementary metrics of aircraft noise, assessing their chronological usefulness in environmental communication to date.
4. To critically evaluate the potential contribution of enhanced auralisation and visualisation to noise communication designed to improve comprehension and thereby facilitate more effective stakeholder engagement, through a series of case studies.
5. To determine the consequent need for further improvement in communication tools in order to contribute towards efforts aimed at reconciling aviation growth with wider community aspirations for quality of environment and subsequently quality of life.

1.6 Thesis Structure

The following chapter, *Aircraft Noise Regulations and Management*, sets out the evolution of the industry and enshrinement of policy throughout history. Chapter 2 also focuses on the Balanced Approach to Aircraft Noise Management document developed by ICAO for the UK aviation industry, and it's efforts to manage aircraft noise in a bid to improve community response towards airports through their 4-pillar approach. Chapter 3, *Human Response to Aircraft Noise*, looks to the rationale for the need to improve community response towards aircraft noise, exploring the psychological interpretation of a sound source and how this influences attitude towards it. Chapter 3 does this through explore the fundamental cause of the negative responses to aircraft noise, developing an understanding of non-acoustic factors i.e. expectation, fear, context, general demographics, and their impact on human perception of a sound source. Chapter 2 and 3 achieve Objective 1.

There is a necessity to understand how to improve community relations surrounding this topic, and indeed the need for it. Chapter 4, *Stakeholder Engagement and Public Participation,* explores a wider discussion of stakeholder engagement methods, as well as the importance being placed on building relations, for the completion of

Objective 2. It is hoped that through understanding the best method through which to communicate with communities in a way that is meaningful to them, and in such a manner that facilitates dialogue necessary in the underpinning of the processes intended to do so, that equitable decisions can be reached; and furthermore, sustainable development of the aviation industry can be worked towards. Whilst the outcome of reaching such discourse is beyond the scope of this research, the means by which to facilitate this are the focus.

In order to ensure a full understanding of the success (or otherwise) to date of such facilitation, Chapter 5, *Historical Descriptors and Communication Efforts to Date*, carries out a review of past supplementary metrics and descriptors used to facilitate dissemination of sound level information. In doing so, the effectiveness of previous environmental communications is determined, with specific focus on relations between airports and their surrounding communities. This addresses Objective 3.

With this in mind, Chapter 6, *Research Methodology*, justifies the research techniques used to construct the SoundLab experiments, carried out within Ove Arup and Partners Ltd (Arup)[3], which seek to determine the impact of visual stimuli on human perception of a sound source. Chapter 6 reviews the methodological use of document analysis, observations, and semi-structured in-depth interviews to build the foundations of the study. Empirical research is then carried out through laboratory testing to gather data, which is processed and analysed.

Addressing Objective 4, Chapter 7 forms an evolutionary overview of Arup's SoundLab through a set of sequential case studies. These cases focus on and evaluate auralisation and visualisation (in the form of Arup's SoundLab) as a communication tool of varying degrees through Arup's projects to date. The case studies explore HS2 Ltd (HS2)[4] dissemination efforts, consultation efforts linked to

[3] Arup is the sponsor company of this thesis, enabling the researcher to spend time working with and learning from the acoustic consultancy team, and to utilise their SoundLab facility as the central focus of the empirical research

[4] 'HS2 Ltd' is the company name, whereas High Speed 2 (HS2) is the follow on railway project to the High Speed 1 (HS1) railway project. HS2 provides the focus for the first case study of this research

assessing the effectiveness of Heathrow Airport Ltd (Heathrow)[5] noise mitigation insulation program, and Heathrow's Respite research. Each case utilises the methods of semi-structured in-depth interviews, observations, and document analysis to assess the rationale for the use of auralisation and visualisation as a communication tool, and it's effectiveness and shortfalls within each of the three processes. The information distilled from the three cases, allied with emerging themes, particularly that of the Heathrow Respite work, forms the structure for the empirical work, documented and analysed in Chapter 8.

The results of the empirical work, carried out in Arup's SoundLab, achieves Objective 5 through determining the extent to which auralisation and visualisation as a communication and research tool effectively contributes towards efforts aimed at reconciling aviation growth with wider community well-being. Finally, after a discussion of the case studies and consequent experiment in Chapter 9, *Conclusions and Recommendations* 10 summarise the thesis, highlights best practice needs of the aviation industry in the context of environmental communications, and identifies ways in which these could be implemented.

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[5] Heathrow Airport provides the setting for both the Insulation scheme and Respite research that form the second and third case study to this research. All cases are based on their use of Arup's SoundLab and associated technologies as a communication tool for varying reasons

Chapter 2 Aircraft Noise Regulations and Management

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

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

2.1 Guidance on the Balanced Approach to Noise Management

The International Civil Aviation Organization (ICAO) is the United Nations Global regulatory body for civil aviation, and it's 'Balanced Approach' document, *Guidance on the Balanced Approach to Noise Management* (2001) is the recommended approach – commonly thought of as a staple guidance - for the introduction of noise management measures within the aviation industry. With increasing attention being given to community noise annoyance at each annual meeting of its Assembly. The

Balanced Approach also examines several practical tools for modelling noise around airports and sets out to offer a suite of priorities and guidance measures with its core goal of supporting all aviation actors to systematically respond to the management of noise (ICAO, 2001); this is achieved through four core approaches for managing noise: reducing noise at the source, land use planning, noise-reducing operational procedures, and operating restrictions. In order to utilise these guiding principles, there is a need to first understand each one and the sequential nature in which their implementation is intended.

2.1.1 Mitigation measures – the four pillars of the Balanced Approach

2.1.1.1 Reduction of noise at source

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

The updates and additions to this appendix are added as new chapters. Since the first Noise Standard of 1972, there have been numerous updates, and amendments the most recent to come in to force being Chapter 14, set at CAEP/10 in February 2013 (Roetger and Adam, 2016). The report of the ICAO 7th Committee on Aviation Environmental Protection [CAEP] meeting summarises the relationship between all actors within the industry and how each one impacts the next for continual improvements: "The prime purpose of noise certification is to ensure that the latest available noise reduction technology is incorporated into aircraft design demonstrated by procedures, which are relevant to day to day operations, to ensure that noise reduction offered by technology is reflected in reductions around airports." (CAEP/7, 2007).

Focusing on reducing noise exposure means that the primary focus has lay on the physical reduction of sound generation through engine and airframe technology and mechanical adaptations to aircraft, as well as upgrades and modernisation to next generation aircraft fleet. The most recent certification standard applies to aircraft that had prototype approval after January 2006, and is being enforced in two stages: to high-weight aircraft in 2017 and to low-weight aircraft in 2020. The new standards aim to reduce Effective Perceived Noise Level by 7dB compared to that of existing Chapter 4 standards. The result of the reduction in sound generation is that the area of land in active noise zones should decrease by 2% by 2026, and by 4% by 2036 compared to that of 2000. This means that up to one million people will no longer be living in what is classed as an active noise zones by 2036 (Roetger and Adam, 2016). The latest ICAO Noise Standards serve as a clear indication of how proactive the aviation industry has become in reducing noise exposure (Airport Business, 2013).

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

Engine technology

Essentially there are two core trajectories of technological improvement, engine and airframe. The aviation industry has previously focused on engine technology as the main source of aircraft noise. Aircraft are today 20-30dB quieter than the first generation of jet engine aircraft of the 1970s due to the turbo fan engine and the application of high bypass ducts and serrated nozzles (Clean Sky, 2018[6]). There has been a shift in focus from engine to airframe over the last 15 years with regard to noise output, particularly during landing when engines tend to operate at low power and high-lift devices and landing gear are deployed (Yang et al, 2013).

[6] Clean Sky is the largest European research programme developing innovative, cutting-edge technology aimed at reducing CO_2, gas emissions and noise levels produced by aircraft. Funded by the EU's Horizon 2020 programme, Clean Sky contributes to strengthening European aero-industry collaboration, global leadership and competitiveness

Airframe technology

Traditionally airframes have been made from aluminium and/or titanium, these materials are gradually being superseded, in up and coming fleets, by carbon composite materials because of weight saving capacities, better performance at lower cost, and lower life-cycle impact due to higher resilience to fatigue and corrosion than traditional metals (Yang et al, 2013; Clean Sky, 2018).

Continued technological innovation

The roll-out of new fleet designs such as NEO [New Engine Option] and A350-XWB (Roetger and Adam, 2016) coincide well with the newly sanctioned Standard and Recommended Practices (SARPs), especially given the long life-cycle of the aviation industry's core technologies, i.e. the aircraft, and shows that aircraft manufacturers are prioritising noise concerns in their designs more prevalently than has previously been seen (Roetger and Adam, 2016; Airport Business, 2013). In fact, it has been suggested that the manufacturing industry saw the new regulation enforcements as an opportunity for technological innovation. As a result, most new aircraft types are being built to anticipate future stringencies (IATA, 2016). A geared turbofan for example, will replace current designs to power the A320 NEO, allowing each part of the engine turbo machinery to rotate at individual optimal speed, reducing both noise and fuel burn.

Whilst the A350-XWB, is said to be up to 16dB below the required standard of 2006's Chapter 4 due to such design modifications. Airbus also highlights the Automatic Noise Abatement Departure Procedure (NADP) as an example of the functionalities available on new aircraft (Airport Business, 2013). Continuing efforts to seek marginal improvements in noise generation are acknowledged by Assistant Director in Aviation Environmental Technology, Thomas Roetger, who notes recently developed 'tweaks' to the nacelles of Boeing's 787 and 747-8 to optimise the way that engine airflow is mixed with ambient air to effectively reduce noise (IATA, 2014).

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

Aircraft noise certification as documented in the ICAO Appendix 16, discussed above, is based on an individual aircraft's performance with both the engine and airframe taken in to account. In line with the progressively stringent chapters of Appendix 16, ICAO recorded a reduction in aircraft noise of 75 per cent in the context of the ICAO Council's adoption of "Chapter 14", measuring noise reduction recommendations in EPNdB [Effective Perceived Noise decibel levels] (Destination Green, 2013; ICAO WP163, 2013; See Figure 2.1).

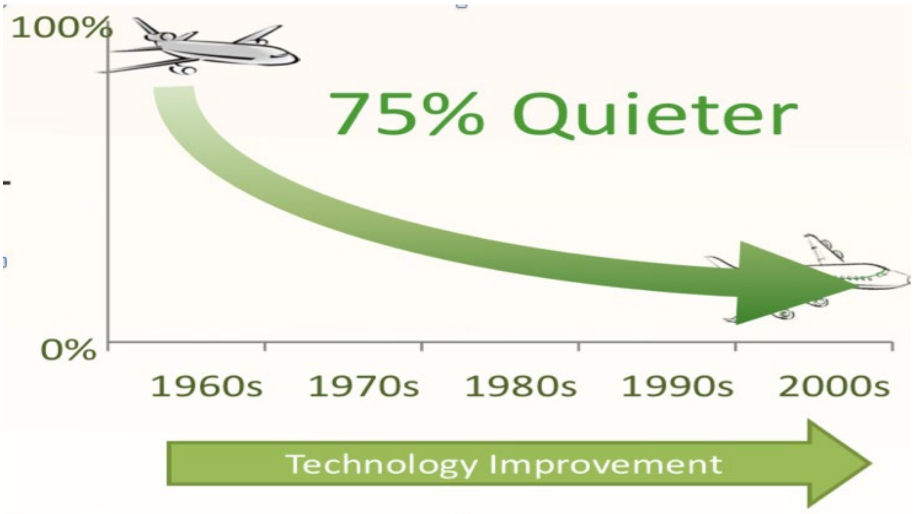


Figure 2.1 'Aircraft Noise Reduction Due to Technological Improvements', Destination Green, 2013

In the same year (2001) that the ICAO Balanced Approach was published as a means of disseminating sequential steps of SARPs [standards and recommended practices], ACARE (Advisory Council for Aeronautics Research in Europe) published somewhat more definitive, 'technically' worded design aspiration: "to achieve between 2000 and 2020 a 10dB reduction in the noise perceived by the community per plane and per operation" (Leylekian et al, 2014:2). With 75 per cent of global fleet (currently in service and on order) due for replacement before 2050, the Clean Sky 2 program is aiming to see these replaced by the novel technologies currently being developed, with 75% of the current Global fleet due for replacement before 2050. If this occurred, it is predicted that this could result in a further 65 per cent reduction in perceived noise by 2050 compared to performance in 2000 (Clean Sky, 2018). Figure 2.2 outlines the target path in both decibel level and means of reaching each stage using Noise Reduction Technologies outlined in FlightPath2050 (Sustainable Aviation, 2011; Clean Sky, 2018).

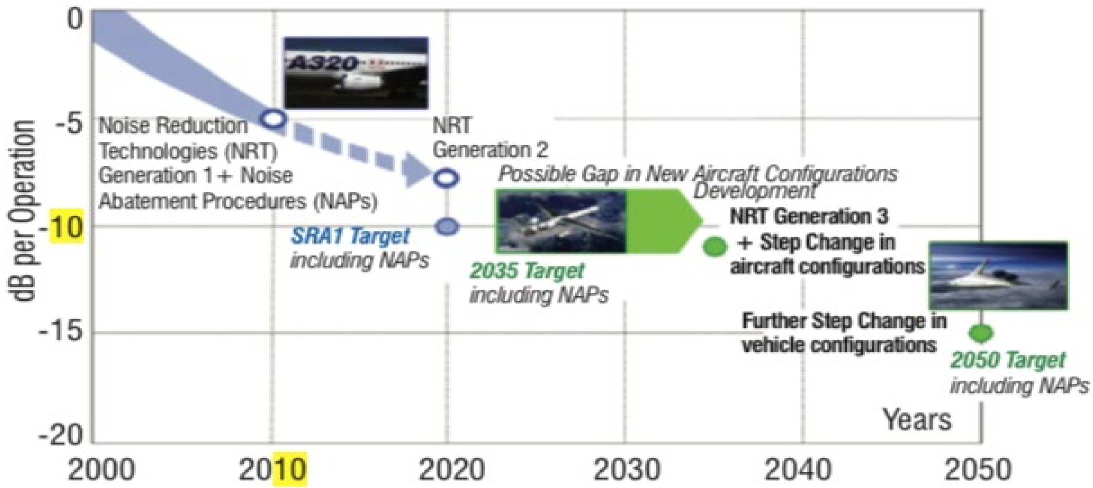


Figure 2.2[7] **Pathway to FlightPath2050 Targets through Noise Reduction Technologies, Clean Sky, 2018**

2.1.1.2 Land-use planning and management policies

Along side continued technological advancements, land-use planning (LUP) has been a long-term strategy in attempts towards aircraft noise reduction. Land-use Planning involves identifying areas affected by higher levels of aircraft noise and then restricting the land use and type of buildings that can be constructed in those areas, e.g. noise sensitive dwellings, hospitals etc. In many cases, there is a requirement that any structures built are fitted with noise insulation.

ICAO set out their guidance on land-use planning and management in Annex 16, Volume I, Part IV and in the Airport Planning Manual, Part 2 — Land Use and Environmental Control (ICAO, 2014). This recognises that not only can aircraft exposure be reduced through technological improvements, but also that there was scope to manage consequences of the noise on the ground. By managing noise exposure as well as its generation, the notion of LUP sets out means by which to ensure that activities around airports are harmonious with aviation activity. The main goal of which, is to minimise the population affected by aircraft noise; this is

[7] NRT1 and NRT2 denote the first and second generation Noise Reduction Technology, respectively, based on whether they will reach a particular Technological Readiness Level (TRL) by 2010 or 2020, respectively

done through the use of land-use zoning in airport-surrounding areas (Dickson, 2016).

It should be recognised that land-use planning is considered a long-term strategy and should not be based on short-term or current contour maps. Thus, there is a continued need to take future levels of aircraft activity at an airport into account during any new land-use planning. A summary of core land-use principles is outlined below in Table 2.1.

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

Table 2.1 Core Principles of Land-Use Planning, Adapted from CANSO, 2015:17

In moderate noise areas, some authorities permit new developments where sound insulation and ventilation requirements are met. However, this does not address outdoor noise levels, or indeed indoor noise levels when windows are open.

Heathrow Airport and Sydney Airport are just two examples of having used retrofitting of noise insulating components to buildings associated with sensitive activities, e.g. residences, schools as one mitigation approach in a suite of approaches to mitigate aircraft noise impacts (CANSO, 2015). Heathrow Airport's mitigation effort through insulation is outlined in a detailed case study in Chapter 7.

Land-use planning provides a mechanism for limiting the number of people affected by aircraft noise now, and in the future as an airport grows. Land-use planning prevents urban encroachment and in so doing, minimises the risks the noise disturbance, which in turn, has the potential to loosen constraints to growth.

2.1.1.3 Noise abatement procedures

Noise abatement procedures are specifically designed to avoid or reduce noise over populated areas through the operation of aircraft as summarised in Table 2.2 below.

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

Table 2.2 Noise Abatement Procedures, Adapted from CANSO, 2015:18

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

It must be highlighted that in designing such procedures, it is not only noise that requires consideration. Despite the notion of trade-offs being outside of the remit of this section's focus, it must be recognised that as a procedure to address one issue is designed, there may indeed be consequences for another issue. In the context of environmental noise, a 'trade-off' with other environmental issues such as CO2 emissions and other operating priorities i.e. safety or cost, may be created (Airports Commission, 2013). All procedures have to meet safety requirements and meet the performance of every aircraft type that uses a particular airport, these factor limit the extent to which it is possible to avoid imposing noise on sensitive areas.

2.1.1.4 Operating restrictions on aircraft

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

The chapterisation of aircraft has ensured that a phase-out process of older and therefore noisier aircraft is introduced in such manner that makes use of the 'life' of the aircraft but equally encourages engine and airframe technological improvement with each fleet renewal (Girvin, 2009). Other shorter-term restriction impositions however, are listed below in Table 2.3.

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

Table 2.3 Types of Operating Restrictions, Adapted from ICAO, 2004; Girvin, 2009

As noted above, noise problems are specific to individual airports (CANSO, 2015). As such, Europe's larger airports tend to impose tailored "more mandatory restrictions and take more diverse approaches to noise mitigation because of varying degrees of local and national pressure" (Girvin, 2009:15). The noise problem at every airport is unique. This is a function of individual operational conditions, the local geography, proximity of the airport to residential areas, differences in climate (that affect lifestyles) and individual attitude to aircraft noise. ICAO regional and national noise regulatory regimes are designed to take this into account. For this reason, and importantly in the context of this research, the noise management programmes adopted at individual airports have to be developed in *consultation* with local communities.

An outline of how restrictions vary in stringency and imposition is detailed below in Table 2.4.

<table>
<tr><th colspan="2">Category of Restrictions</th><th colspan="2">Conditions of Restriction</th></tr>
<tr><td colspan="2">Global</td><td colspan="2">Apply to all traffic at an airport based on total fleet noise performance</td></tr>
<tr><td colspan="2">Aircraft-specific</td><td colspan="2">Apply to a specific aircraft or a group of aircraft based on individual noise performance</td></tr>
<tr><td colspan="2">Partial</td><td colspan="2">Apply for an identified time period during the day, on a specific days of the week, or only for certain runways at the airport</td></tr>
<tr><td colspan="2">Progressive</td><td colspan="2">Provide for a gradual decrease in the maximum level of traffic or noise energy used to define a limit over a period of time. This period is typically defined as a number of years before reaching a final level</td></tr>
<tr><th colspan="4">Ways In Which Restrictions Can Be Implemented</th></tr>
<tr><td>Number of Movements:</td><td>Per period of the day and/or year for the airport or per runway direction i.e. a maximum annual number of movements at the airport</td><td>Quota Counts:</td><td>Expressed as a combination of movements and aircraft acoustic characteristics or a fixed contour. Consequences of quotas may be a restriction on available slots or the closure of certain runway direction during a certain period</td></tr>
</table>

Table 2.4 Operating Restrictions and their Conditions, adapted from ICAO, 2004

A system similar to that of today's *quota count*[8] was predicated purely on the number of aircraft movements, however since the increased stringency of noise certification, evolution of engine and airframe technology has delivered increasingly quieter aircraft over time; this has meant that a classification system can now be used to assign values to aircraft based on take-off/landing and, more specifically, an individual aircraft's noise certification to much more effect than the previous system. The varying value bands differ by 3dB steps with each value band depicting a quota (ICAO, 2014).

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

[8] Quota Count is a system used in the UK by London's Heathrow, Gatwick, and Stansted airports to limit the amount of noise generated by aircraft movements at night time (23:30–06:00)

A quota count (QC) is allocated to each airport per year where airlines must submit requests for slots in line with the airport's allowance. Simply put, Airlines bid for night slots with the noise level of the particular aircraft used to operate that slot resulting in the QC count – In general departures are noisier and therefore 'score' more QC than arrivals. This influences the types of aircraft flown at night, and indeed the numbers of takeoff and landings. Such a system dictates that the number of aircraft versus the noise level of aircraft is weighted, encouraging the use of quieter aircraft in order to maximise the amount of aircraft use within the given quota: "This system does not only reduce noise pollution during night-time hours but also drives home the operational benefits of the latest, quietest aircraft types to global operators" (Roetger, 2014). The equipment and scheduling constraints from the pressure created by airports imposing such restrictions, results in a knock-on effect as airlines continually compel manufacturers to improve the performance of their aircraft (CAA, 2014).

2.2 Recognising the need for an additional approach

The Balanced Approach can be viewed as a significant means by which to mitigate physical noise presence, limit noise sensitive buildings such as houses within maximum noise exposure areas and limit noise at sensitive times and levels through operational means. The associated noise goal is to reduce perceived noise emissions of flying aircraft by 65%, which translates to a 15dB[9] EPNL[10] reduction in noise by 2050 relative to year 2000 technology; the equivalent of a 0.3dB[11] improvement per aircraft operation per year (Sustainable Aviation, 2011). It is thought that through the continual implementation of a range of improvements in aircraft and airspace operational techniques, this is achievable. Despite this, however, measures to reduce the amount of noise per event have centred on the notion that if noise exposure on the ground is reduced, the cumulative L_{eq}'s are therefore lowering, thus, the problem is getting 'better'. In reality, this approach may actually increase

9 Decibel units describing sound level or changes of sound level

10 See Appendix 2.0

11 Sound levels that differ by less than 1 dB are hard to distinguish by the human ear. It is difficult to notice the difference between successive pairs. $10*\log_{10}(1.07) = 0.3$, so to increase the sound level by 0.3 dB, the power must be increased by 7%

annoyance as exposed communities are 'surprised' by changes and an overall average, i.e. L_{eq} may disguise underlying changes inherent in the pattern of intended improvements, in other words, there may well be both winners and losers within an anticipated general improvement.

In line with the Miedema and Oushoorn (2001) curve[12] and further associated exposure-response data comparisons, other variables impacting annoyance have also been considered, with Gelderblom et al (2017) for example, advocating that the nature of change in operational patterns has significant impact on a community's recognition of and therefore response to aircraft noise (Guski, 2017). In addition, Gelderblom et al (2017) introduce the notion that 'high rate change' (HRC) returns a higher annoyance percentage than 'low rate change' (LRC) airports, which see only gradual, or even no, change in operations over a similar time period (Bartels et al, 2018).

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

- Situational factors - the time of day when the noise occurs
- Personal factors - individual attitudes or traits
- Social factors - attitudes towards the noise sources which are shared by the community

Fields (1993) and Miedema and Vos (1999) also consider:

- Attitudes and expectations
- A person's sensitivity to noise

[12] Extension of original 'Scultz (1978) curve' graph of 'percentage highly annoyed' (%HA) – as the measure of community response – against exposure level, based on numerous social survey studies of public reactions to transport noise (CAA, 2018).

- Demographics, i.e. age, gender, occupational status, educational level, homeownership, use of the noise source, length of residence.

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

Indeed, ICAO recognised more needed to be done and began to identify other interventions that might be useful, such as communication and engagement linked to a more proactive management of the response to noise exposure rather than simply the exposure itself. The 2007 revisions to the Balanced Approach include the principal element of 'people issues' focusing on 'information dissemination' and 'information exchange'. This was seen as a significant step forward in addressing the need for interaction with stakeholders if attitudes towards airports and thus levels of tolerance were to be influenced. The rationale is that by better understanding how an individual becomes annoyed by aircraft noise, the improvements can be focused on how the industry responds and communicates.

Sustainable Aviation (2011) believes that in turn this will reduce annoyance surrounding aircraft noise - and its 'source'. Further, it has been recognised that an effective engagement process cannot be designed to be effective in all situations, and the CAA demonstrates recognition of this in the development of tailored mandates for each regulated airport within "a common set of principles…" in line with ICAO's Balanced Approach standards and recommended practices [SARPs] "…but with detailed arrangements according to the prevailing circumstances" (CAA, 2012:4).

2.3 Limitations to aircraft noise management

2.3.1 Limitations of relying solely on engine and airframe technology

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

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

As has been discussed, whilst technological strides have been made as a result of such standards and recommended practices [SARPs], to the tune of a 75% reduction in aircraft output sound level compared to 50 years ago (IATA, 2014; Dickson, 2015), and noise standards adhered to, noise annoyance has not followed a similar pattern of improvement, and has actually increased at some locations that have 'benefited' from reduced noise exposure on the ground over the same period (as measured by L_{eq}) (Dickson, 2016).

2.3.2 Limitations to the four pillars of the Balanced Approach

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

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

2.4 Conclusion

There is evidence that today people are more sensitive towards aircraft noise as represented by long term average noise metrics, than they were decades ago (Guski, 2004). Despite the reduction in noise exposure (measured as a long term averaged aggregate, e.g. L_{den}, L_{Aeq}), expressed disturbance and annoyance has continued to increase over the 50-year period of technological enhancements, suggesting that measures designed to simply reduce long-term average noise exposure may not result in the desired outcome of reduced impact (MMU, 2010).

This highlights a dichotomy between efforts being made to reduce the aircraft noise exposure, and the tolerance of local communities towards it, suggesting that negative human response to aircraft noise stems from perception and interpretation as well as the physical exposure. Indeed, such a claim cannot be made without an explorative look in to non-acoustic factors and their role in influencing human attitudes towards, and the perception and interpretation of, the source of noise. This is carried out in Chapter 3.

Throughout this section it has been made clear that communication and engagement should now be the focus at the heart of aircraft noise management; this is explored in detail in Chapter 4. In order to gain a holistic understanding and outline what the target of that communication and engagement should be however, there is a need to first examine the annoyance response itself and the tenets of which we need to manage; as previously signposted, this is carried out in the following chapter.

Chapter 3 Understanding Human Response to Noise

Chapter 2 presented the acknowledgement by industry (in the form of ICAO's 'Balanced Approach' document) of the disjunct between efforts being made to reduce aircraft noise exposure, and surveys of community annoyance towards it, over a period of time when objectively measured sound has reduced. From identifying the importance placed by industry on understanding such a disjunct, there is a need to investigate the causal factors in more detail. This chapter now takes a detailed look in to non-acoustic factors and their role in influencing human attitudes towards, and the perception and interpretation of, the source of noise. A look will first be taken at the annoyance response itself in order to understand the role of non-acoustic factors and how they might be amenable to management interventions as part of a more holistic approach to noise impact management.

Figure 3.1 demonstrates that there are both inherent aspects of the auditory system and qualities associated with the interpretation of a perceived sound, that come together to define the human response. In order to understand annoyance in response to a sound holistically therefore, there is a need to explore the contribution of both sound perception and interpretation to the outcome. This chapter seeks to unpack those theories and models in order to identify non-acoustic factors that can influence the human response in order to inform potential noise management strategies.

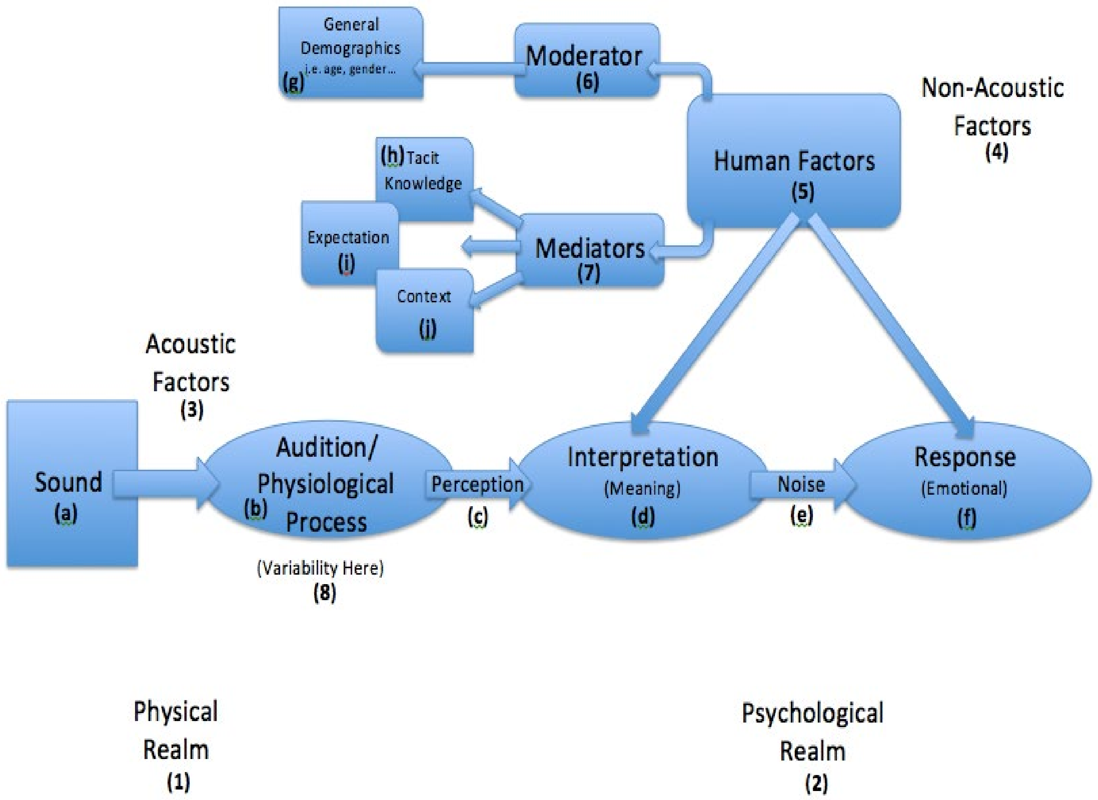


Figure 3.1 Exposure-Response Process Adapted from Literature

Figure 3.1 above, is indicative of a more holistic approach to understanding negative human response to sound. The diagram illustrates both a physical (1) and a psychological (2) realm, where acoustic factors (3) tend to appear within the physical realm, and non-acoustic factors (4) making up the psychological realm. Once a sound (a) has been processed (b) and perceived (c) through a human's physical mechanisms, the non-acoustical elements begin to filter in to the interpretation (d) of the already physically processed sound.

It is here that all aspects of non-acoustic factors (g-j) have impact and determine the subconscious thoughts surrounding the meaning of a sound. At this point, in the context of this thesis, the sound is assumed to be unwanted, and therefore deemed as *noise* (e). The attitudinal response of the sound being heard therefore, is a negative one (f).

In order to understand how each of these factors (a-j) impact the response output to sound exposure, each will be looked at in turn. Key theoretical models will also be discussed further on in the chapter. There is of course also the need to acknowledge an additional factor to this process, human *variability (5)*. Human variability is indeed an inherent trait within each individual. It can be argued that human variability is made up of both physical and psychological factors, and ultimately creates individual personalities, preferences and thoughts. By means of working through Figure 3.1 in logical order, human variability will be discussed in section 3.1.3 once various acoustical elements have been explored.

With Murray Schafer a key source for such research, it seems appropriate to cite his description of the difference in roles between a sound's output and the processing of it by the human ear: "From acoustics and psychoacoustics we will learn about the physical properties of sound and the way sound is interpreted by the human brain. From society we will learn how man behaves with sounds and how sounds affect and change his behaviour" (Schafer, 1994:4). Indeed, it has been advocated that the surrounding environment is experienced holistically, through all sensory modalities. Cassidy (1997) suggests that such processing produces both physiological and psychological effects that lead to either a feeling of wellbeing or a feeling of uneasiness; this becomes common thought throughout the subsequent sections to this chapter. Maffei et al (2008) cite Bangjun et al (2003) when suggesting that the factors with potential to cause uneasiness - or more commonly termed, annoyance – should be divided in to two categories:

- Factors relating to acoustic characteristics
- Non-noise-related factors

Job (1999:57) also looks to categorise varying types of annoyance-causing effects when discussing his idea of noise sensitivity (section 3.3.1.5) and his notion of 'internal states'. When considering these two ideas alongside one another, a common theme begins to emerge and the parallels between potential annoyance-causing factors and the different types of noise sensitivity appear to align. The two correlating notions are outlined in the table below (Table 3.1), along with a brief signposting of where each feature is addressed throughout this chapter.

Bangjun et al's (2003) factors that have potential to cause uneasiness	Job's (1999) "various types of sensitivity"	Related Points of Discussion Throughout Chapter
Relating to the acoustic character of the noise, e.g. sound levels, frequency, noise events, and amount of time exposed to noise	Physiological reactivity to noise in general (the auditory system)	Discussed throughout section 3.1, including: - Threshold Shift - Auditory Looming - Human Variability
Relating to non-noise-related factors, e.g. environmental conditions, age and gender differences, personal sensitivity to noise	Psychological reactivity – including attitudinal	Discussed as part of a pivotal concept of controllability within section 3.3.2
	Degree of coping Related to life style or activities conducted	Potentially the most influential, least accountable and hardest to maintain as a steady-state covariant in terms of impact noise management - section 3.3.3

Table 3.1 Factors causing Uneasiness and Noise Sensitivity Adapted from Literature

3.1 Acoustical Elements of Exposure-Response

It has long been recognised that the manner in which sound is received is dependent upon the place and environmental context in which it is heard, for example the combination of physical characteristics that influence exposure along with sociocultural characteristics that may influence environmental perceptions in different communities (Dubois et al, 2004). Allied to this is the frequency sensitive nature of the human ear, with perceived levels varying by more than 50dB for pure tones at various frequencies in range (Fletcher and Munson, 1933). There is a suggestion here that individual perception and therefore reaction to sound is not simply a function of acoustically measured sound levels being experienced. This will be explored in the following sections.

A certain idea of sociability has become attached to the sense of hearing; Schafer (1994:102) suggested that touch is the most personal of the senses, and that "hearing and touch meet when the lower frequencies of audible sound pass over to tactile vibrations (at about 20 hertz)". Schafer adds that he believes "…[h]earing is a way of touching at a distance", and it is this 'intimacy of the first sense" that creates the sociability; for example when people gather together to hear something special. Blake and Sekuler, (2006:12) further this notion by describing the ear as 'an erotic orifice', suggesting that, in order that it may "concentrate on those [sounds] which truly matter", for example when listening to music in a busy environment (Schafer, 1994), the ear has the ability to filter out indifferent and distracting sounds. Despite this skill developed through evolution (section 3.2), however, the overarching sense of hearing "…cannot be closed off at will" (Blake and Sekuler, 2006:13). There are, for example, no 'earlids', Blake and Sekuler (2006:13) acknowledge. They further explain, "[t]he ear's only protection is an elaborate psychological mechanism for filtering out undesirable sound in order to concentrate on what is desirable [or necessary]. When we go to sleep, our perception of sound is the last door to close and it is also the first to open when we awaken."

Threshold shift goes some way towards the process of a restful sleep. A threshold shift within the auditory system refers to an increase or decrease of the lowest sound level (threshold), which "can be heard at any moment" (Westerkamp, 1972:7). The sensitivity of the auditory system 'shifts' in accordance with the average noise level of any environment, "even for normal environments of modest levels", similar to that of the eye adjusting the size of iris to accommodate varying light levels (Westerkamp, 1988:7). Temporary threshold shift during sleep has been suggested as the reason that such pitches designed to alert – whether naturally, i.e. a baby's cry, or synthetically, i.e. alarms – are more effective and indeed startling during this time (Blake and Sekuler, 2006). In the context of aircraft noise, this might explain why some people are more sensitive and alert to aircraft movements if, for example they have a fear of being overflown, or that the value of their house has diminished as a result of aircraft noise.

3.1.1 Auditory Looming

When a sound is even more short-lived than those with the ability to cause temporary threshold shift, it tends to be non-stationary, or a 'pass-by'. Due to

Doppler shift, characteristics such as level and tonality change during the sound event (Barbot et al, 2008). In the same vein as parallels drawn between landscapes and soundscapes (see section 3.1.2), here too, descriptions of auditory looming draw on characteristics of visual looming. The growing sound's intensity for example, "is analogue to the expanding retinal image you receive when an object moves rapidly toward you" (Neuhoff, 2001:87). Considering the two senses together, evolutionarily, approaching objects are seen at the same time they are heard, masking the full power of auditory looming in its own right (Blake and Sekuler, 2006). The approaching and receding nature of such sounds, when studied under laboratory conditions, produced varying perceptive reactions. During Neuhoff's (2001) experiment, participants listened to the same sound played both forward and backward at the same speed to represent the approach and recede of its loudness, respectively (Neuhoff, 2001:21). The most notable of outcomes was that listeners "reliably overestimate[d] the amount of change in a sound that [was] steadily increasing", relative to the same sound played backwards.

In evolutionary terms, it serves to make sense that an approaching sound source should be perceived as closer than it is. This form of perceptive bias provides an advantage of being able to prepare for the source's arrival. Seifritz et al (2002) carried out brain imaging studies of humans that indeed showed approaching sounds to produce stronger activation than receding sounds in areas of the brain known to facilitate "auditory motion perception and attention (cited in Blake and Sekuler, 2006:100). The notion of auditory looming is suggested to be more powerful while the listener remains stationary (as opposed to both sound source and human moving at different rates) as it enables a clearer sense of the change in distance of the sound source (Barbot et al, 2008). In the context of this study, such a situation tends to correspond to the experience of an over-flying plane. The fact that the way in which the auditory system processes auditory looming produces distorted perceptions – whether for survival purposes or otherwise – suggests that this could go some way to explaining the annoyance levels caused by aircraft fly-overs. This is discussed further in Section 3.4.2.

3.1.2 The Soundscape

Several authors outline the difference between a *hi-fi and lo-fi environment*, (Bartle and Schafer, 1977; Schafer, 1999; Truax, 2000; Santuca and Ludovico, 2014). The authors here identify the impact an environment has on human ability to hear; this echoes similar thoughts to that of temporary to permanent *threshold shift* (Ryan et al, 2016), whereby continuous or repeated exposures to noise that only induce a temporary threshold shift, may evolve to a permanent threshold shift if repeated significantly over a period of time (Ryan et al, 2016:272). It is suggested that a hi-fi environment is one of “acoustic clarity” (Westerkamp, 1988:5), and offers optimum listening conditions. Hi-fi sounds overlap less frequently meaning that they don’t mask one another. It is this acoustical environment in which keynote sounds stand out clearly from the low ambient sound that surrounds them (Santucci and Ludovico, 2014:913).

A ‘keynote’ originates as a musical term to describe the note that identifies the key or tonality of a particular composition. It is “the anchor or fundamental tone and … it is in reference to this point that everything else takes on its special meaning.” Schafer (1994:9) further adds, “[k]ey note sounds do not have to be listened to consciously; they are overheard but cannot be overlooked, for keynote sounds become listening habits in spite of themselves.” Westerkamp (1988:7) gives the example of small countryside communities as places of acoustic clarity, and suggests that the further away, both geographically and socially from “urban mechanized society”, the more likely an individual is to encounter a hi-fi environment.

Schafer’s (1994:43) literature tends to focus more on the characteristics of a lo-fi environment; a congestion of sounds that began post Industrial Revolution, when new sounds appeared and “many archetypal sounds ended up being blacked out” (Santucci and Ludovico, 2014:913). In contemplation of such characteristics, Schafer advocates that the “city abbreviates the facility for distant hearing”, and identifies this as “one of the more important changes in the history of perception”, acknowledging the soundscape transition of pre to post industrialisation.

The *soundscape* is suggested to "denote an auditory equivalent to (visual) landscape, defined as an environment created by sound" (Dubois et al, 2004). The soundscape can be thought of as an "alternative approach to overcome the limits of noise annoyance indicators and to address more general concepts of sound quality" (Dubois et al, 2004; Maffei et al, 2008).

Truax (1978:126) sets out his theory that the soundscape should be thought of as an "…environment of sound… with emphasis on the way it is perceived and understood by the individual, or by society. It thus depends on the relationship between the individual and any such environment". It can be considered that the variance in human ability to hear, due to a surrounding soundscape – either permanent or temporary, also impacts individual perceptions of a sound(s) being experienced (Ryan et al, 2016). The extent of this impact from threshold shift can vary largely, bearing in mind that temporary threshold shifts can last any number of hours or days.

In an urban environment, a lo-fi soundscape causes individual sounds to lose their clarity and consequent identity. This is because the volume of a lo-fi environment requires amplification of even the most basic of sounds in order to be effectively heard by the human ear (Santucci and Ludovico, 2014). Required amplification means that the surrounding soundscape becomes increasingly noisy, and the identification of a sound source becomes more difficult; subsequently, a further amplification of sound is needed. And so the process repeats (Schafer, 1994; Santucci and Ludovico, 2014). With this in mind it is logical to suggest that, whereas a "sparseness" of environmental sounds, found in more rural soundscapes, enables "alert ears and active listening", particularly if the ear rarely gets 'activated' within a more urban soundscape (Westerkamp, 1988:7), the urbanised ear has lower awareness levels of surrounding soundscape, and a higher degree of sensory deprivation in everyday life (Santucci and Ludovico, 2014); such excess of environmental noise Schafer says, produces "sloppy listeners" (1994: 207).

Westerkamp theorised a similar notion in 1988 through her exploration of hi-fi and lo-fi soundscapes, suggesting that a lo-fi *urban* environment constructs "socialized beings" where the ear becomes conditioned to actively *not* listen due to over exposure of often "unpleasant, meaningless and stressful acoustic information" (Westerkamp, 1988:9). Much as Blake and Sekuler (2006) identified (noted earlier in this chapter) that the ear has the ability to filter out indifferent and distracting sounds, Westerkamp's belief is that the temporary threshold shift function within the auditory system will increase so gradually over time to a permanent auditory threshold, that most will be unaware of their own hearing regression (Ryan et al, 2016).

When considering the notion of a permanent threshold shift so gradual that the individual is not aware of it's happening, the question has also been raised as to whether this may be true for attitudinal shift. Huronjeff and Robert (1997:30) explore the possibility of whether, after initial reaction, adaptation occurs and "residents' attitudes slowly shift" over time; in line with a long "pre-history of the same exposure", which indeed aligns with the tenets of a permanent threshold shift. Instead, it could be the case that no adaptation ever takes place and the initial attitudinal reaction simply stays that way and either acceptance/tolerance or annoyance is maintained. Whether it is an individual's threshold *or* attitude shift responsible for the disjunct between "noise performance improvement" and "community perception of noise" (CAA, 2007:2), human variability clearly impacts either cause. With such a fundamental flux between every individual, there is a need to further understand the principles of human variability in order that there might be scope to account for it in future noise impact management strategies.

3.1.3 Human Variability

Ryan et al (2016) believe that acoustical features (such as surrounding soundscape) can be accountable for human variability in perception of noise. Guski (1999:45) suggests that, whilst this is true for "at best, one third of the variance", there is also a strong sense of personal and social values impacting human response to noise.

Seemingly, there is no way to compare one person's perception of loudness to another, with human reaction to noise far more complex than the simple measure of overall sound pressure level. There is no scientific instrument to measure this comparison, nor is it seen as possible to quantitatively study the problem within a realistic environment since "the very process of making the necessary observations has a significant effect upon subjective reaction" (Ollerhead, 1982:2).

Indeed, there is no way of determining the accuracy of individual perceptions of loudness; therefore there can be no categorical right or wrong "…a sound's loudness *is* whatever you experience" (Blake and Sekuler, 2006: 403). Full consensus for example, can often be ascertained (under regular conditions) that a particular sound is indeed louder than another, suggesting that (with exceptions) most "employ the concept of loudness in the same way" (Blake and Sekuler, 2006:403). Despite this however, the concept of loudness remains a subjective one. This can be extremely problematic for noise impact management and planning, for example of airports, when working towards solutions for lowering annoyance and general negative reactions towards aircraft noise. Furthermore, many planning and regulatory aspects of aircraft noise control require noise to be defined in terms that are relatable to human evaluation (Ollerhead, 1982). Verbal discussions therefore, about the loudness of a sound must be relied upon in comparing perceptions (Blake and Sekuler, 2006).

3.2 Perception Theory

Figure 3.1 illustrates the process from acoustical elements being processed (a-b) through the human auditory system to how the sound is interpreted (d-f). It is at the point between physiological processing (b) and interpretation (d) that perception (c) comes in, on Figure 3.1. In reality, the notion of perception could well – illustratively speaking – wrap around the two stages (b and d) in their entirety, instead of acting as a bridge between them. This would reflect the more holistic approach to understanding the negative human response to noise, outlined in section 3.1, as well as the extent to which perception is borne out of both acoustic and non-acoustic elements.

Unquestionably perception theory is a vast subject in and of itself. Neither this chapter, nor indeed this thesis, therefore claims specialist knowledge or to have provided comprehensive coverage of the topic. The content herein discusses the findings of reviews of literature found to be appropriate to perception in the relational context of understanding human response to a sound source and moreover, those functions and attributes that have the ability to render this *annoyance*.

It is suggested that, "…perception accentuates the important and diminishes, or even ignores, the irrelevant" while the object's true appearance may even become distorted by perception if it seems that it might positively enhance a safe interaction with that particular object (Schafer, 1994:67).

There are two main themes to emerge from the literature surrounding perception theory. The first suggests that the most fundamental role of inherent perception is survival and safety. Put simply, the auditory system and perception of sound has been subject to evolutionary selection processes evolved (Darwin, 1859), and seemingly the survival mechanisms that have worked over time are the very reason today's population exists. These inherent survival techniques therefore, remain embedded, whilst others have become obsolete through the same evolutionary process.

After reading Darwin's evolution theory that discusses *natural selection*, Herbert Spencer (1864) coins the phrase *survival of the fittest* and suggests it as an alternative to 'natural selection'. Darwin later introduces the term to his fifth edition of *'On the Origin of the Species'*, in which he explains the phrase to refer to a species that is "better designed for an immediate, local environment" (Chew and Laubichler, 2003). It is logical therefore that such auditory mechanisms as *auditory looming* and *threshold shift* are inherent to perceiving sounds. Moreover, it could be hypothesised that such a theory could go some way to explain the rise in aircraft noise annoyance whilst the sound levels of individual aircraft have decreased dramatically; when taking in to account both acoustic and non-acoustic factors, the increase in the *number* of aircraft could be said to reflect Darwin's 'local environment', whilst a heightened sense of *awareness* surrounding aircraft flyovers could be said to account for recent (within the last 50 years) evolution to ensure humans are 'better designed'.

The second theme to emerge from the literature surrounding perception theory is that perception is an *active* function. Crossing the two principles, Blake and Sekuler (2006:1) summarise, "…[k]nowing about our world allows us to predict the consequences of our actions, a critical skill in a constantly changing world…" and advocates that the crucial point of perception is that it "…provide(s) us with a useful view of the world, where useful means being able to interact safely and effectively within our environment", again echoing Darwin's (1959) sentiment.

Mathers (2006) describes perception as an innate human function and suggests that it is not something that can be learned; he suggests that it is in fact constructed in the brain "by a huge mass of neurons performing complex, but hidden operations" with the entire cerebral cortex devoted entirely to perception (Mathers, 2006:3). While Schafer's view (1994:7) echoes the notion that inherent perception is as common as biologically formed senses of touch, sight, smell for example, he also shares the belief of Blake and Sekuler (2006) that perception must be actively engaged – just as these biological senses must, for optimum effect. As a comparison, whilst the sense of sight naturally enables one to see, in order to gain a more detailed view, "…[y]ou look around in order to see, searching the visual environment until the desired object of regard is located.

Likewise, to make a faint sound audible, you may turn your ear in the direction of the sound." In the context of community responses to aircraft noise this suggests that where only the faintest sound from an aircraft flyover, or indeed even an over flight that is deemed 'acceptable' to most, is heard, an individual may 'turn their ear' to 'better hear' the sound. This may not be a conscious activity, or a desired one, however, if someone is in a pre-existing state of stress – as a function of aircraft noise, or otherwise – the annoyance towards the noise experienced may well be exacerbated by the individuals physiological state, rather than the direct sound level being heard.

3.2.1 Visual Impacts on Auditory Perception

Lui et al (2014) state that soundscape perception is a highly subjective process where the physical characteristics – the visual landscape – vary considerably from place to place and have strong validity for contributing to the context of auditory perception. Indeed, Bangjun et al (2003) had previously set out similar observations when exploring the effects of visibility of a sound source. They concluded that, of two similar acoustic environments, annoyance was higher if the sound source could be seen than if it could not. Maffiolo et al (1999) had previously highlighted this point; "garden soundscape evaluations integrate subjective evaluation of the landscape visual contributions: a positive evaluation of the landscape reduces annoyance of the soundscapes whereas a negative evaluation of the landscape increases annoyance" (cited by Schulte-Fortkamp 2002:13).

Joynt and Kang (2010) note similar importance of audio and visual senses working together. Whilst they suggest "many factors beyond the actual objective noise reduction" to be impacting human perception of a noise source – the most notable of which (in their particular study) was the lack of engagement in the design of construction barriers. It is explained that, because those affected are rarely given information of what they term objective values of noise attenuation levels by noise barriers, both before and after installation. It is not made clear as to whether or not any 'blanket information' was given at all, but simply by not offering comparative information of what is assumed to be an (intended) positive change, opinions could only be formed based largely on a subjective perception. As a result, it was found in this study that sound coming from behind the barriers appeared surprisingly loud (in relation to subjective expectation formed without any before/after information) suggesting overestimation of improvement relative to sound coming from open space (Joynt and Kang, 2010).

While it may be widely agreed that the environment is experienced and perceived through *all* senses, there are indeed many confounding non-acoustic factors to add to such examples as this one. It is of course inevitable that some of these may not be amenable to influence through impact noise management, and certainly some will be more readily responsive than others. There is a sense starting to form however, that if some of these non-acoustic factors could be influenced in the right manner, it may be possible to positively affect human perception of a noise source, comparative to its context. In order to understand this further, there is a need to explore such non-acoustic factors. This is now carried out in the following sections.

3.3 Non-Acoustical Elements

It has already been illustrated through the previous sections within this chapter that factors of an acoustical nature have the capacity to play pivotal roles in negative attitudes towards a sound source, most notably identified and termed as annoyance. Where acoustical factors have indeed been recognised for their contribution to negative attitude, the psychological and physiological ways in which these are perceived, and with varying degrees, have also been explored. This suggests that there is far more to the human response to sound than has traditionally been used as the benchmark from which to plot acceptable levels of sound exposure. Furthermore, it suggests that psychological factors are "at least as important as noise exposure in determining reaction, which is at least as important as noise exposure in determining several noise related [impacts]" (Hatfield et al, 2002:342).

The noise policies adopted by national governments in relation to major airports, for example, look to reduce the noise exposure levels and numbers of people exposed. Kroesen et al (2008) note however, that there is no *specific* relationship between individuals exposed and noise annoyance, and states that only 18% of the variance in noise annoyance is explained by noise exposure. Furthermore, it is proposed that the influence of non-acoustic factors on noise annoyance is an explanation for such weak correlation (Kroesen et al, 2008).

In this and subsequent sections, a more in-depth exploration of non-acoustical factors will take place. It is important to note here that, whilst every effort has been made by the researcher to present findings from the literature in a logical order so that the link and flow between the non-acoustic factors can be easily followed by the reader, as it will become clear in later sections, there is much overlapping and interrelations between many, if not all factors, and thus some may appear before they have been fully introduced and discussed.

3.3.1 Categorising Non-Acoustic Elements

Several reviews and meta-analyses on the relevance of non-acoustical factors in (traffic) noise effects on health or annoyance have been published (Fields, 1993; Jones, 2010; Miedema and Vos, 1999; Smith, 1991; van Kamp and Davies, 2008); the most recent was carried out by Asensio, et al (2017), who presented a review specifically targeting non-acoustical measures pertaining to the effects of aircraft noise. Suggesting that community response *against* aircraft noise is "closely related to" perception, attitudes, and expectations, Asensio et al (2017:232) defined non-acoustical factors as those "which are not directly connected to the nature of the sound". This provides further depth to the exposure-response process illustrated in Figure 3.1, and moreover, suggests the need for a closer look at non-acoustic factors and the varying ways in which they might impact human response to noise.

Figure 3.1 (Section 3) depicts non-acoustic factors as being categorised in to *mediators* or *moderators*, a concept that is said to originate with Saunders (1956), and brought to the forefront of research by Baron and Kenny (1986). Baron and Kenny (1986:1176) distinguish the two terms and their functions neatly: "Mediators explain how external physical events take on internal physical significance […whilst] [m]oderators specify when certain effects will hold. Mediators suggest *how* and *why* such effects occur [emphasis added by researcher]."

Mediators – mediating variables – create the 'primary reaction' (secondary reactions are thought of as symptoms of long-term noise effects) and *can be* dependent upon the moderator (Baron and Kenny, 1986, cited by Guski, 1999). A moderating variable does not depend on the independent variable – also termed the *stimulus* variable – but can change the degree of its effect on a dependent variable. The dependent variable is known as the *reaction* variable, which *can* – but does not always – co-vary with the moderating variable (Guski, 1999: 2017).

Figure 3.2 provides a clear illustration of the relationship between mediators and moderators, and the dependent and independent variables. For clarity, examples have been provided in the context of negative human response (annoyance) to aircraft noise, more specifically its source.

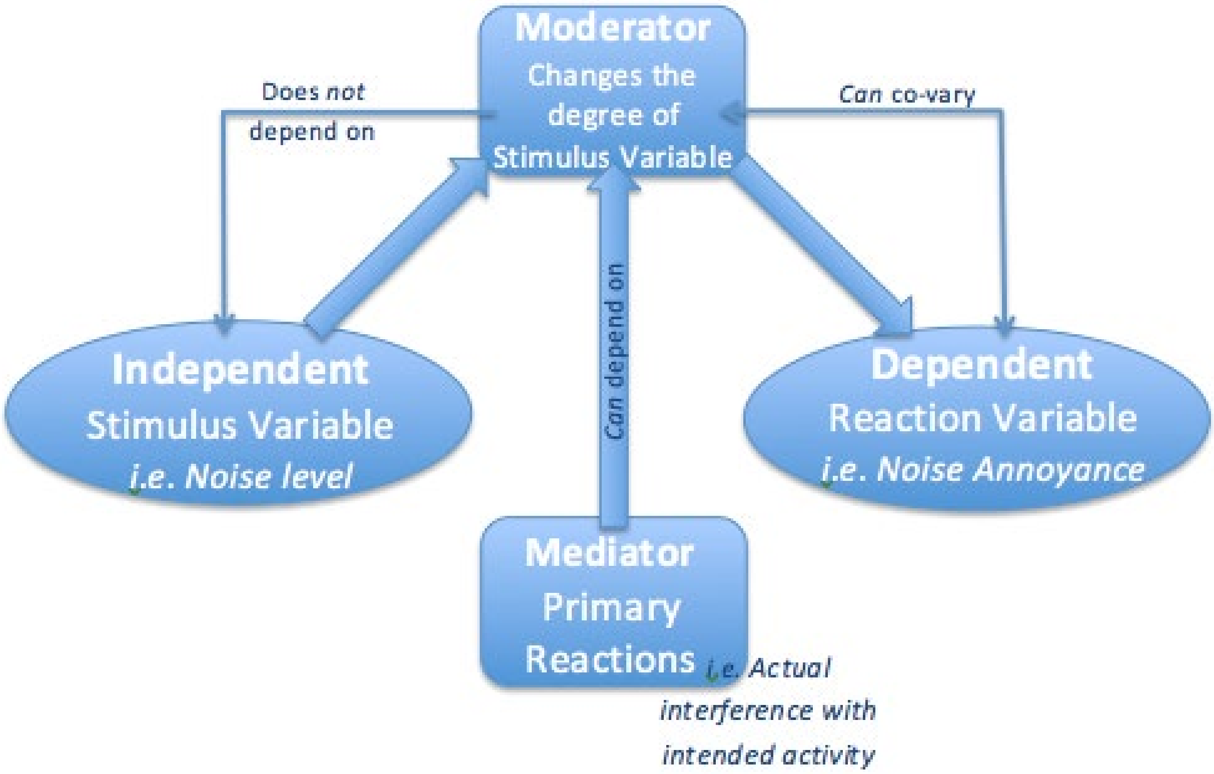
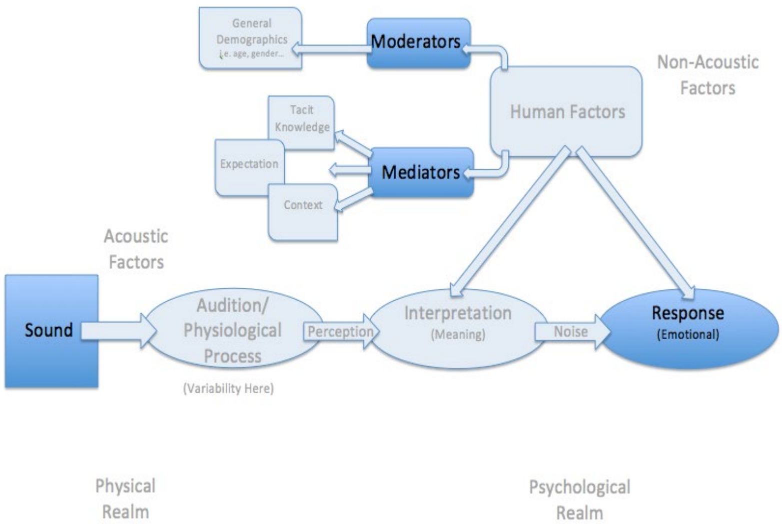


Figure 3.2 **Mediators and Moderators in Relation to Independent and Dependent Variables, Adapted from Literature**

It is interesting to note that when considering the role of mediators and moderators in the exposure response process, allied with a consideration of the fundamental concept of independent and dependent variable, a visual pattern begins to emerge when plotting out the various elements. Figure 3.3, below, shows the exposure response process and the mediators and moderators process side by side. For the purpose of ease within this comparison, the elements that give a deeper understanding of the exposure-response process have been 'faded out' and only the principle elements remain. From this, it is clear to see that the mapping of core elements in both diagrams are in the same place; the mediator/moderator diagram (right) has lowered and centralised the two elements for ease of flow, but they fundamentally remain in place.



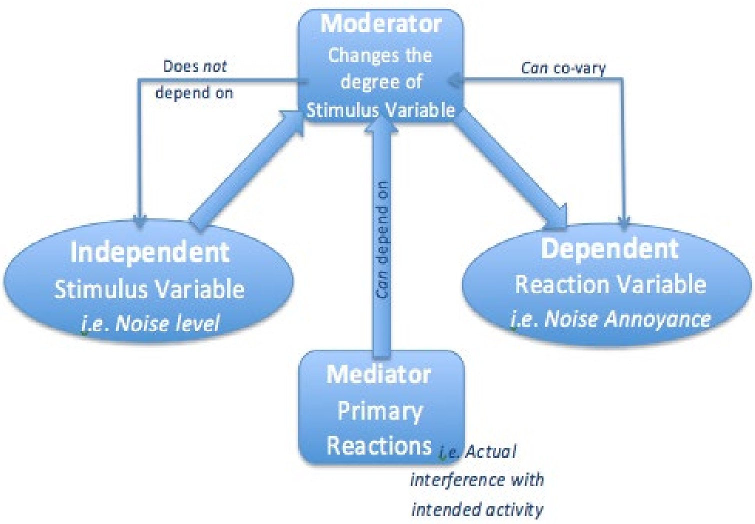


Figure 3.3 **Exposure-Response Process diagram, reflecting the Mediator-Moderator Flow diagram**

With this in mind, a real sense of the holistic nature of human response to a sound source begins to emerge, further informing possible novel approaches to impact noise management.

In 2007, Vader collated 31 non-acoustical factors suggested to affect noise annoyance. In collating such a list, Vader (2007) has taken the idea of identifying non-acoustic factors one step further and categorises them in accordance with the extent to which each factor is amenable to change (modifiability), and therefore more positively influencing human response to noise (see Table 3.2).

The factors have been arranged along two continuums:

- The strength or importance as a factor, i.e. the magnitude of their influence on annoyance (using the categories strong, intermediate, and weak)
- The extent of their modifiability by aviation authorities, which reflects their usability as an instrument (modifiable, not modifiable, and unsure/need to be examined)

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**	Avoidance 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	

Table 3.2 Non-Acoustic Factors Affecting Human Response to Noise, Adapted from Vader (2007, cited in Asensio et al, 2017:5)

It is important to note the varying colour and font that the researcher has added to factors within the table above.

- Green, italic text denotes non-acoustic factors that are addressed and discussed in detail as part of Chapter 4. Whilst it is widely agreed throughout the literature that these particular factors are indeed amenable to influence – or modifiability – it would make for a confusing and over-laden point when they appear again in the following chapter.

- *Attitude towards the source*, highlighted in **red, bold font**, denotes a misalignment with Vadar (2007) suggesting this as a non-acoustic factor at any point within the table. It has been widely stated and discussed that *attitudes towards the source* are a function *of* non-acoustic factors rather than actually being one. It could of course be argued that this does indeed dictate that 'attitudes towards the source' is a non-acoustic factor in and of itself, however, this does have strong potential to become extremely confusing with very little need.

- Bold, blue text denotes non-acoustic factors that are widely discussed across the literature, and therefore addressed throughout the following sections of this chapter.

Past experience with the sound source can be considered to be *tacit knowledge*, a factor that has it's own section below. Reasons for its modifiability are highlighted in Section 3.3.1.4.2.

Fear related to a sound source has also been discussed throughout the literature, and is considered amenable to mitigation through more clear and transparent information dissemination. This is touched upon on Section 3.3.1.3, however is discussed in-depth in Chapter 4.

Media coverage and heightened awareness to noise is discussed below in Section 3.3.1.2 – a section discussing *personal and social factors*. As a 'factor' – singular – this is a somewhat ambiguous section, as many factors fall in to its remit. Furthermore, across the various personal and social factors identified, there are both mediators and moderators. *Media coverage* is indeed discussed as a mediator, in line with Vader's (2007) categorisation.

The nature of categorising the non-acoustic factors as to whether or not they are amenable to influence is indicative of the mediators and moderators notion outlined above. At first glance it appears that, in general, those that Vader (2007) has deemed modifiable can be classed as a mediator, and those that are deemed as *not* modifiable classed as moderators. With the inability of moderators to be influenced/modified borne in mind, it may seem reasonable that elements depicted as such throughout the literature and again in Vader's (2007) research, do not warrant discussion as there is little need to understand any underpinnings (or indeed any underpinnings to understand) that may benefit either communities or authorities. The three non-acoustic factors highlighted in **bold, blue text** (outlined above), that Vader (2007) deems un-modifiable, are however mentioned throughout a number of other studies as significantly impactful non-acoustic factors, and therefore discussed in the following sections.

Finally, there is a need to note *individual sensitivity to a sound source*. While it is agreed that human sensitivity is indeed *not* amenable to influence, it is considered a core, moderating factor in human response to noise. Moreover, as with human variability (to which it is strongly linked), there is a fundamental need to understand the individual noise sensitivity in order to understand that engagement strategies are not effective under a 'one-size-fits-all' approach. This is further discussed in Chapter 5. For the purpose of this chapter however, Section 3.3.1.5 details *noise sensitivity*.

3.3.1.1 Context

While the notion of 'context' is not identified in Vader's (2007) table of modifiable factors, it is identified widely across the literature as an important factor in human perception – not *just* of a sound source, but in general. Given it's large presence throughout the theory of perception, *context* features relatively frequently throughout subsequent sections. This section therefore will focus on defining its use in the realms of understanding human response to sound and the non-acoustics factors that might contribute to it, in order that context as a term can then be used going forward without the need to continuously draw back to it's importance.

Bruce and Davies (2014:2) offer the generic definition of context as the ''circumstances that form the setting for an event, statement, or idea […] in terms of which it can be fully understood and assessed''. Whereas Dubois et al (2006) suggest that the type of noise, type of source and the meaning attributed to it, make up the core tenets of a context.

From a soundscape perspective, context is considered a concept that is crucial in a cognitive approach (Botteldooren et al, 2008); the context in which a sound event occurs holds a fundamental influence on human reaction to environmental sound. An individual's expectation of such context for example, acts as a key factor in perception of a situation (Botteldooren et al, 2008). If the sound does not particularly seem appropriate for the time, place or situation, innate perception alerts fear senses in order to physically and mentally alert the body (Schomer et al, 2013).

3.3.1.2 Personal and Social Factors

Personal factors are considered to be the individual development of a person, whilst social factors considered the result of social developments (Baron and Kenny, 1968; Guski, 1999). Stallen (1999) further adds that there cannot be a clear distinction between the two factors because an individual usually develops *within* a particular society.

When studying historical social factors, changes in noise legislation provide a certain understanding of changing social attitudes and perceptions (Schafer, 1993). It is interesting to note for example, the contrast with those of the modern era; Schafer (1993) notes how early noise abatement legislation was selective and qualitative compared to fixed quantitative limits in decibels and varying metrics of today (see Chapter 2 for aircraft noise legislation). The more stringent approach of today is in place for all sounds, whereas previously noise legislation tended to be directed toward "rougher voices of the lower classes", and certainly never toward much louder sounds of the church bell or machinery of the industrial era (Scafer, 1993:67). To this end, when aircraft took over "birds, wind and church bells" as the "keynotes of the sky…[w]e admired the technical representation of human power so much" that they were greeted as a sign of progress and "…we held our breath" in awe (Broer, 2002:1).

Personal factors tend to refer to general demographics, for example, age, sex, religion. These are suggested as moderators due to their lack of modifiability; there is no influence from either internal or external sources than can modify the effect of these factors – positively or negatively – on an individual's attitude towards a sound (Guski, 1999; Vader, 2007; Asensio et al, 2017).

Social factors in the form of *word of mouth* and *influence* are more aligned with mediating variables in the sense that "…members of the cultural elite" spread the subject of annoyance (Broer, 2002:2-3) – potentially modifying/influencing individuals' attitudes. During the early nineteenth century, 'awareness raising' was carried out by, writers, poets and scientists (the 'cultural elite'). The negative attitude in the first instance is borne out of public complaints and the setting up of political organisations, and scientific associations are all attributed to such (Broer, 2002). In today's society, media and news reports, and key figureheads are being used to advocate particular positions or opinions on a topic (Guski, 1999).

With annoyance considered a psychological phenomenon, as indeed is noise (Stallen, 1999), the subjective nature associated with annoyance tends not to be so naturally considered with noise. *Noise* however is not, nor can it be classed as *sound* in its own right, and actually only occurs upon negative (individual, subjective) appraisal of sound. Stallen (1999:69) therefore, highlights the need for a fundamental understanding of judgmental and attitudinal processes in order to fully understand noise-induced annoyance. This ultimately requires an understanding of social processes.

Finally, there is a need to highlight the last personal and social factor identified by Vader (2007); *Receipt of benefits from the source* appears in Vader's (2007) table of modifiability as 'unsure/needing further research'. Other authors (Fields, 1993; Guski, 1999; Stallen, 1999) have discussed the same non-acoustic factor in a way that aligns it with mediating variables. Indeed, 'receipt of benefits from the source' differs from other mediating variable in the sense that it's ability to impact human response to a sound source is not simply to *mitigate* annoyance, but actually has the potential to *positively* modify the human response by offering a direct personal benefit, and increasing quality of life (Stallen, 1999).

3.3.1.3 Trust and Misfeasance

Trust issues arise as a function of belief that authorities linked to the noise source are acting towards the best outcome for the business – in the context of aircraft noise this refers to airport management seeming to concentrate only on the most lucrative and 'easiest' option for the airport and airlines. Misfeasance in this context, relates to, for example, the airport operating within the limits of night-time curfews, but not taking in to account that operating aircraft on a certain path or right up to the curfew boundaries impacts the local residents. Moreover, little information is offered for the reasons for this, and therefore the lack of control is felt and annoyance builds.

Allied to misfeasance-related annoyance around operations, is the expectation of increased disturbance when future plans are introduced; be it an expansion, airspace change, infrastructure improvement. Regardless of whether or not the future plans are intended as a positive for local residents in the long term, the motivation for complaints is the lack of influence over the process, along with lack of understanding of how they will be impacted (Guski, 1999: Kroesen, 2010); in short, a lack of *perceived control*. Alongside these concerns, it has been noted that residents often feel a lack of consideration, perceiving authorities not to "do their best to reduce noise and improve the situation for residents" (Flindell and Stallen, 1999:12). This, in turn, can be perceived as *unfair*, for example, that the future noise situation may worsen and/or preparation for future plans, might see authorities tailor assessment mechanisms to benefit aviation despite residents' interests and well-being (Kroesen, 2010).

Guski (1999) notes that there is a possibility of mitigating community feelings of misfeasance through actions being taken by the noise authorities. These include:

- Provision of clear data about the acoustic situation and it's development
- An acceptance of the existence of harmful effects of noise
- Transparency of clear data about noise abatement programmes
- A willingness to communicate and cooperate with the residents

By employing independent third party noise management authorities, for example, trust can begin to be built where usually scepticism of misfeasance would typically dominate (Guski, 1999; Kroesen, 2010). These actions by noise authorities suggested by Guski (1999) do indeed fall under the non-acoustic factor of a *lack of trust and feelings of misfeasance* by local communities. They are however, a function of a more comprehensible engagement strategy, and therefore discussed in much greater detail as part of Chapter 4.

3.3.1.4 Expectation Management

The role of *expectation* as a mediating variable has been briefly touched upon throughout this chapter so far. In the context of this thesis, expectation is heavily linked with the notion of soundscapes, and as this section unfolds, the two terms will more often than not appear side by side.

In order to understand the effect that *subjective* expectation has on human perception of an environment, it is important to understand what is actually meant by the term *expectation* (Bruce et al, 2009). The initial step in doing so is to obtain a fundamental knowledge of another mediating non-acoustic factor, *tacit knowledge*. Once this particular term has been explored, this section will return to fully focusing on the notion of expectation as a mediator.

3.3.1.4.1 Tacit Knowledge

Logic dictates that in order to be able to form an expectation of something, there must first be a benchmark or prior experience by which to set the expectation against. With this in mind, Truax (2001:27) introduces the notion of *competence* through *tacit knowledge*. Competence is suggested as "tacit knowledge that people have about the structure of environmental sound"; a subjective knowledge relating to an individual's experience, comprising factors such as:

- Personal beliefs	- Values	- Ideals
- Perspective	- Emotions	- Mental Models

Such factors tend to sit as inherent personality traits and are not necessarily easily identifiable; nevertheless, they are fundamental factors in individual perception of experiences (Bruce and Davies, 2014).

The concept of competence here is considered in terms of having enough knowledge of a past relationship between sound and it's meaning (through learned behaviour from prior experience, or *tacit knowledge*) to make a conscious decision of 'how it should be' (Truax, 2001).

In the absence of tacit knowledge, Huron (2007) notes that the 'un-experienced' individual tries to relate a new occurrence to something similar that they have previously experienced, suggesting that their human perception seemingly always needs a benchmark against which to assess, regardless of whether it is directly relational or not. Interestingly, however, negative 'appraisal perception' does not necessarily mean that a soundscape is not as expected, leading to the summation that tacit knowledge of a soundscape determines the particular types of environments an individual will visit in future (Truax, 2001).

Guski and Flescher-Suhr (1999) discussed a similar concept, using the term 'conceptual knowledge'. Within their research they suggest that as well as using tacit knowledge of the surrounding a sound is being heard in (soundscape) to influence a person's perception of that sound, such knowledge is also used to make judgements of what they believe their annoyance levels *should* be, based on prior knowledge of such an experience. For example, if a person has experienced a particular hotel as extremely noisy due to aircraft over flights and has to stay in the same hotel again and is asked to judge their actual annoyance during the return stay, even if there are no/much fewer over flights and therefore much less sound, the judgement will be based on prior knowledge. This would suggest that, it is entirely feasible for residents of communities local to airports to maintain the same opinion of their everyday soundscape even after an operational change has been implemented (meaning fewer over-flights). Indeed, this state of conceptual or tacit knowledge influencing opinion of the sound environment could take many weeks or even months to perceive their new environment, thus acknowledge the benefits of the change.

Throughout the course of this thesis it will become apparent that the notion of *competence* in its traditional form is used quite notably, particularly in the chapters to follow. As the terms 'competence' and 'tacit knowledge' are used quite interchangeably in the context of soundscape understanding, *tacit knowledge* will be used in representation of both interlinking terms for the sake of avoiding any confusion to the reader going forward.

3.3.1.4.2 The Impacts of Expectation on Perception

Expectation can be defined as a ''…strong belief that something will happen or be the case in the future, or the series of events which are anticipated prior to an experience'' (Bruce and Davies, 2014). As seen throughout earlier sections of this chapter, human attitude to a sound source depends greatly on unique perception of a space and its soundscape. It is through tacit knowledge and context of the situation that expectation is formed and the 'framework of cognition and emotion' begins (Botteldooren and De Coensel, 2006). As an example, specific to aircraft noise annoyance, a consideration is needed of what has been discussed of both *threshold shift* (see section 3.1), and *tacit knowledge* (section 3.3.1.4.1). In the situation of someone moving from a quiet rural area to one that sits under a flight path, they are more likely to notice the aircraft than those that in contrast may have previously lived under a flight path, or indeed moved from a more urban, lowi-fi environment.

Indeed, as the workings of the auditory system, and the principles of threshold shift dictate, a move from a louder to a quieter environment will garner less discernibility than to the contrary. It may well be argued that it could just be the case that there is less to report in the first of the situations. This might well be the case when it comes to annoyance response, however in the capacity of basic human auditory function, a lower discernibility from louder to quieter is widely corroborated (WHO, 2009). Regardless of scientific underpinnings, the core factor to note here is that whether a move from a quieter to louder soundscape or vice versa, an individual's expectation of their new soundscape compared to its reality, based on tacit knowledge, ultimately forms the perception and therefore attitudinal output of the exposure-response process.

Expectation can also be shaped by temporal constraints (Guski, 2004); an individual may not be impacted by a particular sound source in the daytime for example, however expectation of a more peaceful soundscape at night-time might cause a negative change in attitude. Moreover, a look back to the mediator *context* is worthy here. Contextualising the *use* of a space and its soundscape expectation is a very impactful factor of annoyance (Schafer, 1999; Truax, 2000; Dubois et al, 2004). Moreover, the mediator of *controllability* (discussed further in section 3.3.2) allies with expectation here.

Annoyance seems to stem from situations where an individual cannot *control* the actions of fellow users, or noise of a space (Bruce and Davies, 2014). It must be noted however, that mechanical and construction sources of noise appear to hold greater degrees of acceptance due to the expectation that these sounds, despite being unpleasant, will only last for a certain period of time (Bruce and Davies, 2014). This finding raises the question of why an aircraft flyover does not muster a similar acceptance. The only potential hypothesis at this point echoes the increase of annoyance over time despite the decrease in sound output of individual events; it is the volume of flyovers and the lack of knowledge enabling expectation of when it will decrease, or break, or indeed, when to prepare for it starting again. The notion of *respite* and *relief* from aircraft noise is discussed in detail as part of Chapter 7.

The expectation of future plans and its impact on attitude is discussed in section 3.3.1.3 as part of trusting a sound source and worries of misfeasance. The specific reason for negative attitude from expectation of future plans is the *step-change* that occurs as a function of the plans, particularly when there is a lack of information provided, and certainly a lack of tacit knowledge of an expanded capacity. Brink et al (2008: 933, emphasis added) advocate that the “magnitude of a step change can be conceptualised as *exposure difference* to be used in an exposure-effect relationship model in the sense of ‘current exposure’ minus ‘previous exposure’ or ‘new exposure’ minus ‘old exposure’ …”

Here, it is worth considering an airport expansion – the individual will look to their tacit knowledge of the existing situation, and if negative attitudes already occur, there are often few means of looking past the current situation and expecting that the expansion, for example, will improve current situations. Guski (2004) noted that annoyance levels increase *before* the change has been implemented, simply by *expecting* an increase in exposure level causes higher levels of annoyance than would be predicted from a steady state. This is generally termed ‘over reaction’ or ‘over shoot’ (Horonjeff and Robert, 1997; Fidell et al. 2002; Guski, 2004). The amount of *over shoot*, it is suggested, depends on the abruptness of the change (Horonjeff and Robert, 1997). Conversely however, Hatfield et al (2002) suggest that individuals who are able to see past current situations and therefore expect a decrease in sound levels react with less annoyance than would be predicted in a steady state condition. Implications of this for changes in community attitudes where an airport simply grows year on year and a situation where the airport opens a new runway (or perhaps even a new terminal) such that there is a step change in the local situation, even if not in the noise received by an individual.

3.3.1.5 Noise Sensitivity

Allied to the variation in human reaction to noise is the effect of noise sensitivity. Indeed, factors thought to influence subjective reactions to transport noise (Job, 1999, cited in Dubois et al, 2006) such as noise sensitivity and attitudes towards the source of sound have been found to “account for more variations in reaction than does noise exposure given by physical parameters" (acoustical stimuli). Such factors suggested as contributory components of noise sensitivity are (Job, 1999):

- Level of physiological reactivity to stimulation generally
- Hearing acuity
- Attitudes to noise in general (but not to a specific noise source)
- Beliefs about harmful effects of noise in general
- Vulnerability caused by stressors other than noise
- Level of social support and other available coping mechanisms

Noise sensitivity has been identified as an invariable personality trait and, as such, a stable factor (regarding both time and place) when linking self-reported levels of sensitivity to other emotional traits (Miedema and Vos, 2003; Oiamo et al, 2015). That said however, noise sensitivity, like other factors within human variability, is a non-unitary concept (Job, 1999) and tends to have no particular correlation to noise exposure, per se (Ellemeier et al, 2001), whereas noise annoyance does; "[n]oise sensitivity refers to the internal states (…) of any individual, which increases their degree of reactivity to noise in general" (Job, 1999: 59).

Miedema and Vos (2003) consider sensitivity to relate to general dissatisfaction with the surrounding environment, and therefore an individual's perception of any local environmental problems. This consideration gives rise to the idea of noise sensitivity as a "compositional indicator of multiple factors that moderate that relationship between ambient stressors and annoyance, and as such are dependent on community and individual contexts" (Oiamo et al, 2015:72). While this may be the case, it is also highlighted that noise sensitivity and perceived loudness are not interchangeable; "…(r)eactions to noise are stronger among noise sensitive individuals while levels of sensitivity are not associated with perceived loudness or noise exposure" (Miedema and Vos, 2003:1500).

Job (1999) highlights the usefulness of distinguishing between noise sensitivity and the *overall reaction* to noise, or more specifically, other factors determining negative attitudes toward a particular noise source. While this would indeed be useful in determining the underlying cause for negative response to sound, noise sensitivity, whilst being acknowledged as a definite factor of noise annoyance, is a complicated phenomenon within this research field (Oiamo et al, 2015). To elaborate, there is discussion as to how human sensitivity should and could effectively be quantified, and the extent to which any particular sensitivity should be or indeed *is* exclusive to noise, rather than holistically to include visual, taste, touch for example. It is therefore of course widely agreed among scholars that noise sensitivity needs further empirical research (Guski, 1999; Gidlof-Gunnarsson and Ohrstrom, 2007). If such pontifications were to become robust findings of future research, the implications for aircraft noise could see a shift of focus from standard measurements of aircraft noise applying to all, towards a somehow more weighted means of incorporating noise sensitivities; further still, it could be suggested that such outcomes might result in a new generation of aircraft noise metrics.

3.3.2 Transactional Model of Stress and Coping

Following the flow of the exposure-response process illustrated in Figure 3.1, this chapter has discussed acoustical elements, perception theory, and non-acoustic elements, including the categorisation of mediators and moderators; those that are/not amenable to modification. In order to explore human response to sound holistically, there is now a need to explore *interpretation* of the information received – both acoustic and non-acoustic elements – in the context of the exposure-response process.

The transactional model developed by Lazarus and Folkman (1987) is discussed in this section as a means of understanding the psychological process of interpretation that happens as part of the wider exposure-response process. The transactional model echoes the evolutional notion of *survival of the fittest* (section 3.2) with seemingly a theme of ‘survival’, throughout. Although *survival* is not necessarily referred to in its crudest form, there is indeed extensive mention of what could be termed *softer* survival mechanisms, *coping*. Moreover, the term *stress* is explained here as the result of an interaction between environmental and human factors. Lazarus and Folkman (1984:19) describe stressors as, "demands made by the internal or external environment that upset balance, thus affecting physical and psychological well-being and action to restore balance". This could be suggested as a key example of how the study of noise annoyance has evolved from this transactional model; suggesting the initial stimuli to be a *stressor* in the first instance, before any form of interpretation has taken place, assumes the perception of sound to automatically be a *negative* one.

Special importance is attached in this transaction model (see Figure 3.4), to the subjective evaluation of both the stressor and a person's individual resources. When a person is exposed to a stressor, initially - consciously or unconsciously - an interpretation of the stressor takes place (*primary appraisal*). The model suggests that if this is judged as positive or irrelevant, no stress will occur. However, if the stressor is classified as dangerous, it is potentially stress inducing. It can then be:

- A challenge, if the situation seems manageable
- A threat, if there is potential future harm or
- Harm/loss, when harm has already occurred

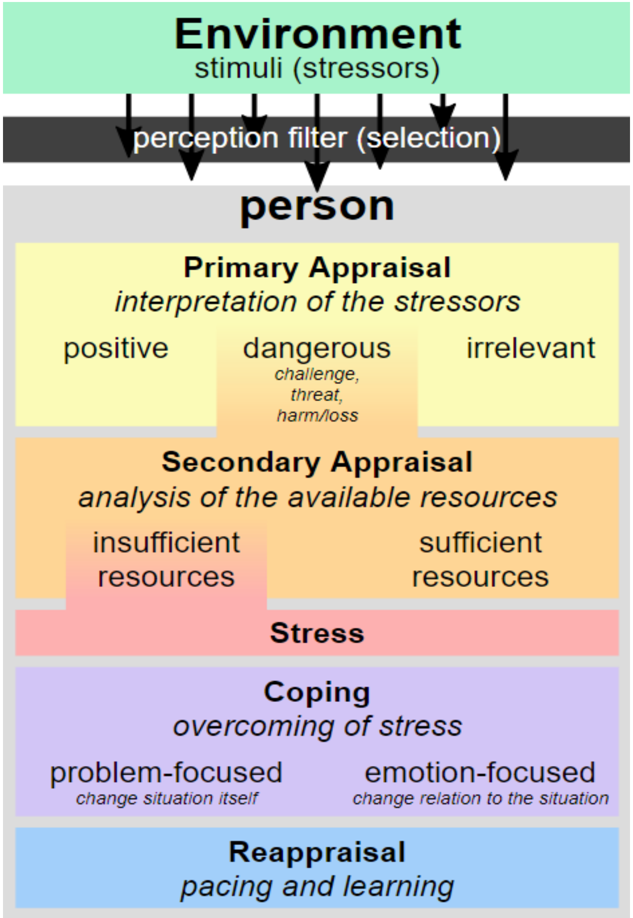


Figure 3.4 Adapted from the Transactional Model of Stress and Coping According to Lazarus and Folkman (1984, cited by Guttmann, 2016)

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

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

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

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

According to this model therefore, cognitive assessment processes and, in particular, the assessment of available resources, serve as the deciding factors of subconscious development of stress; be it mentally, physically, or both. Stress, then, is the result of a complex interaction process between a person and the environment, with a perceived imbalance between the perceived threatening or dangerous requirement of the environment and the perceived resources.

3.3.3 Adapted Model of Noise Annoyance

In a bid to further understand Lazarus' transactional model of stress and coping, Stallen (1999) depicts a corresponding specific noise annoyance model. Many of the models proposed later are essentially extensions or slight modifications from Stallen's model (see Appendix 1.0 for original model). As an example, Figure 3.5 shows the central part of Stallen's model adapted by Schreckenberg (2010). This is the most recent model adaptation.

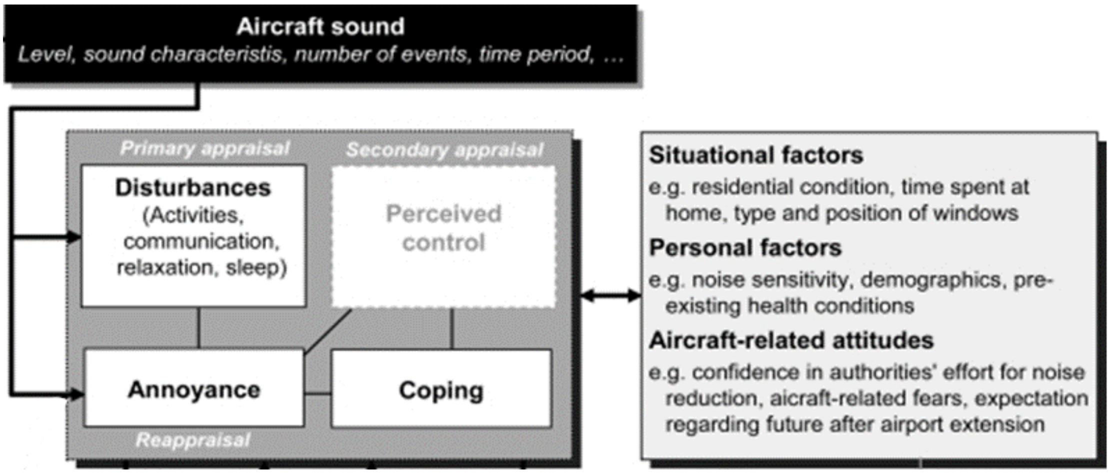


Figure 3.5 Model of noise annoyance according to Schreckenberg, 2010

In this model, similar to the structure seen in the mediator/moderator process (Figure 3.2, Section 3.3.1), the environmental *stressor* a person has to deal with is, of course, sound. The stress *response* is ultimately annoyance. It results, as with the previous model (Figure 3.4, Section 3.3.2), from an interaction between the appraisal of the threat or stressor – *primary appraisal* – and the appraisal of the resources to face or cope with the 'threat' – *secondary appraisal*. Schrekenberg (2010, adapted from Stallen, 1999) points out that in the context of noise annoyance, primary appraisal can be understood as *perceived disturbance* and secondary appraisal as the extent of the *perceived control* of the sound or noise situation.

Perceived control plays a central role in the emergence of noise annoyance, with varying components identified as potentially existing within it:

- Mental (cognitive and affective) components, i.e. the *predictability* of future sound exposure
- Behavioural components, i.e. the ability to *alter* exposure

The meaning and significance of perceived control appears to apply equally to all models of noise annoyance throughout the literature, moreover has been underpinned by some empirical findings. Stallen (1999:77) emphasises, for example, that the various components of perceived control can never be completely subjective, "…[t]o a large extent *perceived control* is rooted in how noise is managed in practice by the source". Here, Stallen (1999) is identifying the *management* of sound levels as an important determinant of noise annoyance.

Bruce and Davies (2014) suggest that the concept of controllability, whereby, even if the *source* is not necessarily controllable, if an individual is able to move away from within the vicinity of the noise source, annoyance can be diminished, “[a] visual annoyance can be removed by looking away, but an auditory annoyance cannot, without having to leave the space or move further away” (Bruce and Davies, 2014:15). Where there is little opportunity to easily leave, e.g. train carriage, bus, home/garden, annoyance is likely to be exacerbated, particularly when allied with feeling a lack of control or influence over the sound source – be it person or machine. There is also a need to consider here that the point made by Bruce and Davies (2014) may be moot when considering the fact that leaving a space to avoid a noise could be seen as disruptive to plans or comfort, and thereby inflammatory to the annoyance anyway.

Coping is seen as a process or reappraisal of the person-environment situation, that is, “a matter of mental (cognitive and/or emotional) change including the formation of new behavioural intentions and […] the undertaking of correspondent actions” (Stallen, 1999:76). At this point, "non-noise related characteristics of the person or environment" become particularly relevant. Coping has a dual meaning and function in the noise annoyance models based on Lazarus and Folkman (1984, cited by Guttmann, 2016). On the one hand, it is to be understood as a *strategy* to deal with experienced stress. In this sense, coping can - analogous to Lazarus' original model - be both problem-focused, for example, acquiring sound insulation measures to minimise the impact of the stressor on the person; and emotion-focused, for example, mindfulness exercises to reduce perceived stress. On the other hand, the *state* of the overall success in overcoming stress is called *coping*, too.

3.4 Attitudinal Elements of Exposure-Response

Whilst the human ear tends to react, shift and filter to its surrounding soundscape naturally, and therefore is not consciously controlled by human intention, in the context of every day soundscape, regular levels of sound being processed and perceived appropriate to each individual will not often provoke reaction – either consciously or otherwise. When it comes to interpretation, it is often not a consciously *thought through* process; it is an innate cognition that may be influenced by multiple psychological factors (Lazarus, 1991). Guski and Flescher-Suhr (1999) discuss the idea that all human cognitions share the property of *evaluation*, suggesting that each evaluation is placed in a definitive position on a scale that ranges 'good' to 'bad'. The notion of human cognition evaluating a particular topic is suggested to be human *attitude*, and can emerge anywhere on the good to bad continuum regardless of personal knowledge of the topic.

Guski and Flescher-Suhr (1999) maintain that any cognitive output, regardless of where it sits on the good to bad scale, is simply known as an attitude towards the particular sound subject or occurrence. Job (1999:57) however, breaks the attitudinal response down further and defines *negative* attitudes as, "subjectively identifiable negative emotional reactions to noise" such as *annoyance* and *dissatisfaction*. Job (1999) also suggests that the extent to which negative reaction occurs is important to understand because profound negative reactions may constitute a health effect in their own right, highlighting the fact that (negative) reaction is a psychological stressor with psychological stress known to harm physical health (Sarafino, 1994; Berglund and Lindvall, 1995). Whilst the subject of noise impacts on health is outside of the remit of this thesis, it is still worth noting here the move away from the direct impact of the noise source on health, with the focus moving toward *reactions to* the noise source causing the impact (Maffei et al, 2008). As a brief example, Job (1999) continues to note the Sydney Airport Health Study and the outcome that identified anticipation of increasing aircraft noise exposure actually produced greater negative attitudinal and physiological responses *prior* to any change being implemented (Job et al, 1996a; Hatfield et al, 1998 both cited in Job, 1999).

3.4.1 Defining Annoyance

The concept of annoyance is said to denote "a feeling of displeasure associated with any agent or condition, known or believed by an individual or group to adversely affect them" (Lindvall and Radford 1973; Koelega 1987). The World Health Organization (2018) defines noise as *unwanted sound*, which seemingly implies that negative reactions will occur (Job, 1996). Barbot et al (2008) suggest that such sensations can cause social and behavioural troubles, which they term 'annoyance'. The meta-term therefore, noise annoyance, is described as a *psychological concept* of the relationship between a sound event and the inconvenience it causes to someone who then cognitively and emotionally evaluates the situation (Guski, 1999). Guski (1999) advocates noise annoyance to be a negative evaluation of environmental conditions (acoustical), but adds that its connotations are much broader than this (personal and social), and notes a list of emotional outputs that could occur as a function of noise annoyance (found in table 3.3 below).

Noise Annoyance as a Multifaceted Psychological Concept Emotional Outcomes of Noise Annoyance		
Initial Short-Term Responses *(Immediate behavioural aspects)*	Disturbance/Interference	Aggravation
	Dissatisfaction	Concern
	Bother	Displeasure
	Harassment	Irritation
	Nuisance	Exasperation
	Discomfort	Uneasiness
	Distress	Hate
Longer-Term Responses *(Evaluative aspects)*	Dissatisfaction	With respect to the acoustic environment
	Disturbance	
	Bother	

Table 3.3 Noise Annoyance as a Multifaceted Psychological Concept, Adapted from Guski, 1999; 2017

3.4.2 Annoyance as an Attitudinal Response

As shown in the previous section, noise annoyance is commonly understood as a complex, multifaceted response to noise (Guski et al, 2017) comprising, behavioural elements, attitudinal-affective-emotional elements, and cognitive elements.

Observing annoyance levels in relation to noise levels from varying modes of transport, Babisch et al (2013) highlighted that interaction between aircraft noise levels and annoyance gave significant results, whereas interaction between traffic noise and annoyance provided none. When taking in to account the accumulation of various types of transport – and frequency of those that make up the road traffic noise – it can be suggested that 'traffic noise' accounts for a much larger proportion of a given soundscape than aircraft noise (with exceptions). With this in mind, this study appears to reiterate the notion of both threshold and attitudinal shift. Moreover, Babisch et al (2013) conclude that because the effect of objective noise responses is stronger than the subjective noise response, "annoyance may function as an effect modifier" (Babisch et al, 2013; Basner et al, 2015:62). The authors here are suggesting that the "involuntary arousals of the sympathetic nervous system" created by all factors feeding in to a 'natural' state of annoyance (objective), accounted for a stronger response than that of human opinion, depicting annoyance as a credible influencer of attitude.

When looking back to Guski's (1999) suggestion that acoustical impacts only account for around 30% of negative human attitude to noise (Section 3.1.3), it seems logical to hypothesise that they evoke such an impactful negative response to noise, that the individual's perception is then amenable to other non-acoustic factors exacerbating the interpretation during the exposure-response process. It might be argued therefore that if the individual had not been so innately sensitive to the acoustical stimuli causing a negative reaction in the first place, their perception would not be amenable to influence from other surrounding factors. This hypothesis certainly draws upon the notion of human variability, and indeed suggests that noise sensitivity may need considering as an additional non-acoustical factor within human response to a sound source.

3.5 Summary

In the context of aircraft noise, it could be said that only individuals who take note of aircraft and the sound output of its over-flight are consciously creating their annoyance through a cognitive process of interpretation. Those who do not *actively* 'notice' and therefore perceive it's sound in the first place, have no facility by which to enable annoyance; "…your behaviour depends on what is perceived, and what is perceived depends on your behaviour" (Schafer, 1994:7). Of course, perception and reaction are not as straightforward as this, and as previously mentioned there are many more non-acoustic factors impacting and affecting human response to sound; if these factors, and indeed this process, are going to be used as part of a management strategy, which of them are open and amenable to influence/modification? This has of course been discussed in detail through Section 3.3 and its sub-sections.

The key point here is that attitude towards the source (a function of perception and interpretation of sound from a sound source) can be hugely influential in determining human response to a given sound stimuli (Schrekenberg et al, 2010). In the case of aviation noise, the generally negative attitude towards airports appears likely to exacerbate any negative response to a given aircraft noise event. Consequently, a valuable line of noise mitigation intervention would appear to be an attempt to positively impact upon attitudes towards airports. So how might this be done? Having gained an appreciation of *both* acoustic and non-acoustic factors amenable to modification, what could a possible intervention look like?

A prerequisite to exerting influence in any context appears throughout this chapter, to be engagement with those expressing the negative attitude. Indeed, with this now more comprehensive appreciation of how attitudinal responses are created, carving an effective engagement process may facilitate the ability to 'counter influence' attitudes towards the source of aircraft noise. The following Chapter 4 offers some insight into how this might be achieved.

Chapter 4 Effective Noise Management – a role for communication and engagement

4.1 Introduction

The noise arising from the operation of aircraft into and out of airports can give rise to significant disturbance and annoyance to residents of communities surrounding airports and living under flight paths. It is logical therefore that the residents of those communities need to be consulted to assess the true nature and extent of that disturbance/annoyance and be actively involved in efforts to reduce it.

The review of the air transport industry and aircraft noise challenge to date, and its consideration of, and interaction with the public, found through Chapters 2 and 3, highlight that in order to facilitate growth airports must seek to build robust and continuing relations with their key stakeholders. Indeed, Chapter 2 suggested that whilst industry efforts have gone a long way in reducing noise at source, there is a need to consider the very people that are affected. Allied with the power of human perception of, and therefore response to noise, explored in Chapter 3, further importance is being placed on not just building those relationships, but understanding the best tools and means of facilitating dialogue necessary in the underpinning of these processes intended to do so.

This chapter investigates the concepts and theories of stakeholder engagement, and public participation, and seeks to understand the importance of facilitating these processes effectively, and indeed, on a level that is meaningful to all participants. The motivation and rationale for involving the public in decision-making is discussed, and set in the context of sustainable development.

Many aviation regulatory bodies are now increasingly emphasising the role of communication and public engagement as a key element in the management of noise impact; as mentioned, Chapter 2 discusses this in much detail. The continued and developing commitments and priorities of authorities in improving communication strategies raise a series of important questions (Webler and Tuler, 2000:567):

- What form should these communication and engagement processes take?
- Who should be involved and in what manner?
- How can technical expertise and local knowledge best be integrated in to the process?
- Can discursive communication be fostered that is respectful, effective and rewarding?

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

4.2 Public Participation – Theory and Practice

German philosopher Jurgen Habermas championed the concept of public participation as an area of serious theoretical consideration in 1962 with his book *The Structural Transformation of the Public Sphere* in which the sphere is suggested as:

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

More generally Webler (1995:42) describes the 'public sphere' to be 'the area of public life where inter-subjective agreement on values can be reached in order to solve socio-political or practical questions'. Indeed this appeared to be one of the first steps towards a more democratic society. Similar principles appeared to fuel the will of capitalist entrepreneurs to achieve independence from the state during the mid 18th century, and the beliefs that individuals have the right to be informed and consulted, and to express their view on matters affecting them personally (Sewell and Coppock, 1977:6; Webler, 1995:43).

Development of societal democracy continued throughout the 19th century as citizens became involved in discussions with the state, and rules were established to resolve disagreements in open, impartial and rational ways (Webler, 1995). To this end, public participation today is becoming increasingly regarded as a normative, democratic right in decision-making processes, particularly within environmental agendas, from local to international scales (Stringer et al, 2007). The United Nations Economic Commission for Europe made a bid to formalise such a right with the Arhus Convention in 1998 (Reed, 2008). There is an assumption associated with participatory processes that, using the right decision-making procedure means that a wide range of diverse 'knowledge and values' are considered.

A decision-making process that has the capacity to consider such a broad range of viewpoints is able to flexibly adapt to 'complex, uncertain, and multi-scale problems' that affect multiple actors and agencies within any given situation (Huxley and Yiftachel, 2000; Reed, 2008). It has been suggested however, that public participatory decision-making processes are not the answer to every situation. Roberts (1996:230) notes the situations in which organisations *should* consider the use of public participation; these have been outlined below in Table 4.1, and examples appropriate to this study are given alongside. It must be noted that these examples are not exhaustive, and are provided as relevant representation only.

The 'potential applications' outlined in Table 4.1, if implemented, could facilitate greater organisational transparency, and develop community trust in, and an understanding of, an organisation's proposal (Reed, 2008). There is also a need to consider (Petts, 1999:147):

- How to ensure all involved will have the same capacity as one another to participate in 'a process of engagement, where people are enlisted into the decision process to contribute to it' and;
- '…Those initiating the process are open to the potential need for change and are prepared to work with different interests to develop plans or amend or even drop existing proposals'.

Situations in which organisations should consider the use of public participation	Potential application to aircraft noise impact management by airports
Reaching a decision requires choosing between important social values	The trade-offs that often have to be considered between noise reduction and management of air pollution (or carbon emissions) by aircraft
The results of a decision will significantly affect the environmental, economic, political, cultural or social interests of certain individuals and groups more than others	The expansion or closure of an airport *should be* based on collaborative decision-making, and has the means to significantly change a communities income, social status/property value, air quality, health etc, either favourably or adversely dependant upon outcome/location
The public perceives that it has a lot to gain or lose by the decision The issue to be decided is already a source of controversy	When factual information has not been given, has been contested, or has been misconstrued either through the misinformed word of mouth, opposition groups, factually incorrect media reports – public participation affords the organisation opportunity to communicate factual information i.e. what, why, how, whilst allowing the issue to then be discussed, tested and challenged openly
The organisation needs positive public support to implement a decision	If airports are to satisfy increasing global demand, and therefore benefit national economic growth – particularly where there is genuine scope to positively impact local community (significantly outweighing the negative impacts)
Considerable social or environmental impacts may be expected	Airports (indeed organisations of any kind) have ethical, and in many cases legal, obligations to inform the public where environmental changes have the capacity to impact quality of life in any way – for example, air quality, strained transport infrastructure etc. This would help expose the importance of these impacts and thereby reach some social contract around how best to manage the dis-benefits as well as the benefits

Table 4.1 Situations in which organisations should consider the use of public participation, adapted from Richards, 1996; Reed, 2008

In order to address this consideration, it is worth looking to Habermas (1984:95) who advocates that the roots of cooperation are found in the very structure of language; '[b]uilt into language is the assumption that the speaker can defend his or her statements [opinions] if needed', and without this assumption, all forms of language would fail (Webler, 1995). Further purposes of public participation are considered by Innes and Booher (2007:422) and summarised below in Table 4.2.

	Purposes for Public Participation
1	For decision makers to find out what the public's preferences are so these can play a part in their decision
2	To improve decisions by incorporating citizens' local knowledge into the calculus
3	Public participation advances fairness and justice
4	Public participation is about getting legitimacy for public decisions
5	Public participation is something planners and public do because the law requires it
6	*To build civil society and create adaptive self-organizing polity (state) to address problems*
7	*'6' in an informed and effective way*

Table 4.2 Purpose of public participation, Adapted from Innes and Booher, 2007:422

Purposes 1 to 3 (Table 4.2) are suggested to address 'collaborative practice' (Innes and Booher, 2007:423), a concept that sees "polity interests and citizenry co-evolve". Innes and Booher (2007) advocate that governance is no longer just about *government* but now involves a wider distribution of societal power. Here, multi levels of stakeholders are now interacting in numerous ways, in a "common framework where all are interacting and influencing one another" whilst acting independently in a *multi-dimensional participation model* of 'communication, learning and action' (Innes and Booher, 2007:422).

Purposes 4 and 5 are seen merely as tick boxes for either legal or procedural reasons in order to facilitate development (Beierle, 2002). Purposes 6 and 7 are suggested to be formed by experience of the previous five, and actually appear to act as a summary for collaborative practice, with Innes and Booher (2007) regarding the 'pivotal' attributes of a participatory process as collaboration, dialogue, and interaction. Indeed it is important to highlight here that public participation is essential to deliver more sustainable outcomes (Beierle, 2002). There has not however, been the best balance between the concern of local people and the interests of the airport and other stakeholders; this re-iterates the question addressed by Porter and Norman (2018) in Chapter 1 of, how to balance conflicting needs, benefits and costs, when some may be measured in terms of sleepless nights for example, and others in terms of jobs or profit?

4.2.1 Communicative Rationality

The normative theory of language and communication is part of a larger project by Habermas (1984) to explain the evolution of modern society as a process of rationalization (Webler, 1995). The set of theories philosophised by Jürgen Habermas, termed *communicative rationality*, or *communicative reasoning*, describes human rationality as a necessary outcome of successful communication whereby people seek to reach 'shared understanding and cooperate to solve a common problem on the basis of discussion and consensus', where reason is regarded as the principle source – and test – of knowledge (Reed et al, 2009; 1935; Jonker and Foster, 2002). In seeking communicative rationality, an 'institution of communication' and accessible *channels* of communication must be established, as there must be an 'implicit commitment between any two persons talking with each other to cooperate'; a process described as *collaborative practice,* and a strong indication of communicative rationality (Sewell and Coppock, 1977; Webler, 1995; Innes and Booher, 2007).

In the context of this research, airports face a real challenge due to the significant imbalance in power between the organisation and individual local residents, because of the highly technical nature of noise exposure assessment and indicators, and the disconnect between these indictors and perceived disturbance. This arises because rarely do representatives of the airport live in noise-affected areas and with the associated experience; they do not therefore fully understand the concerns of local people. Furthermore, it is difficult - or indeed impossible - to make a rational argument for the benefits and costs that accrue to different stakeholders from the continuing operation and growth of the airport and airlines (Porter et al, 2014).

4.2.1 Ideal Speech Situation

Habermas (1962) supposed that 'this form of rationality, put into practice via discourses …aspires to (but can never be expected to achieve) the ideal speech situation…' (Webler, 1995:39). Indeed, any democratic process requires governance through basic rules ensuring participants have equal capacity to enter in to discourse and that public democracy can develop. In an ideal speech situation, Habermas believed that participants were able to evaluate each other's assertion of truth (opinions) in a non-coercive, rational manner with the sole motivation to reach mutual understanding and reasoning (Habermas, 1979:1; 1984:8, cited in Webler, 1995).

The theory of reason is founded on the philosophical field of logic, in which the argument of logic is used to make sense of things through a process of thinking, cognition, and intellect. Philosopher, Immanuel Kant (1788) advocated that *reason* is the source of morality. Webler et al (1995:446) emphasise that when participants act morally, they 'set aside their egoistic demands and act for the good of all', and in doing so create a fair and democratic platform. It must be acknowledged however, that whilst such actions promote fair outcomes, the holistic concept of an ideal speech situation 'must be grounded in the ideals of fairness *and* competence' (Webler, 1995:39). Put simply, creating a fair platform from which all opinions and viewpoints are heard, is of course a fundamental value of a participation process, however, if people do not have the means to competently understand the information, the process is instantly inaccessible to them, and therefore not particularly fair.

4.3 Fairness and Competence

In search of the ideal speech situation, and in line with the values of communicative rationality, fairness and competence are suggested as the predominant values of any public participation process (Webler et al, 1995).

4.3.1 Fairness

Fairness provides an essential platform for equality and democracy to emerge and competence to develop. In a fair participation process participants are provided with equal opportunities to (Webler, 1995:38):

- Act meaningfully;

- Determine agenda and rules for discourse;
- Speak and raise questions;
- Attain equal access to knowledge and interpretations.

Furthermore, Figure 4.1 outlines four fundamental actions that must be within the remit and capability of each participant in order for a process to be fair as dictated by Habermas' ideal speech situation (1962). Each of the four requirements of fair discourse is relevant in each of the three core activities required within a public participation process (Webler, 1995:39).

Requirements of a Fair Process	**Action**	
Attend	Be a participant in the discourse	
Initiate	Make speech acts	
Discuss	Challenge and defend claims	
Decide	Influence the collective consensus	
Staple Activities of a Public Participation Process:		
Agenda and rule making	Moderation and rule enforcement	Discussion

Figure 4.1 **Needs and Activities of a fair discourse, Adapted from Webler, 1995**

Following a simplistic yet robust requirement framework is suggested to increase the likelihood of trust and the perception of a fair and valid decision-making process, building a sense of mutual respect and self-value (Tippett et al, 2007).

This is especially difficult for an airport when it may be dealing with a number of different local communities and stakeholder groups whose priorities and interests do not coincide, raising fundamental questions of, Who do you talk to? Whose interests do you prioritise?

It is not enough simply to provide an opportunity for participation in the decision-making process; participants must have full access, particularly in terms of highly technical information, for example (Weber and Christopherson, 2002). In such a case, there may be a need to first educate participants, and provide a platform for continuous knowledge development. It is theorised that such efforts create confidence in competence to participate, leading to a sense of empowerment and perception of an engagement that is meaningful to the participant. This again, is a problem because of the difference between noise events, noise exposure, annoyance and disturbance, effectively the meaning of words and phrases fundamental to discussions surrounding aircraft noise at a 'professional' level. This points towards the need for a *common language* (Hooper and Flindell, 2013).

4.3.2 Competence

Competence relates to the performance and ability of the participant within a discourse process, in the context of information and knowledge available to them, and what can be reasonably expected (Webler, 1995). Essentially, competence is the construction of the most valid understandings and agreements possible, given what is 'reasonably knowable' at the time. It is the job of the facilitating organisation to provide participants with the 'procedural tools and knowledge needed to make the best possible decisions' (Petts, 1999:159).

Table 4.3 provides a summary interlinking Webler's (1995) fairness and competence values borne out of the normative model for participation with the ideal speech situation theorised by Habermas (1962).

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

Table 4.3 Conditions for fair and competent ideal speech situation, Adapted from Webler, 1995:60

Section 4.3 outlined the meta-concept of morality borne out of communicative reasoning and the holistic values of the ideal speech situation; if participants do not develop morally or enhance their level of cognition and process of thought, the participation exercise will be “based upon individual benefits and group preferences” and will no longer constitute an equitable process (Webler et al, 1995; Reed et al, 2009). Participants must therefore be encouraged to concentrate on the process of social learning, which can help them to “appreciate their mutual interdependence and learn constructively to handle their differences” (Woods, 2008:259).

4.4 Social Learning

Social learning refers to the process by which changes in a social condition occur, particularly how individuals see their private interests linked with the shared interests of their fellow citizens (Webler et al, 1995:445). Individuals learn how to solve their shared problems through a process that involves learning, which happens both inside (immediately and intensive) and outside of the process. Both elements are as important as each other to the social learning process as every member of the one community are affected by the problem, yet not all can participate in the process (Webler et al, 1995).

Social learning is much more than individuals learning in a social situation, more a diverse community of people with varying needs and wants, coming together to address the same problem, collectively. Equally, social learning has the potential to facilitate what Habermas (1979, cited in Webler et al, 1995:445) describes as social change, a process of “coordinated learning with cognitive and normative dimensions” where society learns to change in order to moderate problems impacting health and environment. It is from the same principle of cognitive dimensions that Webler et al (1995) identify what they believe to be the key underpinnings of social learning in its totality: cognitive enhancement and moral development.

Cognitive enhancement is said to be the acquisition of knowledge (learning), whilst moral development describes how, when individuals become aware of others' situations they begin to set aside egoistic tendencies, being able to make wider judgement and act more collectively. Key components of *both* core values of social learning are detailed in Table 4.4 below. When considering these components, it is clear to see how they resonate with and complement Habermas' (1984) theory that understanding values, beliefs and intentions of oneself *and others* is a direct result of the social learning premise; a process that Habermas termed 'self development'.

Cognitive Enhancement	Moral Development
Learning about the state of the problem (information and knowledge)	Developing a sense of self-respect and responsibility to oneself and others, regardless of how these may impact on one's own personal interests or values, and acting accordingly
Learning the possible solutions and accompanying the consequences	Being able to take on the perspective of others
Learning about other peoples' and groups' interests and values (information and explanation)	Developing skills for moral reasoning and problem solving that enables one to solve conflicts as they arise
Learning about ones own personal interests (reflection)	Developing a sense of solidarity with the group (adoption of collective interests as one's own)
Learning about methods, strategies and tools to communicate well and reach agreement (rhetoric, decision theory and small group interaction)	Learning how to integrate new cognitive knowledge into one's opinion of which choice is preferred
Practising holistic or integrative thinking	Learning how to cooperate with others in solving collective problems

Table 4.4 Cognitive Enhancement Links to Moral Development, Adapted from Webler et al, 1995:446

Carrying the concept of social learning a step further, Innes and Booher (2007) introduce the notion of social capital; attributes gained from social learning. These are summarised in Table 4.5.

Social Capital
Helps to build networks
Helps to build new professional and personal relationships
Facilitates better understanding of others' perspectives
Helps to build considerable trust

Table 4.5 *Components of Social Capital,* Adapted from Innes and Booher, 2004 cited in Innes and Booher, 2007:429

The social and economic benefits that accrue from the operation and growth of airports and airlines are spread over entire regions. The adverse noise effects are however borne by people living locally, around the airport. While it may be comparatively easy to articulate the wider benefits, it is very hard to explain to local residents why they have to carry the burden for the wider good.

From the results of a study in which these summarised attributes were noted, participants also reported transposition of social capital to other issues and situations outside of the collaborative process they had been part of for the study (Innes and Booher, 2007). Tellingly however, as with communicative competence and other theories founding effective public participation, these same participants suggested 'unattainability' (of social capital) without a common language (and therefore effective discourse). Innes and Booher (2007) equally advocate the need for authentic dialogue in order to fully reach social capital. Perpetuating the key relationship between effective communication and social capital, the process by which social capital occurs is illustrated in Table 4.6.

When Conditions for Authentic Dialogue Are Met
Genuine learning takes place
Trust and social capital can be built
The quality, understanding and acceptance of information can be increased
Jointly developed objectives and solutions with joint gain can emerge
Innovative approaches to seemingly intractable problems can be developed

Table 4.6 *Outcomes of Authentic Dialogue,* Adapted from Innes and Booher, 2004 cited in Innes and Booher, 2007:429

4.4.1 Social Capital

Social capital is a concept that refers to 'networks, norms and social trust that facilitate coordination and cooperation for mutual benefit' (Putnam, 1995:67). Through the fundamental act of participating in a decision-making process, the norms and values of social learning dictate natural network and relationship development. Allied to this, the prerequisite for engagement and willingness to learn new knowledge of the integrated and dynamic social and organisational environment directly impacting an individual, social learning is indicative of building robust social capital (Wilson, 1997:747; Gilchrist, 2000:264). As social learning and social capital interact in a reciprocal nature, one enhances the others' development and ultimately the "cultural will to solve community problems collaboratively" (Wilson, 1997:747).

4.4.2 Trust and Transparency

The core norms and values of a given decision-making process outlined throughout the chapter, creates the potential to increase participants' trust in the organisation and indeed the outcome of the process itself (Richards et al, 2004). Through the educational development of knowledge, and multi-faceted involvement and interaction in process, participants can also develop a sense of empowerment to influence decisions, and indeed disseminate informed knowledge (MacNaughten and Jacobs, 1997). Moreover, given the sense of empowerment and emotional and temporal investment in the process, there is a likelihood that the outcomes are not only trusted, but perceived to be holistic and fair, regardless of whether mutual agreement has been reached (Richards et al, 2004).

4.5 Limitations

Despite advantages of relationship building between institutions and communities, public participation is not clear-cut and even a perfect process does not necessarily guarantee a secure decision as an outcome (Pratchett, 1999). Theories of core attributes underpinning effective public participation appear to present idealistic outcomes (Habermas, 1962), however when applying theory to practice, feasibility comes in to question. Challenges and criticism have been seen most notably within the process of environmental impact assessments [EIA]. Lee (1993, cited in Petts, 1999) advocates that EIA can never be a neutral process as it is a 'civic science' where perception and values, and social and economic priorities determine outcomes as much as the data and methods of impact prediction, suggesting that how participants react is *as pivotal* to the effectiveness as the process itself. Essentially, both the inputs to the process, *and* the process itself, must be right in order that the required outcome is reached.

Indeed, transparency, mutual engagement and responsibility, and the reasonableness of the people in producing workable decisions must be considered when building a fair and competent process (Reber, 2018). Waddock and Rahman (2002) raise the assertion that those who place demands on organizations have some responsibility for ensuring their demands do not have significant unintended negative consequences (Freeman, 1984:15). Equally, it is suggested that successful companies are those who recognise their responsibility to the public and go beyond legal compliance (Waddock and Rahman, 2002).

4.5.1 NIMBYism

Furthering the discussion on the need for shared responsibility and 'reasonableness of the people' (Reber, 2018) in order to reach social learning and Webler's (1995) ideal speech situation (see Section 4.2.1 for discussion) is NIMBYsim [Not in My Back Yard]. NIMBYism is said to refer to a person or collective group of people opposing an initiative that has effects at a local level, particularly with regard to its environmental qualities (Suau-Sanchez et al, 2010).

Theoretical design of communicative rationality (Habermas, 1984) and reasoning (Kant, 1788), and indeed ideal speech (Webler, 1995), create a feasible platform from which to take an optimistic view of world, and an assumption that applying theory to practice realises such ideals. Faced with a rational argument of a contrary position, which might offer a legitimate, other stance in such an optimistic position then, has the means to facilitate consensus to be formed. Regardless of difference in fundamental opinion the legitimacy of an alternative position is acknowledged. As social capital is formed (Innes and Booher, 2007), trust and transparency builds, empathy and tolerance increases, and communities and airports reach mutually beneficial decisions.

Whilst theory provides an impression that such aligned cohesion can be reached, reports to date, and indeed the rationale for this study outlined in Chapters 1 and 2, dictate that this is not the case. The reality of many situations is that there are those whom are immediately affected by, in the context of aircraft noise annoyance, changes to flight path operations for example, who are baring disproportionate amounts of the cost. For those baring such cost, the change proposed will be unacceptable. Theory can be hypothesised and gleaned upon within an ideal world of public participation; if members of a community however, do not wish to entertain such ideals and processes, or indeed do not want to listen to the 'what's in it for me' (Hooper and Flindell, 2013), there is little scope of moving forward. It is this lack of willingness to take part, and the unacceptability of change, that embodies the notion of NIMBYism (Dear, 1992).

Chapter 3 (Section 3.3.1) saw the discussion of non-acoustic factors such as fear; of being overflown, and therefore a rise in possibility of being inadvertent victims of a plane crash; and fear of deleterious impacts on house prices. Adey et al (2007) suggest this as just one of the reasons underpinning NIMBYism. Suau-Sanchez et al (2010) discuss the concept of *environmental capacity*, and it's many interpretations. Where it could be suggested that such belief might conjure the thoughts of physical constraints, such as noise and environment, Suau-Sanchez et al (2010) refer to Upham et al's (2004) additional interpretations outlined below in Table 4.7.

Interpretations of the Concept of Environmental Capacity
The extent to which the environment (and the local community) is able to receive and tolerate, assimilate or process, outputs deriving from airport activities
The component of capacity constraint at airports or airspace described by environmental factors
The level of an airport's operational capacity at which those deciding on the future of an airport agree that the adverse environmental and social non-benefits arising from its development and operation outweigh the benefits that the airport would otherwise have brought
The limit of environmental tolerance
A concept that allows for a certain amount of environmental impact without overt disruption

Table 4.7 Interpretations of Environmental Capacity, Adapted from Upham et al, 2004

In consideration of such interpretations (Table 4.7), Suau-Sanchez et al (2010) go on to note that, "[e]nvironmental capacity could therefore be defined as the level of airport operational ability that can be reached after airport activity is limited due to socio-environmental factors" (Suau-Sanchez et al, 2010:4). Adey et al (2007:783) suggest for example, that such groups are contesting aviation by those "apparently concerned with the environmental impact (rather that social costs) of air travel."

Whilst Dear (1992:288) proposes that the term NIMBY refers to "the protectionist attitudes of the oppositional tactics adopted by community groups facing an unwelcome development in their neighbourhood", O'Hare (2008:10) suggests it as a term used to "dismiss the arguments of a group as purely self-interested or to discredit the activities of those that mobilise". O'Hare (2008) discusses the relevance of 'sustainable community' here, suggesting that such groups should not simply be seen as "[s]elf interested or irrational citizens who misuse the democratic process" (McAvoy 1999:1); whilst 'Not in My Back Yard' is the clear message of these groups and indeed individuals, there is often consensus that proposed changes *are* necessary, just not near *their* homes (O'Hare, 2008). With this in mind, such "turf-protectionist behaviour" (Dear, 1992:288) gives rise to active attempts at protecting and promoting 'their community' with "those very attributes deemed characteristic of" an idealised *sustainable community* (O'Hare, 2008:10). Prior to this observation, Heiman (1990) had introduced the term NOABY to denote Not in *Anybody's* Back Yard, further adding to the notion of a sustainable community.

Whilst such a paradoxical view could be seen as somewhat feasible, it still leaves little scope for any form of communicative reasoning (Habermas 1984) or indeed an ideal speech situation (Webler 1995). Further discussion and dissection surrounding NIMBYism is outwith the remit of this thesis. The second objective of this research, stated in Section 1.5 of Chapter 1, outlines the need to explore the importance of stakeholder engagement in influencing attitudinal factors. Through exploration of communication and engagement throughout the research thus far, it is appropriate to ask, is the expectation of an effective communication and engagement approach likely to affect those who are strongly affected because of what it does for them?

The answer to date is no. It is not therefore within the scope of this thesis to imply that NIMBYism can be overcome through idealistic theory; this is indeed an area for other focused research. Whilst there are some who explore the notion of NIMBY principles under the guise of 'sustainable community' (Heiman, 1990; O'Hare, 2008), it can be concluded that the concept of NIMBYism is very much founded in self-interest and not wider community interest. In reality, and in the context of this research, if airports were to react to NIMBYs consistently, the discussion of aircraft noise impact management would not be moved along; it would be allowing an approach of 'loudest voice wins' – the antithesis of social learning. Whether social learning, ideal speech, and communicative rationality are deemed idealistic or not, the reasonableness of such concepts are at least a starting point for exploration of their in-practice counterpart.

4.5.2 Scientization

As mentioned in section 4.5 above, even where processes are sound, they can still be undermined by provision of incomprehensible information and very quickly lose participatory value. Webler (1995:41) explains that a principle concern of Habermas is the "scientization" of politics; the over use of technological and scientific rationale within debates and explanatory processes, despite educational efforts to increase competence. When it comes to decision-making, often the language becomes very technical because the context is around the application of science and technology to society; this can be a barrier to public engagement. Situations failing to provide a fair and competent participation process are at best providing tokenistic engagement (Webler, 1995).

Chapter 2, and later Chapter 5, discusses conventional long-term averaged, aggregated metrics. It is suggested that they are symptomatic of a techno-centric approach, and are widely known to alienate and very quickly dis-engage the public. This has meant a more conscious effort in communication by the aviation industry in terms of language and empowerment to competently engage in a participatory process (Hooper et al, 2009). The acknowledgement of public disconnect with conventional metrics has seen a move towards supplementary metrics, which are seen as providing more transparency to information being given, facilitating a re-building of trust (Hooper and Flindell, 2013). This is discussed in detail in the following Chapter 5.

4.5.3 Timing of Participation

It is reported that EIA's have reformed governmental decision-making by ensuring information is more readily available to the public (Ortolano & Shepard, 1995). "Even a cursory glance at the literature on environmental impact assessments (EIA) reveals that public participation is increasingly being considered as an integral part of the assessment method" (Glucker et al, 2013:104). Whilst this view may be true in terms of formal procedure, the point at which public participation is included in a decision-making process has been brought into question (Rowe and Frewer, 2000); "EIA is not EIA without consultation and public participation," professes Wood (1995:225). It has however, long been argued that both transparency of information (public access to information), and the available process by which to participate, mean little without comprehensibility (Petts, 2003); a reason perhaps, why Petts and Leach (2000) suggest that theorists encourage taking stock of the participation *process*, rather than focusing on the outcome. In the same vein, the point at which participation should be considered is said to also be of significance in participant satisfaction and overall success of it's impact on reaching mutuality, and high quality, durable decisions. Reed et al (2006) advocate the consideration of public participation from concept development and advise that it should be maintained through planning, implementation, monitoring, and evaluation of outcomes (Estrella and Gaventa, 2000).

Petts (2003:19) notes that the required assessment should be determined *through* discussion with the public, not in *advance* of discussion with them. She adds, "This challenges the proceduralisation culture that tends to dominate decision authorities and the culture of experts who do not recognise the potential value of public input." In other words corroborating the widely unwritten opinion that, despite the premise of a thorough, staged public participation process, the EIA process is somewhat weakened by the stage at which the public is involved in the decision-making. This explains why public participation is often described as "an add-on" (Petts, 2003:20). EIA practice has also highlighted unfair timescales often letting down the credibility of a process. In Petts' (2003:20) recommendations of key participatory principles, the process, it is suggested, should allow "plenty of time for stakeholders and the public to assimilate and understand information so that assessments can be cross-examined and if necessary revised assessments produced". Warburton (2002) suggests discourse to only be truly effective if consultation remains open long enough to afford cross-examination and possible revision. If time is cut short on this part of the process, little opportunity is provided for digesting and understanding information, leaving little time for equitable discourse. It is when this part of a process is not fairly orchestrated that the trust of participants is lost.

4.5.4 Consultation Fatigue

Whilst Petts (2003) argues that participatory processes are weakened where inadequate time is given for participant contributions, an equally pertinent problem is 'consultation fatigue'; often related to a feel of disillusionment arising from a sense that participants' views are not taken into account in the planning process (Burton et al, 2004; Warburton, 2002). Equally, as a participant perceives, their participation gains them little reward or capacity to influence decisions affecting them (Cosgrove et al, 2000; Burton et al, 2004).

There has not however, been the best balance between the concern of local people and the interests of the airport and other stakeholders; this re-iterates the question addressed by Porter and Norman (2018) in Chapter 1 of, how do you balance conflicting needs, benefits and costs, when some may be measured in terms of sleepless nights for example, and others in terms of jobs or profit?

This is especially difficult for an airport when it may be dealing with a number of different local communities and stakeholder groups whose priorities and interests do not coincide, raising fundamental questions of, Who do you talk to? Whose interests do you prioritise?

Despite advantages of relationship building between institutions and communities, public participation is not clear-cut and even a perfect process does not necessarily guarantee a secure decision as an outcome (Pratchett, 1999). Theories of core attributes underpinning effective public participation appear to present idealistic outcomes (Habermas, 1962), however when applying theory to practice, feasibility comes in to question

4.6 Summary

Stakeholder theory states that in order to communicate with someone in a way that is meaningful, there is a need to speak a language that is understood by both sides. The literature depicts the core elements needed for an effective engagement process, at the heart of which the majority of theories point to the need for a 'common language' to overcome, in particular scientization, causing an imbalance to the outcomes process.

One such method for 'counter influencing' attitude is outlined in theory developed by Habermas (1962, 1979, 1984). Through the understanding and implementation of theory gathered from the literature, it is hoped that the engagement process will be effective enough to employ an element of social learning (Habermas, 1985), a process that is not simply about comprehensibility and consensus building, but where the community and authority have the chance to work together on decision-making; in essence it is about each actor becoming aware of the others' position and gaining mutual understanding, respect and community cohesion, whether in agreement or not. This builds more appreciation of one another's position and the ability to begin discussing compromise.

Chapter 5 Historical Descriptors and Communication Efforts to Date

Noise remains one of the most important concerns for local communities whilst evidence suggests that despite “considerable resources being expended by airports to improve communication with local residents many are failing to engage effectively with this key group of stakeholders” (Hooper and Flindell, 2013:2).

The literature review presented in pervious chapters suggests that effective noise impact management requires that both acoustical and non-acoustical factors be considered. Whilst clearly fundamental, this is however, only the beginning of what is necessary. The primary function of civil aviation is transportation. Yet, as Chapter 1 discussed, while the economic and social benefits are widely (if somewhat unevenly) spread across the population, the environmental costs in terms of aircraft noise and pollution tends to fall disproportionately upon the airports’ nearest residents; notwithstanding the extent to which they may also benefit from employment, social, and/or travel opportunities.

Chapter 2 provided an overview of the significant investment in noise reduction through engine and airframe technologies, and novel operational procedures, all of which continue to be developed and implemented at airports across the world. These efforts have resulted in a reduction in the area of noise contours and therefore populations affected – at least around mature airports (Hooper and Flindell, 2013), This decline has not been matched by a reduction in annoyance over the same timeframe, as evidenced by noise complaints and active opposition from local residents. This suggests that the link between aircraft noise effects and potential impacts is “neither simple, nor linear, as commonly presented” (Porter et al, 2014:8) owing to the many aspects of non-acoustic factors, the number of effects, cumulative exposure, and individual sensitivity to both noise and risk factors (Porter et al, 2014).

Chapter 3, continued to explore this link and in doing so sought to gather a wider understanding of human variability; the tenets of which see individual perception, and indeed interpretation, impact on human responses to a sound, and – more importantly in the context of aircraft noise – to the sound source.

Chapter 4 explored ways in which airports should use this understanding of the role of non-acoustic factors and implement the most effective engagement and communication strategies. In doing so, core values have been highlighted as imperative to ensure that they are enabled through such effective engagement strategies; the most notable of which are trust, fairness and competence, seemingly achieved through transparency and adequate amounts – and timing – of communication efforts. Whilst this appears a straightforward recipe to adhere to, research to date has seen airports' attempts at such engagement strategies be unsuccessful (Heathrow 2.0, 2019), and often, exacerbate annoyance rather than reduce it.

Within this context, Sanchez et al (2015:2) identify the core set of challenges facing the aviation industry:

- The development of actions to tackle community perception and integrate non-acoustic factors within current airport noise management strategies
- The need for more targeted metrics to describe noise and its impacts in a meaningful and transparent way
- How to address the trade-off between sharing and concentrating the noise burden
- Understanding the perceived value of respite for communities and delivering effective respite from aviation. In this context, respite is referred to as a measure to mitigate the impact of aircraft noise over communities exposed. It is related to periods of time when residents get a break from over-flight noise.

The second point in this list of challenges identifies the technical and misplaced (within the context of community engagement) use of conventional metrics. Regulators and assessors have attempted to describe this overall exposure using conventional long time average metrics such as L_{Aeq}[13], L_{dn}[14], and L_{den}[15] (Guski, 2004). The simplest type of long-time averaged metric, L_{Aeq}, is in fact representative of a fundamental or basic physical quantity: the long-time averaged acoustic intensity at the defined receiver point (see Figure 5.1).

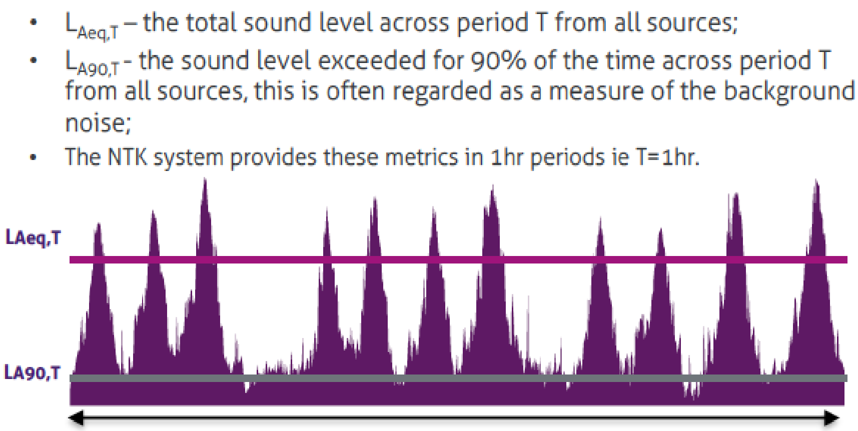


Figure 5.1 **Calculation of L_{eq} from Aggregation of Flyover Events, Adapted from Heathrow Airport Ltd, 2018**

Metrics, as touched on in Chapter 2, are varying ways of measuring and describing sound pressure levels (decibels). Traditionally, a variety of average-energy noise descriptors (metrics) have been used, often to display noise exposure contours on a map (Hooper et al, 2015), for example L_{den} in the EU, L_{Aeq} in the UK, and DNL in the USA. There is an underlying tension however, between the need to develop simple single-number numerical metrics based on overall average quantities, and the need to properly reflect the full range of input variables, which may need to be considered to properly reflect key input variables in specific situations (Brink et al, 2011).

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13 L_{Aeq} Definition: Equivalent sound level of aircraft noise, often called equivalent continuous sound level. L_{eq} is most often measure on the A-weighted scale, giving the abbreviation L_{Aeq}

14 L_{dn} Definition: 24-hour L_{eq} measure with an un-weighted 15-hour daytime period (0700-2200) and a 10dB weighting for any noise events occurring during a 9-hour night-time period (2200-0700). This metric is commonly referred to as the Day-Night Level (DNL)

15 L_{den} Definition: Equivalent sound level of aircraft noise in dBA for the 24-hour annual day, and evening, and night where the evening movements are weighted by 5dB and night movements are weighted by 10dB

Indeed it is common thought within aircraft noise impact management, that such conventional descriptors are not a direct representation of the 'noise' levels or repeated noise events people hear, rather, "a result of complex scientific calculations of exposure of noise energy over a defined time-period" (Goldschagg, 2013:14). More importantly than this, these descriptors tend to be far too technical for the layperson to understand, are not trusted, thus increasing annoyance towards noise, simply through not being able to understand the language used to discuss the very phenomenon that is causing the initial annoyance.

A notable example here is that of the PNdB, or *Perceived Noise Level*[16]. This is a "relatively complex family of indicators" (Fiumicelli et al, 2014:13) defined in international agreements for the standardised measurement of aircraft take-off and landing noise during aircraft noise certification procedures. The PNdB procedures were devised in the late 1950s and early 1960s to achieve the highest possible correlation between objective measurements of frequency and time weighted sound levels and relative subjective judgements of '*perceived noisiness*' (Smith, 2004). This was done under carefully controlled laboratory conditions using loudspeakers, presenting sequences of separate simulated aircraft flyover event sounds. '*Perceived noisiness*' was defined at the time as being a *specific subjective attribute of aircraft noise, which falls between subjective loudness* (Kryter, 2013). This was essentially considered to be neutral, i.e. neither pleasant or unpleasant, and *subjective annoyance*, which was considered to be essentially an attitude or response of *the listener*, not necessarily a reflection of underlying physical properties *of* the sound being heard.

From the clear need for airports to engage with their 'neighbours' in efforts to demonstrate commitment to minimising negative environmental and social impacts (identified in Chapter 4), varying methods of communicating aircraft noise information have been explored (Hooper et al, 2015). As Chapter 4 identified, until

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[16] Perceived Noise Level, measured in PNdB. Its measurement involves analyses of the frequency spectra of noise events as well as the maximum level

this is achieved, the challenges listed above (see Sanchez et al, 2015:2) cannot be tackled.

5.1 Evolution of the Conventional Aircraft Noise Metric

Based on observed correlations between average reported annoyance and measurements of aircraft noise levels around Heathrow in the early 1960's, (Wilson Committee Report, 1963) the UK government adopted the *Noise and Number Index* [NNI][17] (Flindell, 2008). Comparing this metric to the L_{Aeq}, placed greater emphasis on the number of events within the determination of the indicator. After extended consultation in 1982, which included some empirical research (Brooker et al, 1985) the UK government adopted the 16-hour L_{Aeq} as it's preferred aircraft noise indicator for a 3-month period during the summer. During the same time-period, a general international convergence was emerging towards the universal adoption of L_{Aeq} and L_{Aeq}-type metrics for aircraft noise assessment and regulation (Porter et al, 2014).

Through the gradual replacement of older, noisier aircraft types with quieter ones, the UK government utilised the averaging nature of the new metric to demonstrate a more rapid reduction in the areas of annually produced aircraft noise contours around airports than would have otherwise been the case with NNI (Hooper and Flindell, 2013). This was more than enough to offset any increase in aircraft numbers during the period. During that same period however, increasing (but largely anecdotal) evidence suggested that reductions in aircraft noise contours were not leading to commensurate reductions in reported disturbance and annoyance around airports (Hooper and Flindell, 2013). In addition local residents began to complain about number of noise events rather than the noisiness of individual aircraft movements.

By 2005, L_{Aeq} had become sufficiently entrenched within long established regulations and assessment procedures that any upheaval from further changes in preferred aircraft noise indicator would not have been welcomed (Pronello and Comusso,

[17] Noise and Number Index: the noise exposure measure that preceded L_{eq} for airport noise exposure contours in the UK (CAA, 2018)

2012; Hooper and Flindell, 2013). Increasing pressure from members of the public, and from local amenity groups however, did indeed lead eventually to further research in 2005, and spanning in to 2006 (Le Masurier et al, 2007). This research found higher overall correlations between noise and annoyance by taking greater account of the number of events within the determination of the indicator than implicit in L_{Aeq}. Despite findings, limitations of experimental design, which could not be changed retrospectively, meant that statistical comparisons against the earlier research carried out in 1961 and 1982 were not possible (Flindell et al, 2013). This meant that explanatory data comparisons could not be drawn and the entrenched metrics remained (Ollerhead, 1992; Flindell et al, 1998).

5.1.1 Current Use of Conventional Metrics within the UK

The *current* practice by the UK Department for Transport (DfT) is 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 $L_{Aeq16\text{-}hour}$, with firstly, the *onset of low annoyance*, and more recently, with the onset of *significant* annoyance[18] (Flindell, 2013). This was done for two main reasons. First, as an engineering metric based on decibels, L_{Aeq} is very poorly understood by the layperson, 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 (Barbot et al, 2008; Hooper and Flindell, 2013).

5.2 Conventional Metrics and their Appropriate Context

At any defined receiver point on the ground, the physical amount of aircraft noise is determined by the type of aircraft, i.e. engineering design, and how the aircraft is operated (Smillie, 1999). This is in particular relation to time varying distance from

[18] The 2003 Air Transport White Paper subsequently defined 57dB LAeq,16h as marking the approximate onset of significant community annoyance, and this was reaffirmed in the Government's 2013 Aviation Policy Framework (CAA, 2018)

aircraft to receiver point while flying overhead or nearby. There are many different variables involved, including the atmospheric and meteorological conditions at the time of operation, which can significantly affect the acoustic propagation of sound waves from the aircraft down to the ground (Pronello and Comusso, 2012). These variables can be reflected in variations in the overall sound level time history, both in terms of the overall duration, and changes in sound quality, during the flyover event (Smith, 2004). Acoustic features such as the Doppler effects and the relative balance between high and low frequency components at different times during the flyover can be interpreted or perceived by listeners in terms of differences in the type of aircraft and the type of operation being performed (Kryter, 2013).

Whilst such metrics have been identified as not particularly appropriate for capturing subjective factors, they do indeed remain relevant, even with only weak correlations, particularly for the purpose or function of measurement to inform noise control engineering decisions or resolve contractual or regulatory disputes. Torija et al (2017) suggest that subjective judgement alone is insufficient when measuring the effects of engineering noise control, which is where objective acoustic metrics have been found to offer the most value. Equally, the opposite viewpoint needs to be noted that, just because a small reduction in L_{Amax} (or any similar flyover event metric) might be measureable using precision grade instrumentation, and could even be sufficient to turn a fail into a pass when tested against some defined sound level criterion or noise limit, does not necessarily mean that any human listener would automatically be able to perceive the difference, or further, be impressed by it (Torija et al, 2017). This should be seen as an impactful point, one that makes a clear argument for needing metrics appropriate to the context in which they are required.

Moreover, this could equally offer an explanation as to why residents are often unaware of noise control efforts applied on their behalf (Porter et al, 2014). Indeed, such changes may be small in comparison to the variation in noise events, which inevitably occur regardless, from one aircraft flyover to the next, as a result of changing operational and atmospheric conditions (Barbot et al, 2008). 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 responsive to, easily observable differences in aircraft operations (Sanchez et al, 2015). This is in comparison to more *perceptually ambiguous* differences in aircraft flyover event sound levels.

5.3 Challenges of Conventional Descriptors

It has long been standard practice to represent aircraft noise exposure in terms of *basic standardised acoustic metrics* – commonly termed 'conventional metrics'. Standardised acoustic metrics are a means of avoiding subjectivity, which would otherwise compromise the accuracy and reliability of assessments based only on reported noise complaint statistics (Torija et al, 2017).

While conventional metrics/descriptors have specific roles within strategic noise assessment, regulatory requirements, planning decisions, and preferred noise route designations, they do not adequately describe the *actual community experience* (Porter et al, 2014). Indeed, few members of the public appreciate being told how 'annoyed' they are depending on where they live, and those people who *are* annoyed but happen to live outside of the contour defined 'annoyance area' are even less likely to be appreciative (Greaves and Collins, 2006).

The presentation of different issues to different stakeholder groups therefore, may require a wide range of tools carefully adapted to each stakeholder and groups' level of interest, motivation and understanding (Greaves and Collins, 2006). For some tasks and stakeholders, detailed technical presentations involving relatively complex objective physical (conventional) metrics may be entirely appropriate; regulators and administrators may wish to publish the results of strategic comparison to justify resulting decisions made. For many other tasks and stakeholders, something much less technical may be required, depending on the ultimate purpose of the communication exercise (Flindell and Stallen, 1999). In reality however, providing a more accessible form of information to the conventional style 'technical' metrics, while increasing understanding, does not necessarily lead to increased acceptance of those decisions by individual residents likely to be adversely affected. Moreover, noise indicators have two roles, one of to describe the noise itself and therefore allow management as well as describing environmental conditions. The other role is to support dialogue. If people don't understand or indeed trust these indicators, then the value in supporting dialogue is minimal.

Further challenges with conventional metrics have been identified by Hooper and Flindell (2013) and are outlined below in Table 5.1. Formed of the literature reviewed and discussed throughout this thesis to date, the second column of the chart below identifies perceptual implications of conventional metrics use.

Common Problems with Conventional Noise Metrics	
Information Provision	**Sound Perception Relative to Descriptors**
Misplaced focus on long time average aggregated metrics such as L_{Aeq}, L_{den}, L_{night}, N60, N70, etc, which are not understood by the public and are only really suited to planning and other strategic developmental decisions	Actual sound exposure varies over a wide range of situations and dimensions leading to a range of attempts to capture aspects of sound: - *Instantaneous sound quality*, represented by the short-time varying frequency spectrum; - *Longer time temporal distribution*, represented by the sound level time history; and - *Spatial distribution,* which can only be represented using multiple measurement positions
A failure to understand that long time average aggregated metrics can conceal information provided by simpler metrics of more direct relevance to the public such as the numbers and times of day at which aircraft noise events of different relative magnitudes occur. The public can much better relate to metrics that quantify the relative magnitude and times of occurrence of events than to any long time average aggregated metrics	
Difficulties in the interpretation of contour representations overlaid on maps. Inappropriate linking of objective noise exposure information to predicted levels of disturbance - residents struggle to accept aviation actors when they associate a given exposure with, for example, the 'onset of significant community annoyance', particularly when their place of residence lies outside of the relevant noise contour boundary. Resulting in the frustrated 'who are you to tell me if I'm annoyed or not' response.	Human auditory perception does not function in the same way as a calibrated sound level meter. This creates challenges when attempting to relate noise exposure to annoyance responses

Table 5.1 Common Problems with Conventional Noise Metrics, Adapted from Hooper and Flindell, 2013

Such perceptual issues outlined in Table 5.1, as previously discussed in Chapter 3, arise because of the significant variation that can occur in the external soundscape and because of the different ways that human auditory perception has evolved, primarily to extract information from that environment (Kryter, 2013). Community perception of aircraft noise is affected by the totality of individual experience and not just by single isolated events (see Chapter 3), important though these may be. In addition to human variability (Chapter 3, Section 3.1.3) in the context of perceiving sound, actual aircraft sound exposure can, and does, vary over a wide range of different situations and soundscapes, often leading to considerable differences in subjective outcome (Flindell and Stallen, 1999).

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 in the context of aircraft noise (Filippone, 2014). This can prove difficult to represent using just one specific metric, and as outlined in Section 5.2 above, often only averaged exposure focused metrics end up being used.

Given the continued channels of communication by the aviation industry to this point, it seems extraordinarily novel that Hooper and Flindell (2013:2) noted how "quite remarkable [it is] that when providing noise information to local communities, airports often fail to ask the basic question – 'what do people actually want?" Indeed, attempts by airports to address such questions may well explain the increase in the range of noise descriptors and metrics being used by airports to communicate with affected communities; the most notable of which, is the disaggregation of information from conventional metrics in to single events.

5.4 Attempts to Add to Conventional Noise Descriptors

Borne out of the move to disaggregating conventional long-term averaged metrics, was the ability to offer supplementary visual aids and focus on location specific information. One of the most significant and earliest developments to the use of conventional long-time averaged acoustic metrics and indicators is iso-contours and noise ‘footprints’ overlaid onto geographic maps of areas around airports (Flindell et al, 2013). Such contours are used to summarise the spatial distribution of noise, and can show calculated overall numbers of residents exposed within geographically defined bands of L_{Amax}, L_{Aeq} or L_{den}. EU Environmental Noise Directives require all airports with more than 50,000 ATM (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 (Figure 5.1).

To capture the spatial implications of airport operations and thereby inform management interventions such as those associated with land-use planning, and as an overall decision-making tool, contours are used to calculate effects on (Konovalova, 2015):

- Total areas
- Residential populations
- Number of schools and hospitals
- Other potentially noise sensitive locations
-

Once these have been identified, the contours are used to compare between, for example, different runway locations and orientations (see Figure 5.2 below), or air space changes and new flight paths. It should be noted that this type of comparison is useful for high-level strategic assessment, but, as outlined in the challenges discussed towards the end of Section 5.1 above, may be considered essentially meaningless in respect of individual and potentially affected residents (Flindell et al, 2013; Pronello and Comusso, 2012).

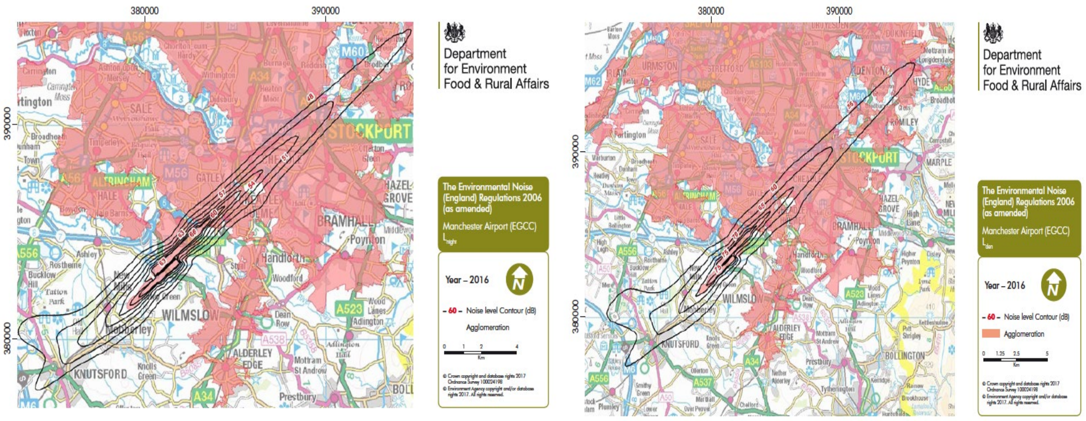


Figure 5.2 Examples of Noise contours required for large airports under the EU ENDS Directive, Heathrow, 2018

Whilst 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, it has no higher correlation than L_{Amax}[19] with individual reported short-term loudness (Brink et al, 2011). The main reason suggested for such low correlation, is the already identified complex causation of individual human attitudes and opinions, and once again, the lack of ability to capture such factors in simple long-time averaged physical measures. In attempts to capture some of the potentially measurable factors and sensitivities influencing attitude, variations on the simplest type of long-time averaged metric, L_{Aeq}, have been devised and adopted (Hooper and Flindell, 2013). The most notable of variations are L_{dn} and L_{den} with different day, evening and night-time weighting factors applied; the somewhat arbitrary addition of 5dB to evening and 10dB to night-time events[20] however, calls in to question the validity of such weightings (Sanchez et al, 2015).

5.4.1 Metric Weightings and Variations

Many possibilities exist for adding weightings to metrics, which are applied to reflect given situations, for example time of day. The extent to which these specific weightings are 'correct' or not however, is often unknown, and may well lead to inappropriate or misleading assessments (Flindell, 2013); particularly when used for

[19] The maximum A-weighted sound level (in dBA) measured during an aircraft fly-by

[20] This has been scientifically calculated for specific reasons, the exploration of which is outside of the remit of this study

predictive purposes and without proper consideration. Indeed, uncertainties of measurement and prediction can be significant, and depend on (Porter et al, 2014; Hooper et al, 2015):

- The accuracy and precision of measuring instruments
- Inherent variability within successive sample measurements
- The extent to which any defined metric represents the desired quantity
- The degree of correlation between different variables
- To what extent deviation in the exposure variable causes variation in the response variable.

Research has shown numerous attempts to devise *reliable* exposure-response relationships capable of accurately predicting average reported annoyance and other effects from simple combinations of objectively quantifiable input variables (Fields et al, 1997; Dubois et al, 2006). Such attempts revealed considerable variation amongst studies, with anecdotal evidence of uncertainty where exposure-response relationships have been used for predictive purpose (Brink et al, 2011). Some main causes of this have been identified as:

- The large number of ways in which both sound level and human response can be measured, and
- The consequential statistical constraints on being able to differentiate between all potentially relevant combinations of input and output variables.

Such varied use of metrics compromises the practicality of any regulatory application. On the other hand, this progression allows for more detailed representation of a given situation, which can significantly enhance public understanding when used in communication and consultation (Pronello and Comusso, 2012). Supplementary information metrics often fall in to two forms (Konovalova, 2015):

- Number, duration and loudness and time of day/night of individually monitored events, or

- Modelling multiple noise events experienced over a specific period and expressed as an average continuous equivalent noise level, additionally weighted for time-of-day.

Location specific information that allows for differentiation between the loudness, timing and frequency of events, is suggested as the most effective for improving understanding (Hooper et al, 2009; Hooper and Flindell, 2013). Moreover, such information has been demonstrated to “aid wider appreciation of the operational causes of aircraft noise, airport efforts to minimise noise exposure and mitigate the effects” (Hooper and Flindell, 2013:3).

5.4.2 Histograms as a Supplementary Metric

Presentational material of a more acoustical nature, illustrating metrics and averaged contour areas have been found to be more inflammatory of negative attitudes, and have only been found as ‘helpful’ in cases where eligibility (or otherwise) for noise insulation and other forms of compensation is shown on a sound level contour map, for example (Sanchez et al, 2015).

Hooper and Flindell (2013) explored the use of histograms as a key supplement to traditional averaged contours, and the effectiveness of doing so in their 2013 research.

The histograms are used specifically to illustrate data deemed meaningful to specific resident groups, by addressing the above – number, timing and loudness of events.

In Figure 5.3 (below), an early attempt at providing average day information of noise events is shown. The standard UK CAA definitions of day, evening and night are used here.

Initial response suggested the need for amendments:

- Colour differentiation with the histograms seemed to imply some significance for events over 60dBA - *this was not intended and subsequently dropped*

- The y-axis scales had been adjusted to provide for larger bars during periods of fewer operations, i.e. evenings and nights - *this did not help understanding and thus future illustrations used the same scale for all time periods*

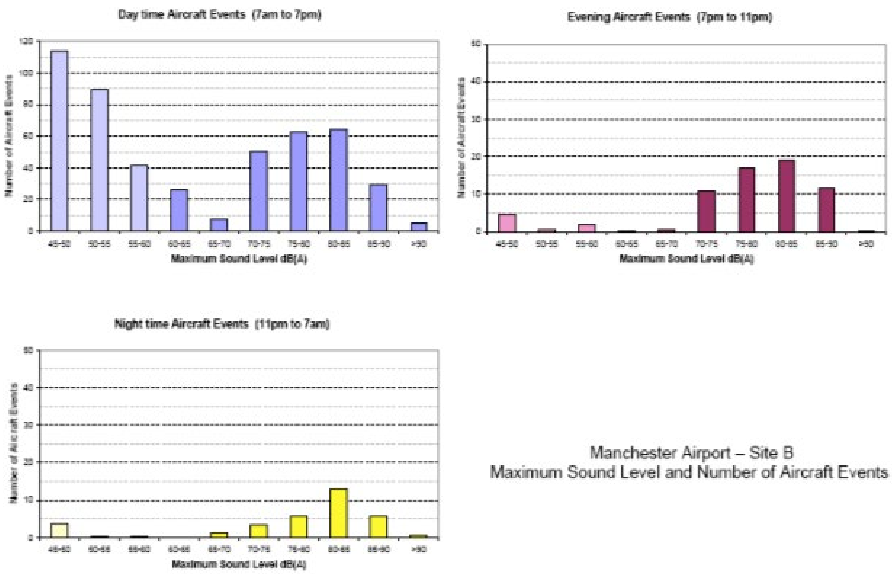


Figure 5.3 **Histograms of Maximum Sound Levels and Number of Aircraft Events, Adapted from Hooper and Flindell, 2013**

Once these amendments had been made however, feedback proved much more positive and almost immediately appreciation of the value of dis-aggregated information becomes apparent. Such appreciation equally highlights the widely-understood aggravation caused by the conventional long time averaging over all runway modes: "Residents experience different amounts of noise on different days depending on which runways are in use for take-offs and landings, and very few have any understanding at all of the reasons for this variation. For an airport like Heathrow that operates three primary runway modes, the information requirements can become quite onerous…" (Hooper and Flindell, 2013:4).

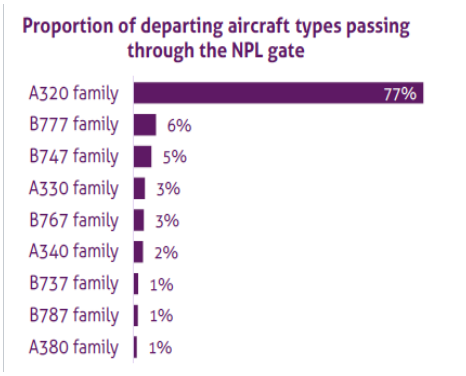
Whilst the results of their research returned positive outcomes of such supplementation to information dissemination, and the nature in which this was delivered, i.e. direct communication to small groups, Hooper and Flindell (2013) were very clear that this research had been commissioned and therefore funded significantly. In the context of a large-scale communication operation, the researchers acknowledge that this form of relation-building effort would evidently be a costly one, implying that a cost-benefit analysis would need serious consideration for this type of approach. It is important to take away however, the value that such disaggregation and simplification of information had to the participants.

5.4.3 Operational Indicators

Human perception of a sound source dictates that the most important difference between operational indicators and acoustical metrics is that operational indicators tend to depict aircraft movement *relative* to an on the ground 'observer' (Fiumicelli et al, 2014). Acoustic metrics however, tend to illustrate exposure effects of aircraft events at defined receiver points, proximal to the observer and distance from source (Pronello and Comusso, 2012). An aircraft at a *large distance* from an observer, for example, could generate similar sound exposure levels to a *quieter* aircraft at a *much nearer distance* to the observer. Despite this, each of these events could be perceived completely differently. In such cases, operational indicators that show for example, the type, operating configuration, and changing position of the aircraft relative to an observer, could be of more relevance to human perception than any indicator of sound level during the same flyover (Posterino and Mantecchini, 2016).

Operational indicators used by airports and other stakeholders in communication efforts, come in varying forms. Examples can be seen in Figures 5.4a – 5.4c (Flindell et al, 2013). These are:

- Lists of aircraft operations i.e. time of day, type of aircraft, distance to/from destination, aircraft weight (Figure 5.4a);
- Cross-sectional charts showing aircraft height and track when passing a defined observer point, known as gate analyses (Figure 5.4b);
- Maps showing individual flight tracks and the distributions of multiple flight tracks across the ground in relation to defined observer points on the ground (Figure 5.4c).



	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%

Figure 5.4a **Lists of aircraft operations – Numbers of departures on a given route and proportion of different aircraft types, Adapted from Heathrow Airport Ltd, 2018**

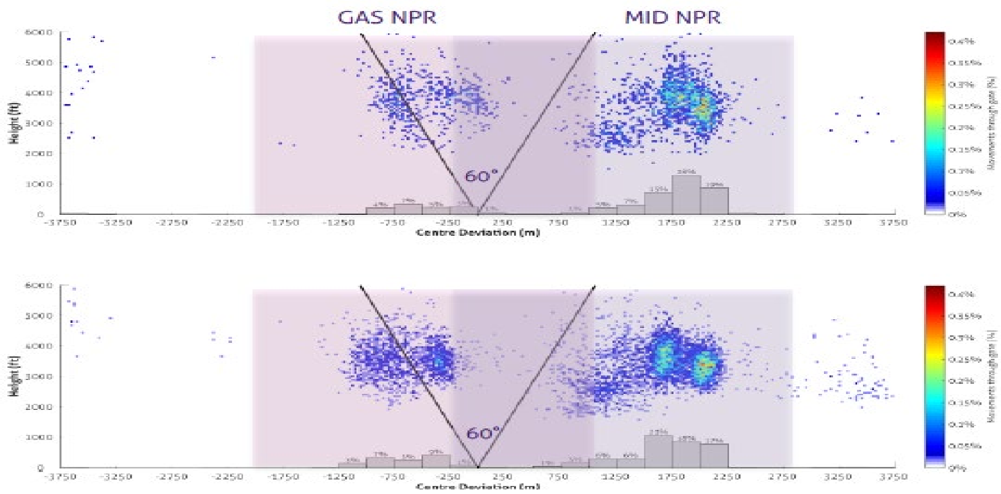


Figure 5.4b **Cross-sectional charts - Heat maps showing concentration of aircraft as they pass through a gate, Adapted from Heathrow Airport Ltd, 2018**

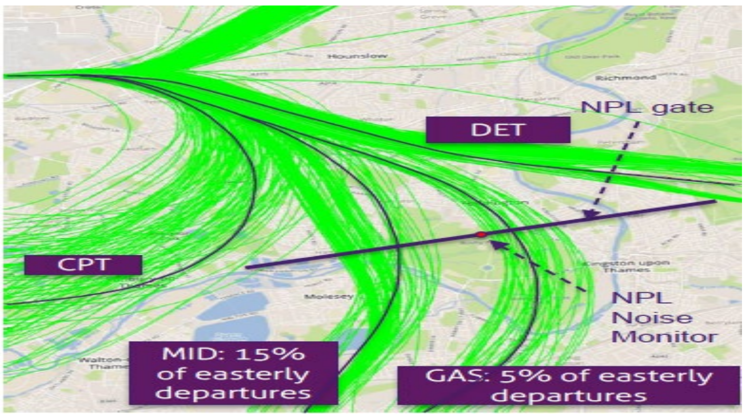


Figure 5.4c **Flight tracks - Radar flight tracks on specific routes, Adapted from Heathrow Airport Ltd, 2018**

In addition to these operational indicators, it is also possible to apply various quantitative metrics to each type of indicator (Porter et al, 2014), 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
- Counting the number of aircraft movements above or below a specified height at a specified distance along the flight tracks, as used at Sydney Kingsford Airport, for example
- Counting the total numbers meeting (or not) some industry targets or noise limits.

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 when compared to other airports (using similar operational indicators), than any acoustic metrics (Hooper et al, 2015).

Operational indicators are indeed suggested as the more effective for engaging with local communities on matters surrounding aircraft noise; the information that can be provided in varying formats allows for understanding on a level, which is meaningful its audience (Porter et al, 2014). Nevertheless, these operational indicators are indeed still *supplementary* descriptors, and therefore some form of acoustical metric is often also needed; it is important to note their remaining limitations, *as well as* their improvements to date.

It is in a situational context such as this, that supplementary histograms (illustrated in Figure 5.5) can aid in illustration of flyover events over time, helping to form a sense of the range of options that could be possible (Hooper and Flindell, 2013).

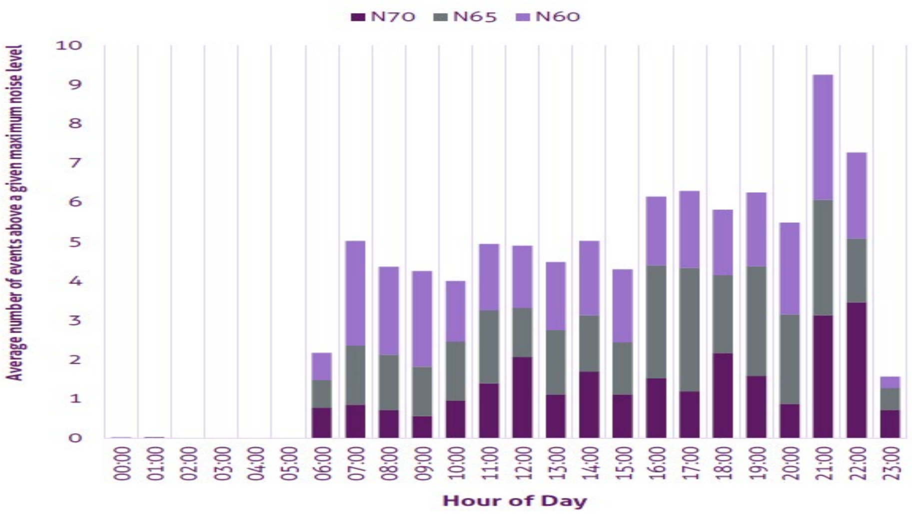


Figure 5.5 **Change Over the Day of Number of Events of Over L_{Amax} 60, 65 and 70 for a Specific Location, Adapted from Heathrow Airport Ltd, 2018**

5.5 Summary

This chapter has discussed the historical use of traditional aircraft sound level metrics, for their original purpose, and within engagement and communication attempts. It has been seen that standardised metrics and indicators discussed, are useful for regulatory and strategic assessment purposes. When used for engagement purposes with communities however, the degree of understanding required may be much greater. It is now widely accepted that the expectation put on the layperson to be able to understand and interpret historical descriptors of this nature, has led to aircraft noise communication being labelled as unhelpful, lacking transparency, and sending the wrong messages; this echoes the issues discussed throughout Chapter 4.

On the other hand, if those residents can be convinced that any decision made, while having adverse effects on them as individuals, has nevertheless been made with the greater good of the whole community in mind, increased understanding and an increased degree of individual acceptance may be possible. Indeed, as Chapter 4 addressed, this is an important application area for effective public engagement, which may fail if presentation materials are overly technical or complicated, or fail to consider the individual objectives and priorities of target audiences; indeed, disaggregated metrics have already gone some way to improving this, but the questions need to be explored of, why is this not enough, and how can these be built on? Given that opinions vary regarding the best combination of metrics per given purpose, it is seemingly likely that the rational selection between combinations should be based upon specific requirements of each.

With this importance for a more comprehensive engagement process now widely acknowledged, pressure to adopt additional or supplementary descriptors has increased, borne not least from issues outlined above in Table 5.1 surrounding conventional metrics. There is a need to consider acoustic input variables, which are not properly accounted for within the standard formulation of L_{Aeq} and L_{Aeq} type metrics and indicators. Given the information now reviewed throughout this chapter, the question must be asked, 'with improved metrics and development of supplementary descriptors, is it enough to just get people to comprehend the information being presented?' If aircraft noise management strategists are trying to positively affect attitudes, and thus lower annoyance, it must surely be concluded that the comprehension that is now (hopefully) achievable, needs to be used in a meaningful way to *further* improve engagement processes.

Consideration of course must be given towards the non-acoustical factors that have been identified as being amenable to influence. Indeed, Chapter 3 recognised for example, malfeasance, lack of trustworthiness, and lack of fairness as key factors needing focus. Chapter 4 however, showed how these factors *have* received such attention through for example, EIA processes, illustrating that whilst there have been developments through the work afforded to disaggregated and consequent improved metrics, there are still many areas for improvement.

Given that the now disaggregated metrics and supplementary descriptors enable actual community experiences to be identified and illustrated, could this add value to peoples' comprehension? Furthermore, through the prospect of being able to enhance such descriptors through communication tools, for example, auralisation and visualisation, is an effective and comprehensible communication process even more achievable? The use of auralisation and visualisation, while seemingly still relatively novel as a communication tool, has been featured increasingly more frequently over the last 5 years; most notably for Heathrow Airport Ltd and HS2 Ltd engagement purposes. Indeed, in order to understand more of the value in such a communication tool, Chapter 7, below explores the evolution of *the SoundLab* – a novel communication tool developed by Ove Arup and Partners Ltd – and its facilitation of the afore mentioned engagement stages.

Chapter 6 Methodology

The research aim and objectives were identified in Chapter One. Chapters 2 - 5 gave a review of relevant literature, and set the scene for the empirical research undertaken. The review of literature revealed the key components relating to human response to noise, and public participation, both of which can be applied to the need for enhanced communication processes and tools in aircraft noise management.

In this chapter, the methods used to achieve the research aim are described. To understand the rationale behind the research design and methods used, there is first a discussion of the philosophical paradigm that frames and guides this study. Links are made to the theoretical framework, which informs the empirical approach adopted. As a convenient recap, these theoretical underpinnings are captured and summarised in an illustrative framework, below (Figure 6.1). Through reviewing the strengths and weaknesses of the data collection methods and analytical techniques used, the chapter demonstrates how the objectives are achieved.

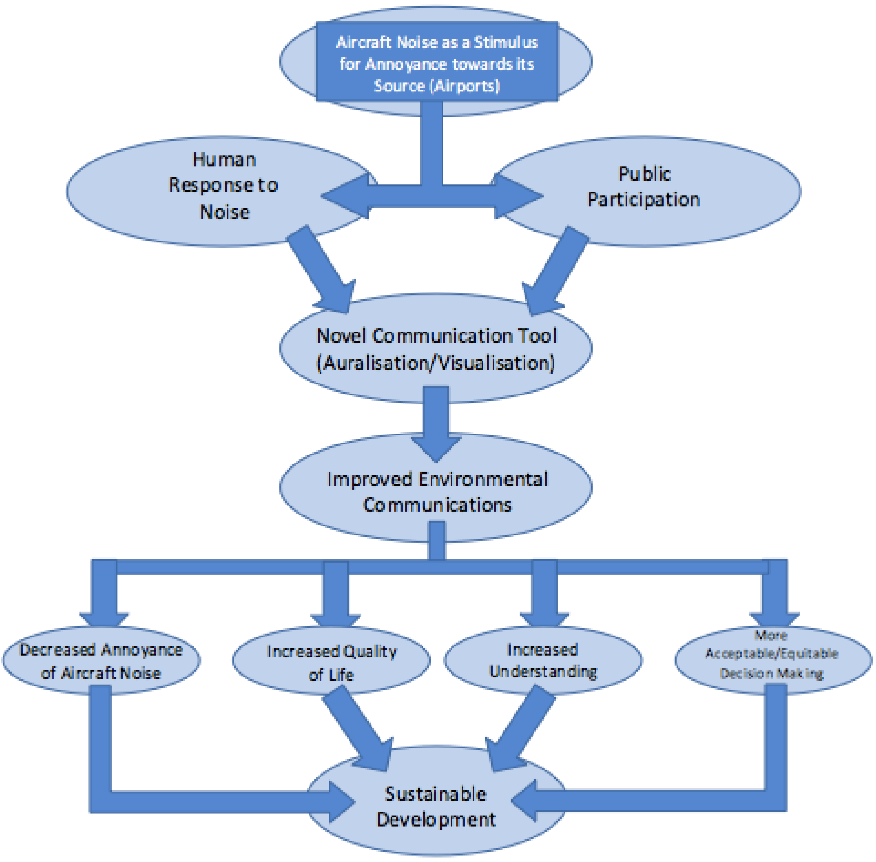


Figure 6.1 Non-acoustical approach to improved environmental communications

Figure 6.1 highlights that the efforts towards improved environmental communication are founded in the fundamental goal of achieving sustainable development. The relationship between a novel understanding of both human response to noise and a robust engagement process and the notion surrounding public participation, gives rise to improving environmental communications between airports and their surrounding communities. In doing so it is thought that some core goals of aircraft noise management can be achieved. Furthermore, it provides a framework against which the novel communication process can be assessed in determining its effectiveness in response to the challenge set within this research aim. This chapter therefore will explore and justify the research methods applied to recent utility, and future potential, of the engagement process through a series of phases.

6.1 Philosophical Paradigm

Sometimes referred to as a *world-view*, a philosophical paradigm denotes a collection of beliefs that guide a researcher's actions (Creswell, 2009). This set of beliefs is underpinned by 5 distinct orientations that act as a framework through which the paradigm guides the researcher (Guba and Lincoln, 1994). These 5 orientations – methods, logic, epistemology, ontology, and axiology – are shown below in Figure 6.2.

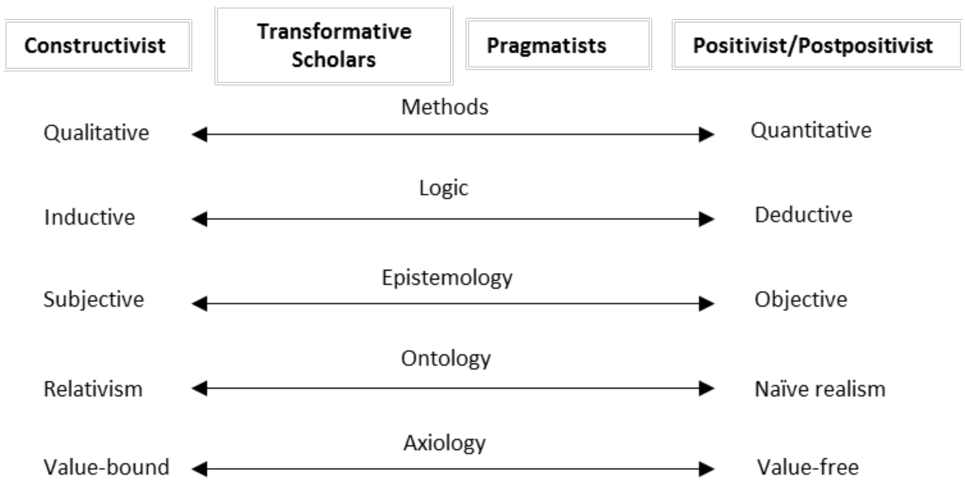


Figure 6.2 Spectrum of philosophical orientations, Adapted from Teddlie and Tashakkori (2009)

Whilst referring to their original version of Figure 6.2, Teddlie and Tashakkori (2009:94) discuss a "*continua* of philosophical considerations" as being a more accurate representation of a researcher's philosophical stance, to "dichotomous distinctions". Figure 6.2 therefore, depicts the four distinct paradigms as a spectrum, suggesting that actually an infinite number of paradigms could be possible. Robson (1993:291) advocates against researchers having to be "prisoners of a particular research method or technique", and indeed this speaks to the paradigm stance of this thesis well; whilst many tenets of the constructivist paradigm are fundamental to this research, there are also elements that stretch the first half of the spectrum through to pragmatism, particularly focusing towards community specific underpinnings of the transformative paradigm, and further, adopting a degree of the mixed methods orientation more analogous to the pragmatists paradigm.

The social constructivist viewpoint dictates that individuals seek understanding of the world in which they live and work (Crotty, 1998) and, in doing so, construct their own world-view – or philosophical paradigm (Creswell, 2014). The social constructivist world-view particularly resonates with research of a social science nature, often relying upon the viewpoints of participants as they develop subjective meanings of their experiences (Creswell, 2014); the transformative view actively aligns with this, as it involves "community members in the initial discussions of the research focus", through for example, focus groups, interviews, surveys, and threaded discussions (Mertens, 2007:212). Equally, the social constructivist looks to gain a wider knowledge of the settings and lives of a research participant, and applies this to the analytical context (Charmaz, 2014). Indeed, such a study would not be warranted if individuals did not have a view (founded in social context) of aircraft noise in the first place, (Creswell, 1999). Equally, if individuals did not seek understanding of "what's in it for me" they would not actively take part in the engagement process (Mertens, 1998).

The constructivist researcher is aware that participants' own experiences and backgrounds can have an impact on the research (Johnson and Onwuegbuzie, 2004). As such, multiple, subjective realities are socially constructed and therefore not discovered through strict, scientific methods (Mertens, 2007). This is of course the core of social science, and indeed one of the fundamental reasons that a more constructivist/transformative paradigm is adopted for this thesis. Furthermore, the notion of multiple and subjective realities, echoes the characteristics of the *relativist* view. With this in mind, it has been deemed imperative that whilst a test that investigates the point at which participants discern a sound level change (the final case study on Respite, see Section 7.4), the empirical work, the notion of human variability and subjectivity must be explored. It is for this reason, the empirical research found in Chapter 8, looks to understand the extent to which (if any) a visual stimulus impacts participants' perception of a sound source. After all, one person's reality can vary significantly to that of their neighbour (in home or SoundLab).

6.1.1 Epistemological and Ontological Stance

At the heart of Greek thinking was the relationship between reality and perception (ed. McKenzie et al, 1997), a foundation that led *The Academy's*[21] philosophers to study the process of knowledge formation and understanding the reasoning mind, termed as *epistemology* (ed. McKenzie et al, 1997). While epistemology regards the objectivity or subjectivity of facts however, ontology is also important to acknowledge in tandem as it more fundamentally regards the existence of facts and objects. The philosophical relationship between reality and perception is entirely appropriate to this study, given the extensive discussion of perception and interpretation impacting the human response to sound throughout Chapter 3. Both ontological and epistemological theory therefore is necessary to informing the choice of research methods *within,* and indeed their application and interpretation *of*, social science studies. Inherent to the constructivist, and to a large extent, the transformative paradigm is the orientation of the ontological *relativist* view. This is of course – and inline with the paradigm continuum in Figure 6.2, above – epistemologically subjective in nature.

[21] School founded by Plato in c.387BC in Athens; attended by great philosophers including Aristotle, Socrates, Archimedes

As mentioned above, relativism suggests the acknowledgement of "multiple realities having multiple meanings, with findings that are observer dependent" (Yin, 2014:17). When applied to this study, relativism reflects the non-acoustic factors influencing individual perceptions and therefore the impact of aircraft noise upon each individual. The *relativist* perspective denotes reality to be 'multiple and relative', a function of context as well as absolutes (Hooper, 2013); knowledge subjectively gained by individuals is 'socially constructed' from contextual surroundings and situations, rather than being objectively determined and perceived (generalised without context).

Aligned with the community focus and guided by aspects of social justice (Teddlie and Tashakkori, 2009), the principles of the transformative paradigm is evident here; within this study, dependency on the local airport for jobs and, therefore, income can considerably increase a household's tolerance of the aircraft noise generated by airport activity (Porter et al, 2015). Equally, the context of location could well contribute towards tolerance/annoyance levels to aircraft noise; for example, a house in a quieter setting may be more aware of the noise of an aircraft to that experienced in a busy city centre environment. This, again, reinforces the concept that an individual's perception, built on their surroundings and life context, facilitates a personal view of aircraft noise, *relative* to their situation. This is explored further in Chapter 3.

As highlighted, the relativist viewpoint adapts a more flexible and personal research approach, which Crotty (1998) suggests is conducive to capturing the meaning of human interaction and decodes what is perceived as their reality. The real-life context of this study and the anthropocentric nature of the issue being addressed, dictates that varying perspectives of different participants will likely emerge due to fundamental human variability and interpretation (see Chapter 3). It is here that the stretch along the paradigm continuum (Figure 6.2), from a constructivist-transformative viewpoint towards a pragmatic stance becomes evident. After all, Kuhn (1962:23) described the pragmatist paradigm as, "a deeper philosophical position relating to the nature of social phenomena and social structures". To this end, Feilzer (2012:9) summarises how she deduces pragmatism has evolved (citing, Creswell and Plano Clark, 2007; Dewey, 1925, Rorty, 1999):

“Pragmatism, when regarded as an alternative paradigm, sidesteps contentious issues of truth and reality, accepts, philosophically, that there are singular and multiple realities that are open to empirical inquiry and orients itself toward solving practical problems in the “real world”.”

From this more open-minded pragmatic approach, and indeed the centre-left constructivist-transformative-pragmatist approach, the researcher is “free of mental and practical constraints imposed by the forced choice dichotomy between positivism and constructivism” (Creswell and Plano Clark, 2007:27). More simply put, through the identification of this more modernised approach, the researcher is free to use the method(s) most suited to the research aim. Teddlie and Tashakkori (2009) believe that it is actually more important to prioritise the research question over a rigid paradigmatic view. This school of thought seemingly adds weight to the researchers nod to all of the three paradigms in approaching this research. Furthermore, the centre-left pragmatic viewpoint seamlessly guides the researcher to what could indeed be described as a more centre-left spin on a mixed methods approach. This is discussed further in the following section.

6.2 Mixed Methods Research

With the acknowledgement of a more modernised pragmatic approach, leaving the researcher more open to explore the research method most suited to the aim, a combination of both qualitative and quantitative methods have been employed. This class of research, where the two methods are mixed in to one single study, is often termed ‘mixed methods’ (Yin, 2009; Johnson and Onwuegbuzie, 2014).

While both methods are used, they do not necessarily have to be used to an equal extent in order to denote a mixed methods approach. Just as the ‘centre-left’ paradigm has been adopted and applied thus far, the mixed methods approach to this study could *also* be described as a somewhat ‘centre-left’ approach. To understand this notion, Figure 6.3 illustrates a similar continuum to that seen in Figure 6.2, above; indeed, it echoes the same continuum principles to that of the philosophical paradigms: where the constructivist paradigm erred fully towards the use of qualitative methods, the post-positivist paradigm had the direct opposite principles, advocating full use of quantitative methods. As can be seen here in Figure 6.3, the mixed use of the two data collection foci again appears on a continuum, relative to the paradigmatic stance (Teddlie and Tashakkori, 2009).

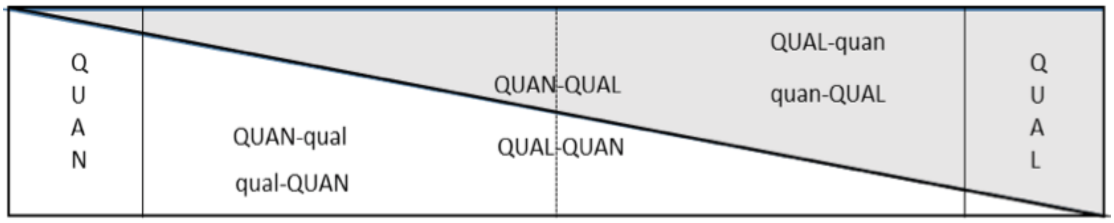


Figure 6.3 **Mixed Methods as a Continuum of QUAN (quantitative) and QUAL (Qualitative) Integration, Adapted from Teddlie and Tashakkori (2009)**

This research requires an in-depth understanding of the human response to noise, stakeholder engagement, and the use to date of aircraft noise metrics, necessitating methods, which facilitate more nuanced insights to be developed. Thus, under the same constructivist-transformative-pragmatic paradigm (centre-left), a qualitative-heavy (QUAL-quan) approach to data collection was employed; this allowed for varying viewpoints to be garnered necessary to this study.

6.2.1 Methodological Approach

The case study method is the principal methodological approach for this thesis, one that is said to be a core empirical inquiry method. The case study method "investigates a contemporary phenomenon within its real-life context" and, in particular, at a time when "the boundaries between phenomenon and context are not clearly evident" (Yin, 2009: 18). The purpose of the case study approach within this thesis is to highlight the novel utilisation of an existing phenomenon (Arup's SoundLab), and its evolution throughout varying scenarios – 3 stages (or cases) in total. The rationale for exploring each case individually was to gather an up-close understanding "of a single or small number of 'cases' set in their real-world contexts

(Bromley, 1986:1; Yin, 2009), with each case aiming “to examine a complementary facet of the main research question” (Yin, 2009:8).

Whereas the reader of this research study could be forgiven for thinking that the phenomenon here is aircraft noise, it is actually the use of auralisation and visualisation as a communication tool that is explored in terms of the extent to which it can increase comprehensibility, and indeed the extent to which it can impact human perception of one stimuli through introducing a second. This reflects the findings that in order for a more effective engagement process can take place; the community member must first be able to understand the information being provided. This also reflects the finding however, that in order for this more accessible information to be provided, airports must first find a means to understand the true causal factors of annoyance. These points of consideration are discussed in Chapters 3 and 4.

Indeed, there is no ‘real-life context’ per se in which the phenomenon of auralisation and visualisation as a communication tool can be used, as the very nature of the tool is such that it *simulates* context. However, for the organisations using this technological ‘phenomenon’ in an attempt to ‘solve’ a communication problem, this is undeniably a part of their ‘real-life context’ whereby there is hope that it will explain previously misunderstood situations and thereby go some way to helping their attempts to enter into effective dialogue. This echoes Yin’s description of the “boundaries [not being] clearly evident” (2009: 18).

Borne in mind that within this multiple-case design the 3 sequential cases span the one chapter to form an evolutionary picture of the SoundLab’s use, a lesser-used method of the *embedded* case studies approach is used. To best understand this approach, Yin (2009) provides a useful summative illustration, shown below (Figure 6.4). In accordance with Figured 6.4, this thesis takes on the form of the ‘embedded, single-case design’ (bottom left). This particular research however, has *three* embedded units of analysis, rather than the 2 show in the example: HS2 Ltd, Heathrow Insulation project, Heathrow Respite project.

Moreover, this research uses the *replication* approach, whereby all three cases test the same conditions (Yin, 2012), i.e. Arup's SoundLab technology; intentionally mimicking the same principle used across all cases (*direct replication*) (Hersen and Barlow, 1976). It is the outcome of the tool design relative to each consultancy brief that is monitored. Indeed, Yin (2009:18) suggests that this invaluable, deeper understanding of the cases will hopefully provide "new learning about real-world behaviour and its meaning".

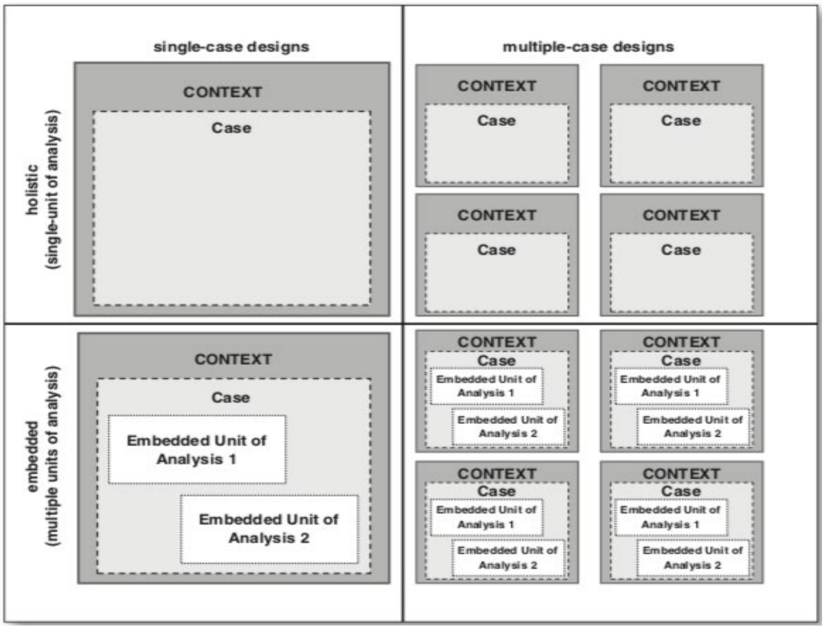


Figure 6.4 Basic Types of Designs for Case Studies, Adapted from Yin (2009)

6.2.2 Adopting the QUAL-quan Method

The methodological approach to this research takes the form of embedded case studies. In a similar manner, the *design* of this research is an embedded one. The *Embedded Design* "mixes the different data sets at the design level, with one type of data being embedded within a methodology framed by the other data type" (Caracelli and Greene, 1997, cited in Creswell, 2006:68). The Embedded Design method includes both quantitative and qualitative data with one of the data types taking on a 'supplemental role' within the overall design.

In methodological design terms, this study proves to be a relatively complex one. Whilst taking on the principles of a phenomenology design (Creswell, 2006, see

Figure 6.5), however, for the latter stage of research (the experiment, found in Chapter 8), an *experimental design* is used. Simply put, the quantitative and qualitative data are used to answer different questions within the study. Where the *embedded case studies* methodology forms the first data gathering design (Chapter 7), a quantitative data collection is embedded within the third 'embedded case'. The *experiment* is then conceptually designed and carried out by the researcher (Chapter 8); a stage that is predominantly quantitative in approach, but has a qualitative data collection step embedded. The two-phase approach (Hanson et al, 2005), in which these two designs are joined, is depicted below in Figure 6.5.

Schramm (1971:21) stated, a case study attempts to 'clarify a decision or set of decisions: why they were taken, how they were implemented, and with what result'. It can be seen in Figure 6.5 that a *sequential* approach has been taken, where the qualitative information has been gathered before the experiment (quantitative) through the embedded case studies, to *shape* the experiment (Crewell, Plano Clark et al, 2003; Teddlie and Tashakkori, 2009). This set of 'decisions' (Schramm, 1971) gathered from each sequential case (Chapter 7) forms the framework by which to explore the evolution of Arup's SoundLab in Chapter 8.

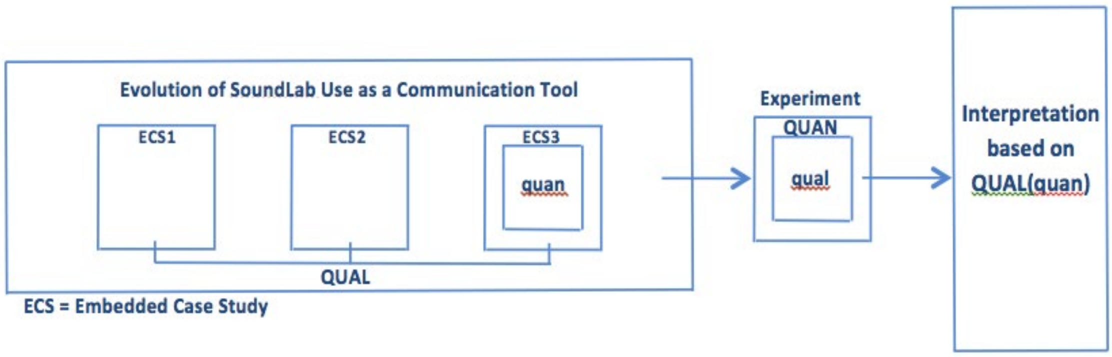


Figure 6.5 Mixed Methods Design: Embedded, two-phase, sequential Approach, Adapted from Creswell, Plano Clark et al, 2003; Hanson et al, 2005; Creswell, 2006; Teddlie and Tashakkori, 2009

6.3 Grounded Theory

Given the weighting of this study's mixed methods largely towards a qualitative approach, *Grounded Theory* is employed as lens through which to conduct its research. The Grounded Theory Method is a qualitative method used to systematically analyse large bodies of text, to construct theoretical models that are ‘grounded’ in the text (Corbin and Strauss, 1990). It is performed by reading texts with specific questions in mind, coding passages using key words as answers emerge, and using the keywords to sort quotes into themes from which theory can be derived (Reed, 2008).

The fundamental characteristic of this research study is that it is set in real-life context and so the aim and objectives, whilst establishing the frame of reference and informing the selection of methodology and data acquisition techniques, must be flexibly applied to allow evolution over time (Yin, 2009:129). The context in which they occur, and the perspectives of individuals are important to the broad underpinning of this research. An interpretive grounded theory approach is taken therefore, building theory from evidence in an iterative process.

Grounded Theory is a general research method and thus does not belong to any one school or discipline (McCallin, 2010), however its approach to engaging in data collection and analysis simultaneously in an iterative process, proves extremely conducive to research that combines a social science study with a scientific phenomenon (Charmaz & Bryant, 2009:292). Indeed, in the last of the 3 embedded case studies (Chapter 7), a quantitative element was seen. Whilst this data was used as part of the collection and analysis and therefore does of course need to be recognised as such, it was actually *embedded within* a qualitative exploration of the case. It is for this reason that reflection and interpretation of its impact was still very much of a qualitative nature (Section 6.2).

Using comparative methods, grounded theory fosters the analysis of actions and processes rather than themes and topics. In analysing actions, grounded theorists code the collected data for actions and evaluate how these actions “might contribute to the fundamental processes occurring in the …research participants’ lives” (Silverman, 2014:123). Allied with the constructivist-transformative, centre-left philosophical stance on the paradigm continuum (Section 6.1) – being driven by social injustice – this echoes the research focus of this study on aircraft noise as it affects the daily lives of neighbouring airport communities. Analysing ‘actions’ in this context relates to attitudinal human responses to aircraft noise, and whether or not with effective communication, this can be improved/modified. This anthropocentric, observatory technique is fundamental to the grounded theory method; by understanding the statements and actions of a participant, a grounded theorist has a clearer focus of the data to be collected (Charmaz, 2014).

6.3.1 Coding

At the heart of the grounded theory method is the process of coding data that is collected; the breaking down of various forms of data into distinct units of meaning and attaching labels to them that denote what each is about in order to generate concepts (Goulding, 2002; Charmaz, 2014). The collected data must be coded *whilst* being analysed and in order to *further* analyse the categories depicted through coding. Categories begin to emerge as data is collected and interpreted. Coding generates analytical questions from the beginning of the research. Through re-evaluation of descriptive categories and through a series of progressive, sequential analytical steps, the categories become more theoretical through the identification of emergent and underlying core themes (Goulding, 2002).

By distilling and sorting the data, the process of coding deduces an "analytical handle for making comparisons with other segments" (Charmaz, 2014:4). As more categories emerge, analysis can begin *between* the categories in a process of *cross-segmental analysis*; the relationships found between these analytical categories provide the conceptual framework for the study (Charmaz, 2014).

6.4 Case Study Selection

The systematic analysis principles of grounded theory align with the sequential format of the embedded case studies of Chapter 7. The three studies have been chosen in a bid to gain understanding of the use of SoundLab as a communication tool to date. The first two cases – HS2 Ltd, and Heathrow insulation scheme – are less aligned with the research aim than the third. HS2 (high speed rail) is a different form of transport, and as a result there are many fundamental differences to emerge in the use of SoundLab simply as a function of their inherently different form, a key example being the visual context of ground versus sky as a background. The Heathrow insulation scheme SoundLab demonstrations were created only as a means of showcasing a prototype to few elite stakeholders. When it came to the researcher studying this as a means of knowledge contribution towards a larger aim, there was a lack of access to retrospective participants, i.e. government officials no longer in office, which meant that only information surrounding the development of the tool itself could be gathered through Arup consultants that had been involved at the time, rather than being able to incorporate feedback and opinions, and official documentation.

The Heathrow respite study however, followed the process of developing a SoundLab based tool for the purpose of in-depth trials used for key data gathering that formed the heart of the study. The researcher was either involved in, or had access to much of the full process. The limitations set against the first two studies then, dictate that these only be used as *exploratory scoping* means; a form of knowledge synthesis aimed at mapping key concepts that build to inform a wider experiment (O'Brien et at al, 2016).

6.5 Data Collection Methods

The notion of complex reasoning dictates that building patterns, categories and themes from the "bottom up" allows for increasingly more units of information (Creswell, 2013:45). This process, known as *inductive logic* forms the basis for the grounded theory method as it relies on iterative strategies; the researcher works back and forth between research and database studying the early data, beginning to separate, sort, synthesise and code until a complex set of themes is established. Through using this process in a cyclical manner throughout the study, grounded theory methods have indeed helped the researcher to "direct, manage and streamline" the data being collected (Scott, 1997 ed. McKenzie et al, 1997; Creswell, 2013).

Effectively, the three sequential embedded case studies are separate cases of auralisation and visualisation being used as a communication tool that the researcher is looking to explore. This follows the “systematic, grounded theory guidelines” for data collection and analysis as described by Charmaz (2014:98). It is suggested that, by outlining flexible guidelines, the grounded theory method enables the researcher to construct theories *from* the data (observations, interactions, materials gathered), resulting in an overarching theory grounded *in* the data (Charmaz, 2014).

6.5.1 The Two-Fold Definition

A twofold definition of a case study consists of both the *scope* of a case study, and the *features* of a case study (Yin, 2014:16-17). Fundamentally, the twofold definition shows how case study research comprises an “all-encompassing method” (Yin, 2014:17), covering the logic of design, data collection techniques and specific approaches to data analysis, embracing potentially more than one philosophical view. Section 6.1 identified this to be the case, where continua of constructivist-transformative-pragmatist viewpoints aligned against the values of this study. The relatable tenets of a twofold definition approach to this particular research project are outlined in Table 6.1, below.

Within such a delicate real-world case, the information communicated through auralisation and visualisation needs to be individually tailored per contextual condition pertinent to each case (Yin & Davis, 2007).

Methodological characteristics relevant to a twofold definition approach	Thesis characteristics
An empirical inquiry that investigates a contemporary phenomenon (the "case") in depth and within its real-world context	The phenomenon at the heart of this research is auralisation/visualisation, and how useful it is as a contribution to a communication process…
…Especially when the boundaries between phenomenon and context may not be clearly evident	…Acknowledging that a laboratory setting cannot replicate real world experiences, and so focusing on a specific context of aircraft noise scenarios per case.
Copes with the technically distinctive situation in which there will be many more variables of interest than data points, all of which are found in just one result	Both acoustic and non-acoustic variables, and both audio/visual perception and discernibility data points to consider
Relies on multiple sources of evidence, with data needing to converge in a triangulation fashion, and as another result	Triangulating data collection methods including document analysis, in-depth interviews, participant-observations and statistical analysis, and triangulation between examples of application of the technology (between the cases), provide context-rich results over one-dimensional data collection.
Benefits from the prior development of theoretical propositions to guide data collection and analysis	Theoretical frameworks* developed from literature review prior to empirical research, whilst researcher also adheres to Grounded Theory principles.

Table 6.1 **Methodological Characteristics of a Twofold Approach, Relative to this Thesis, Adapted from Yin (2014: 17)**

Table 6.2 lays out the strengths and weaknesses of varying evidence sources (data collection methods) used throughout the data collection stage of any given research, noted by both Yin (2009) and Grant (2014). The methods used and the strengths and weaknesses appropriate to this study have been highlighted here in **bold red text**.

Sources of Evidence	Strengths	Weaknesses
Documentation	**Stable – can be reviewed repeatedly**	**Access – problems of confidentiality in many organisations**
	Unobtrusive – not created as a result of the case study	Reporting bias – reflects (unknown) bias of document author
	Exact – contains precise details of names, positions, events	
	Broad coverage – long span of time, events and settings	
Archival records	(Same as above for documentation)	(Same as above for documentation)
	Precise and quantitative	
Interviews	**Targeted – focus directly on case study topic**	**Danger of bias due to poor recall**
		Reflexivity – interviewee gives interviewer wants to hear
Direct observation	Reality – covers events in real time	Time-consuming and costly
	Contextual – covers context of events	Narrow focus – unless broad coverage
		Reflexivity – event may proceed differently because it is being observed
Participant observation	**(Same as for direct observation)**	(Same as for direct observation)
	Insightful into interpersonal behaviour and motives	**Bias because investigator unwittingly manipulates events**
Physical artifacts	Insightful into cultural features and technical operations	Selectivity – may be based upon idiosyncratic choices

Table 6.2 Strengths and Weaknesses of Evidence Sources, Adapted from Yin, 2009; Grant, 2014

6.5.2 Literature Review

The process of a literature review scrutinises existing literature surrounding the topic in preparation for beginning the research process (Gomm, 2009). With this in mind, objectives 1 to 3 have been achieved through reviewing literature inclusive of academic journal papers, conference papers, NGO roadmaps and industry guidelines, governmental sources and reports produced from previous consultation projects. Chapters 1 to 5 examine the above forms of literature addressing sustainability, the aviation industry, human response to noise, communications and engagement, and supplementary metrics of aviation noise. This review of the relevant literature serves as a framework for the grounded theory approach to exploring how Arup's SoundLab has evolved as a communication tool; done through a sequential, three stage embedded case study approach.

6.5.3 Document Analysis

Document analysis was used to achieve objectives 1 – 3, used in both the literature review and case study research. Academic literature provides a vast and credible body of information, upon which the literature review that frames this study is founded. However, due to the nature of this thesis topic, and the rapid evolution of the aviation industry, relevant and up to date information can only be gathered through official documentation such as airport Noise Action Plans, NGO Noise Road Maps, governmental reports, White Papers from core aviation organisations and aviation regulators, the CAA. The mix of academic literature and varied documentation ensures quality control of an increasingly prevalent, yet relatively, new and ever-evolving issue.

6.5.4 Interviews

"The interview is probably the most widely employed method in qualitative research" (Bryman, 2012: 469). Semi-structured interviews were central to all phases of this study. The first of the embedded case studies utilised the interview method in a retrospective manner, seeking knowledge of the rationale, process and refinements of the HS2 public engagement events using Arup's portable auralisation and visualisation tool, the SoundBooths. Due to the retrospective nature of the majority of these events, but also the highly politically sensitive stature of any public participation event happening at the time of data collection, the researcher only had permission to conduct elite interviews rather than gather any public feedback.

The second embedded case study also studied a retrospective case, meaning that only interviews with key actors of the Arup design and acoustics teams were possible. Whilst there was no public engagement involved in these particular demonstrations, there were a number of stakeholders involved, however were either not contactable, or previous members of government that had left their post or were no longer in office.

As outlined earlier (Section 6.2.1), the researcher was able to get involved in several stages of the third embedded case study. The focus for interview material for this case study, however, did not necessarily require the view of consultants and developers; due to the progressive nature of the overarching research through the case study phases, the focus here was on the opinion of the participants for Heathrow's respite study.

Section 6.5 addressed the importance of using data collection techniques to maintain open topics and conversations with participants. As Gomm (2008:240) states "(t)he qualitative interview is regarded as an important facility for forming relationships between interviewer and interviewee and for allowing the interviewee's ideas and understandings to be articulated without being distorted by a more structured framework". It is in this context that the researcher chose semi-structured techniques to guide the interviews, but not so rigidly that the interviewee had no room to elaborate on any valuable information. After all, constructivist perspectives frame how interviews proceed, thus language and meaning must be considered (Gray, 2004). As this research follows a constructivist-based paradigm, the researcher relies on the viewpoint of the interviewee and, therefore, must ensure enough leeway to allow development of subjective opinions of their experience (Creswell, 2014).

By employing the grounded theory method for this study's data collection, the interview data gathered from using an open-ended and participant-centred style of interviews as part of the semi-structured technique, helped shift the potentially formal feel into mutual conversation about theoretical categories (Charmaz, 2014). This was true for both the community participant interviews and the elite interviews; by employing these techniques, the researcher could learn how community participants, in the respite trial interviews in particular, make sense of their experiences, and through memo writing and analysis, made analytical sense of their meaning and action (Charmaz, 2014).

6.5.4.1 Employing the Delphi Technique

A key feature of the case study is its flexibility (Gray, 2014) meaning that multiple data collection sources can be used, but also that “controlled opportunism” (Eisenhardt, 1989: 539) or, additional techniques can be added in, if and when required. The researcher took advantage of such flexibility and applied the use of the *delphi technique*, referring to an individual or group of people who are either involved or interested in the research topic to generate and select a more specific research idea (Saunders et al, 2009:590). Whilst involved in the SoundLab demonstrations of Phase Three – the Case Study of Heathrow Ltd Respite Trials, the researcher found that as part of continued efforts to maintain relations with opposition groups, Heathrow had invited the leader of HACAN[22] (Heathrow Association for the Control of Aircraft Noise), John Stewart, to participate in the SoundLab experiment. The researcher took the opportunity here to interview John Stewart under the Delphi technique, not only directly related to the experiment at the time, but also regarding John’s views on aircraft noise and environmental communications in general. The details of this interview can be found as part of Chapter 7.

6.5.5 Questionnaire Data Collection

Questionnaire data collection was carried out in both the latter case study of Chapter 7, and the experiment in Chapter 8. In the final embedded case study, participants of the SoundLab demonstrations were asked to determine the discernible decibel difference. Throughout each listening demonstration, participants were asked to follow and mark a question sheet to give feedback on what they were hearing. Further to the SoundLab demonstrations, participants were also asked reflective questions outside of the demonstration in a semi-structured

[22] HACAN is Heathrow Airport’s largest and most notable opposition group. Leader, John Stewart has forged solid relations with Heathrow over the years, in order that rational and congruent goals can be worked towards

interview format. The questionnaire method within the experiment stage followed a similar method.

The third embedded case study included questions surrounding the quantitative element of the respite study, although it must be highlighted that this was a reflection of its value rather than direct quantitative data collection itself. In order to set this investigation into context, it is important to understand what that core research was aiming to do. Therefore, the researcher must look at the research conducted as part of the respite study as a phenomenon in its own right, discuss it and its quantitative elements, and collect and analyse participant questionnaires as a qualitative method.

Assessing and deciding the scope of the survey was deemed imperative for the experiment (Gray, 2014), despite guidelines having already been set by the afore used survey questions that had been determined by the research consultants of the Respite Working Group (RWG)[23]. The empirical experiment carried out by the researcher was intended and therefore designed as a continuation of the embedded case study. In line with the grounded theory method, each case study of this research has been a systematic reflection and continuation of the effort to satisfy the research aim. Through each sequential stage, the narrowed research focus became clearer, and from the third case study it was felt that the need to explore (through empirical work) the impact visual information has on the perception of audio information was both logical and essential in being able to meet the research aim. For this reason, the survey questions and format had to echo that of the Respite study.

Conducting qualitative analysis alongside the quantitative data collection allows opportunity to identify the extent to which it was possible to use the technique to ascertain changes in the dB levels of sound recording that respondents were able to classify as significant. Such research has the potential to provide policy makers with

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[23] Heathrow Airport appointed and funded the Respite Working Group in 2014, made up of Anderson Acoustics, SYSTRA, and Arup.

objective rationale for the design of operational regimes than can work to benefit both airport and communities.

6.6 Ethics

The nature of data collected as part of a social science study, and in case study form, means that what a researcher is able to do and ask within the setting depends on how the participants identify with and know the researcher; this highlights how the conditions set by the researcher can influence the outcome (Charmaz, 2014). As the overall rationale for this study is to try and improve environmental communications between two groups, the researcher must tread carefully in not appearing to be on either 'side' and remain fully impartial at all stages. As a fundamental part of the empirical research design for the experiments carried out and documented in Chapters 7 and 8, the researcher had to carry out a rigorous ethics process that was then submitted for validation and acceptance to the ethics board of Manchester Metropolitan University. Further details of this are given in Chapter 7, and appropriate documents attached as a part of Appendix 3.0.

6.7 Summary

This chapter has described the methodological approach employed. It set out the techniques adopted and the reasons for doing so, as well as the way in which they complement each other, i.e. the sequential case studies that act as context setting for the empirical SoundLab experiment. The combination of an innovative approach to communication and engagement, and the complementary grounded theory framework, have facilitated the development of more nuanced understandings of people's response to aviation noise. The following chapters build on this methodological context and seek to explore the extent to which the use of auralisation and visualisation can facilitate improvement of communications and therefore relations between airports and their neighbouring communities in the context of technical information surrounding aircraft noise – if indeed at all.

Chapter 7 Evolution of Arup's SoundLab as a Communication Tool

7.0 Introduction

Chapter 1 outlined the aim and objectives of this research, while Chapters 2 – 5 identified key literature and the gaps in knowledge to justify this focus. Chapter 6 then, introduced the theoretical underpinnings of the methodology of the research reported in this chapter. From these underpinnings, this Chapter now addresses Objective 3, in evaluating the contribution of enhanced auralisation and visualisation to noise communication, designed to improve comprehension and thereby facilitate more effective stakeholder engagement. It utilises a case study approach to analyse the progress of Arup's inaugural use of auralisation and visualisation – in the form of their SoundLab – as a communication tool, and the technological developments that evolve. It is worth emphasising at this point that this is the first of *sequence of case studies* that were designed to track the development and utilisation of the SoundLab as a communication tool; the three embedded studies examine the technology and its deployment by:

- HS2 Ltd – Public Engagement Road Shows (herein known as 'HS2')
- Heathrow Airport Ltd – Insulation Scheme (herein known as 'Insulation')
- Heathrow Airport Ltd – Respite Trials (herein known as 'Respite')

As outlined in Chapter 6, the case studies are of an embedded nature as each serve as only an element of the overall evolution of Arup's SoundLab in its capacity as a communication tool. The 3 studies are explored in chronological order so that a logical picture can be formed of the progress of the tool through time; hence the *sequential* form. The embedded case study approach utilised in-depth semi-structured interview data to gather organisational insights into the value-added (or lack there of) in the operational management of noise communication in public-impacting plans. Where the researcher was afforded the opportunity to actively contribute to the process of the Respite trials in Case Study 3, the in-depth interview data was utilised in the analysis of public participant opinions of the contribution of SoundLab technology to improving (or otherwise) comprehension of noise related information. This chapter also explores the employment of SoundLab as a comprehension tool to facilitate key data gathering, for example in the final case study exploring the respite research for Heathrow Airport; the SoundLab was used as an experimental tool. The point at which participants were able to discern a sound level change was investigated, and in doing so the experiment saw the SoundLab's auralisation and visualisation technology facilitate the listening tests.

Much of the information gathered was intended to provide insight into how SoundLab came to be used in such a novel way; the design, implementation and evolution of that use, and indeed how SoundLab in its new guise (as a communication tool in public consultation) enhanced (or otherwise) the public engagement process. It must be noted here that, while factual, technical and procedural information can be gathered through tangible methods, such as document analysis for example, the real means of how a situation came about, the learnings of a new challenge integral to a particular discipline or firm, or the intrinsic experiences of a project evolving, can only be gathered through interviews with the people involved. Where interviews are usually used to corroborate data collection through document analysis or first hand observations then, throughout the first two case studies below (HS2 and Insulation), interviews are the predominant source of data.

For ease of the reader, and anonymity for the interview respondent, Table 7.1 below sets out a list of respondent codes, the company they are a part of, and the position they hold. Names are not given.

Organisation	Respondent	Code
Ove Arup and Partners Ltd.	Director – Environmental Acoustics	A.R.I-1
	Acoustic Consultant	A.R.I-2
	Acoustic Consultant	A.R.I-3
	Acoustic Consultant	A.R.I-4
	Acoustic Consultant	A.R.I-5
HS2 Ltd.	Environmental Manager	H.S.I-1
	Environmental Advisor	H.S.I-2
Heathrow Airport Ltd.	Noise Management Team Representative	H.R.I-1
	Noise Management Team Representative	H.R.I-2
Respite Working Group	Anderson Acoustics Representative	R.W.I-1
	Independent Advisor	R.W.I-2
	SYSTRA Representative	R.W.I-3

Table 7.1 List of Respondents and Assigned Codes

7.1 Ove Arup and Partners Ltd – Developers of SoundLab

Ove Arup and Partners Ltd (Arup) is a consultant-engineering firm, founded in 1946 by Sir Ove Arup in London. Today the firm has around 14,000 partners (staff members), across 35 countries, in 92 offices. Arup now consists of many engineering disciplines including for example, offshore, facades, seismic and acoustical engineers; and is responsible for projects across more that 160 countries (Arup, 2019). The focus of this research is noise impact management (ultimately aircraft noise); it is therefore, Arup's acoustic engineers making this research possible. Notable acoustical projects to date include completion of the Sydney Opera House and Melbourne Recital Centre, with the focus having traditionally been on "beautiful sound in concert halls around the world" (Arup, 2019b). Today, the acoustic design team provides architectural, building, transport and environmental acoustics services, helping to reduce both noise and vibration impacts from airports, highways, and stadiums. Significant domestic projects include Crossrail and HS1 – the UK's high-speed rail Channel Tunnel Connection (Arup, 2012). Arup's acoustic team also use their novel, innovative SoundLab technology (and associated offshoots, for example Soundbooths) to enable clients and designers to "hear the sound of existing spaces, and to test the sound of design" (Arup, 2019a).

The SoundLab is a sound proof anechoic chamber, similar to a recording studio, that utilises auralisation (sound simulations) and visualisation to help clients demonstrate to members of the public and other key stakeholders, the impact that major projects can have in the future. Arup describes its SoundLab as taking a "human-centric view of design to give people objective, quantifiable information in an accessible format […] by making the intangible tangible" (Arup, 2019c); further reinforcing its applicability for demonstrations to the public and other stakeholders.

Figure 7.1 Participants taking part in an experiment in SoundLab, Arup London

7.2 The Use of Rail as a Case Study Topic

This thesis focuses on the adverse impacts of aircraft noise on human response to the sound source (airports) and how management of such impact-response might help towards improving relations between airports and their surrounding communities. It is important therefore, to acknowledge the anomaly of turning to rail for the first of these sequential case studies.

The Aim of this thesis, outlined in Chapter 1 (Section 1.4) is to,

…*critically investigate the potential contribution of a combined audio and visual engagement tool to enhance environmental communications relating to aircraft noise, specifically the impact visualisation has on stakeholder perception of audio stimuli*.

From this aim there is a clear need to focus, not just upon aircraft noise, but also equally upon the combined audio and visual engagement tool in the form of Arup's SoundLab. Whilst Arup have used their SoundLab in consultation with clients for many years, it has been for the purpose of concert hall design, until it's use as an engagement tool for HS2. With the use of SoundLab as an engagement tool in its infancy, and the need of this thesis to chart the evolution of such use, the crossover to a case study on rail noise was deemed a necessity.

Furthermore, the subsequent transposition of the engagement tool across transport modes highlighted some interesting challenges of perception that comes with moving from land to air; visualisation is notably impacted due to the lack of background providing perceptual markers, whilst even more pertinently to this study, is the difference in propagation of sound; "a result of complex scientific calculations of exposure of noise energy over a defined time-period" (Goldschagg, 2013:14). Dimitriu (2007:216) notes, for example, that there are far more factors that make up the propagation of sound for a train than a plane; there are far more "ground properties" (made up of, for example, buildings, traffic, nature, mitigation). Of the fewer properties making up propagation of aircraft sound however, there is more variability. Wind direction and strength for example, have more implications on sound propagation of an aircraft taking flight than that of a train at ground level between houses or shielded by trees or bunding (Fields and Walker, 1982). Allied to such factors of difference, is of course the notion discussed in Chapter 5 of, '*perceived noisiness*', a specific subjective attribute of aircraft noise, which falls between subjective loudness (Kryter, 2013).

The influence of perception on human response to noise has been discussed at length throughout Chapter 3. It is worth reiterating here however, the importance of perception when considering the differences and similarities between rail noise and aircraft noise. The outlining of *hi-fi and lo-fi environments* (Bartle and Schafer, 1977; Schafer, 1999; Truax, 2000; Santuca and Ludovico, 2014) for example, is pertinent here (full discussion can be found in Section 3.1.2). A lo-fi environment is described as a "congestion of sounds" in such environment as a built up city full of buildings and objects that "…abbreviate the facility for distant hearing" (Schafer's, 1994:43). When considering these physical mechanisms of sound and how it travels within varying environments, and the notion of *ground properties* (Dimitriu, 2007), the difference between a hi-fi and lo-fi environment gains further clarity in the reasoning of why aircraft noise (moving above such 'ground properties' once taken off) tends to dictate more annoyance than rail noise (the infrastructure of which is firmly embedded within 'ground properties'). It has of course already been discussed within Chapter 3 (Section 3.2.1) that physical characteristics – the visual landscape – vary considerably from place to place and have strong validity for contributing to the context of auditory perception and thus, annoyance is found to be higher if a sound source can be seen than if it cannot (Lui et al, 2014; Bangjun et al, 2003).

Such contribution of physical characteristics to the context of auditory perception however, is more complex in differentiation of rail to aviation than just whether the vehicle can be seen or not. Railway lines sit amongst landscape and/or 'ground properties' that all create backdrop and field depth perception; context. Whereas an aircraft taking flight, or even more so mid-flight, has little in the way of such backdrop and surrounding landscape to provide such context, giving rise to wider human variability in the perception and interpretation of the flyover. Furthermore, physical mitigation measures such as bunding (Manning and Harris, 2003) are not so easy to apply to an airborne noise source. It is interesting to note here the results of a study carried out by Elmenhorst et al (2019), comparing physiological reactions to the three main sources of transport noise, road, rail and air, through the monitoring of nighttime awakenings from sleep. Miedema and Vos (1998) note that residents tend to feel more annoyed by sound from aircraft, and least annoyed by railway sound, with road traffic impacts between the two. Elmenhorst et al’s (2019) laboratory study using a systematic approach of polysomnographic assessments of sleep structure however, suggests that the impact of each transport mode to be inversed; sleep disturbances increased in the order of air < road < rail.

Whilst there are many differences to be drawn between the varying transport modes and the negative human response they create, there are indeed also parallels. Although varying in levels of annoyance produced by rail and air transport, the non-acoustic factors apparent from both transport modes as causation, are aligned, for example, residents still have fear of train crashes as with aircraft crashes; house prices can be affected by a train line running through a back garden; sleep and educational disturbance through both noise and vibrations.

In such instances that a new train line or indeed alterations to a current route or service may be planned, a combined auralisation and visualisation communication tool such as Arup’s SoundLab might be beneficial in improving communications between the planners and residents. Regardless of the transport mode, the purpose here is to allow people to understand what is creating the current environment, and if there were to be a change to that, what the implications for noise might be.
It is for this reason, along with those outlined through the discussions above, which warrant the need for the study of HS2 Ltd as the first of the sequential case studies for this research. With this in mind, the following sections outline such detail.

7.3 HS2 Ltd

In 2003, High Speed 1 (HS1), then known as the Channel Tunnel Rail Link, was build between London St Pancras and the Channel Tunnel, and in 2007 it was completed on time and on budget (DfT, 2010). In 2009 a second high-speed line, High Speed Two (HS2) was proposed by the then Labour Government to address capacity constraints of the current rail infrastructure, namely on the West Coast Mainline. The initial route proposal was between London and the West Midlands, with extensions from the West Midlands and up through to the North West of England added to the proposals in a later independent study by Network Rail. In March 2010, HS2's report and the Government's Command Paper were published, and later the same year the new Conservative – Liberal Democrat coalition Government confirmed their continued support for the scheme. In December 2010, the then Secretary of State for Transport, Philip Hammond, announced the revised proposed line route (see Figure 7.2, below) in preparation for public consultation beginning in February 2011.

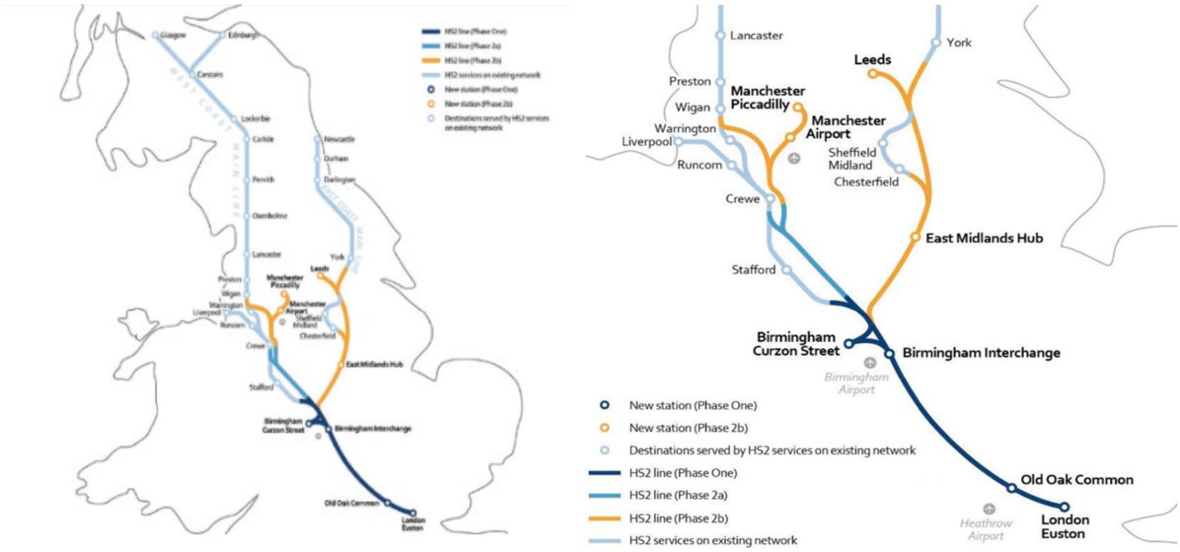

Figure 7.2 **HS2 Ltd Proposed Route, Adapted from BBC, 2019**

7.3.1 HS2 meets Arup SoundLab

During the mid to late 1990's, HS1 (then known as the Channel Tunnel Rail Link) was fully underway, from the planning through to the beginning of construction. During this time an Arup director (A.R.I-1) had been drafted in as an external technical reviewer. When HS2 was first proposed, Arup bid for the first trials of consultancy work, for both the engineering (which included noise and vibration), and the environmental and sustainability tenders; they only won the engineering tender. With roots in both acoustic engineering and environmental planning, the Arup representative was an integral part of the Arup consultancy. By 2009, HS2 Ltd were becoming concerned about the direction of the environmental consultants regarding noise management provision, and in particular the means of engaging with local communities regarding their concerns over noise intrusion; this, along with the relationship built as a trusted advisor throughout the HS1 process, resulted in the Arup representative being called upon by HS2 Ltd.'s Director for Planning as an expert advisor.

From the combination of introducing the idea of HS2 to the public with little foresight for addressing noise concerns alongside the plans, and then a year long silence on the matter between the outgoing Labour government and incoming Coalition Government, noise concerns had grown. The concerns had evolved from "being what it always is, which is a major concern of the communities, to being toxic for HS2. It became toxic because the protest groups within this time gained traction, and carried out long running protests…" (A.R.I-1). The protesting gained so much traction that it managed to attract the attention of prime time BBC television show, Countryfile, which ran a feature segment on a show that ended up becoming misconstrued. The television segment showed protesters travelling around parts of the country with loud speakers on the back of a truck playing train sounds in excess of 100dB (A.R.I-2). Viewers of this came to believe that this was the actual sound played by HS2 Ltd. and the protestors were protesting *around* the train sounds being played. This of course only added further traction to the protesters cause (A.R.I-3).

From observing the ill-informed and therefore inaccurate information gaining a larger platform in the public arena, the key Arup representative (A.R.I-1) came up with the idea of using Arup's SoundLab as a means of providing objective sound demonstrations. Upon reflection of the rationale for suggesting SoundLab in this capacity, the Arup representative interviewed emphasised that, "people aren't scared about the imposition of noise for no reason; because the fact of the matter is big trains *are* noisy. So it was about putting together a series of demonstrations that were honest and transparent, and addressing the fact that, yes there are places for it (HS2) that are going to be a bit difficult, but this [a series of mitigation measures shown as part of the SoundLab demos] is how you could make it better".

The Arup director (A.R.I-1) fought hard to maintain that the demonstrations should always have the visualisation with the auralisation because “all our senses are connected”.
“Practical experience and human nature, and all of our senses [being] connected, proves that you’ve got to link them together when you’re trying to inform somebody to ask them to make an informed decision.”

Arup invited HS2’s then Director of Planning in to the SoundLab to showcase the idea of how it could be used. In late December 2010 Arup were consequently asked to host the Board of Directors for HS2 Ltd., and later the then Transport Secretary, Philip Hammond in January 2011. Following these successful demonstrations the brief was set, and HS2 Ltd. commissioned Arup to design and produce demonstrations using auralisation and visualisation to showcase HS2’s Ltd.’s future visions and plans at public consultation road shows.

7.3.2 Arup’s Methodology

From the date of commissioning, to the first public consultation, the acoustics team at Arup had 4 months to design, model and implement the auralisation and visualisation demonstrations (demos).

Ensuring that the accuracy of the train sound (auralisation) was as close to perfect as a simulation could provide, was the core focus of the initial developments. Whilst the UK already had HS1, the train only runs at the same speed as the planned HS2 (300 kilometres per hour) on part of the track (outside of the City of London, between Thames and Folkestone). Because of this, the trains are not designed to the same specifications as some European trains built exclusively for high-speed use. The sound recordings taken therefore were of the ICE (Inter-City Express) trains in Germany (H.S.I-1). The ambient element of the demos however, was recorded in the UK to accurately represent the prevailing atmosphere and pressure levels (H.S.I-2). The sound data was then gathered, processed and calibrated. The visuals team would later be appointed to design verified visuals (“we didn’t even *know* there was such a thing at that point!”) of specific areas around the proposed HS2 route (depicting various scenarios, i.e. a quiet rural soundscape versus a louder urban soundscape). Up until this point however, only a still street scene would be added to the auralisation (A.R.I-2).

In these first stages there was little consideration of user experience involved, instead the focus was on getting the demos as technically accurate as possible within the limitations of how to play it to the public outside of the actual SoundLab, and moreover, how this was presented; "…[how do you] balance between the very best and probably [relevant to] a small number of people, versus something that is simplified and access[ible] to a larger number of people[?]" (A.R.I.1). Borne from this consideration of mobilising the technology, was the SoundBooth[24]; sound proof booths that could be constructed and de-constructed with ease, i.e. at the start and end of a 12 hour day, that would house an screen so that an individual could enter the booth and hear the auralisation through a set of calibrated headphones (the volume could not be turned up or down). In order that the individual could be guided through the demonstrations, voice-overs had to be added, and text added to the visualisation for clarity of information. Figure 7.3 below gives an early depiction of the visualisation used.

[24] The Soundbooths needed to be deployed at consultation events, a very busy and noisy environment. Specifying and delivering sound-controlled booths was therefore a key focus. We worked closely with Strata to undertake controlled listening tests in our SoundLab™ facility. This included simulating the expected reverberant noise levels from a busy consultation event and using this experience (a purpose-built sound booth for acoustic assessment) to define a required sound insulation performance for the SoundBooth (Arup, 2019)

Figure 7.4 **Screen Capture of an Hs2 Auralisation and Visualisation Demo, from Public Consultation and HS2 Website, respectively, Adapted from HS2 Ltd, 2019**

7.3.3 The Public Consultation Road Shows

7.3.3.1 Consultation Process

The SoundBooths were only one element of the consultation road shows; there were many other information stands, each supported by Arup staff[25] that were either experts of the relevant discipline, or well versed in the information (where such technical or specialist information wasn't required). The experts on hand could provide more in-depth information than could otherwise be gained from literature or websites. Examples of the guidance information banners are seen below in Figure 7.4.

7.5.

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25 Members of the acoustic team who had been drafted in as auralisation and visualisation demonstration experts

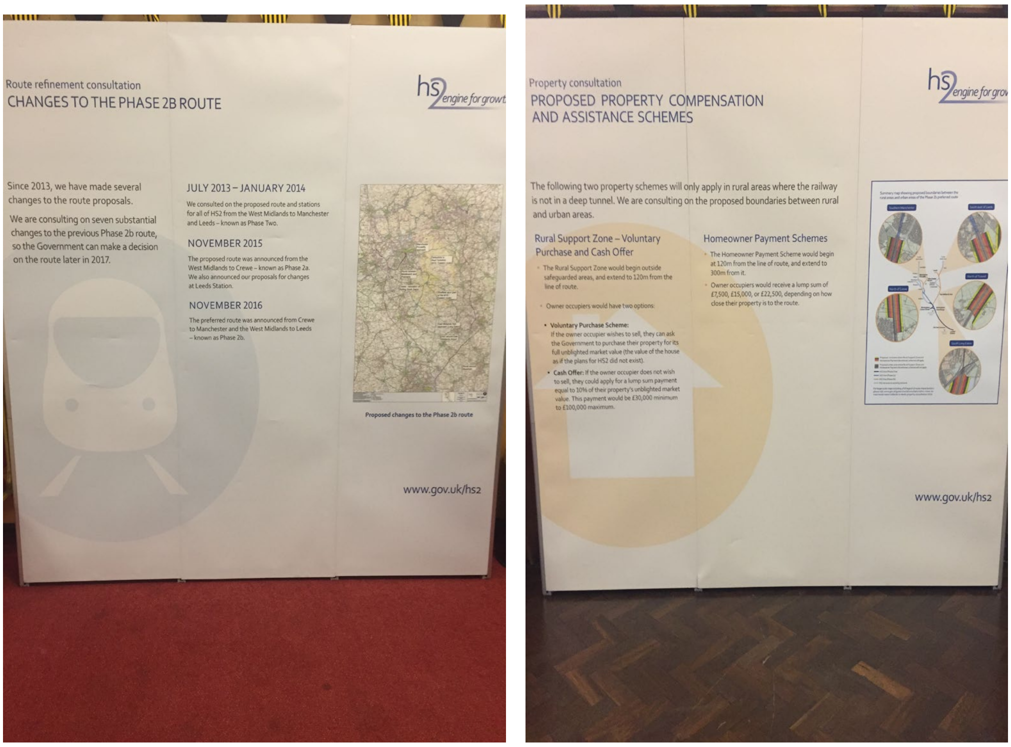


Figure 7.4 Examples of Promotional Material for Phase 2 Consultation Road Shows, HS2 Ltd, 2015

When it came to SoundBooth visits, the helpers on hand (Arup acoustics engineers) would escort the participant to the appropriate booth (each booth played a different demo representative of area types along the route), provide instructions for getting started and then leave the attendee to the experience by themselves. Where possible, it was felt better to let people go straight in to the SoundBooth rather than discuss anything about the consultation beforehand so as to not affect their thoughts (H.S.I-2). Following the demonstrations, some would be very keen to discuss their experience, and others would just simply leave (A.R.I-4).

Figure 7.5 Example of Arup's SoundBooth (Arup, 2019)

The centrepiece to the consultation was a large-scale map of the route with information on various topics of impact shown along the map. For each of the topics, expert consultants were available to answer any questions members of the public might have.

7.3.3.2 Experience, observation and reflection of interviewees

Attendees of the earlier consultation road shows had very different approaches and attitudes, and reasons for attending the events than the later consultation attendees. This became apparent in the first few consultation events where attendees were "rude, aggressive; *personally* nasty". It was suggested that this might have been due to the very early stage of the process at which the consultations took place, allowing for opponents to believe that they still had a chance to stop the scheme if they tried hard enough (HS-A2). Further, it was suggested that as more attendees from the same area acted in a similar manner to one another, it appeared that this derogatory attitude could simply be a function of affluence and a culture of *I get what I want*, with the HS2 scheme being the first of its kind where something/one had "turned up on their doorstep" with something that might be happening in their area that they weren't in control of (A.R.I-2).

As the consultations moved further north and began to reach Warwickshire, people were less personally aggressive, despite still not being happy about the HS2 development proposals. By the time the consultations reached Birmingham, “people really didn’t seem to care; they had far more important things going on in their life” and the prospect of additional jobs to the area appeared attractive to many (A.R.I-3). These reactions of the public serve as a marked reflection of the non-acoustic factors discussed as part of Chapters 3 and 4 of the literature review.

Overall people further north had “a more balanced view of life and had no illusion that they are in control of everything”; people were there because they were interested to see what was being proposed in their area at the time rather than going along once it had been decided (A.R.I-3). Whilst these deductions can only be viewed as the opinion of Arup employees charged with supporting the delivery of the consultation materials, more factual they do demonstrate greater satisfaction with the consultation process as the road show moved north, reflected in the following cross-section of comments,

- Far fewer attendees, which allowed for more time and attention with each
- …And less wait times to speak to experts/section representatives
- Staff had received more training, to even the smaller point of ensuring a clock was always visible so that experts were not seen by attendees ‘checking their watch’
- The media ‘hype’ had settled
- Climate and general comfort of consultation venue had improved given fewer attendees

7.3.3.3 Reactions to the Demonstrations and the SoundBooth Experience

By the later stages of consultations, an Arup representative (A.R.I-2) began to recognise that when people became genuinely angry, it was an emotion borne out of fear for most of them; the more aggressive opponents to the scheme had quietened down and actively aggressive attendees had become few and far between. It was considered whether this might be that by these later consultations the process was so far along in it’s planning stage that people felt far less powerful to make a considerable difference. Arup staff clearly felt that much of the original negative response had not been warranted, but that some concerns where ‘genuine’, ‘reasonable’ and ‘logical’ – but that these tended to be expressed in a more measured fashion with less annoyance in evidence as time went on.

One of the Arup acoustic members (A.R.I-3) recognised one woman in particular; the woman had been a staunch member of an opposition group in the earlier stages of Phase 2, and had ended up having to take a step back from *the cause* as it had been impacting her emotional health so significantly that she had become physically unwell; she was at the later route consultation only for updated information.

Upon being recognised by the Arup representatives at the later consultations, she made it known that she was surprised (pleasantly) to see the same members of staff and consultants, feeling that feedback and processes were actually followed through, instilling trust in the information she was now being provided with where there had, until that point, been none. Chapter 4 discussed the public participation process and the limitations that feelings of mistrust and malfeasance create. The attendee here, recognising – and more importantly, *being recognised by* – a consultation expert, provides a real example of the positive effects this can have in building relations between an organisation and its local community members; “…if there’s anything I’ve learned from this project it’s that you have to engage to get the best [out of people] …people feel like they are being heard” (H.S.I-1). Indeed, going to them, far in to the middle of the community also made a positive difference (H.S.I-2). HS2 Ltd. believed that it was important because the consultations were an opportunity *for them as an organisation* to gather information about local knowledge, but also an opportunity for local residents and opposition groups to voice their concerns and have direct conversations; “it is tangible communication” (H.S.I-1).

7.3.3.4 Consultations without SoundLab

Public consultation road shows were a means of giving the representatives of communities along the proposed route of HS2, a chance to gather all information wanted or missed, ask more in-depth or specific information of the experts that not could be extracted from the literature or websites, and experience the operational implications of proposed routes in their area by means of auralisation and visualisation within the Soundbooths. From such events, the public had the opportunity to provide feedback, be it their views, ideas, or complaints about the proposals. The opportunity to feedback to HS2 Ltd. was available regardless of attending the consultations or not, however the idea was to provide as much clear, accessible information as community members felt they needed to feed an informed opinion back through the appropriate channel; one specifically set to receive, acknowledge and consider the feedback given (H.S.I-1). Once all feedback was gathered and processed and included in (or discarded from) plan amendments, a draft environmental impact assessment statement (EIA) was drawn up.

An EIA is about maximising the benefits whilst minimising the adverse significant effects; put simply, implementing mitigation measures as far as is reasonably practicable (DfT, 2019a). Through an EIA, adherence is also ensured to environmental minimum requirements (EMRs), which include: Code of Construction Practice (CoCP), a Planning Memorandum, a Heritage Memorandum, and an Environmental Memorandum (DfT, 2019a). In the context of HS2 Ltd and its environmental noise mitigation strategies this included, cuttings (where the train line is dropped down in to a hill side rather than being overtly above ground), barriers and bunding, which were all ‘drawn’ on to the visualisation video for demonstrations; the demos were then be updated both visually and aurally from the new information and decisions. The demos and information prior to the feedback and consequent EIA had been kept “quite deliberately generic so far” (H.S.I-1), whilst the updated demos and information then enabled people to “get an impression of not only what they sound[ed] like, but what it will …look like as well”, with specific mitigation relative to particular areas having been showcased.

The updated demos however, were only utilised for the websites. Part of the protocol for an EIA is to engage effectively, however it is not a statutory requirement to run events in order to inform. HS2 Ltd. believed that it was important to take the information out to the individual areas however, the consultation (EIA) is different in not needing demos because it is simply about confirming the route, “…so the route

[was] announced, and therefore opinions [had] already been gathered and taken in to consideration" (H.S.I-2). HS2 Ltd. saw these information events as being designed to "provide an update to the public on a more personal note" and enable the public to see how HS2 have reached the decisions of each amendment (H.S.I-1). Because the EIA events were not a statutory requirement, and were a means of showcasing the changes that had been made rather than an opinion gathering exercise to inform design/project development, HS2 Ltd. felt they could not justify spending additional money on taking the SoundBooths back out to the same locations again. To the experts running the events, however, the lack of SoundBooth technology was apparent, with some finding it more difficult not having the back up of the demos when discussing with customers, "…some of the conversations I had about noise were definitely hampered by the fact that we couldn't show them examples of the sounds in the EIA information updates […] people asked if there were updated sound demos to reflect the updated information" (H.S.I-1).

Throughout all of the interviews with people involved in developing the SoundLab (and SoundBooth) technology as a HS2 communication tool, many benefits were mentioned, both from their own perspectives, but also derived from opinions gathered through discussions with the attendees. An HS2 Ltd. representative in particular noted that it, "enhances our 'sale' of package at consultation events; in terms of pushing technology forward, with HS2 striving to be the innovators when it comes to the trains, the design of the track, the stations…" (H.S.I-2).

Allied to this, the main HS2 representative interviewed, had been integral to implementing the SoundLab technology in to the consultation road shows, and significantly had extensive experience of other public consultation events. He believed that the interactive nature, and novelty of such a tool, was more engaging for the attendees than conventional information boards and maps (H.S.I-1). Indeed the second HS2 representative noted that that having something "functional and immersive" provided stakeholders with additional information that they would not otherwise have accessed and understood (H.S.I-2). The main HS2 Ltd. representative (H.S.I-1) went on to state that he believed that SoundLab as a communication tool on consultation road shows, made so much difference and positive impact to engagement with public members, that he wanted to ensure that such demos would be used on all future consultations (both before and *as part of* EIA processes) as part of his legacy to the company (he was due to leave the company soon after the interview).

7.3.4 Considerations and Development of the Technology as a Communication Tool

Outlined in section 7.3.1, the Arup acoustics team had only 4 months from commission of the communication tool, to implementation. Indeed, with focus largely on getting the technology as accurate as possible, there was little scope at that point for comprehensive consideration of user experience. There was however, consideration of the extent of information that could realistically be provided through the demonstrations in a short enough time that afforded attention enough to listen all the way through; operationally speaking, this also served to allow for more people through the SoundBooths (A.R.I-4).

When considering the means by which to enable access to a wider audience, it was of course decided that a mobile version of the SoundLab, namely a 'SoundBooth', would be developed and used. With the addition of this mobile technology attendees would be able to go in to the SoundBooth and be guided through the demos without the need for a 'host', formal presentation was a critical worry that was raised. Developing this technology from its traditional SoundLab consultation approach, Arup were conscious that the inbuilt presentation of the SoundBooth demos needed to reflect their usual professional and therefore credible nature. On consideration of this, the core question became, *what is it that we're presenting?* A series of different generic "benchmarking" presentations were developed, which became the standard format for all subsequent presentations then remained the format throughout all phases of the consultation process.

These presentations were:

- 'In Your Area', illustrating what high-speed trains might sound like in different locations along the route – from quiet rural locations to suburban areas – and at different distances from the line

- Frequently Asked Questions; 9 questions covering topics surrounding the visualisation and auralisation being experienced

The idea of the ‘in your area’ presentations was developed largely within the first three months of design and remained central to the structure of presentations throughout the consultation phases. Technological updates, for example improvements to visualisation, evolved over time, quite simply because Arup’s technology naturally developed and therefore incremental improvements to the demos incorporated through regular updates to the software. As was the case for the auralisation, in order to create verified visuals for the demos, visualisation recordings were taken of the German ICE trains and embedded into visual recordings of specific locations along the proposed HS2 route using CGI (computer generated imagery).

In the second round of 2013/4 consultations, an additional SoundBooth was added to the original 3 to provide a wheelchair accessible space. The real focus of improvement was still getting the balance right between “how you differentiate between best quality-small number of people in a lab, versus slightly lower quality to get a much large number of people in the booths” (A.R.I-1). From the desire to improve the user experience, Arup developed a move away from the SoundBooths and in 2017, the listening trucks were implemented; essentially HGV sized trucks that were turned into listening suites. This was an anechoic chamber (sound proofed room) with individual screens and two headsets per screen. Rather than the initial SoundBooths that could only play one particular location, the user now had the option to choose the location appropriate to them.

This significant change of facility ultimately emerged because of pressure from the consultation team for a more flexible solution; “they didn’t want to be constrained by the venues …hav[ing] to fit the venues because they needed the SoundBooths to fit inside” (H.S.I-1). To facilitate an effective engagement process as much as possible, and “physically speak their language” (A.R.I-3) the point was to go to the communities and embed within their local surroundings, rather than having to go to a large hall outside of the community simply to facilitate the SoundBooths. The only problem that then arose from the use of the trucks was that the trailer took up around 6 car park spaces, which was not ideal for every location either; it was however much more conducive to many local venues than the SoundBooths had been (H.S.I-1).

A further improvement borne from the demo trucks is that there was a vestibule within the truck, between the entrance and the demo suite, where people were greeted by Arup acoustic consultants meaning that they were also there for when the individual came out of the suite. This encouraged dialogue with attendees both before and after the demos even with some who were not inclined to do so (the latter in the opinion of some of the interviewees). Furthermore, if people had gone in together, the Arup consultant had the opportunity to hear their discussion as they came out. Interestingly, an Arup representative mentioned a couple who had particularly stuck in her mind, "the man came out saying that it hadn't sounded anywhere near as bad as he had expected, whilst the woman was furious at the loudness and the look of it" (A.R.I-2). This is an interesting observation of two people from the same living environment, experiencing the same demonstration, having polarised perceptions of the auralisation and visualisation, reflecting the pivotal notion of human variability as part of perception discussed in Chapter 3.

Furthermore, another woman and her daughter chose to actively engage with the Arup representative and commented that they were not bothered by the sound of the new train line at all as they had been used to the existing line at the bottom of their garden for years, and have come to know it as a part of their every day soundscape. It was in fact the visual representation of the suggested mitigation on show in the demonstrations that was of more of a concern to them. Having seen several grass cuttings[26] and examples where it had been difficult to even tell where the train was, the visual representation on this particular demo had been of a (much less visually appealing and 'background-blending') concrete wall. Although this was

[26] The term 'cutting' is given to a landscape design that sees the train line dropped down – often in to a hill side – rather than being overtly above ground.

actually one of the louder sections to the route, the two attendees were much less concerned with the sounds because of what they were used to, whereas many others having heard demos of much lower sound levels than this had been far more concerned and upset. This once again echoes the notion of individual perception, and indeed the factor of individual expectations based on their tacit knowledge of a given situation. In this particular situation this information was fed back to HS2 via one of the official forms, and the visual format of the proposed mitigation measure was changed; a strong example of the power of public consultation, but more pertinent to this study, a strong example of the knowledge-gain provided by the SoundLab in order for such constructive feedback to be given.

7.3.5 Reflection on the Strengths and Weaknesses of SoundBooths as a Communication Tool by Those Who Developed It

When directly asking the interviewees of their perceptions of the value of the SoundLab technology as a communication tool, having been integral to the design, implementation and incremental improvements during deployment – and also witnessing the difference between the consultation events with *and without* the tool – the answers were surprisingly honest.

The Arup representative who had initially suggested the technology in this new capacity, and having been integral to its full journey, very honestly stated, “I don’t think they [auralisation and visualisation tools] ever on their own are special” (A.R.I-1). In parallel, the HS2 representative had a similar viewpoint, “It’s not enough by itself to give a better understanding of what will happen. Given it’s constraints it’s enough, but needs the engagement also” (H.S.I-1). The Arup representative (A.R.I-1) believed that the sound demonstrations in themselves are an “important ingredient, but it’s only one ingredient”, and highlighted the importance of finding a means to give people confidence that the demonstrations are being provided objectively. While Arup have maintained their objectivity throughout the process, and indeed Arup has “put [it’s] name against *not* being biased; all of the promotional material states objectivity, to the point that the term ‘sound’ is used rather than noise (noise is unwanted sound and therefore implies a judge on sound quality, see Chapter 3), because ‘it is not up to us to decide people’s opinion of whether it is noise or not” (A.R.I-1).

There is always some degree of risk of unconscious bias however, that “you’ve just got to be alive to” (A.R.I-1). In doing so, Arup stipulated that they would only take on the SoundLab demonstrations if HS2 Ltd allowed them to show all recordings, whether good or bad. Where some areas of the proposed routes might appear worse than had been hoped, Arup maintained that these locations still be a part of the demonstrations. HS2 Ltd also wanted to provide an accurate representation of the proposed routes, and ensure that their consultations were as overtly transparent as possible. Allied to this, HS2 Ltd’s main rationale for using such a tool for public consultation was to be able to identify the areas that the public were least happy with and their suggestions for improvement, “…all of the whole language and process of respecting anybody that comes, be it member of the public or secretary of state, we’re just trying our best to give the best information possible to allow them to understand the issue and then engage in it” (H.S.I-2). The woman and her daughter with the visual rather than sound concerns is a prime example of this.

The key Arup representative (A.R.I-1) however, points out that the auralisation and visualisation demonstrations are “only 25% of what happens throughout the process”. Similarly, when posing the question of whether the engagement process or the demonstrations themselves that have more of an impact, the key HS2 representative (H.S.I-1) expressed a similar opinion, “It’s absolutely the process itself that has the impact”. Once again, this is a direct reflection of the literature in Chapter 4, suggesting that all elements of the engagement process must be interact with one another in order to achieve a successful outcome. This of course means that the SoundLab technology as a communication tool does have added value to the engagement process overall in enabling members of the public to better understand proposals put forward by the HS2 scheme. Whether consultees are more or less appeased by the information they gain from the consultation events, they are at least correctly informed enough that the feedback will then be more accurate to the process, and any responses better understood; the aim essentially, is to inform and allow participants to form their own judgements.

While the Arup representative clearly champions the use of SoundLab technology in its role as a communication tool, he was not – as became apparent during the interview – under any illusion that it is a magical solution to the noise impact management challenge, in any form of transport. When lastly asking the Arup representative an ad hoc question reflecting upon the use of SoundLab as a communication tool throughout the HS2 process – and how integral he then believes sound demonstrations should be in the future of aviation engagement – the answer similarly reflected earlier views, “I think they [auralisation/visualisation] have a role. My view on all of this is that there is no one size fits all. They are only ever a way to give easier access to customer information, so they have a role, and the role varies depending on the project and circumstance. The law of reasonableness and proportionality has to conclude that every project has to have a balance of elements” (A.R.I-1).

When encouraged to expand on the notion of a *balance of elements*, the idea of it all being a part of a *process* was reiterated, “…it’s worth keeping in mind the starting point, and the starting point isn’t doing demonstrations, the starting point is what is the question – what is the issue? Who are you trying to inform and why?” This logical fundamental step in any given engagement process, it can be argued, is possibly the step that shapes the framework for the rest of the process, yet is possibly the step that is also often overlooked. Where Chapter 4 sets out processes by which to engage most effectively and efficiently, and elements that are crucial to include, it is worth considering how often this initial question is asked.

Indeed, without prompt, the Arup representative offered reasons for why it took so long (after HS2) for SoundLab to be commissioned and implemented in and aviation noise management context as a communication tool. Through working with Heathrow Airport on various projects throughout 2011, the idea of utilising the SoundLab was suggested to them, and from this, aviation demos were presented to the Department for Transport (DfT). It was presented to them however, without specific narrative," …we didn't know what the questions were, we didn't know what the issues were, we hadn't got under the hood of what makes people in communities uncomfortable. We know what makes them uncomfortable in aviation, but we didn't know what we had to do to make it better" (A.R.I-1). This comes back to the key point, which is that all elements must be present, not least that there must be a framework and an aim by which to work from; without this, such tools as SoundLab or SoundBooth have no purpose – no question or information to help people understand or access. "There's got to be a reason for doing a demonstration otherwise they become, at worst, sound propaganda – and that's toxic" (A.R.I-1).

7.3.6 Summary

The key challenge in developing auralisation and visualisation demonstrations for communication purposes, as found in this case study, is to ensure that the recordings used accurately reflect the sound that is likely to arise from the proposed development, and further, that these are situated in appropriate ambient contexts, both audio and visual.

When delivering any form of consultation to the public, challenges are always likely; never more so than when a consultation is surrounding events seemingly likely to impact people's lives and well-being. HS2 Ltd learned such challenges very quickly during their consultation road shows; the point at which extensive queues for the SoundBooths allowed for concerns to fester, and arguably saw tensions heightened, exacerbating pre-formed annoyance instead of having any opportunity of the SoundBooth experience to lower it. Interestingly, this does reflect the notion of tacit knowledge, discussed in Chapter 3 (Section 3.3.1.4.1). Here however, the tacit knowledge has not been formed by the soundscape directly – or a previous similar experience – more, the attitude towards the sound and its source. Where tensions and annoyance has risen, little room is afforded to positively influence human attitude, and the pre-formed annoyance is taken in to the SoundBooth and will continue to view any information experienced, in a negative light.

Furthermore, such tacit knowledge, and indeed pre-built expectations, were found to differ between differing audiences, i.e. from location to location, tending to depend upon demographic factors, for example, affluence. It became very apparent that areas in which potentially affected residents would benefit from more jobs to the area, and better links to areas with more job opportunities for example, were much less disturbed by the prospect of the 'noise intrusion'.

This case study has shown that auralisation and visualisation can offer an enhanced means of informing the public about potential consequences of a development or change, and thus facilitate engagement that is useful to both participant and developer, where each party benefit from the facilitated dialogue on a level that is meaningful to both. It can be suggested therefore that auralisation and visualisation used in such context adds value to the 'informing' step necessary in reaching effective dialogue. In order to reach such a stage, however, participants must agree on the nature and detail of what is to be discussed if effective dialogue is to be achieved. It is important therefore, to know the targeted audience; their requirements and perspectives for example, if appropriate engagement events are to be designed to effectively inform and allow for participants to form opinions and comprehensibly take part in discussions. Indeed, Chapter 2 introduces and charts communication surrounding aircraft noise to date. In short, aircraft noise communication has not been effective. Throughout the literature, this has been predominantly attributed to a misuse of explanatory measures (conventional metrics) that were developed in principle for peers of the same technical understanding in the planning sector. These 'information tools' therefore were not fit for purpose when communicating to community members.

This logical fundamental step in any given engagement process, it can be argued, is possibly the step that shapes the framework for the rest of the process, yet is possibly the step that is also often overlooked. Where Chapter 4 sets out processes by which to engage most effectively and efficiently, and elements that are crucial to include, it is worth considering how often these initial questions of 'do you understand?' and 'to what extent is this information meaningful to you?' are asked.

One of the key benefits of auralisation and visualisation, as a communication tool for the HS2 process that appeared to be significant, was the capacity it provided to contextualise the sound source in the landscape/backdrop. From the literature reviewed in Chapter 3, it is thought that this could have profound influence over a person's perception of what they are hearing because there is depth and distance - context. The visual element of HS2's SoundLab demonstrations allowed various mitigation scenes to be explored, which can, therefore, aid and inform decision-making, the process of planning, and various other needs.

7.4 The Use of Arup's SoundLab for Heathrow Airport's Insulation Scheme Consultation

The previous case study explored the use of auralisation and visualisation as a communication tool for HS2 public consultation road shows. There were many positive points to draw from, not least the positive impact the facilitation of understanding the technology had on attendees. After what can safely be described as the 'success' of Aup's auralisation and visualisation in such a capacity, Heathrow Airport commissioned Arup to design an auralisation and visualisation demonstration for their insulation scheme core product.

This case study begins to explore the application of auralisaton and visualisation as a communication tool set within the realms of aircraft noise, to see if facilitating the ability to experience how these aircraft events would indeed sound, has any real benefit to aircraft noise communications. Arup consultants followed a brief, set by London Heathrow, the world's busiest international airport, serving over 67 million passengers annually, to over 180 destinations in over 90 countries. The brief was to showcase the latest insulation scheme benefits to the government; the auralisation and visualisation was used at corporate stakeholder level to facilitate a more informed discussion ahead of the Davies Commission (also know as the Airports Commission) report. It must be noted here that the focus of this embedded case study phase was not on the use of auralisation and visualisation *as an aid for public* *participation* or indeed public understanding; the focus of this second phase looks to the transposing of auralisation and visualisation from rail to aviation.

The semi-structured interviews conducted for this phase are with members of the Arup acoustic team with an aim of reviewing the degree to which this transposition was successful. Before exploring the use of Arup's SoundLab for Heathrow's insulation demonstrations, there is a need to first note the background to the present day scheme as a means of understanding the importance enough that it warrants employing the novel use of SoundLab.

7.4.1 The Independent Airports Commission

"The London airport capacity problem has perplexed governments for over fifty years, for reasons that are not hard to find" (Davies Commission, 2015:3). Heathrow Airport for example, is operating at full capacity, with Gatwick Airport not far behind, meaning that new routes to significant long-haul destinations are being set up at airports across Europe, rather than the UK. With the aviation industry adding significantly to the global economy and employing millions of people (Heathrow, 2019), the UK cannot afford to fall behind on "even more benefits of flight" (Heathrow, 2019). There has not been a full-length runway built since the late 1940s in the South East of the UK, and with the evolving business demands of international inter-city connectivity, a new runway is considered essential before 2030 (Davies Commission, 2015). And yet, whilst the Labour government had backed the third runway in 2009, the incoming coalition government of 2010 overturned the decision and the expansion proposal failed its judicial review (Financial Times, 2019).

A pivotal point to come out of the judicial review was that it became a policy decision for Heathrow as the aviation industry actor, and the polarised representatives of the debate, the opponents, to sit down and work more favourably together. "[A]s part of this we got to agree some common ground; we disagreed about the third runway. But we agreed the need for different metrics to describe noise impacts, and the need to think about respite as an option – providing more people respite within our communities" (I.H.1).

Borne out of the failed judicial review, but acknowledging the remaining capacity constraints of UK aviation, the Independent Airports Commission was set up towards the end of 2012; chaired by Sir Howard Davies, it is often referred to as *the Davies Commission*. Through extensive analysis the Commission quickly deduced that without expansion to the South-East's aviation capacity via an additional runway, London's position – and therefore the UK's – as a key player across global business will deteriorate until reaching full capacity by 2040. Indeed, suggestions of finding an alternative location within the UK for such expansion has been ruled incompatible with carbon emission reduction goals due to additional infrastructure and transfer needs that would be required, leaving a solution needed within the South-East area of the country (Airports Commission, 2015).

As addressed throughout Chapters 1 and 2 of this thesis, the impact of aviation is of course, not all positive; benefits are felt nationally and globally, while locally negative impacts to quality of life are often felt to outweigh the benefits. Indeed, Heathrow recognises this, and believes that, not only is there a responsibility to reduce those negative impacts locally, but to also "leave a better planet for the next generation" (Heathrow, 2019).

In recognition of the previous efforts to secure expansion approval, the Davies Commission (2015) recommended a "comprehensive package of accompanying measures", seeing a more "acceptable" proposal to its local community, and indeed towards Heathrow's commitment to sustainability. This would include:

- A ban on all scheduled night flights in the period 23:30 to 06:00; this is only possible with an expansion
- More reliable respite for overflown communities
- A legally-enforced *noise envelope*; this could include stipulating no overall increase above current levels
- Compensation for those who would lose their homes, at full market value plus an additional 25% and reasonable costs, to be made available as soon as possible

- New measures to ensure acceptable air quality around the airport
- A Community Engagement Board should be established under an independent Chair, with real influence over the airport's operations, and over spending on compensation and community support, including enhanced noise insulation and support for schools included as a priority
- An independent aviation noise authority should be established with a statutory right to be consulted on flight paths and other operating procedures.

With such a stringent review and consequent recommendations, the noise impact management team at Heathrow realised they had to "be prepared to let go of a bit of control" and led to the establishment of a number of forums and changed the way they thought (I.H.1). While sustainability efforts have been embedded in Heathrow's ethos for many years, they had not been articulating this particularly well. Heathrow's noise management team realised it was time to start thinking more about sustainability *strategy* and how they "take that to a leadership position" (I.H.1). As part of this, the focus would be on moving the conversation surrounding the airport and aviation onto a wider agenda - "*bigger* than just the negatives […t]his is not just about a third runway; this is about making a business case for sustainability" (I.H.1).

"It has to be about more than just the decibel; because we're not seeing changes in terms of responses within our communities. If anything, we're seeing more people becoming motivated to complain. But we must have something more to ask questions about. So, the challenge is how are we addressing that; how are we addressing the non-acoustic factors?" (I.H.1).

A pivotal first step in this new strategy was the recognition that it needed to be "a collaborative piece" with the community, which meant that the first steps were to go out in to the community asking stakeholders what they think sustainability should look like.

7.4.2 Heathrow 2.0 and the 2019-2023 Noise Action Plan

In 2015, the Heathrow Community Noise Forum (HCNF) was set up, made up of representatives from local authorities around Heathrow, National Air Traffic Services (NATS), British Airways (BA), Department for Transport (DfT), Civil Aviation Authority (CAA) and Heathrow (Heathrow, 2018). During 2016 the airport carried out wider consultation with their stakeholders, inclusive of community members, to "understand their needs and expectations regarding sustainability, and the potential for Heathrow to deliver on them" (Heathrow, 2017). The HCNF continues to meet on a regular basis. Further, from wider consultations, Heathrow launched its new plan for sustainable growth: Heathrow 2.0, in 2017.

The sustainability strategy (and indeed the later mentioned Noise Action Plan) in its totality is not directly within the remit of this thesis' narrow focus. However, in the context of its sustainable development foundations and the means through which airports are striving to improve their noise impact management and engagement, it is important to acknowledge and to an extent illustrate the efforts of Heathrow Airport. There will not therefore be an in-depth exploration in to each of the key areas; each will be acknowledged and those relevant to this thesis will be highlighted.

Heathrow describes its *Heathrow 2.0* strategy as representing "a step-change for our business and captures the momentum of an industry-wide shift towards a sustainable future for aviation". The airport structured their new strategy framework around four key areas:

1. **A Great Place to Work** is about helping our people fulfil their potential
2. **A Great Place to Live** is about working better with our neighbours to improve their quality of life
3. **A Thriving Sustainable Economy** focuses on creating opportunities for business to deliver a stronger future for the UK
4. **A World Worth Travelling** is all about working with our industry and regulator to deliver fair and sustainable air travel for future generations to enjoy.

The Environmental Noise (England) Regulations set in 2006 require airport operators to develop Action Plans designed to manage resultant noise issues and effects from aircraft departing from and arriving at their airport; Heathrow's third, and current plan looks specifically to the five-year period 2019-2023. The first Noise Action Plan (NAP) was developed for 2010-2015, superseded by the second in 2013-2018. Where appropriate the Noise Action Plan set by Heathrow is kept under review, and where needed will be updated or amended on an annual basis by Heathrow Strategy Noise Advisory Group (Heathrow, 2019a). The 2019-2023 NAP is discussed in further detail below in the following section.

In June 2018, the House of Commons voted in favour of the Airports National Policy Statement (ANSP), which provided policy support for Heathrow's expansion proposal. The support was for the additional northwest runway construction next to the existing Heathrow site. Under the terms of the Planning Act of 2008, the airport now needs to submit a Development Consent Order (DCO) application. To allow time for further consultation with local communities and various stakeholders, Heathrow plans to submit their application in 2020, which would see the start of construction in 2021 for completion of the new runway in 2026 (Heathrow, 2019a:11).

It is explicitly stated in the current plan, that where a DCO may be granted signifying the 'go ahead' for the expansion plans, the NAP will be revised and amended where needed to "take any new noise mitigation measures into account" (Heathrow, 2019a:11). Whilst the 2019-2023 NAP does not include the airport's expansion plan in full, considered interim measures are outlined in order than the airport begins accommodation of larger capacity needs with sufficient mitigation and sustainability needs in place. Such interim measures include the raising of air traffic movement (ATM) limits (currently 480,000 by an additional 25,000), and modification of taxiways on the existing northern runway (in order to accommodate easterly operations).

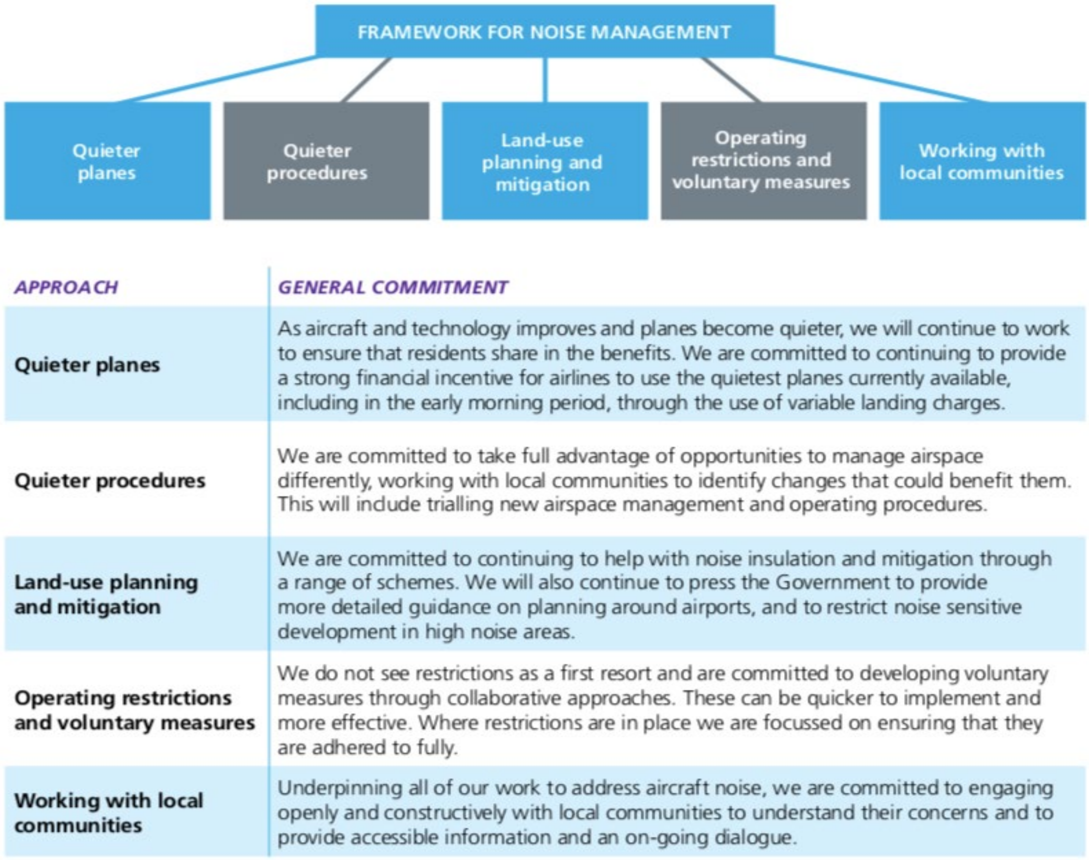
Heathrow have suggested that expansion and mitigation go hand in hand, "…as the former can provide the financial resources for the later" (Heathrow, 2019a). With this in mind, there are already provisions in place for strategic steps to ensure the interim measures fall in line with Heathrow's NAP, despite the lack of 'hand in hand financial resources" from the expansion yet being realised. These steps have been engineered in order that they can be maintained and instilled in future iterations of the plan. Where *key areas of activity* for example, reflect a *Great Place to Live* objective from the Heathrow 2.0 sustainable aviation scheme, it looks specifically to work better with their neighbours to improve their quality of life. Steps outlined for carrying forward in to future revisions include:

- On-going modernisation of the fleet and incentives to use aircraft with the newest noise reduction technologies
- Investigation and appropriate implementation of effective noise abatement procedures
- Airspace design and management to minimise adverse noise impacts and, where appropriate, to maximise respite for residents
- Provision of a comprehensive sound insulation scheme for the most affected houses and schools
- Continual improvement of voluntary measures especially for reducing the impacts of night operations
- Enhanced monitoring, reporting and management of all ground- and air-based noise sources
- Clear and transparent engagement with community groups and industry stakeholders to achieve collaborative and beneficial improvements
- Promotion of a research agenda that enhances our understanding of the impacts of aviation and the effectiveness of the interventions used to reduce noise impacts.

Whilst the interim measures are catered for within the 2019-2023 NAP, the longer-term strategies for post 2025 are only deliverable in the context of the additional runway. This imposes limits on a sustainability strategy in what could be perceived as a tactical move; with sustainable development being such an important topic, the ability to meet such targets (of a strategy structured around 4 key stakeholder groups) appear to fall on the continued backing (or otherwise) of various stakeholders for the expansion plans.

7.4.2.1 ICAO's Balanced Approach to Noise Management and its Continued Influence

Guidance on producing the plan was updated in 2017 by DEFRA (the UK government's Department for the Environment, Food, and Rural Affairs). Chapter 2 of this thesis explored in detail the Balanced Approach to Noise Management Guide (the Balanced Approach) by the International Civil Aviation Organization (ICAO). This recommended a detailed framework from which airports should look to manage their noise impacts, and where possible, reduce them. It is made clear throughout Heathrow's Noise Action Plan 2019-2023 that the ICAO Balanced Approach document is still staunchly adhered to 18 years on. Furthermore, the new addition of a *Working with Communities* pillar is also taken in to account (Heathrow, 2019a). This is evident in the five-point noise management framework through which Heathrow plan to realise their long-term objective of "limiting and where possible reducing aircraft noise impacts". This is set out in Section 5 of the Noise Action Plan. Figure 7.6, below, sets out the five points of the framework in full, while Table 7.2 depicts the five points and shows how they echo the pillars of the Balanced Approach.



APPROACH	*GENERAL COMMITMENT*
Quieter planes	As aircraft and technology improves and planes become quieter, we will continue to work to ensure that residents share in the benefits. We are committed to continuing to provide a strong financial incentive for airlines to use the quietest planes currently available, including in the early morning period, through the use of variable landing charges.
Quieter procedures	We are committed to take full advantage of opportunities to manage airspace differently, working with local communities to identify changes that could benefit them. This will include trialling new airspace management and operating procedures.
Land-use planning and mitigation	We are committed to continuing to help with noise insulation and mitigation through a range of schemes. We will also continue to press the Government to provide more detailed guidance on planning around airports, and to restrict noise sensitive development in high noise areas.
Operating restrictions and voluntary measures	We do not see restrictions as a first resort and are committed to developing voluntary measures through collaborative approaches. These can be quicker to implement and more effective. Where restrictions are in place we are focussed on ensuring that they are adhered to fully.
Working with local communities	Underpinning all of our work to address aircraft noise, we are committed to engaging openly and constructively with local communities to understand their concerns and to provide accessible information and an on-going dialogue.

Figure 7.6 Framework for Noise Management, Environmental Noise Directive Noise Action Plan 2019-2023, 2019:25

Framework for Noise Management	
Heathrow 2.0	**Similarities to ICAO's Balanced Approach to Noise Management**
Quieter Planes	Based on the Reduction at Source
Quieter Procedures	Reflects the element of Noise Abatement Operational Procedures
Land-use Planning and Mitigation	Includes sound insulation and land-use
Operating Restrictions	Expands to include Voluntary Measures
Heathrow's fifth pillar, **Working with Local Communities**, goes beyond the Balanced Approach as they recognise the importance of community engagement and collaboration in identifying and understanding issues and working towards improvements	

Table 7.2 Framework for Noise Management, Adapted from Environmental Noise Directive Noise Action Plan 2019-2023, 2019:25

In keeping with the more pronounced focus of airports engaging with local communities as part of such management, the guidance published by DEFRA in 2017 for airports preparing their noise action plans, recommended that “the public is consulted about proposals for actions plans, given time to participate in the preparation and review of the actions plan, have their views taken into account and be informed of decisions taken” (Heathrow, 2019b). Indeed, the five points of the noise management framework produced by Heathrow, seen above, also echoes this more pronounced focus. The fifth point here is reminiscent of the fifth pillar to ICAO’s Balanced Approach of *People Issues*; although this was added in 2007, ICAO never formally issued a revised version of the guidance document, meaning that there is little recognition of the fifth pillar today.

7.4.2.2 The Pertinence of Noise Insulation Schemes

Much earlier than any form of sustainability plan or action plan was even a consideration, noise insulation schemes were key mitigation measures that were implemented as some of the first means of consideration to the airport’s residents, beginning in the 1960s. As such, when the Davies Commission was assembled in 2011 to explore the various options of facilitating the growing air capacity in the south-east of the UK, as one of it’s core examples of how Heathrow were not only looking after its local residents, but indeed going ‘above and beyond’ requirements, it was Heathrow’s insulation scheme that was showcased to the government above all other efforts. It was stated that a further £700m for noise insulation to cover 160,000 homes would be delivered through the third runway addition, with a promise that, “[a]s well as minimising the noise we create and extending the period without scheduled night flights as part of our expansion, we will continue to help residents insulate their homes” (Heathrow, 2019a). The following sections look first to the history of Heathrow’s insulation schemes, and later, Arup’s involvement in the demonstration of how dwellings would sound with the addition of varying types of insulation.

7.4.3 The Insulation Scheme

7.4.3.1 Historical Heathrow Noise Insulation Schemes

Noise insulation schemes at Heathrow began in the 1960s. The introduction of heavy long-range jet aircraft saw the number of complaints received increase significantly, peaking in the summer of 1960 (Wilson Committee Report on Noise, 1963). Experiments by the Building Research Station looking at the feasibility of insulating homes against aircraft noise in the early years of the scheme, found that "in a room with II-inch-cavity [2 inch] structural walls, no external doors, no flues, and on the ground floor, the installation of good double windows and a sound-attenuating ventilator unit gave an insulation against aircraft noise of 40 to 45dB (average: 100-3150 Hz)" (Scholes and Parkin, 1968:37). Based on these results, the Wilson Committee suggested that the Government should pay grants to house owners near the airport "to help them to insulate their houses in this way, the full cost (up to £200) to be paid in the areas most affected by noise, and a diminishing proportion of the full cost further away as the noise got less (Scholes and Parkin, 1968:37).

By 1966, British Airports Authority (the then airport operator) was authorised by Government to pay 50 per cent of the cost of insulation, i.e. a maximum grant of £100 to house owners, in an area, defined mainly by the local authority, on or within the estimated 55 NNI [Noise and Number Index] contour (Scholes and Parkin, 1968:38). A number of subsequent Noise Insulation Grant Schemes (NIGS) were set up around Heathrow over the following 20 years under various Civil Aviation Acts. Each scheme provided internal secondary glazing, acoustic ventilators and secondary works such as additional ceiling insulation and the blocking up of chimneys, within fixed cost limits. In their research, Scholes and Parkin (1968), examined the transmission of aircraft noise into dwellings near Heathrow. In doing so, they found that the addition of mineral wool insulation between the ceiling joists would be more effective at reducing the noise in the dwelling than the addition of sheets of lead under the roof (cited by Mahn and Pearse, 2010:1). There is no evidence to suggest that this finding was implemented in to Heathrow's noise insulation scheme, or whether the findings were suggesting that there was potential for a more effective course of insulation.

The 1995 Noise Insulation Scheme (NIS) differed from historic NIGS in that it was set up and administered on an entirely voluntary basis by BAA Heathrow. All residential properties within a defined 69 $L_{Aeq,18hrs}$ aircraft noise contour were eligible whether or not they had been insulated under any previous scheme. The 69 $L_{Aeq,18hrs}$ contour was constructed using predicted 1994 05:00 to 23:00 (18 hours) daytime traffic, with all movements between 05:00 and 07:00 counted twice (weighted by 3dB) to reflect local concerns of early morning traffic at the airport. When the aircraft noise contours, based on actual 1994 summer traffic, were published in 1997, they were found to extend beyond the contours; the scheme was subsequently extended to take these findings into account.

As part of this scheme, residents were offered traditional internal secondary glazing at no cost, or a 50% contribution towards the cost of replacement windows with either standard or high performance sealed unit double-glazing. Loft insulation and acoustic ventilators were also provided at no cost. Field trials at Heathrow showed that replacement windows fitted with sealed unit double glazing could outperform the standard secondary glazing systems specified in earlier schemes (Davis, 1993), although this intervention would be at a higher cost. 62% of the 7,385 eligible properties during the 1996 pilot scheme took up the offer, based on which, the total estimated cost of the scheme to BAA Heathrow would be around £10,000,000 (Flindell and Witter, 1999).

7.4.3.2 Heathrow's Modern Day Insulation Scheme

Today, Heathrow has implemented a variety of mitigation schemes, all of which documented in their 2019-2023 NAP, and discussed below. As part of the 2019-2023 Noise Action Plan, Heathrow is focusing its core efforts on five mitigation schemes, four of which are insulation related. These are:

Community buildings noise insulation scheme, which falls in to the *noise-sensitive, community buildings* within the 2002 63dBA $L_{eq16\ hour}$ noise contour, i.e. hospitals, schools, nursing homes, libraries. Heathrow Airport suggests that at present, 64 community buildings in the area are eligible (H.R.I-1). Experts assess measures needed in the most-cost-effective way, and on a case-by-case basis, and approved contractors carry out the work. Such insulation measures can include window replacements and mechanical ventilation (Heathrow, 2019:29). Heathrow developed the community buildings noise insulation scheme in consultation with local residents and businesses, campaign groups, and local authorities (H.R.I-1).

Day noise insulation scheme, is similar to that mentioned about for community buildings; acoustic insulation is provided to residential buildings registered for the scheme, inclusive of secondary glazing or half price double-glazing to external windows and doors, and free loft insulation and ventilation. Around 8,500 homes fall within the Day Noise Insulation Scheme remit. This scheme is restricted to the 1994 69dBA $L_{eq18hour}$ noise contour, which is an enhancement of the above contour to take in to consideration early morning over flights (Heathrow, 2019:29; Heathrow, 2019b:37).

Night noise insulation scheme, designed to address night flight impacts on residents within the 'footprint' of the noisiest recorded aircraft that regularly operates between 23.30 – 06.00. This 'eligibility area' was set as part of the 2004/5 90dBA SEL contours, and captures around 41,000 residential buildings. As with the Day noise scheme, it includes secondary glazing or half price double-glazing to external windows and doors, and free loft insulation and ventilation, however does only apply to bedrooms or bed-sitting rooms (Heathrow, 2019:29; Heathrow, 2019b:37).

Quieter homes scheme, similarly to the community-building scheme, carries out expert, case-by-case assessments for the most effective measures, inclusive of secondary glazing or replacement double-glazing to external windows and doors only. Also included in available measures is mechanical or passive ventilation, as well as ceiling over-boarding and loft insulation; Heathrow airport pays the full cost of any measures suggested. This scheme is available to residents within the 2011 set 69dBA $L_{eq16hour}$ contour, which Heathrow currently estimates to include around 1,200 homes.

The final scheme is the home relocation assistance. This however is outside of the remit of this case study and does not require an overview.

7.4.4 Heathrow Airport meets Arup SoundLab

It was seen earlier in Section 7.2.6, that the idea of using SoundLab was posed to Heathrow in 2011, after inaugural success of the technology as a communication tool for HS2. Whilst the Director at Arup (A.G.1) recognised that the suggestion of SoundLab use in 2011 was a little hasty and put forward "maybe, pre-conception" (A.G.1). The suggestion and 'concept in principle' had however, remained in the mind of noise management specialists at Heathrow, and as the Airports Commission was being set up, Heathrow employed Arup to help showcase their noise insulation scheme to the government in preparation for expansion enquiry.

7.4.5 Arup's Methodology

Arup acousticians were tasked with the brief of simulating an aircraft fly-over through auralisation, and then using visualisation to illustrate viewing the plane outside through a window; the window would vary between open and closed with the auralisation changing in sound level to reflect this. This was Arup's second design consultation where SoundLab was being commissioned as a potential communication tool, the first of course, having been HS2. While both are similar in principle – simulating a transport pass-by in order to see how it *could* sound in a new position or context, a new train line or a new flight path – setting the aircraft in to visual context has its challenges to visualisation. Indeed, "visualisation is quite a key element of this, because …well, you can't convey acoustics without conveying some sort of visual" (A.R.I-3).

For the auralisation, recordings were taken simultaneously in three different locations at exactly the same time to mimic the three different runways; the two principle locations used for the recordings were Hounslow and Richmond as these are at opposite ends of Heathrow's runways. Where each (Hounslow or Richmond) was the principle location (on different recordings), two further locations were used for the simultaneous recordings relative to the distance needed to mimic the runway distances, "…out of clear necessity" (A.R.I-1). Simulation of the aircraft pass-by directly overhead is illustrated by the principal location, the location that is used for the visual. Then rationale for recording the three locations simultaneously is to maintain the same aircraft use per pass-by; because the "variability between the subjective nature of even the same aircraft is more than enough to confound any changes" (A.R.I-2).

The concept for the visualisation is that people are in their bedrooms asleep and the aircraft pass-by occurs first thing in the morning. There is therefore a 'still street scene' (photo of the street) from the principle location of each audio recording. Surrounding this on the screen is a visual of a window frame, and an info-graphic banner sitting across the top of the screen; it was a means of identifying the location of the plane in relation to the listener.

Sound data was collected on a range of aircraft – an Airbus 320, an Airbus 380 and a Boeing 747-400 – this was in order to capture varying aircraft sounds for the demonstrations. From the range of aircraft sounds sampled by Heathrow and the consulting team, it was decided that A320s were the aircraft to use for the main demonstration; the others would be readily available, but the A320 best represented the majority of sounds experienced, and complained about (H.R.I-1). With the initial focus of insulation demonstrations focusing on daytime issues of noise (specifically first thing in the morning when the majority of people will still be asleep or just waking up) it was agreed that the focus should be on A320s comparing old technology to the retrofitted upgraded technology, so showing the A320s both with and without aerodynamical mitigation to reduce the 'whine' (A.R.I-2). "The other thing is, [when an A380 was played in comparison to the A320] it's bigger on the image, so does this alter perception at all?" (H.R.I-2). It was considered here that, as had been mentioned before, there was enough variability even just within one aircraft between multiple locations, the addition of differing aircraft visual representation was thought of as too confounding in the context of what this demonstration was trying to convey.

As mentioned, the character of an A320s sound has a 'whine' to it, whilst the 787 is a lot smoother in sound, but with a far deeper rumble and sounds far more imposing and 'scary' "…psychologically it's more of a primitive threat" (H.R.I.1). All sounds are demonstrated with ambient noise added. This can be 'switched off', "but in trying to simulate a real time fly over event, the ambient noise is maintained" (A.R.I-2). As with HS2, varying ambient noises were used to best represent particular types of areas in which the noise was experienced, i.e. hi-fi/lo-fi soundscapes (see Chapter 3). In order that the inside sound – with the window open – can be conveyed, a 'room filter' is applied. This is done through an acoustical calculation to add room reverberation and absorption. When the window is shown as closed, more of the high frequencies are removed.

7.4.6 The Consultation

Due to this consultation being developed purely for the means of demonstration to elite stakeholders, and not for the wider public, i.e. needing to reach large amounts of people in various places, specific individuals were invited to Arup London's SoundLab, as opposed to the SoundBooth method seen for HS2 consultations. The SoundLab is an anechoic chamber, consisting of a 16-speaker ambisonic system, with a calibrated area central to the sound sphere, in which up to 3 participants at a time sit on stools. The participants faced a screen, on which the still street scene, described above, was shown.

Heathrow's invitations for these demonstrations went out to the Department for Transport (DfT), the Airports Commission, and key opposition groups, including HACAN and HCNF representatives – each on separate occasions. Once the representatives had been greeted at reception and taken downstairs to the SoundLab facility, they entered SoundLab to ambient music playing. This is to defuse the unusually quiet sound of the anechoic chamber; put simply, SoundLab is sound proofed so that it fully absorbs all sound, leaving no reverberations. This can cause feelings of disorientation when first experienced; the ambient sound therefore allows for a more comfortable entry in to the room, providing 'background sound' rather than 'dead sound'.

The attendees were seated and given a brief overview of SoundLab and how it works, i.e. the amount of speakers, the type of sound, the reasons for sitting in the calibrated area, for example. Little information was given about the demonstrations coming up, however. This was to avoid any form of influence on what was about to be seen and heard. Attendees were asked not to voice opinions during demonstration so as not to influence each other's perception of what they were experiencing.

A range of pass-by flights of different distances and therefore heights were played. Each had multiple demonstrations, showing the window being open, or closed, and also showcasing a range of different insulation options.

7.4.6.1 Experience, Observations and Reflections of Interviewees

From the first demonstration where the plane could be seen moving across the banner, reactions were of confusion, and in the first 'break' between demonstrations Arup consultants were asked questions about banner at the top of the screen, and the look of the plane 'in profile', which actually appeared as though it was on it's side. "Many of the guests mentioned instantly that nature of the plane in 2D on its side was 'disturbing'" (A.R.I-3). Indeed, visual challenges had already been recognised by both Arup and Heathrow when designing these particular demonstrations, in comparison to the HS2, the only other demonstrations of such nature.

Where HS2 ran over ground (unless under ground in which case it could not be seen) as opposed to overhead, landscape acted as visual context for the train passing by i.e. context of its speed and size in comparison to its surroundings. Where there is no landscape when looking up to the sky, there is very little context, and this perception, in size of the aircraft or the speed at which it is travelling, is lost. From the initial designs of the demonstrations, it was agreed that an additional info-graphic was needed to show which runway the aircraft was landing on during the demonstration; this was seen as "key to conveying the message" (A.R.I-2). Nevertheless it was acknowledged by the design team that this was a somewhat artificial construct, i.e. not realistic, and was thus something of a compromise to provide an indication of the fly-over event.

7.4.7 Reflection of Strengths and Weaknesses of Communication Tool

The use of Arup's SoundLab as a demonstration tool to showcase their core mitigation measurement to key stakeholder groups, was a novel one for Heathrow at this point. Whilst it was considered a risk (A.R.I-1), it was decided that the opportunity for people to understand the subtleties (or not) of these mitigation interventions, outweighed the possible risks (H.R.I-1). When asked how this decision was reached, the director of noise management at Heathrow explained that he could "see that the value of this sort of approach would add to the investment [they]'ve put in so far, because it gives [them] an opportunity to do some testing around its potential application".

The feedback from attendees was reasonably consistent – inclusive of the views of opponents to Heathrow's expansion plans – that the demonstrations were valuable in being able to listen the various types of sound insulation options, and the difference they make with/out the window open. Visually however, the banner depicting the location of the aircraft throughout the pass-by was described as "disturbing" and "distracting". Disturbing in the sense that the "plane appears to be on its side!" (D.T.R-2), with the size of the *plane on its side* being distracting to the perceiving of the sound being heard. Indeed, the banner itself (without the plane) was distracting, with many not understanding what it was or it's reason for being there until the plane began scrolling across it. Even at the point that the plane was visible across the banner, it was questioned why the banner was needed, and why the plane could not just move across the screen (G.R-1).

7.4.8 Summary

After experiencing the considered success of the technology as part of the HS2 public consultation road shows, this study illustrated and explored the 'what ifs' arising regarding visual context. Initial challenges that became clear from the outset were to do with the positioning of aircraft: when simulating a vision of being inside the home, it is not possible to see the planes that fly overhead. Trying to introduce sound and demonstrate the impact of varying insulation packages, without being able to see the aircraft position, presented particular challenges, which were only partially addressed through the compromise of presenting aircraft in profile. Further, this raised points about how the position of the aircraft can be illustrated and whether a representation of its position de-values the visual element of the auralisation and visualisation tool. Put simply, the visual elements to these demonstrations caused much more confusion and raised many more questions than having no moving visuals might have done; detracting from the main purpose of the consultation.

The following case study section explores the use of this technology for a much larger consultancy project surrounding respite at Heathrow. With the same Arup acoustics team and noise management team from Heathrow Airport involved as the insulation demonstrations, the challenges with visualisation that have arisen and been highlighted throughout this case study section are addressed and discussed throughout the respite project, below.

7.5 The Use of Arup's SoundLab for Heathrow Airport's Respite Trials

Phase three of this case studies approach, is the most in-depth of the phases, looking at Heathrow's respite study, both the refined use of auralisation and visualisation as a research tool for Heathrow's operational management research, as a communication tool to both stakeholders and public alike; and as an integral part of the public participation process itself.

7.5.1 Introduction

Reflecting on the new 2010 coalition government's blocking of Heathrow's new runway proposal, a key representative of the CAA (C.A.I-1) explains that, "[t]he CAAs assessment of why we got to the 'no ifs, no buts, no third runway' pledge from the incoming government based on the 2003 white paper is that it was to do with noise, and a failure to engage communities effectively." While spectres of other issues such as local air quality and carbon emissions were raised, the main topic of concern had indeed been on the aircraft noise.

The overarching view of the CAA from their assessment therefore was "…that if industry doesn't do more to lower the noise problem, and to engage communities more effectively, we won't see additional capacity being developed" (C.R.1). Despite being aware of the work needed to be seen from Heathrow, the CAA were also very aware that "[w]ithout additional capacity consumers will begin to suffer" as well as UK's GDP as a whole (C.R.2). Following the recommendation of the Davies Commission therefore, the CAA advocated the need for a new runway. "But perhaps where we differ slightly [to Heathrow] is that we don't want it at all costs. And what does 'at all costs' mean, is the question that I'd be inclined to answer" (C.R.1). Borne out of this 'not at all costs' stance, the CAA produced the *Managing Aviation Noise* document in early 2014; a document strongly echoing the principles outlined in the Balanced Approach document from ICAO (see Chapter 2). The document served as a 'warning' for the industry to say, *"if you're wanting to get additional capacity, the trade off there is that you've got to come to the table more on noise, and more on showing communities how they benefit from this"*. With this 'call for change' type warning issued, the UK's National Air Traffic Services (NATS) produced their London Airspace Management Programme (LAMP) that set out to restructure London's airspace and make it more efficient, and fit for the 21st century; fit to have a new runway.

7.5.2 Heathrow 2.0 and the 2019-2023 Noise Action Plan

Indeed, Heathrow recognised the opportunities arising from such overhaul of airspace under NAT's LAMP and incorporated the concept of providing respite through changes in flight paths and incoming improvements in technology, in to their Heathrow 2.0 document and their Noise Action Plan. Section 7.3.2 highlights the second key area of the strategy, *A Great Place to Live*, and outlines the steps through which they will seek to achieve their strategy.

The third of the 8 steps, *highlighted in blue italics*, focuses on maximising respite for residents through airspace design and management, suggesting it has been an important key step from the outset, and not just a box-ticking exercise. Indeed, it has been recognised throughout the Action Plan that even without a new runway being permitted, “a redesigned airspace at Heathrow is required to accommodate new satellite-based Performance Based Navigation (PBN) as well as changes required for the efficient operation of a two-runway Heathrow” (NAP, full, 2019:12).

7.5.3 The Rationale for Respite

Performance-based Navigation (PBN) redefines the aircraft’s required navigation capability from sensor (equipment) based to performance based (ICAO, 2019), improving the accuracy of where aircraft fly (Heathow, 2017c). Aircraft makes and models have unique characteristics and therefore, under conventional navigation, used to naturally take varying lines of a particular route, causing a variation track width of up to 1500 metres either side of a given route, causing flight track ‘corridors’ (Barhydt and Adams, 2006). Satellite based navigation negates such flexibility and the 1500m wide corridor reduces greatly in to a much more concentrated centre line.

A move to utilising satellite-based navigation will see savings of time and fuel, and reduction in emissions (CAA, 2015). PBN technology is being adopted globally and will affect high-level airways, as well as low-level arrival and departure routes in and out of airports. The expectation that many routes will remain the same as the switch to PBN use takes place across the aviation network, is seen as a positive by many (CAA, 2015). Where residential areas heavily surround airports however, this poses negative impacts; while far fewer residents may be over flown due to the concentrated trajectory, those that remain under the centre line will see a marked increase in over flights. Indeed, a key member of the noise management team at Heathrow recognised this arising issue, when asked about the rationale behind embarking upon the respite research: “In terms of airspace change, the new PBN where we take flight tracks and concentrate them down to very few routes, which probably makes the noise contours a bit smaller, may [reduce] the number of people affected within that noise contour. But the results outside of those contours [are] communities that suddenly have a concentrated flight path over them – albeit at 5 or 6,000 feet" (H.R.1).

Heathrow noise management team also recognised however, that with now 'cleaner', narrower centre lines, there was potential to fit more flight path variations within the original 'swathes' of where the original fewer flight paths operated under the conventional navigation system, "I think we should be taking advantage of that if we can" (H.R.1). The task was not a simple one however, and required a multi-disciplinary team of experts – later formed as the Respite Working Group (RWG) – to be assembled in order to first under take research, which would enable robust findings to be taken to the airspace design team.

7.5.3.1 The Rationale for the Use of SoundLab in Respite Research

From the need to gather robust information that informs airspace design change around one of the busiest airports globally, there is a need to first understand the parameters in which there is to work. Put simply, before designers can begin re-structuring airspace, it must first be established how far apart the flight paths must be from one another to ascertain how many flight paths are able to be included in design. Under the remit of using airspace re-structuring to provide respite to residents overflown, the distance between each flight path must be indicative of the distance that constitutes respite; if one flight path sees a concentrated flight path directly overhead for a period of time, at what distance away from this particular flight path would then provide a meaningful break from the over flight noise? In order to find this answer, it was decided that a consensus would need to be drawn on the sound level at which someone could discern the difference between two sounds. Put simply, if they hear one noise at, for example 70 decibels (dB) and then played a second sound at 73dB the listener may not be able to discern any difference between the two. If there was then the 70dB sound played, followed by a second sound of, for example, 75dB, the listener may discern a slight difference, or even consider this second sound to have been considerably louder than the first.

While this is simply an illustration in terms of decibel levels, this idea of sound testing formed the basis for the first SoundLab test.

The official RWG research aim is stated as:
"to better understand the key characteristics of an effective respite strategy for the airport and its noise affected communities" (RWG,2017:1).
With its objectives noted as 'key issues that needed to be explored in relation to developing a set of principles that underpin community preferred options for effective respite'.
These are stated as (RWG, 2017:1):

a) By how far do you need to **spatially change routes** to make a perceived difference (in terms of height and track, and for arrivals and departures)? For example, to provide effective respite through route alternation, the routes must be spatially separated to a sufficient extent to make meaningful difference in sound levels as perceived on the ground.

b) What are the optimum **temporal distribution patterns** required? In theory, and subject to operational constraints, it may be possibly to provide respite according to any preferred temporal distribution, and it could be of considerable value to better understand community preferences in this respect.

Objective 'a' was investigated through *laboratory simulations* (RWG, 2017) in ARUP's SoundLab, exploring discernible differences between pairs of over flights reflecting varying height and lateral differences from the measurement point on the ground. The fundamental aim is to explore the value of these differences in the context of respite.

It must be noted here, that whilst both experiments are as important as each other within the context of the Respite Working Group research, only experiment (objective) 'a' is explored within the case study. This is due to the narrowed focus of the research aim to this thesis and the need to explore Arup's SoundLab technology rather than the respite research in its totality. Objective ‘a’ is the only one of the two that takes place within SoundLab.

It must also be highlighted that whilst the aircraft fly over sounds used for the experiment are designed to sound as realistic as possible, there is no denying that the SoundLab environment is a simulation only; in no way are the experiments utilised as a substitute for real life. The SoundLab here has been chosen as the appropriate test environment as there is no way of conducting such a test using real aircraft in a real setting. For the purpose of the information needing to be extracted, a controlled environment was deemed more appropriate as variables can be controlled and limited/added with the view to keeping the actual over flight sounds as realistic to the participants as they experience in their own home. The core focus here is to identify the difference in sound level at which a significant majority of participants notice a change – both from louder to quieter, and quieter to louder.

7.5.4 The Respite Working Group

Heathrow Airport appointed and funded the Respite Working Group in 2014, made up of Anderson Acoustics, SYSTRA, and Arup.

The multi-disciplinary team did not only consist of acousticians and noise management experts. For any airspace change, the CAA stipulates that the appropriate sponsor [airport, in this context] must follow the process in the newly published CAP1616[27] Airspace Design: Guidance on the regulatory process for changing airspace design, including community engagement requirements. Rather than viewing this as an additional *measure* to adhere to, Heathrow again saw this as an opportunity to really engage and collaborate with their neighbouring communities (H.R.1), and community engagement experts were brought in to the team as well. Indeed every stage at which community members can be considered and included, they have been. Heathrow have had a noise strategy for many years, but by their own admittance, it has been “quite disparate and not particularly well

[27] All CAA publications are available in PDF documents, all titles of which begin with CAP; the numbers correspond to the publication topic area and publication sequence

publicised" (H.R.1). The process of having to forge better relations forced the airport to not just talk with their community, but *engage with* them, and change plans where possible in reaction to that (C.R.1). This falls in line with the NAP guidance set by DEFRA in preparation for the draft action plan. With a substantial section of the guidance document focused on *Collaboration and Consultation* the following criteria was advised:

- The public is consulted about proposals for actions plans
- The public is given early and effective opportunities to participate in the preparation and review of actions plans
- The results of the public participation are taken into account
- The public is informed of the decisions taken and
- Reasonable time frames are provided allowing sufficient time for each stage of public participation.

With the multi-disciplinary team in place, their role was to design, implement and execute the experiments, later analysing the results and presenting them in the Technical Report. The team, whilst consulting with Heathrow on the experiment designs and ensuring they operated within the needs of the brief, remained impartial at all times; regardless of implication for Heathrow, all opinions of participants would be gathered and all outcomes would be published.

7.5.4 The Respite Working Group's Methodology

12 base level sounds were used, made up of two different aircraft, namely an A380 and A320. For each of these, both arrivals and departures were used, and then for each of those sets, a high, medium and low base level sound was used. The high, medium and low base level sounds denoted the varying distant points around the airport at which the data had been captured. Each of these base level sound demonstrations was then played alongside another demonstration subject to plus or minus variations (or indeed a zero difference) as illustrated in Table 7.3a below.

base	LA_{max}		decibel differences						
	arrivals	departures							
A380 high	86	85	0	+3	+6	+9	-3	-6	-9
A380 medium	74	71	0	+3	+6	+9	-3	-6	-9
A380 low	61	57	0	+3	+6	+9	-3	-6	-9
A320 high	80	75	0	+3	+6	+9	-3	-6	-9
A320 medium	71	67	0	+3	+6	+9	-3	-6	-9
A320 low	58	58	0	+3	+6	+9	-3	-6	-9

Table 7.3a Base Level Sounds and Varying Discernible Difference Pairings used for the RWG Experiment

It can be seen in Table 7.3a that the A320 and A380 aircraft were used for the SoundLab test. Both were chosen for very specific reasons within the RWG design and planning meeting. Due to the synergistic alignment between the respite research and this thesis, as well as Arup's involvement in the RWG, the researcher was invited to the design and planning meeting, where permission was sought to gather information for this case study and conduct interviews with members of the Group.

When members of the Group were interviewed (individually) and asked of the rationale for using the A320 and A380s, one replied, "…[t]he reason we picked on A320s just to begin with is that they're the most common aircraft, but I think actually in the early tests we need to bring in either an A380 or [Boeing] 747 (RWG.1). Another member of the group – A Heathrow representative – to be interviewed, when being asked about the discussion had in the group earlier on that day about the need for adding additional aircraft to the A320 in demonstrations, commented, "I can see the justification for saying the A380, 1: because it's the aircraft grabbing headlines for – well there's a view out there that they're noisier than the 74s [Boeing 747] …that may or may not be true at certain implications" (H.R.1).

7.5.4.1 The Respite Working Group's Planning and Discussion

The A380 was quickly confirmed to be the operative choice over the B747, the consideration then was whether to include the A380 or simply to keep the demonstrations to just showing the A320 audio. Within the extensive team discussion, the key Heathrow representative (H.R.1) brought the concern back to the rationale for the research, and indeed the new airspace change design that will allow for the respite scheme, "…another complication that comes from just [using] the A320 is that, that is the most frequent aircraft, but again thinking about the [airspace above and surrounding Heathrow] parameters we're playing with here." Bringing the argument back to the A380, the RWG member continues, "…the noisiest, well the most noise dominant aircraft that we've got [A380], might create a bigger swathe in the sky [of airspace], so then we've got a value around frequency of *those* events [arrival/departure] that comes in to this debate as well, which is another confounder" (H.R.1). Put simply, the discernible difference in sound level change might be a difference of, for example 4dB for A320 demonstrations; If A380 audio is introduced and played against an A320, due to the more noticeable tone and frequency and therefore overall louder engine sound, it was hypothesised that the flight path separation would need to be greater.

During this discussion between the group, focus on the ultimate goal was maintained by Heathrow noise management members central to commissioning of the respite research, "This has eventually got to lead us to handing something to the designers, and say, '*here's your 180 degree of airspace, you've got to get 480,000 movements off this runway, inside of 16 hours, every day, all year, and you've got to be quiet'*. We effectively have to instruct [them to not] put an aircraft that is going to make 'x' dB or above; any closer in its flight track other than 'x' miles away [and] you're *eroding* the change from [conventional flight track methods to PBN technology]". Indeed the realism of the rationale and the RWG discussions and goals in totality later formed the base of a key objective in the Heathrow 2.0 (2019:33) document:

Our Respite for Residents objective outlines how we will work with local groups to manage our noise impact. For example, the airspace around London is still operating based on designs developed in the 1950's. By reforming airspace in consultation with local residents, we can explore options like alternating flight paths, reducing the effects of noise and providing increased predictability of relief. We will also find new *ways to incentivise airlines to use the quietest planes and work with them to take off and land in ways that minimise noise at key times.*

It was observed that the RWG, including members of the Heathrow noise management team (H.R.1), were seeking the most accurate and realistic results from the research, despite the operational restrictions that wider distance and therefore fewer flight paths would bring, “[…these experiments will tell you] the difference you need to achieve for *any* type [of aircraft]. And then you’ve got to understand where – well there’s a point at which [the noticeability of aircraft noise] stops; and it stops further out for a louder aircraft [A380] than it does for a ‘lighter’ aircraft [A320]. A SYSTRA contributor clarifies the research experiment as an appropriate tool for understanding the parameters of this, “…the ‘discernible differences’ [test] will tell you at what stage you’re even going to get *anything* that could be ‘of benefit’; it’s setting the base, which will tell us a lot” (R.W.G, 2).

When considering such implications, a second member of the Heathrow noise management team (H.R.2) voiced varying operational method possibilities, “…thinking about the design of routes, you get to *a* threshold with the light aircraft, which you then say, beyond here actually people don’t even notice whether this aircraft is here or not; it’s at a threshold. It’s, ‘yeah I can hear it, but I’m not bothered by that’, is the lay answer to that, if you like”.

Adding clarity to these considerations, RWG member from Anderson Acoustics (RWG. 3) suggested, “…that threshold is probably 5 miles from the end of the runway for an A320, and 15 miles for a [Boeing] 747”. The Heathrow noise management contributor responded to the discussion rhetorically asking, “But that has airspace connotations for us as well in terms of, do we design different routes then? …[routes] that allow us to get the flexibility we need in terms of [sending] aircraft out from the efficiency point of view, but you’ve also got the space you need to segregate the 74s [Boeing 747] and the A380s, because you keep them on a different route…” (H.R.1).

This in-depth discussion of potential outcomes and implications from the research, and reiterations of the rationale underpinning such an undertaking, provides a clear picture of the scale and importance of the decision to provide respite through airspace change. Not only is it seemingly important that Heathrow Airport's neighbours' quality of life is improved by the scheme, but that the efforts to manage and hopefully improve noise impact, gives rise to backing for a third runway. Indeed, the hypothesis is that airspace design facilitating an effect respite programme would be made more achievable through an additional runway; this is stated in the documents, Heathrow 2.0, and the 2019-2023 Noise Action Plan (Heathrow 2017; Heathrow 2019a; also see section 7.3.1.2 of this Chapter).

When conducting the interviews with the CAA representatives, the same sentiment and hopes of holistic improvements in a pro-active rather than re-active nature were echoed, "It's not about just ploughing money in to the areas that are complaining in the initial planning stages, you've got to think much more widely around how and why you're going to do it. Since publishing Managing Aviation Noise in May 2014, that's probably been the biggest change in my perspective on what needs to happen for industry next; there's got to be a much more coordinated picture of industry, about not just the runway side of things, but about the airspace side of things as well" (C.R.1).

7.5.5 Arup's Methodology

Within the RWG, Arup was tasked with collecting the aircraft sound data and processing it in to auralisation files for the SoundLab demonstrations. As with the initial interview for the Director in Arup who initially made the suggestion of using SoundLab as this form of communication tool, it remained imperative to explore auralisation and visualisation being used together, because "all our senses are connected …[p]ractical experience and human nature, and all of our senses [being] connected, proves that you've got to link them together when you're trying to inform somebody to ask them to make an informed decision" (A.G.1). This meant that the intention of every Arup commission to produce SoundLab – as a communication tool – demonstrations, would include both the visual as well as audio element.

7.5.5.1 Visualisation

At the point of implementing this ethos however, there had not yet been the challenges surrounding transposing visual context from ground-based rail, to sky-borne aircraft, as encountered in the second case study of Heathrow's Insulation scheme (Section 7.3). As the same consultant team from Arup, and the same noise management team from Heathrow were involved in the Insulation scheme and the Respite research, initial conversations around the pilot study suggested that benefits of the visual element of the communication tool may be uncertain for this study as the challenges and limitations that arose in the Insulation work were at the forefront of design discussions. Essentially, the key concerns raised were around how realistic the banner approach was and whether it could be modified to reflect distance, or whether the better solution was to discard moving visuals altogether.

7.5.5.2 Auralisation Data Collection

In order to make the audio demonstrations, Arup's acoustics team carried out *aircraft noise surveys*. These consisted of taking acoustical measurements of aircraft flyovers at meticulously calculated points from Heathrow, at varying community locations; for this particular data, Hounslow and Richmond were used to ensure both departure and take off routes were captured. A sound level meter was used to then record a temporally specific set of data at the varying distance points from the airport. It was common for these to be carried out before sunrise – circa 4am – to capture the first few arrival and departures of the day (carried out on different days). This was to get as neutral an ambient background noise per location as possible.

Once the data had been collected, Arup's acoustic engineers collated the data and 'cleaned it up', in so much as, taking out as much interference as was possible without disturbing any of the actual aircraft sound, and also ensuring all were temporally matched to start and finish times of recordings in case any of the location points had started or ended their recordings at slightly different times.

7.5.6 The Experiment

7.5.6.1 Before the Experiment

The participants were collected at the reception area 5 minutes before each session, to allow for getting to the SoundLab, and getting them comfortable; this involved a brief description of the SoundLab environment before they walked in, and then setting them up with clipboards and explanations of the process before the demonstrations began. This also included a full run through of safety and ethical conduct information. Once the participants were set up and comfortable, the lights were dimmed so that the screen was more prominent, and a member of Arup's acoustic team controlled the play of audio pairings, whilst the visual on the screen in front remained at all times.

7.5.6.2 Test Environment

The experiment was conducted within the SoundLab at Arup, London. The SoundLab is an anechoic chamber, consisting of a 16-speaker ambisonic system, with a calibrated area central to the sound sphere, in which 3 participants sit on stools. 60 participants (3 per hour session) will be asked to listen to audio and view a still street scene projected on to a screen in front of them. Participants experienced 2 sets of 7 pairs of these audio/visual demonstrations and were asked to mark down whether they thought the second aircraft flyover was louder, the same or quieter than the first, for each.

7.5.6.3 During the Listening Experience

The participants were played 2 sets of 7 'pairs' of audio demonstrations along with a 'base' sound level 'pair' from which to compare. As illustrated in Table 7.3a (reiterated below as Table 7.3b, for ease) the base level varied between the 12 options; ranging between 58dB and 86dB. Upon hearing the *second* of each pair – +/- 3, 6, 9dB of the base level as shown under the 'decibel differences' section of Table 7.3b – participants were asked to mark down on an answer sheet (a full version of which can be found in Appendix 3.5) whether they thought the *second* sound was (one of):

- much quieter than the first
- a bit quieter than the first
- the same as the first

- a bit louder than the first
- much louder than the first

base	LA_{max}		decibel differences						
	arrivals	departures							
A380 high	86	85	0	+3	+6	+9	-3	-6	-9
A380 medium	74	71	0	+3	+6	+9	-3	-6	-9
A380 low	61	57	0	+3	+6	+9	-3	-6	-9
A320 high	80	75	0	+3	+6	+9	-3	-6	-9
A320 medium	71	67	0	+3	+6	+9	-3	-6	-9
A320 low	58	58	0	+3	+6	+9	-3	-6	-9

Figure 7.3b **Base Level Sounds and Varying Discernible Difference Pairings used for the RWG Experiment**

Between each of the sound pairs played, the researcher ensured that all participants had marked down an answer and were happy to carry on and then made sure it was clear which of the pairs was next (from A-G). During the introductory information about the format of the experiment, participants were asked very clearly to not discuss their thoughts or allow each other to see answers, so as to gather fully individual opinion. To ensure this remained the case throughout the full length of all three listening sets, participants were asked to refrain from asking any questions regarding the experiment until after all three sets had been demonstrated and answers noted. The researcher also made very clear that participants' *opinions* were wanted, rather than having them fall in to a 'guessing game' of what they thought to be 'right or wrong'.

The first of the sound pairs sequence was carried out and after a short break a 'sequence' section took place; an auralisation and visualisation demonstration of A320 and A380 aircraft in 2x 7 minute-long sequences. The idea of these two sequences was to see which participants thought was louder or quieter as with the sets of pairs. The difference in this experiment section was that the flyovers were delivered in continuous sequences, designed to 'more realistically' imitate real-life; with 90 second long flyovers delivered in pair sequences as with the first listening test, participants tend to be 'ready' to listen to each one, however this is not necessarily true in real-life. The sequences section therefore was designed to test whether the noticeability was held over a sustained period of time. While this section of the experiment was seen as *important* as the first, it was not taken forward to the experiment carried out by the researcher (documented in Chapter 8) due to time and resources. For this reason it is not focused on throughout this thesis.

Between the sequence section and the second of the 7x listening pairs session, participants were taken out of SoundLab and to a seating area where a semi-structured focus group type discussion was conducted. As the researcher had become so involved in the planning and designing stages, opportunity arose to become an integral part of the run of experiments also. This enabled the researcher to conduct some of the focus group style discussions between SoundLab tests, as well as facilitating some of the sessions. Permission had been granted by the RWG for the researcher to carry out her own recordings of these interviews and (within time remit of sessions) expand further on any questions posed by the RWG that was believed to be of additional benefit to the work of this thesis on top of the RWG research. Due to the intended publication of the RWG final Technical Review far ahead of completion date for this study, this was viewed as viable and not intrusive to the RWG.

Once the experiments were completed, participants were thanked for their time and input and escorted back to reception where passes were collected, and participants were signed out.

7.5.7 Results and Observations

It is important to reiterate here that the purpose of this case study, in the context of this thesis, is to understand the results and analysis of the SoundLab discernible difference tests for comparison to the extended SoundLab experiments carried out by the researcher for *this* study. The SoundLab experiment results from the *respite* study therefore are a pertinent foundation to the following Chapter 8. The second, and equally important purpose of this case study is to understand participant opinions, having experienced the SoundLab in the context of information provision; key opinions gathered addressed the experience of SoundLab and the extent to which the visual element added (or indeed detracted) value, as well as discussing the value of respite, and what that would look like to each participant.

With this in mind, the core quantitative results of the respite study are noted here, but actually discussed in detail alongside the results of the experiment conducted as part of this thesis, set out in Chapter 8. This section then, focuses on the discussions and opinions of participants. Opinions were gathered in semi-structured interviews as part of the official respite study, but also as part of additional semi-structured questions of the researcher, incorporated in to initial questions, under permission of the RWG.

The key results of the SoundLab experiment revealed that:

- Participants were more easily able to discern a louder event <u>if</u> it was the second of the two sounds presented, than <u>if</u> it was the first;
- A clear majority (~60%) of participants discerned the difference in sound level when it reached circa -6dB and +3dB;
- Up to the thresholds above, only a minority of participants correctly discerned the sound difference;
- Only a minority of participants (31%) were able to correctly discern hearing the <u>same</u> sound within quick succession (most thought they were different).

While these results provide an interesting initial insight in to perception of a sound source, the conversations taking place through the semi-structured interviews proved far more insightful, in terms of the value of respite, and of SoundLab as a communication tool.

In order to maintain anonymity of participants, and for ease of following conversations to the reader, the table below lists the participant day and session number, and then simplifies these in to one single participant number, or code.

Interview Session	Day	Participant Number/Code
1	2	**1**
3	2	**2**
1	3	**3**
2	3	**4**
3	3	**5**
1	4	**6**
2	4	**7**
3	4	**8**
1	5	**9**
2	5	**10**
3	5	**11**

Table 7.4 Participant Code Allocations

There is a need here to acknowledge how few participant opinions are being used, despite the experiment having 60 participants overall. Because of the nature of the RWG methodology, wanting to keep the flow going as much as possible, but equally wanting to interview each participant individually, and further, because the researcher was asking additional questions *within* the interview sessions of the respite experiments, only one out of the three participants per session was accessible. Moreover, the interviews were carried out in a public area just outside of the SoundLab in the London office, where gatherings were held, and people would congregate before going in to meeting rooms; because this was a busy area therefore, much noise was created, and whilst the conditions were fine for face to face discussions, a considerable amount of the recordings were inaudible. Out of the remaining interviews recorded and audible, some were discarded simply for having very little feedback or unhelpful one-word answers. Nevertheless, most of the interesting and useful opinions were captured, and as such, used below.

7.5.7.1 Key Findings

Working towards the core aim of this thesis – to establish the potential value of a combined audio and visual tool in enhancing communication and thereby community engagement over noise issues - it was important at this stage to determine the extent to which – if any – visualisation has an impact on human perception of sound. With this in mind, a review of the respite study is particularly important as the point against which the experiment documented in Chapter 8 can be compared. In exploring participants opinion on the value of respite, based on the

SoundLab tests, revealed mixed results; many felt that the visual that was provided – a still street scene with no active aircraft – was of little use as most closed their eyes and imagined they were in their own environment, "…it was all about the sound" (Participant 2). Indeed, it is important to remember here that these participants were all local residents of Heathrow Airport and so all experienced aircraft flyovers to some degree. However, even though the banner portraying the aircraft position that had been used in the insulation study had been discarded, others felt that even just the still street scene was distracting, with some admitting they began playing 'spot the difference' between houses (Participant 6 and 11), whereas some went further, and added, "if there were more comprehensive or active visuals, I might be influenced by [them]" (Participant 9) and Participant 1 similarly suggesting, "…it would probably affect the level I thought the noise was at depending on what I could see (plane wise)". A couple of participants felt they would appreciate a more comprehensive visual element to help them contextualise the sound, with Participant 7 commenting, "it was useful, it just puts you in the environment a bit more …an aircraft would've been useful"; while Participant 8 said he kept looking out for the aircraft and waiting for it to appear on screen, consequently distracting him from the audio task.

A topic that produced particularly interesting discussions, and really got participants thinking about their own, every day experiences, was around the concept of respite; of what it means to them as individuals, but also the extent to which they would use it, if they had control over when to install respite periods from aircraft noise when in their home. Some answers were rooted in perception based thought processes, for example, "[w]hen we're not out in the garden the planes don't seem to appear, but when we use the garden they seem to come along!" (Participant 3). When probed further as to whether Participant 3 thought this might be a matter of just not noticing them when she was in her house, the participant disagreed and was sure that there were no aircraft flyovers when she was inside the home, expanding further on this reason, Participant 3 explained that they were so loud when outside in the garden that she was sure that they would be heard when inside also.

On a slightly different track, Participant 1 noted that expectation plays a big part in annoyance of the noise, “once I hear one, I know that’s it, there’s one coming every minute – I try to block it out, but it’s difficult” “And you’re right, I’m not exactly right close to the airport [South Kensington] but it still does effect us”. Similarly, Participant 7 suggested, “You find that you’re waiting for the next one; when there’s a big gap… *when’s the next one coming?*...” before adding, “I notice it more in the mornings because it’s a more concentrated sound in the mornings; [I’m b]usy with life other times”. Whereas Participant 2 added some rather contradicting sentences in to his (out loud) thought process, “I’m so immune to it [the noise] …but still really annoyed at [05.30 – 6.15 and 17.30 – 19.30] …I think you just get used to the noise eventually.”

Furthering the conversation to preference of respite periods, the answers were somewhat varied, but overall similar to what was expected. Where it was hypothesised that most would choose longer periods of respite, and key time periods i.e. first thing in the morning, and evening, for many, this was the case, “…alternating would be better… every week would be better than every day” (Participant 1). Participant 2 however, where he began by naming his preferred time of day for respite, he then took the *longer respite period* to the extreme, [I would prefer f]irst thing in the morning, [with the aircraft noise as it is] I don’t even need to use my alarms [in the morning], specifying a time of between 05.30 and 06.15. It was then added, “When an operational schedule is set it needs to be set for the next few years. People need routine” (Participant 2).

An interesting idea mentioned by a couple of participants when asked how they would like to be notified of when a respite period was about to start, was that they would prefer not to be notified, “…because [I} would be waiting for it. [It w]ould just be a nice surprise” (Participant 8). Participant 9 equally suggested that they would “tune in” if they knew when to expect it. Adding to the notion of personal expectation management, Participant 9 provided a really interesting thought, “…[I w]ouldn’t want too much of a long quiet period because [I] would get used to it and then notice aircraft even more when [they] came back – [I would suggest] 1 hour max[imum respite period].”

The final most pertinent of the interview questions, was around the reasons for the participants attending the experiment, and the extent to which they felt as though their opinions mattered, or indeed would make any kind of a difference. It was firstly explained that the experiments were exploring the discernible difference in sound levels in order to potentially help in the re-design of flight paths at Heathrow Airport, and in doing so, hopefully provide periods of respite to areas of residents living close the airport.

While there was inevitably some scepticism, “once things have been decided they’ve been decided” (Participant 4), and what could be described as tentative scepticism, “[It w]ill be interesting to see the outcomes of this research …If it didn’t go the way [Heathrow] want they might try and bury the research” (Participant 10), the majority of participants were actually extremely positive about both the reasons for the experiments, and the effort being afforded by Heathrow, and the confidence that their opinions would indeed be heard and make a difference. This positivity was actually surprising to the researcher, albeit pleasantly so.

7.5.8 Summary

The discussions to come out of the semi-structured interviews between respite listening tests, provided some really interesting insight into the thoughts and opinions of those living in close proximity to Heathrow Airport and therefore experience considerable aircraft noise almost every day.

The key themes to be distilled from the interviews were:

- Most prefer keeping a consistent schedule
- The most recurring reason for wanting the respite were sleep and being outside in the garden
- Some mentioned that they work from home so the noise can get a little much, however even these people were more concerned with times of sleep for respite

- The most preferred time for respite was first thing in the morning, with most of the participants giving this answer willing to forfeit any other time of day or week to have early morning respite every day
- All but 2 participants that were interviewed felt that their input is valued.

The answers discussed above and the key themes to arise from the interviews echo many of the non-acoustic factor outlined in Chapter 3, most notably, expectation and expectation management, personal and social factors, particularly where lifestyle was mentioned, and context. It was interesting to note that almost all participants felt heard through the experience of attending the experiment, and most appeared excited by the opportunity of being able to really get in to giving their opinion, particularly after having experienced the auralisation and visualisation; the use of the SoundLab in this sense appeared to really open up conversation.

Finally, the varied views on the visual representation within the SoundLab demonstrations provided a sense that, while a substantial number of participants in the respite experiment felt it more useful to close their eyes and imagine their own situations, these are participants that experience aircraft noise every day. There were also considerable opinions that a more active visual would have helped to provide context of what was being heard. These opinions of visualisation possibly providing more context to what was being heard were interesting ones, particularly given that participants recruited for the study would not specifically be from areas under a flight path, and so provision of visual context may well serve to aid in the experience.

The following chapter now explores this, and other questions surrounding the extent to which visual stimuli impacts human perception of sound. As mentioned at the beginning of this section, the quantitative results from the respite study are outlined in further details and used in comparison to the data collected and analysed in the following chapter.

Chapter 8 Experiment and Analysis

This research aims to explore whether visual stimuli impacts participants' perception of the sound they are hearing, and therefore alters the point at which they discern a sound level change, either louder or quieter. From the experiments that were carried out, the data was gathered and processed, and section 8.3 of this chapter analyses the results, looking to identify trends and any potential significance of results to the research objectives overall.

The results will focus on the average performance of the participant group in order to determine the onset of discernibility, as defined by 60% of participants 'correctly' identifying the sound level change. Figure 8.1 below, depicts 'correct answer' data sets for both the Respite study, and this study. The way in which the two data sets were arrived at is discussed in detail throughout section 8.2.3, below. It is important that Figure 8.1 is shown here however, to clearly illustrate confidence levels of this study's data set before continuing the analysis. Examination of the group performance and also of specific demographics highlights that whilst there is a degree of uncertainty, it is not unacceptable. This is true for the whole group, as well as the sub-groups relating to gender, age, employment status, or proximity of living to the nearest airport. Whilst sub-groups have been examined, it must be noted that Figure 8.1 depicts the holistic data of each study only, due to the lack of significance in variability among sub-groups, and therefore lack of any noteworthy results per group.

When looking to identify the validity of data that is analysed throughout this chapter then, a 95% confidence level has been used for the data set of this research; this is illustrated on Figure 8.1 by vertical lines at each key decibel intersect.

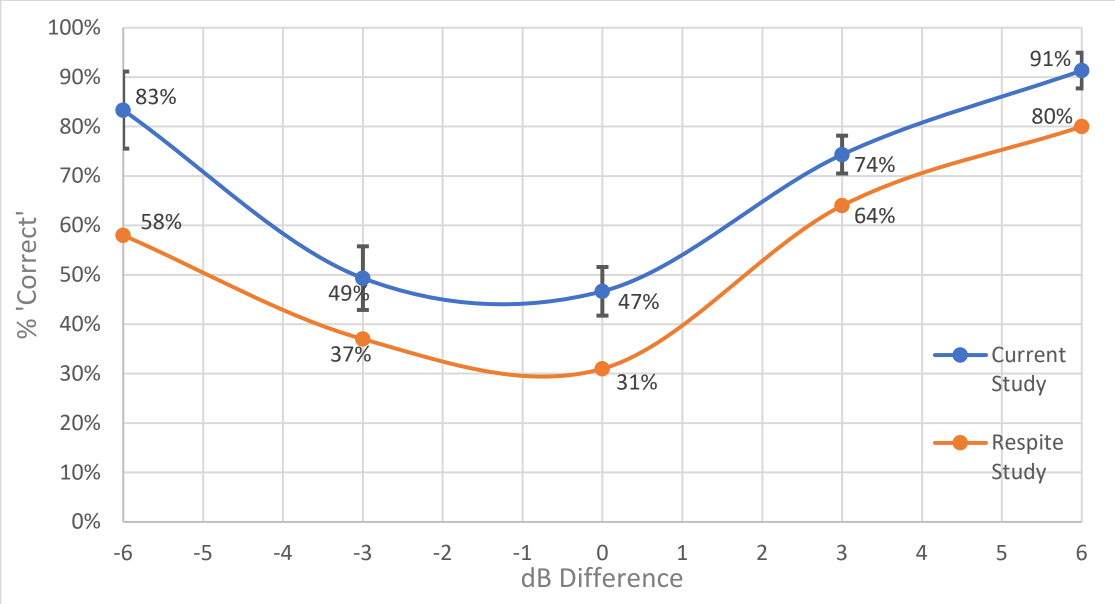


Figure 8.1 **95% Confidence Intervals for This Study**

The confidence level markers show an average of 5%, with a maximum interval difference of 9% at a -6dB difference, and down to a 3% interval at +6dB difference. It is interesting to note that the confidence interval becomes far greater when the second flyover sound was *quieter* than the first.

In the context of comparing data sets of this study and the Respite study, even at its largest confidence interval of 9% at -6dB difference, there is still over 15% difference to the 58% of the Respite study. At the smallest difference point between the two studies, +6dB difference, there is only a 3% confidence interval, leaving over 5% still to the Respite study result of 80%. As a consequence, reasonable confidence can be assumed in the onset positions that will be focused on for the rest of this chapter.

8.1 The Experiment

This experiment took place within the SoundLab at Arup, Manchester. 90 participants (3 per hour session) were asked to listen to audio and view corresponding visuals. Participants experienced 3 sets of 5 pairs of these audio/visual demonstrations and were asked to mark down whether they thought the second aircraft flyover was louder, the same or quieter than the first, for each.

8.1.1 The Rationale

Chapter 7 charted the evolution of the Arup's SoundLab use in the context of auralisation and visualisation as communication tools to various stakeholder groups. The HS2 experiment (Chapter 7, Section 7.2) saw that auralisation and visualisation did indeed appear to improve public engagement. Equally concluded however, was that auralisation and visualisation as a communication tool is no 'silver bullet', and can only be improve the public engagement process as one cog in a far larger 'effective engagement process' wheel. The latter part of Chapter 7 (Section 7.4 onwards) explored the most recent use of such a tool, for Heathrow's respite research, culminating in a laboratory setting experiment – as opposed to the usual consultation. This concluded that the point at which 60% of respondents were able to accurately discern a flyover event as being either louder of quieter was +3dB and -6dB, respectively.

The overall aim of *this* experiment is to ascertain whether visual stimuli have any impact on human perception of what is being heard. For the Heathrow respite study, the visual stimulus was that of a still street scene, which remained on the screen, unchanged throughout the experiment. The initial respite research was particularly important to Heathrow as it helped to provide guidance for how far apart new flight paths (arrivals and departures) would have to be to provide respite for residential communities surrounding the immediate airport vicinity; and potentially allowing for larger operational capacity. Put simply, if visual information brings forward the point of discernibility, this could have implications for the separation of flight paths required to deliver meaningful respite. Through the addition of visual stimuli, this experiment sought to explore whether human perception of the discernible difference point (according to the respite research) is impacted in any way, and therefore narrowing or widening flight path designs over Heathrow airspace.

It is hypothesised at this point, that where an audio stimulus is over emphasised through visual stimuli, the point of discernment (of a sound level change) is brought forward where a sound change increases – and therefore the visual represents a larger sound increase, i.e. is discerned at a smaller change in decibels. Equally, the point of discernment is brought forward where a sound change *decreases* – and therefore the visual represents a larger decrease, i.e. discerned at a louder level.

Where an audio stimulus is *under* emphasised by visual stimuli, the point of discernment, it is hypothesised, is pushed back. For example, where a sound change increases and the visual stimuli represent a *lesser* increase, the sound level change will be discerned at a louder level; where a sound change decreases and visual stimuli represent a lesser decrease, the discernment will be at a quieter level. Fundamentally, if the visuals under represent the sound level change then the hypothesis is that the decibel change between events at which the majority of respondents (60%) accurately distinguish an event to be quieter or louder with be greater than for circumstances where there are no visuals and/or where the visual reinforce the aural stimuli.

If this hypothesis is realised, the implication for Heathrow's airspace design could potentially see a reduction in distant between flights paths required to deliver meaningful respite, with a potential to include more within the airspace. Whilst this would offer scope for better operational management for Heathrow, it also has the potential to offer a wider range of respite options. Whilst results resembling this hypothesis would be a positive outcome, this experiment could well reveal that visual stimuli have no impact on human interpretation of sound – so the results set would look similar to those of the respite study. This would not necessarily be a negative outcome, simply that the results of the respite study remain the data by which Heathrow base their future airspace design.

The results of this experiment are discussed further in the following sections, with each variation of the experiment analysed individually. The areas in which the lead is taken from the respite study are made clear. In order to maintain a reasonable flow of comparison, the order of analysis of the respite study is followed as much as possible. For this reason, this chapter first shows the aggregated data set, and the disaggregated, more distilled findings are shown thereafter. The Chapter ends with the most concentrated results being shown in one final chart for comparison and conclusion.

8.1.2 Experimental Approach and Results Presentation

The experiment consisted of a constructed standard test, which exposed 90 participants to a suite of stimuli and asked them what their interpretation of that was. The stimuli were pairs of audio and visual representations of aircraft flyovers. There are 3 sets of 5 pairs (audio and visual), and participants were asked to judge each one against the base level pair (sound and consistent visual stimulus), which was played before every pair being judged against the first.

The answer options were in a Likert style 1 – 5 rating (these 1 – 5 ratings were given descriptive labels, i.e. 'the second sound was much louder than the first') and the environment in which the experiment took place was controlled. For further detail of experimental set up, see Section 8.1.7; for an example of the answer sheet see Appendix 3.5.

The approach has been designed to allow for comparison with the original piece of work carried out as part of the respite study (Section 7.4). The respite experiment did not use moving visuals; rather, a still street scene was in place and did not change throughout the experiment. The rationale for this at the time was that there had been numerous problems with how the visual had been presented in the run up to the study and then throughout the pilot tests (see Section 7.4).

In order to identify the point at which the visual stimuli had any impact on the participants' perception of the sound stimuli, the suite of ways in which the visual stimuli were presented in relation to the auditory decibel differences, have been separated and analysed accordingly. The categories used to separate the visual stimuli in relation to the changing audio are:

- **Over emphasis**, i.e. audio stimuli increases by 3dB, visual stimuli represents a 6dB increase; audio stimuli decreases by 3 dB, visual stimuli represents a 6dB decrease

- **Under emphasis**, i.e. audio stimuli increase by 3dB, visual stimuli represent no increase; audio decrease by 3dB, visual stimuli represent no increase
- **No emphasis**, i.e. audio stimuli increase by 3dB, visual stimuli represent a 3dB increase; audio stimuli decrease by 3dB, visual stimuli represent a 3dB decrease
- Where the second **auditory stimuli remain consistent** with the base line audio, but the second **visual representation varies**, a separate analysis takes place.

To clarify, while the audio stimuli increases or decreases by 3 or 6dB (if at all), the visual stimuli will never represent an audio in/decrease and greater than 3dB of that audio change. In order to fully understand this, a table is provided below:

Pair A	Pair B	
Audio & Visual	Audio	Visual
67dB	-6	-9
		-6
		-3
	-3	-6
		-3
		0
	0	-3
		0
		3
	3	0
		3
		6
	6	3
		6
		9

Table 8.1 Summary of Sound Pairs (B) to Compare to the Base Level Sound (A)

It must be noted here that each of the charts throughout this chapter use 'line of best fit' to join the data points, and so, whilst the data points are illustrated in percentage at each core intersect, the 'line of best fit' may continue either slightly above or below a point. This is simply pointing to the fact that whilst a percentage is being used to represent the mean data, the most *extreme* answer given by participants may be slightly above or below this, and is a more than acceptable tenet of statistical data analysis.

It is also important to note here, that the term 'correct answer' is used throughout this chapter. When speaking to participants it is maintained that there *is no correct answer*, rather, the 'answer sheet seeks to capture *opinions* of participants based on their perception of the sound stimulus in comparison to the base level sound stimulus'. The term *correct* however, is used to denote the opinion, which matches that of the *actual* differentiation in decibel level that occurs in relation to the first one presented. An explanation of how the 'correct' answer is arrived at in Section 8.3.3, below.

As Section 8.1 outlines, the participant is not given specific decibel levels to identify, they are given an option of 5 opinion statements ranging from much quieter through to much louder. The degree of variance is then matched to the degree of differentiation in sound level to that of the base level sound.

8.1.3 Test Environment

The tests took place in Arup's Manchester SoundLab; an anechoic chamber, consisting of a 16-speaker ambisonic system, with a calibrated area central to the sound sphere, in which up to 3 participants sit on stools. The participants faced a screen, on to which was projected a still street scene with moving aircraft flyovers. Figure 8.2 is a screen grab of the actual street scene used, and one of the aircraft flyover variations passing across the screen.

Figure 8.2 **Visual Representation Presented During the Experiments**

8.1.4 Testing and Piloting

Just as the respite study stated, the subject matter, stimuli and options researched for *this* study are complex, and considerable cognitive testing is also required to ensure materials were fit for purpose prior to conducting the main laboratory experiments; even more so with the additional variable of visual stimuli to consider. Three pilot experiments therefore, were carried out in the SoundLab at Arup Manchester, each testing visual representations, and the set up of comparative material. All pilot testing was informal, with members of the thesis supervisory team, and Arup acousticians. Once all visual stimuli and order of sound level pairs were streamlined for a neat, efficient experiment, one final pilot experiment was carried out as a full run through. This was with voluntary members of the Arup acoustics team as part of a weekly morning briefing. Whilst the answers had the potential to be biased based on an acoustician's 'attuned' ear, this was more a run through of logistics and efficacy rather than to gather results. All results gathered within this experiment were discarded to ensure they were *not* included in overall data collection.

8.1.5 Before the Experiment

The participants were collected at the reception area 5 minutes before each session, to allow for getting to the SoundLab, and getting them comfortable; this involved a brief description of SoundLab's environment before they walked in, and then setting them up with clipboards and explanations of the process before the demonstrations began. This also included a full run through of safety and ethical conduct information. Once the participants were set up and comfortable, the lights were dimmed so that the screen was more prominent, and the researcher controlled the play of audio and visuals presented together.

8.1.6 The Set-Up

In order that the experiment could take place, the audio and visual stimuli needed constructing. Arup acousticians were called upon to help design this – once put together as a demonstrable piece this is known as a *patch*.

8.1.6.1 Audio Stimuli of Aircraft Flyovers

A robust amount of data in the form of *aircraft noise surveys* had already been gathered and 'engineered' for the Heathrow respite study, which the researcher had been a part of. Permission had been acquired from Heathrow in order that their sound demonstrations could be used for this study, however, as Arup own the rights to the work they had carried out, permission was not necessarily needed, as long as the demonstrations were not used for public measures under the guise of Heathrow research. While Heathrow Airport Ltd is happy for this research to look at theirs in a case study-style, this thesis is not in anyway claiming Heathrow results as its own, nor is there any dissemination to the public in any other way than forming background to this experiment process.

The aircraft noise survey involved taking acoustical measurements of aircraft flyovers at meticulously calculated points from Heathrow, at varying community locations; for this particular data, Hounslow and Richmond were used to ensure both departure and take off routes were captured. A sound level meter was used to then record a temporally specific set of data at the varying distance points from the airport. It was common for these to be carried out before sunrise – circa 4am – to capture the first few arrival and departures of the day (carried out on different days). This was to get as neutral an ambient background noise per location as possible.

Once the data had been collected, Arup's acoustic engineers collated and 'cleaned it up', in so much as, take out as much interference as was possible without disturbing any of the actual aircraft sound, and also ensuring all were temporally matched to start and finish times of recordings in case any of the location points had started or ended their recordings at slightly different times.

For the Heathrow respite work, a set of 12 different base level sounds was used. These were made up of two different aircraft, namely an A380 and A320. For each of these, both arrivals and departures were used, and then for each of those sets, a high, medium and low base level sound was used. The high medium and low base level sounds denoted varying distant points around the airport where the data had been captured. Table 8.2 below is the chart used to collate this information in the respite study.

Base	**L_{Amax}**		**Decibel Differences**						
	Arrivals	**Departures**							
A380 high	86	85	0	+3	+6	+9	-3	-6	-9
A380 medium	74	71	0	+3	+6	+9	-3	-6	-9
A380 low	61	57	0	+3	+6	+9	-3	-6	-9
A320 high	80	75	0	+3	+6	+9	-3	-6	-9
A320 medium	71	**67**	0	+3	+6	+9	-3	-6	-9
A320 low	58	58	0	+3	+6	+9	-3	-6	-9

Table 8.2 12 Base Level Sounds used in Respite Study, Selected Base Level Sound Highlighted for Current Study

It can be seen in Table 8.2, that the A320 medium, departures base level sound of 67dB L_{Amax} is the one selected for this research. This was carefully considered and discussed in conjunction with the acousticians at Arup. The aircraft provides a slightly clearer sound in terms of tone and pitch compared to the A380, and a higher L_{Amax} peak, all of which make for a marginally better choice for a listening test subject, when having to choose between the two.

A conscious decision was made to have no ambient sound playing for any of the demonstrations. Due to the nature of how the varying sound levels were calibrated, the ambient sound level would have changed along with each aircraft flyover. Given the ambient sound would be heard before any of the aircraft flyovers, participants may have started comparing these sounds rather than waiting a little while longer to hear the aircraft pass-by.

Table 8.2 also shows a suite of 'decibel differences' for each of the base level sounds. This denotes the sound level variances to which participants compare the base level sound. It has already been outlined above that this experiment followed a similar method, although, due to only having one base level sound compared to the 12 seen in the respite work, it was feasible that each participant here could experience each of the sound level pairs. To avoid maintaining the same sequencing – which has the potential to influence results, for example if a quieter sound level change was always heard after hearing no sound level change, a graeco-latin square was followed to randomise the sound pairs, but also ensure each sound pair was presented the same number of times. Table 8.3 below summarises the outcome of the graeco-latin square workings out.

Pair A	Pair B		Code
Audio & Visual	Audio	Visual	
67dB	-6	-9	15
		-6	14
		-3	12
	-3	-6	13
		-3	11
		0	9
	0	-3	10
		0	8
		3	6
	3	0	7
		3	5
		6	3
	6	3	4
		6	2
		9	1

Table 8.3 Summary of Sound Pairs (B) to Compare to the Base Level Sound (A)

The respite study tested an additional +/-9dB variable (illustrated in Table 8.2). As Chapter 7 (Section 7.4) has reported, the results concluded that the onset of discernibility fell at just above -6dB at its lowest point (This was for instances when the second event was quieter than the first, whereas when the second event was louder than the first, the onset of discernibility almost halved in decibel change). During the design stage, the rationale for this study therefore, was that the additional +/-9 dB variable was not necessary to this experiment, and could well be explored at a further stage if the results suggested it was warranted. This decision was significantly reinforced when considering the additional element of the visual stimuli. Not only would omitting the +/- 9dB audio/visual variable maintain a neater data set, but when working to design the visual aid to exact scale, the fewer visuals enabled a more realistic spread of aircraft positioning, whilst still being far enough apart to at least provide a chance of discerning a difference between them. This is discussed in further detail in the following section.

8.1.6.2 Visualisation

In order that this experiment furthers that of the respite research, the addition of visual stimuli was added. Whilst the respite study had a still street scene to give participants some from of reference to a residential area of low flying aircraft, no active aircraft visuals were involved.

From the review of issues identified previously throughout Chapter 7 with visual contextualisation, the researcher worked closely with the virtual and visualisations team at Arup to fulfil the brief of 7 aircraft flyovers representative of the 7 varying sound level audio files. It was specified that the aircraft needed to be seen in profile as they would during a real life pass-by, rather than something similar to that seen in the Insulation case study in Chapter 7 (Section 7.3).

To maintain as fewer variable changes as possible, the still street was used from the respite study, and the aircraft flyover simulations were overlaid. Each sound level representation visual was calculated to the distance and height specific to each sound level according to their recording location relative to Heathrow Airport. This meant that the aircraft weren't necessarily evenly spaced vertically across the screen due to the logarithmic nature of distance and height of an aircraft relative to its sound level. Nevertheless, the result was a true-to-life visual representation of each audio simulation.

8.1.6.3 Recruiting Participants

Given the lack of budget and therefore resources to offer 'thank you gifts' or cover travel costs to encourage participation, or indeed to spend on advertisings, an invitation email was sent to all businesses within 3 and 4 Piccadilly Place (the business complex in which Arup is located). Email invites were also sent to surrounding businesses, including gyms, cafes, hotels, supermarkets, and further business buildings. The emails were circulated to all those in each business, from the cleaning staff through to CEO's. Further to targeting local businesses, invitations were also sent via alumni to Salford University, University of Manchester, and Manchester Metropolitan University. It was also made clear in the invitation emails that people were welcome to forward it on to friends and family, although travel cost was at their own discretion.

The rationale for target invitees was that the sample would be made up of those already working in the local vicinity and therefore did not require additional travel time or cost to their working day. Varying businesses both in and around the business complex meant that a broad demographic of age, gender, monetary and residential status were captured, as well as varying types of residential areas with people travelling from all corners of the city and beyond for work. The only major demographic group that had not been catered for was the unemployed. For this reason, invites were extended out to friends and family of those receiving the emails, which further captured retired, unemployed and student relatives; the invites to students also had the potential to capture the unemployed. A wide variety of demographics did indeed volunteer.

The only two stipulations made were that participants must be over the age of 18, and both hearing and sight must be in tact. As the experiment was based on individual perception, the extent to which this was present was not of concern. If for example, someone had use of a hearing aid, this did not impact *their* perception of what were normal sound levels to *them* in everyday life.

8.1.7 During the Listening Experiment

The participants were played 3 sets of 5 'pairs' of audio and visual demonstrations along with a 'base' sound level 'pair' from which to compare. The base pair was always the same 67dB sound level and visual representation of height and distance of this sound level – appropriate to the aircraft that the sound was modelled from. More detail of both audio and visual stimuli is outlined in the two following sections. Upon hearing the *second* (base level) pair, participants were asked to mark down on an answer sheet (a full version of which can be found in Appendix 3.5) whether they thought the *second* sound was (one of):

- much quieter than the first
- a bit quieter than the first
- the same as the first
- a bit louder than the first
- much louder than the first

Between each of the sound pairs (and of course their base pair) played, the researcher ensured that all participants had marked down an answer and were happy to carry on and then made sure it was clear which of the pairs was next (from A – E). During the introductory information about the format of the experiment, participants were asked very clearly to not discuss their thoughts or allow each other to see answers, so as to gather fully individual opinion. To ensure this remained the case throughout the full length of all three listening sets, participants were asked to refrain from asking any questions regarding the experiment until after all three sets had been demonstrated and answers noted. The researcher also made very clear that participants' *opinions* were wanted, rather than having them fall in to a 'guessing game' of what they thought to be 'right or wrong'.

Between the three listening sets, the participants had a brief break. This came in the form of the researcher providing pieces of information relevant to the research, for example, a brief outline of the respite study and how it had set up this research. A full copy of the researcher's guidance document can be found in Appendix 3.4, which includes the 'script' for each of the two breaks between listening sets.

8.2 Analysis of Results

8.2.1 Base Level Aircraft Flyover

For each pair of audio and visual representation of an aircraft flyover, there must first be a baseline audio and visual pairing that is demonstrated in order to have a level from which to compare. As explained in detail in Section 8.1, each base level flyover is illustrating an aircraft at 67dB, and the visual that is seen with this accurately represents the distance and height, and therefore sound level of the aircraft flyover. For each of the comparison demonstrations therefore, this base level audio and visual representation (pair) is shown, before a second pair; both pairs shown are always of the same temporal length. As section 8.1 outlined in detail, the second pair will either be the same, or +/- 3 or 6dB, with a visual representation either consistent with, or +/- 3dB.

8.2.2 An Overview of the Analysis

Before the data is disaggregated to begin analysing various uses of visual stimuli individually, the researcher thought it was first important to gain an overarching view of the full range dataset. Figure 8.3a below shows the results for the sample overall. To understand the nature of responses in relation to the sound and visual stimuli, the Mean response is used, from -2 = 'the second aircraft was much quieter than the first' to +2 = 'the second aircraft was much louder than the first'.

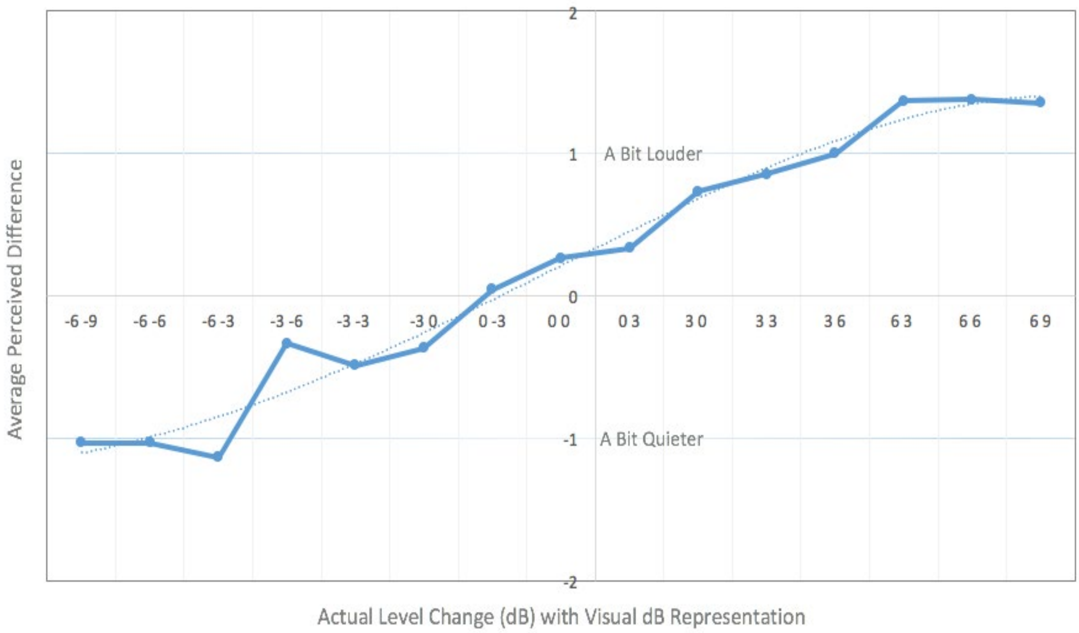


Figure 8.3a **Mean Discernible Difference Response by Change in dB Presented for This Study**

Set against the same data from the respite study (Figure 8.3b), the results are very similar in trend, in that as the second sound gets louder than the first, i.e. moving from left to right across the chart, the mean response generally increases, as expected. There is however, a clear interruption in the data from the visual stimuli, creating a sense of *segmented* data, insomuch as, where each of the sound level variables change, the visuals seemingly have varying degrees of influence. This is explored further in more disaggregated form in Section 8.2.4 onwards.

The results show that:

- Whilst the general trend reflects that of the sound only data set (8.2b) of the respite study, there appears to be some anomalies within some of the sound levels groups in accordance with the over or under emphasis provided by the visual stimuli. These are discussed in more detail in the sections below.

- At the limits, i.e. the stimuli presented differences in sound level of +/-6dB, the average response does not exceed -1 and +1.5 (‘a bit quieter’ and between ‘a bit louder’ and ‘much louder’), respectively, *except for* where both are *under emphasised* by the visual stimuli (-6dB with a -3dB visual representation, and +6dB with a +3dB representation, respectively). While this is an anomaly to the general trend, it is interesting that the only occurrence of this is at the same point either side of the scale. This could suggest that as with the respite results, in general, not everyone was convinced of what they perceived, even at the larger decibel difference.
- Moreover, the *over emphasising* of visual representation only appears to have consistently impacted perception of the sound level change where the audio stimuli increases by 3dB from the base level.
- Where the sound level does not change from the base level sound, all perceptions reflect the increase or decrease of visual representation of sound level. Regardless of the extent to which this sound level is perceived to change, the mean perception is positive at every point, i.e. whether the visual represented an increase or decrease in sound, suggesting a tendency across the whole sample to consider the second sound to be louder. Once again this strongly echoes the results of the respite study (see Figure 8.2b).

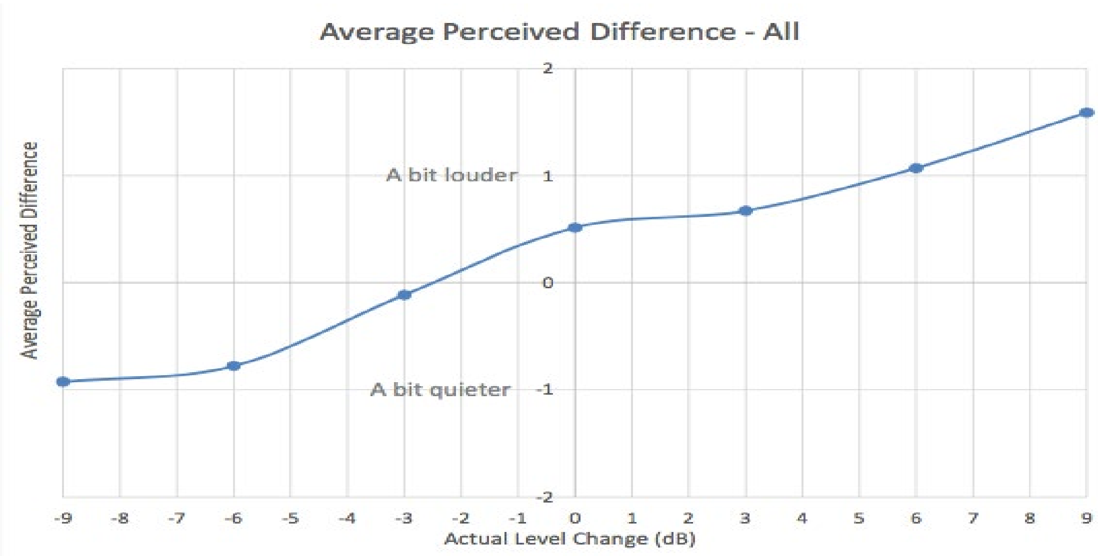


Figure 8.3b **Respite Study Mean Discernible Difference Response by Change in dB Presented, Adapted from RWG Technical Report, 2017**

8.2.3 'Correctly' Discerning Whether the Second Event Illustration (pair) was Louder of Quieter than the Base Level Pair and the Impact of Visuals

'Correct' answers for each pair option were identified and coded under the same method as the respite study. It is important to note here that the 5-point scale was condensed so that, in essence, the two 'correct' answers for both *louder* and *quieter* – that is, the subjective opinions of *a bit* and *much* – were combined. This means that for an answer to be deemed *correct*, participants would have to mark a quieter second sound as *either* 'a bit' or 'much' quieter, or mark a louder second sound as *either* 'a bit' or 'much' louder.

Below, Table 8.4a depicts the chart developed as part of the respite study, showing the workings out of the above. Table 8.4b shows the outcome of results that illustrate this. The coding has been used within the respite analysis in order that a 'data at random' line can be illustrated. This simply gives a visual depiction of the notion that there are two 'correct answers' per louder/quieter options, but only one for 'the same' (seen in Figure 8.4); so for example, the probability of discerning the 'correct' answer at random is only 20% (1 out 5 answers). When considering the combining of 'a bit/much louder/quieter' as explained above, there is actually only 20% probability for 'no change', but only 40% probability of discerning either louder or quieter.

1=correct and 0=incorrect answers					
	-2	-1	0	1	2
	much quieter	a bit quieter	no different	a bit louder	much louder
dbDiff	5	4	3	2	1
-9	1	1	0	0	0
-6	1	1	0	0	0
-3	1	1	0	0	0
0	0	0	1	0	0
3	0	0	0	1	1
6	0	0	0	1	1
9	0	0	0	1	1

Table 8.4a **Discernible Difference Acceptance Criteria, Adapter from RWG, 2017**

	-6,-9	-6,-6	-6,-3	-3,-6	-3,-3	-3,0	0,-3	0,0	0,3	3,0	3,3	3,6	6,3	6,6	6,9
Much quieter (-2)	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
A bit quieter (-1)	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
Same (0)	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
A bit louder (1)	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1
Much louder (2)	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1

Table 8.4b Discernible Difference Acceptance Criteria for This Study

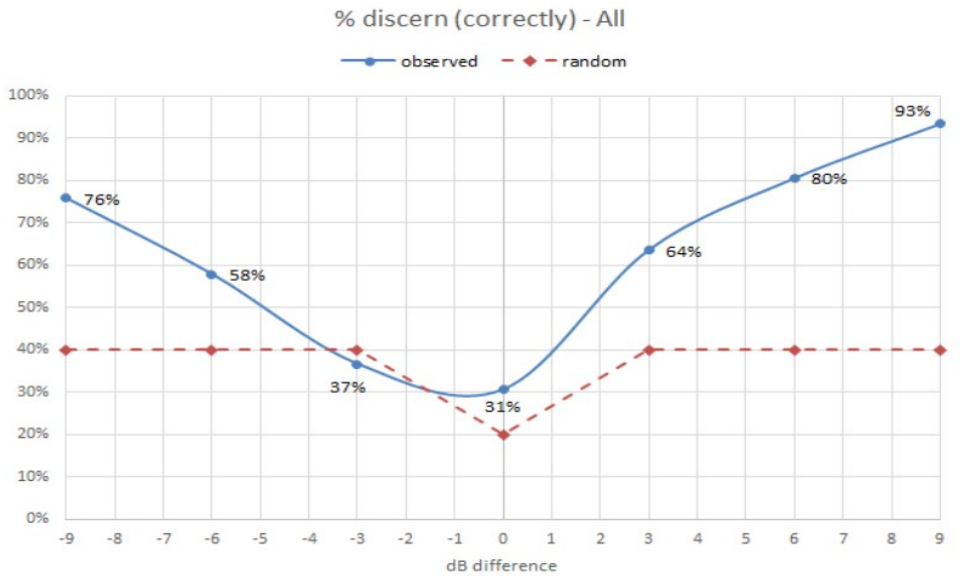


Figure 8.4 Discernible Difference Results – Whole Sample, Adapter from RWG, 2017

While a relatively similar process has been applied to the data gathered within this study, the outcome of percentage curve appears a little differently. The experiment within this study of course, also has the visual stimuli to consider when looking at the information needing to be extracted and analysed. The data at this point still focuses on the 'correct' answer with respect to whether a sound is louder or quieter than the base level sound heard beforehand. The y axis of Figure 8.5 identifies the percentage of average perceived difference – the percentage of sample who were presented with each dB difference who said they noticed a difference between the two sounds and 'correctly' stated which was louder – as does the respite results (Figure 8.4).

Table 8.5 shows all of the responses for all of the pairs within this study; highlighted in yellow are the modal responses of that data set. Interestingly, this shows a perfect correlation between Tables 8.4a (respite) and 8.4b (this study), i.e. for every answer, the modal set of respondents correctly discerned the difference in sound level, suggesting that regardless of what visual stimuli was added, the majority of respondents 'got it right'.

Audio/Visual -->	-6, -9	-6, -6	-6,-3	-3, -6	-3, -3	-3, 0	0, -3	0,0	0,3	3,0	3, 3	3, 6	6, 3	6, 6	6, 9
Quiter	79%	80%	91%	44%	57%	47%	23%	12%	14%	6%	6%	1%	3%	2%	4%
Same	14%	17%	9%	39%	31%	40%	49%	49%	42%	30%	16%	19%	7%	4%	4%
Louder	7%	3%	0%	17%	12%	13%	27%	38%	43%	64%	79%	80%	90%	93%	91%

Table 8.5 Full Results Set in Percentage, showing the Modal Response for Each Pairing Highlighted Yellow (this study)

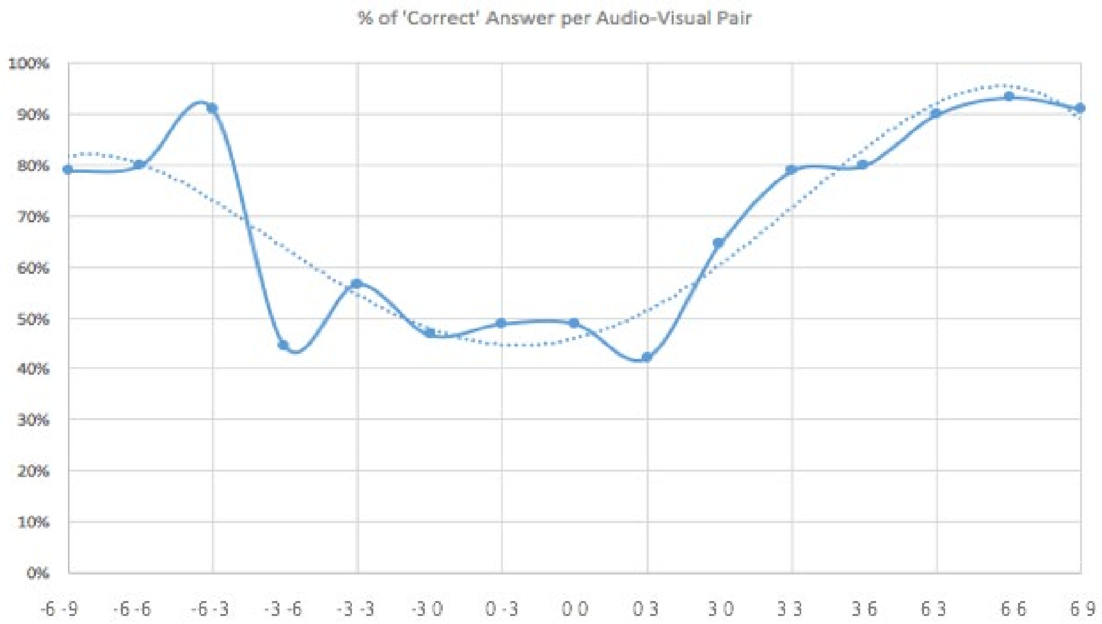


Figure 8.5 Percentage of Correct Answer per Audio/Visual Pair

There must be consideration given however, towards the way in which the sound is presented to the participant with the visual stimuli added. The same notion discussed in Section 8.2 above therefore, applies here; this means that, the degree to which the answer is correct *is swayed* by whether a visual representation was also used to either under or over emphasise a sound level change, or whether that visual is simply consistent with the change. The x-axis illustrates this, with the audio and visual pairs ranging from quietest to loudest, with over, none, under emphasising visuals, respectively. For example, where '-6 -3' appears, the second 'pair' demonstration shows the sound level has changed to 6 decibels lower than the base level sound, while the visual shown represents only a -3dB change from the base level.

As mentioned above, these visual impacts are discussed in the following sections in more detail. Here however, the results consider what the overall data set shows:

- The public were more easily able to discern a louder aircraft flyover event when the second of the two sounds is louder than the first – this is still the case regardless of the visual emphasis (or lack of)
- While Figure 8.5 does indeed show disturbance in the data, the overall shape of the 'curve' follows a similar pattern to that of Figure 8.4 illustrated by the dotted trend line.

To be able to get a direct comparative between the respite data and this research, with respect to percentages of 'correctly' discerned sound level changes, the data collected and presented in Table 8.5 has been distilled (Table 8.6a and Table 8.6b) and converted in to chart format to directly reflect Figure 8.4 of the respite results. Table 8.6a has taken all answers across each of the sound level changes and averaged them for every 'quieter/same/louder' response. So, for example, where a sound level change of -6dB is accompanied by over/no/under emphasising visuals, i.e. '-6 -9' = 79% '-6 -6' = 80% '-6 -3' = 91%

These are then averaged to 83% (example found as part of Figure 8.12, below).

Audio/Visual	-6	-3	0	3	6
Quieter	83%	49%	16%	4%	3%
Same	13%	37%	47%	22%	5%
Louder	3%	14%	36%	74%	91%

Table 8.6a Discernible Difference with Audio Averaged

Audio/Visual	-6	-3	0	3	6
Correct	83%	49%	47%	74%	91%

Table 8.6b Discernible Difference with Audio Averaged – Correct Answers Only

This is repeated for each sound level change group, to average out visual impacts. Table 8.6b then, has collated the 'correct' answers only, and Figure 8.6 depicts the data. For ease of comparison, the data set from Figure 8.3 has been overlaid. The key result points are identified below:

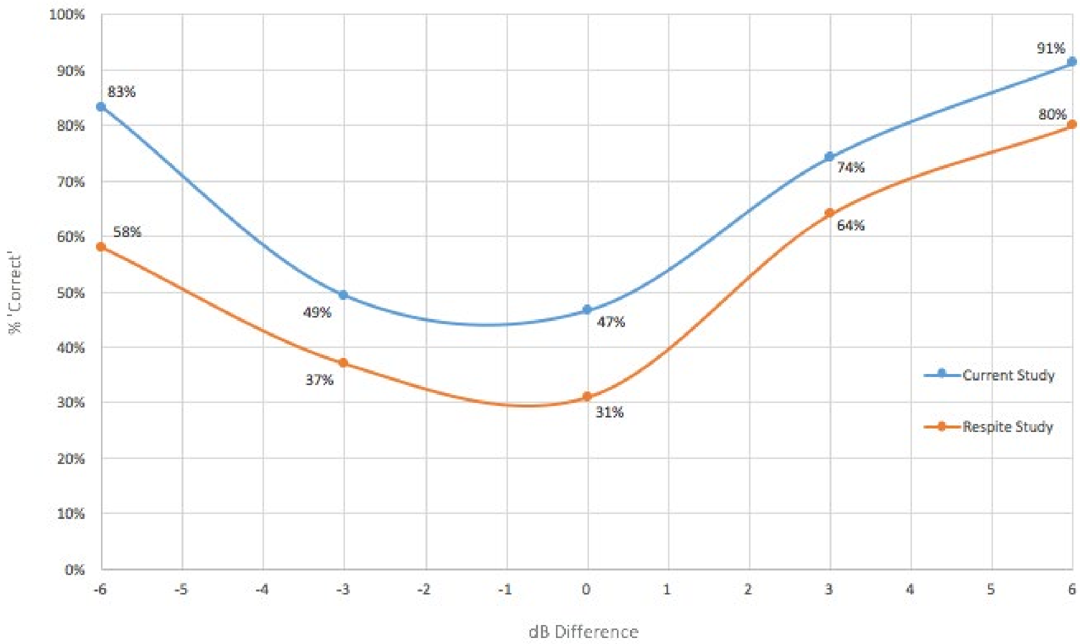


Figure 8.6 **Percentage of Correct Answer per Audio/Visual Pair**

With the addition of visual stimuli impacting on participants' perception of the sound they are hearing, there appears a very similar *pattern* in data; however, the visuals have seemingly enforced people's confidence in their opinion of sound change. For example, the respite study notes the majority of respondents (~60%) discerned the difference in sound level when it reached circa -6dB and +3dB. In this current study - with added visual stimuli – at the same ~60% point of discernment, the percentage of participants correctly discerning audio stimuli with the addition of visual stimuli (this study) is significantly higher; 58% (respite) up to 83% (this study) at the -6dB point, and 64% (respite) up to 74% (this study) at +3dB.

Up to these thresholds, only a minority of people could correctly discern the sound differences. Whilst in this study this is still true, with the addition of the visual stimuli it is up to nearly half of respondents being able to correctly discern the sound level difference at 49% and 47% respectively.

The following sections now provide segmented analysis for varying degrees of visual representation.

8.2.4 No Change in Sound Level

Where the audio stimuli do not changed, but the visual representation does – whether it be +/-3dB or remaining the same, it is not considered an emphasis of any kind; if the audio stimulus has not changed, you cannot emphasise – to any order – 'no change'; there is however a reinforcement of the 'no change' with the visuals being the same for both the first and second flyover event. For this reason, these three sets of stimuli change pairs are plotted and analysed in this separate section before going on to explore the impacts of emphasising visuals within this study.

The previous chart (Figure 8.6) identified that an average of 47% of participants 'correctly' discerned hearing the same sound (as the base level sound). It had been established however, that this percentage was indeed an average of the three visual variances (over/no/under emphasis), and for all audio options (quieter/same/louder to the base level, to each visual variance). This data has now been disaggregated and Figure 8.7 below shows the three variances of audio and visual pair 'options' as separate data lines of the same chart. This data is not concerned with 'correct' discernments, but the full range of data for each scenario. Thus, the x-axis denotes the answers given in accordance with the 5-point Likert scale explained in Section 8.2.1, and the y-axis identifies the percentage of those discerning each of those answers within any one of the three given scenarios (depicted by the three trend lines).

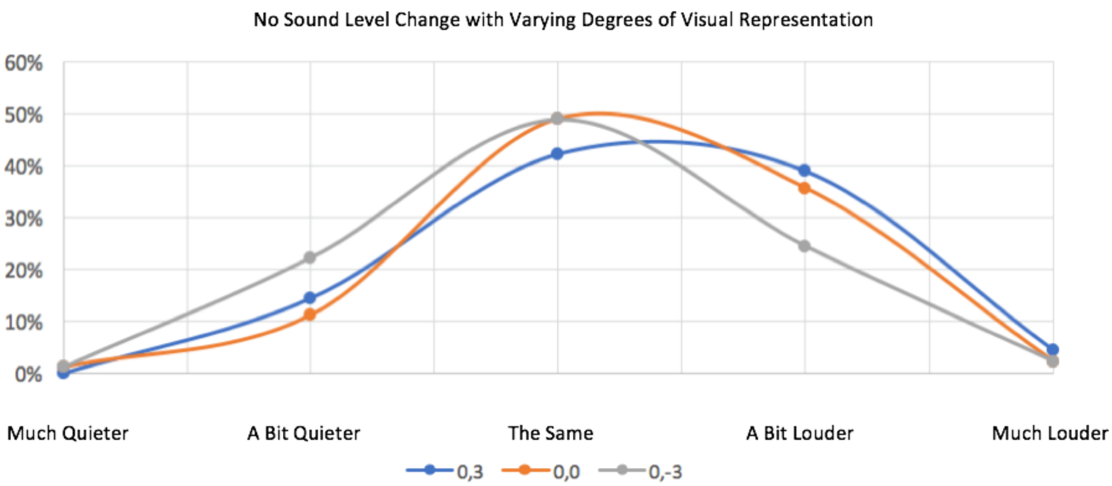


Figure 8.7 **No Sound Level Change with Percentage of Correct Answer per Audio/Visual Pair**

The data reveals:

- The orange line denotes no change to the visual stimuli. Given that there is no change to the audio stimuli depicted in this chart, the centre vertical gridline is the 'correct' point and therefore where it is expected the majority of opinions would fall for the orange line. This is indeed the case with 49% discerning no change.
- Moving away from the centre line, 36% of participants discerned the sound level difference (of the second sound) to be 'a bit' louder than the base level sound, compared to only 11% discerning the second sound to be 'a bit' quieter than the base level (+/-3dB, respectively). This appears to suggest that where people are unsure of what they are hearing, they tend to adopt an unconscious bias towards an increase in sound level.

Where the sound level remains the same as the base level, but the visuals represent a sound level *increase* of 3dB (blue line), the hypothesis is that opinion would be of a greater percentage than the orange line (denoting no change in visual representation) and the grey line (denoting a *decrease* of 3dB) to the right hand side of the chart ('a bit' and 'much' louder). It would equally be expected that the blue line showed a higher percentage than the grey line (only) where the visuals remain the same as the base level (the centre gridline). Conversely, the hypothesis would be of a lesser percentage than both the orange and grey line to the left hand side of the chart ('a bit' and 'much' quieter). The results for the blue line (increase in sound level representation) show:

- A higher percentage (39%) of participants do indeed discern the (unchanged) sound level to be 'a bit' louder where the visual representation has increased, than the percentages for both a decrease in visual representation (24%) and visuals remaining the same (36%).
- Moreover, a *lower* percentage level (8% lower) of participants discerned the sound level to have gotten 'a bit' quieter (where the visual representation increased), than those 'correctly' discerning a decrease (grey line).

However,

- A lower percentage of participants (8% lower), discern the sound level to remain the same, where there has been a visual increase, than both the discernment of a sound level decrease and no change (grey and orange line, respectively).
- Furthermore, while the percentage is indeed lower at discerning ‘a bit’ quieter than those ‘correctly’ discerning a decrease, this was not true in comparison to the orange line.

The grey line, which depicts a visual representation decrease of 3 and 6dB, respectively, appeared much more in line with what would (crudely speaking) logically be expected. The results show:

- A considerably higher percentage (26%) of participants discerned the sound level change to be ‘a bit’ quieter, compared to when hearing the unchanged sound level with an unchanged visual (11%), and a visual representation of a 3dB *increase* (14%).
- At the other end of the spectrum, the percentage of participants discerning a sound level increase of ‘a bit’ louder (when visual representation is of a 3dB *decrease*) is considerably less (~13% less) than both the orange and blue lines.

It should be noted here that a *minimal* number of participants (1%) discerned either of the outer limits, i.e. +/- 6dB visual representational change. While the visual representation of sound level changes did only reach +/- 3dB, there is still some suggestion here that there was an air of uncertainty to participant perceptions of what they were hearing.

Overall, there is a definite difference in the shape of the curves when considering the visual representational changes, which would suggest that visual stimuli do have *some* impact. There are however some clear outliers, and for all three visual scenarios, the most recurring answer was that people thought the sound level stayed the same – which is ‘correct’. This does call in to question the *extent* to which the visuals really impact perception of sounds being heard where there has been no sound level change. In order to explore this further, the following sections look at the varying degrees of visual emphasis on changing sound levels (to that of the base level).

8.2.5 Changing Sound Levels but No Visual Emphasis (Consistent Visuals)

The data shown in Figure 8.8 shows the sound level changing to the order of +/- 3 and 6dB to that of the base level sound, while the visuals remain consistently representative of these changes. So, where for example, there is a sound level increase of 6dB, the visual represents a sound level increase of 6dB. While it could be suggested that this pairing is not warranted due to the close reflection in criteria of the respite study, there was of course no visual aircraft stimuli at all in that study, and it is therefore important to gauge here the extent to which the visual may help to *reinforce* what the participant perceives as a sound level change (or not) as well as the extent to which the visual may skew perception. In some respects it could be argued that this is the most important of the data sets.

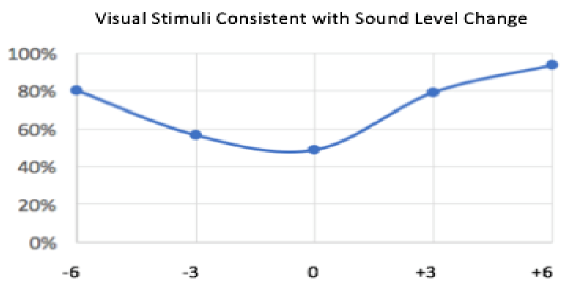


Figure 8.8 Visual Stimuli Consistent with Sound Level Change

It is important to note here that accurate identification of sound change is increased at all points with consistent visual accompaniment as compared to the respite study and the averages for this study. The findings reinforce the point that louder second events (audio and visual pairs) are more frequently distinguished correctly than quieter pairs, at both the 3 and 6 dB change levels. The most notable of statistic is that at +/-3dB, the percentage of correct discernment is 80% compared to just below 60%, respectively.

The step change discernment does however, ease off for an increasing sound level change here, where between +3dB and +6dB, the difference in the percentage of those who discerned correctly is only 10%, compared to the difference between -3dB and -6dB, which sees a 20% rise. This again could be an indication that a quieter sound is more difficult to identify correctly than a louder sound, when compared to the base level sound; suggesting human perception needs a larger difference to be able to consciously notice it.

8.2.6 Comparing Varying Degrees of Emphasising Visual Stimuli

Figure 8.11 below presents the varying degrees of emphasising the audio stimuli through under or over emphasising the visual stimuli. Before these are seen and explored in relation to each other, Figures 8.8 – 8.10 show each data set in a disaggregated version.

8.2.7 Visualisation Over Emphasis of Sound Level Changes

Figure 8.9 illustrates that the audio has *increased* by 3 and 6dB, whereas the visual representation of a sound level change has increased by 6 and 9dB, respectively. This means that where a participant hears an aircraft increase in relation to the base level sound (played first in every instance), they will see a visual representation that *over-emphasises* the increased sound to the order of 3dB each time.

Equally, at the opposing end of the spectrum, where the audio is decreased by -3dB and -6dB, the visual representation being shown is once again *over-emphasising* the direction of decibel difference, so in this instance, will show a visual representation of a -6dB and -9dB decrease, respectively.

It could be expected that accurate identification of a sound level change would be higher, this however is not the case, indeed at -3dB, a proportion or respondents correctly identifying the change as quieter is lower than for Figure 8.7 at all other points the same.

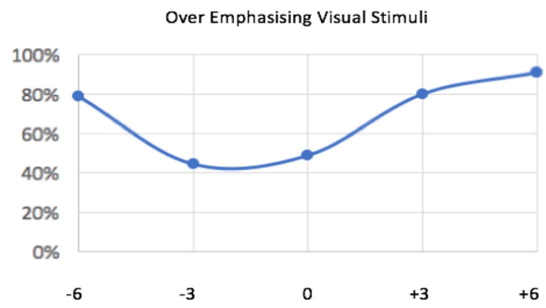


Figure 8.9 Sound Level Change with Over Emphasising Visual Stimuli

8.2.8 Visualisation Under Emphasis of Sound Level Changes

Figure 8.10 shows that, for example, where the sound has increased by 6dB, the visual representation has only increased by 3dB, however. Where the audio has been increase by 3dB, the visual representation has not been increased at all. On the opposite side of the spectrum, where the sound is decreased by 3dB, the visual remains unchanged. Equally, where the audio stimuli have been decreased by 6dB the visual representation depicts a decrease of only 3dB.

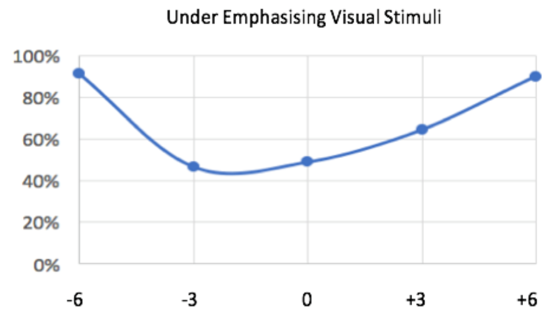


Figure 8.10 Sound Level Change with Under Emphasising Visual Stimuli

Here a lower accuracy of identifying correct sound level changes would be expected, however this is not the case.

Figure 8.11 below, now presents the three together in order to better compare them against one another, making for easier determination of whether visual stimuli do indeed impact human perception of a sound stimulus, in a logical manner.

For ease of data interpretation, it is assumed that for any given sound level change (depicted on the x-axis), an over or under emphasis of visual by plus or minus 3dB (respectively) is applied, illustrated within each of the trend lines. Indeed, where the 'no emphasis' data is given, this denotes a change in visual stimuli *consistent with* the sound level change, for example, where a sound level change differs from the base level sound to the order of -3dB, the visual will be representative in height and distance of a -3dB sound level change. The percentage shown against the y-axis then, denotes the percentage of the 90 participants who gave this option as their answer. For clarity, of answer options see Section 8.1.2 above.

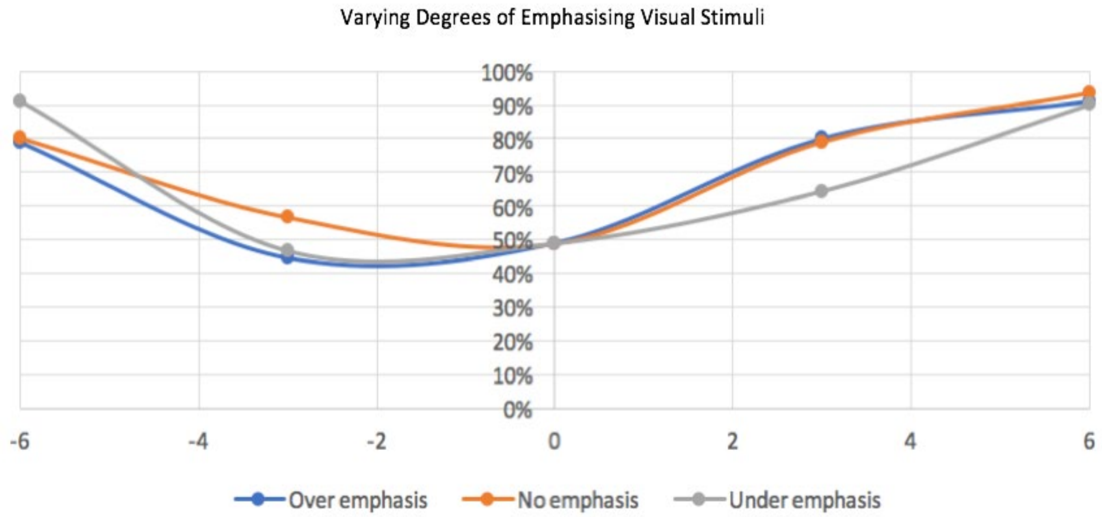


Figure 8.11 **Varying Degrees of Emphasising Visual Stimuli and Percentage of Correct Discernment**

8.2.9 Summary

While discernment at +6dB sound level change does show very little difference between the three visual 'options', all three percentages of discernment do still produce a very high rate (90 – 93%) of participants 'correctly' perceiving this 6dB increase relative to the base level audio and visual stimulus pair experienced.

Where a higher levels of accurate identification of sound level change might be expected here, it appears to have a similar impact to the under emphasising visuals, and certainly not as high a level of accuracy as the consistent visuals. This anomaly appears even further pronounced where a much higher 91% correctly identified the -6dB sound level change with the *under* emphasising visual stimulus, compared to that of the 79% correctly discerning the sound level change with an *over* emphasising visual (at the same -6dB sound level change). There are a number of reasons that could be suggested here, for example, simple confusion, or consultation fatigue (see Petts, 2003, Section 4.5.3), or indeed, consequential guesswork. These are only suggestions however, with no way of identifying a specific reason. Indeed, if +/-3dB data points weren't there, both data lines would track the no emphasis line almost perfectly.

Similar to the hypothesised trends in Section 8.1.1, where the visual representation *over emphasises* the sound level change (see Section 8.2.7), the line (depicted in Figure 8.11 in blue) would always trend *above*, i.e. at a higher percentage, than both the 'under emphasis' an 'no change' lines. Conversely, it was hypothesised that where the visual representation *under emphasises* the sound level change (Figure 8.11 in grey) the line would always trend *below*, i.e. at a lower percentage, than both the 'over emphasis' and 'no change' lines.

In comparison to the above, the results show that the over emphasising visuals seemingly have more of an impact where a sound level increases from the base level, whereas the *under* emphasising visual representations appear to have more of an impact where a sound level *decreases* from the base level. Where the sound level increases to the order of 3dB and 6dB, the trend lines appear to sit more in line with the hypothesis, certainly at a sound level increase of +3dB. Here, it can be seen that 80% perceive the sound level increase with an over emphasised visual, where only 64% perceive the sound level increase when under emphasised by the visual. This is in comparison to the 79% who perceived this increase while the visual remained consistent with what was heard. Equally accurate to the hypothesis outlined above, the under emphasising visual representation line (grey, Figure 8.11) trends considerably under the *consistent visual* line (orange) at a 3dB *decrease* in sound level, to the order of 47% and 57%, respectively.

Where it might be postulated that a visual stimulus influences the quality of human discernibility at a higher sound level to increase accuracy of perception, at a 6dB increase, visuals tend to have little impact in comparison to the use of a visual representation *consistent* with the sound level. Indeed, at either end of the spectrum, the visual representations have no logical pattern. For example, where the visual represents an *over* emphasis of the sound level change, 90% correctly discern the sound level change at a +6dB increase, where 93% correctly discern the same sound level change when the visual representation *under emphasises* the audio. 91% of participants correctly discerned the sound level change correctly when paired with a consistent visual stimulus. One plausible explanation for this could be that a 6dB change in sound level is considerable, and even the hard of hearing would struggle not to notice an increase of this order to some extent (see Section 2.2). In the context of the exposure-response process discussed in Chapter 3 therefore, the extent to which this sound level increase is influenced by a visual stimulus may well fall to insignificance in the interpretation of sound level change once the immediate perception has taken place. It does however, appear to bring forward the point of discernibility in a consistent fashion (for both louder and quieter events), and thus imply that in 'real-life' settings where people are exposed to a combination of stimuli, the onset of discernibility may be lower than that suggested by the respite study. This finding does indeed need to be caveated however, by acknowledging that this is an active listening study. Further, this consistent pattern of visual stimuli enhancing the perception of a sound level change is not the case for the over emphasising visuals nor for the under emphasising visuals.

Chapter 9 Conclusions and Recommendations

This final chapter draws out the primary conclusions by reviewing the research outcomes and provides discussion around the key topics pertinent to addressing the research aim. Firstly, a brief overview of the chapters and how they link together is provided to resituate the reader in the overall research piece. The key findings from the literature, case studies and experiment are then presented along with the implications for practice. Finally, the contribution to knowledge is acknowledged, along with recommendations for further research opportunities.

9.1 Summary and Discussion of Findings

Chapters 1 and 2 set the core tenets of the rationale to this study. Chapter 1 identified the founding principles of sustainable development and further, how these apply in the context of aviation. Indeed, the 'triple bottom line' of sustainable development (Koc and Durmaz, 2015), balancing economic, social and environmental needs, has become evermore prevalent in recent years for the aviation industry. This has caused key actors of aviation management (airports and authorities) to put much effort in to understanding how to balance the need for growth of the industry, with the need to avoid environmental impact increase; specifically, this study focuses on the impacts of noise exposure on the ground from aircraft, and the consequent annoyance from airport-neighbouring communities.

Chapter 2 explored the Guidance on the Balanced Approach to Noise Management (2001) document (Balanced Approach), developed by ICAO in a more concerted effort to guide the industry to tackle the noise impact challenge. The Chapter identified previous efforts by the industry to mitigate actual noise exposure in the form of engine and airframe technology improvements, and the need – from the slowing of these technological improvements in recent years – to now focus more on non-acoustic factors that may be affecting community annoyance towards the aircraft noise. Through these initial chapters, Objective 1 was achieved.

Chapters 3 and 4 discussed key non-acoustic factors impacting human response to noise, and how to use the understanding of those non-acoustic factors to create and deliver effective communication; and more importantly, two-way engagement. These chapters sought to answer Objective 2, and the findings are outlined in further detail in the following section.

Chapter 5 outlined the problems with descriptors and uses of conventional metrics to date, highlighting the more recently introduced supplementary metrics, further enforcing the need for a novel approach to noise impact management through effective communication processes; addressing Objective 3. Key findings of Chapters 3 – 5 are noted below in further discussion.

9.1.1 Key Findings of the Literature

Prior to the first case study, as a foundation for the exploration of auralisation and visualisation as a communication tool, Chapter 5 first discussed the historical use of conventional noise descriptors to date, and concluded that these have not been useful in the context of providing comprehensibility and therefore a platform for an effective engagement process. Within this exploration, a key question to be noted, was that from Hooper and Flindell (2013:2), who acknowledged that to date, the aviation industry has "…fail[ed] to ask the basic question – 'what do people actually want?" Since this question was raised within their novel research in 2013, there has seemingly be attempts by airports to address such a question, through for example the disaggregation of noise metrics. *This* research however, now offers the novel use of auralisation and visualisation in attempts at furthering it.

Indeed, few members of the public appreciate being told how 'annoyed' they are depending on where they live, and those people who *are* annoyed but happen to live outside of the contour-defined 'annoyance area' are even less likely to be appreciative (Greaves and Collins, 2006). In essence people simply want to know 'what goes in to that metric/descriptor', so the descriptors need to be disaggregated for full transparency; 'transparency is key' (H.R.I-2). Such disaggregation has the ability then to clearly show the nature of individual aircraft events, i.e. loudness, timing, and number. A key question of this research, and one that featured in the rationale for the use of visualisation and auralisation as a communication tool was, once this disaggregation shows single event information, how can that then be described in a way that is meaningful to community members? With the use of such technology in this capacity, the ability is created to '*re-aggregate'*; aggregate 'pictures' of single events to provide insights in to numbers and magnitude of noise events over time, in order to gain a holistic picture of what people actually experience (Porter et al, 2014). Not forgetting of course, the potential of auralisation and visualisation to 'bring single events to life'. This is indeed acknowledged throughout Chapter 5 (see Section 5.2, specifically).

Being able to identify with sounds and situations that resonate on a personal level, of people's perceptual routes, is a suggestion of why the SoundLab experiments in both this and the respite study appeared so popular with participants. Indeed, being afforded the means of responding to experiences that resonate on a personal level strongly reflects the notion of human variability, which Chapter 3 outlined, is founded heavily in personal and social values impacting human response to noise. With this, Guski (1999:45, Section 3.1.3) suggested that, such non-acoustic factors impact on human perception of sound, that "at best, [only] one third of the variance" stems from acoustical influences; "…your behaviour depends on what is perceived, and what is perceived depends on your behaviour" (Schafer, 1994:7). This could indeed provide a robust explanation for the significant inconsistency in experimental results when varying visuals are added. Simply put, where perception tells someone that 'something is not aligning' with what is being seen and heard in conjunction with each other, a whole suite of non-acoustical factors might come in to play; this is where interpretation takes place during the exposure-response process (discussed in Chapter 1).

When applying this suggestion to the experiment for this study, there is a need to consider the difference between the overall results showing a significant correlation to that of the respite study; yet when the visual stimuli is added to influence perception of what is being heard, the results begin to 'scatter' in a non-consistent pattern.

9.1.2 Key Findings of Case Studies

A case study approach was used throughout Chapter 7 to gain understanding of, and analyse the progress of Arup's inaugural use of auralisation and visualisation – in the form of their SoundLab – as a communication tool, and the technological developments that evolve.

The first of the case studies found in Section 7.2 explored the use of auralisation and visualisation as a communication tool in public consultation for HS2, and in doing so began to address Objective 4. While this was not an aviation specific consultation, it was the first use of Arup's SoundLab as a consultation tool, and produced interesting learnings in the context of communication and engagement. It was made clear that the auralisation and visualisation made significant improvement in the engagement process, and facilitated more effective conversations between the attendee and consultants at the road show, indeed it was noted, with one of the HS2 representatives discussing the impact of the later EIA consultations carried out where no SoundBooths were use, "…some of the conversations I had about noise were definitely hampered by the fact that we couldn't show them examples of the sounds in the EIA information updates […] people asked if there were updated sound demos to reflect the updated information" (H.S.I-1). Chapter 4 saw Lee (1993, cited in Petts, 1999) suggest that EIA can never be a neutral process as it is a 'civic science' where perception and values, and social and economic priorities determine outcomes as much as the data and methods of impact prediction. This put emphasis on how participants react as being *as pivotal* to the effectiveness as the process itself. Essentially, both the inputs to the process, *and* the process itself, must be right in order that the required outcome is reached.

When applying this to the HS2 EIA road shows, it reinforces the notion of what the HS2 representative alluded to when noting that the lack of SoundBooths hampered his conversations with the public. A 'fair and competent process' of course, was outlined in Chapter 4 as being founded on transparency, mutual engagement and responsibility, and the reasonableness of the people in producing workable decisions must be considered when building a fair and competent process (Reber, 2018, Chapter 4, Section 4.3).

With this in mind, it was also suggested in Chapter 4 that successful companies are those who recognise their responsibility to the public and go beyond legal compliances (Waddock and Rahman, 2002). This was the case with HS2, and it appeared (from observation by the researcher), that the actions taken by HS2 to offer as comprehensive a consultation process as they did, bore significant success in the eyes of a majority of the public effected.

This seemingly effective engagement process achieved in consultation is not necessarily considered as such because HS2 managed 'to get everyone on side' and happy with what they were being shown; the element of considered successfulness was borne from the attendees feeling more understanding of the information being given to them, and therefore empowered to have that conversation with the experts, or write that complaint letter, or give their opinion, because of how they could now interact with the information. The comprehensibility of the situation more importantly allowed for the attending members of public to then understand varying options that would arise, and further, have the means to understand even those options – and more importantly, the reasons why – that they did not particularly agree with.

The learnings from using auralisation and visualisation for HS2 consultation road shows were applied to the SoundLab demonstrations showcasing the insulation scheme. Whilst the demonstrations were of course not used for the purpose of facilitating *public* engagement per se, however, its private use for the government and other elite stakeholders was still a vital (and costly) exercise at an important time where Heathrow Airport were hoping to gain Government and NGO backing for their proposed third runway bid. This was indeed a relatively simplistic case study step, insomuch as there was no engagement process facilitating layperson understanding of technical information for example, to convey or analyse. It did however, meet its limited ends to illustrate the effectiveness of insulation and gain opinion of the value of the sound level change indoors. In doing so, some important key findings were marshalled, not least, confirming the value of 'getting the visuals right' within the demonstrations.

With this in mind, the RWG (Respite Working Group) did indeed make the decision to not use 'active' visuals within their demonstrations, instead opting for a still street scene image. The key findings of the respite research are best discussed alongside and in comparison to the empirical research experiment conducted as part of this study; this is carried out below.

9.1.3 Key Findings of the Experiment

Of the core objectives for this thesis outlined in Chapter 1 (Section 1.5), Objective 4 seeks to, critically evaluate the potential contribution of enhanced auralisation and visualisation to noise communication designed to improve comprehension and thereby facilitate more effective stakeholder engagement, through a series of case studies. Exploration to answering Objective 4 is carried out through the empirical experiment stage of this research. The Respite Working Group's (RWG) headline findings showed that the onset of discernibility sits at -6dB and +3dB; with these results stemming from an auralisation and visualisation experiment that used only a 'still' visual image, it quickly became important to explore whether visualisation brings forward the onset of discernible difference.

Before the analysis began to explore the results through systematically disaggregating visual 'options', the first data set to be analysed was that of aggregated experiment data for this study against the same for the respite study.
The results showed a similar trend line illustrating all second sounds getting louder than the first, with the mean response generally increases, as expected. A clear interruption in the data line for this study however, set out initial visual depictions that the visuals seemingly have varying degrees of influence on each of the sound level changes. Whether a significant pattern is created through visual impacts at this point in the analysis is not apparent.

Notably, Figure 8.5 shows that the onset of discernibility is brought forward by some margin; at the ~60% point for example, where respite results showed discernment of 58% at -6dB, this study's percentage of correct discernment showed an increase of 26%, up to 83%. Moreover, where respite results showed correct discernment at +3dB of 64%, this study increased at the same point by 10%, to 74%. Whilst there is substantially less of an increase where the discernment for a sound level *increases*, it must be borne in mind that this is at a lower decibel discernment level (+3dB as opposed to -6dB).

9.1.3.1 Implications for Heathrow

While this can be thought of as a significant finding it is important here to consider what this might mean. An earlier onset of discernibility for example, would see Heathrow being able to design flight paths with a narrower distance between each in order to offer a discernible difference in the sound environment in the first instance. This has potential for the future to enable Heathrow to employ more flight paths and therefore more potential operational variations. For this to be the case however, the onset of discernibility of a sound level change would need to be a robust one. While the results of varying visuals in order to 'skew' participants' perceptions (summarised in Section 8.2.9), may have yielded a varying and inconsistent picture, it might be worth considering Figure 8.7 in Section 8.2.5; this charts the results of consistent visuals to sound level changes. Fundamentally, this echoes that of the respite study, but with visuals added (no variations of under/over emphasis). The results here provide considerable correlation to that of the respite study results, yet with an earlier onset of discernibility as defined by a 60% correct change level. It of course does need to be acknowledged that these are the results of an *active* listening test and therefore allowances may need to be made when implementing these onset thresholds in to real life flight path designs.

When a disaggregated picture of the varying under/over emphasis visual 'options' was considered, the summary of analysis (Section 8.2.9, above) illustrates a mixed results set. Comparing the trend line of a full data set with that of the respite study (Figure 8.5) shows that there is clear correlation in results, with in fact a considerable increase in percentage of correct answers. When beginning to disaggregate the way in which the visual stimuli were used to impact perception of sound, varying results could be seen; whilst visuals clearly have impacted human perception of what was being heard, Figures 8.6 – 8.9 show very little pattern, and no consistent correlation to hypotheses. One consideration for the inconsistency in discernibility at +/-3dB compared to that of +/-6dB is the logarithmic scale by which the visual aircraft representations were plotted.

When considering design of the visualisation, it was agreed that representation of each sound level change should be realistic in height and distance, as opposed to simply spacing the 7 visual points evenly. The aircraft visuals therefore were calculated logarithmically in accordance with the decibel levels, denoting distance from the point of the listener; this included of course, size of aircraft seemingly getting larger/smaller as it moved closer/further from view. Due to the nature of the logarithmic scaling, the quieter, and therefore further away, aircraft were not just '7 times' smaller than the loudest/closest, but considerably so. Equally, the louder/closer aircraft was intended to appear, it did so significantly, in comparison to even the base level visual representation. With this methodology design in mind, it could be theorised that in the context of discernibility, the visual stimuli provided far greater influence at the outer limits of in/decreased depiction.

9.1.4 The Extent to Which Results Show Visual Impacts on Perception of Sound

There is indeed evidence that visual stimuli do play an important part of sound interpretation, not least in the notion of visual looming, expectation and tacit knowledge of a landscape (see Section 3.2.1; 3.3.1.4; 3.3.1.4.1. respectively).

Indeed, it was seen in Chapter 7 that the key Arup representative (A.R.I-1), responsible for suggesting the SoundLab technology to both HS2 and Heathrow, had *fought hard to maintain that the demonstrations should always have the visualisation with the auralisation because "all our senses are connected"* (Section 7.2.1). Further to this, the Arup director acknowledges *"…[p]ractical experience and human nature, and all of our senses [being] connected, proves that you've got to link them together when you're trying to inform somebody to ask them to make an* *informed decision"* (A.R.I-1). In consideration of this point, it could be argued that the data from this study provide a much more coherent and logical set of results (where the visuals match the audio being demonstrated), given that both sound and visual senses are being stimulated in order for the participant to cast opinion. Where this study's research results resembles some level of uniformity despite the added skewing of visual to audio representation, the question is raised here, of whether the point of discernment of a sound level change be robustly determined from an experiment only focusing on audio stimuli?

On reflection of the respite research results, a similar question was raised by a member of the noise management team at Heathrow, "…[w]e've got some outcomes, which suggest that onset requires quite a significant change in decibel level, i.e. more than twice the sound energy [referring to the -6dB and +3dB discernment]; so sound energy has to change by 100% to be discernible. But we also know that we haven't had a visual stimulus because we weren't happy with it because it seemed distracting (see insulation case study, Section 7.4.5.1). This of course formed part of the hypothesis tested as part of this study.

Indeed, there was considerable thought and development of experiment methodology, and equal amounts of work with the Arup visual design team to develop something much more sophisticated than the info-graphic banner seen in Chapter 7, Section 7.3 (insulation consultations). The extent of improvements made over the Respite Study to accurately reflect visual changes with their associated sound was marked, and indeed, subsequently produced a robust experiment through which to extend Heathrow's respite research, and as a result, explore the hypothesis of the extent to which visual stimuli might impact perception of sound.

9.1.5 The Role of Perception in Interpretation of Audio Stimuli

The question of inconsistent results in the under/overemphasising visuals cannot be ignored; it could be considered however, that – as discussed above in Section 9.1.3.1 – the visual differences were considerable due to the logarithmic nature of the design, which consequently led to participants becoming wise to the experimental design. This could provide one possible reason as to why this may not have ‘tricked’ participants’ perception of what they were hearing.

There of course needs to be consideration given to the role *perceived control* plays in perceiving and interpreting a sound source. Chapter 3 identified the following potentially existing components:

- Mental (cognitive and affective) components, i.e. the *predictability* of future sound exposure
- Behavioural components, i.e. the ability to *alter* exposure

These components could indeed be applied to the inconsistent results of discernibility with added varying visual stimuli. Whilst it was noted by many of the 90 participants after the SoundLab experiments that they ‘cottoned on’ quite quickly to the ‘mixing up’ of visuals to audio (Section 7.4), interestingly, the results of these participants didn’t appear to differ from those who didn’t notice the ‘trick’.

9.1.6 Improving Noise Impact Management Through a Communication Tool

Improvements to date in noise impact management have been recognised by one of the key representatives interviewed from Heathrow’s noise management team (H.R.I-1), “…there are things we can do something about in terms of changing attitudes towards Heathrow, for example peoples’ satisfaction with their noise insulation. Many millions of pounds as an in industry in terms of noise insulation that comes from passengers, through the airlines, through us as an operator of airports, but are we asking people how they feel about the airport afterwards? How do [they] feel about that point?” This particular point from the Heathrow representative puts emphasis on the need to be using auralisation and visualisation as a communication tool to be gaining people’s feedback once they are able to engage on a level that is meaningful to them. More crucially however, is facilitating the means by which airports feel they are able to ask for feedback at the end of information dissemination, and the means by which to do so in a timely and effective manner.

Indeed, Arup describes its SoundLab as “An extremely powerful tool” and advocates that SoundLab “takes a human-centric view of design to give people objective, quantifiable information in an accessible format. It enables them to make up their own minds about what they hear” (Arup, 2019b). It could certainly be suggested that this enforces the notion of SoundLab’s strength as a qualitative, *communication* tool, as opposed to a means of gathering quantitative data that, due to the mere nature of the experience it provides to participants, and further, what is being asked of them in order to gather such information, cannot realistically be used as a robust discourse facilitator at the same time. Whilst participants of the respite experiments, and indeed those from this research experiment for example, found the experience interesting, active listening tests are often of course very different in real life. *For clients, SoundLab clarifies a design by making the intangible tangible* (Arup, 2019b). Indeed, it is acknowledged by the industry that, “Noise is the thing that drives the most opposition – anger, if you like, at the airport” (H.R.I-1). Furthermore, where perception of sound is used as a tool of design clarity in both of these experiments, in the real world, perception is a key factor in the exposure-response process (see Chapter 1) that has the ability to interpret sound as noise and produce annoyance.

With this in mind, it is concluded that there may be two roles for SoundLab as a communication tool.

- The basis of experiments that can identify responses to controlled stimuli and thus arrive at objective average outcomes from defined situations (realistic or otherwise), which can be used to justify a rational approach to the design of noise management interventions
- And also as a means of capturing subjective responses to illustrated situations (again bound by the ability of the technology to reflect ‘real-life’), which can be quantitative and used to inform decision-making, i.e. *‘60% of participants valued this option more highly than that one’*.

9.2 Concluding Summary

As Chapter 3 discussed in detail, the generally negative attitude towards airports appears likely to exacerbate any negative response to a given aircraft noise event. Consequently, a valuable line of noise mitigation intervention would appear to be an attempt to positively impact upon attitudes towards airports. So how might this be done? Having gained an appreciation of *both* acoustic and non-acoustic factors amenable to modification, Chapter 4 explored what this form of intervention might look like. The identification that, a prerequisite to exerting influence in any context appears to be effective engagement with those expressing the negative attitude, is done so multiple times throughout the course of this thesis. This holds little weight and longevity however if only followed when the airports and industry *need* that cooperation from their neighbouring communities. The industry then, and particularly airports, need to develop a comprehensive dialogue *over a long period of time* that demonstrates to local residents the social and economic benefits of growth, and not simply when a new development is planned. Further, the industry/airports needs to invest locally to bring some benefit to those communities, not simply argue that the residents have to bear the 'costs' for the wider good.

Key findings of this research centre around the extent to which results show visual impacts on perception of sound. Findings suggest that overall, visual stimuli do impact human perception of sound, however, when mixing the visual stimuli so that it does not match the sound it is being presented with, perception does skews; not however of any particular significance, nor in any particular pattern. The overarching results reinforce the notion of non-acoustic factors having significant impact on human perception of sound, yet the addition of over/under emphasising visuals against their associated audio, could be suggested to do little to add value to results surrounding the onset of discernibility. The use of auralisation and visualisation as a communication tool can be considered to have been found to be useful in facilitating two-way dialogue in the case of the HS2 consultation road shows.

The respite research and experiment for this study were both of quantitative nature, and indeed successful in their design and delivery, yielding some significant results.

Furthermore, the experimental design to establish whether there was a consistent response to the visual stimuli in terms of the over lay with sounds proceeded to test robustness of auralisation and visualisation. Where sound and visual was 'skewed' (emphasised) in same direction, for example, the onset of discernibility was brought forward. Where the sound and visual was 'skewed' in conflicting directions, the onset of discernibility was put back and no consistent pattern was observed.

Throughout the experiment the role of perception in interpretation of audio stimuli has been demonstrated as significant, and such a result is indicative of many of the non-acoustic factors discussed throughout Chapter 3 that are indeed key elements of the perception. This raises the question of the extent to which any respite-facilitating flight path design will ever be 'satisfactory' or acceptable to residents overflown, as such variance in results suggests that human perception always has the ability to be skewed, through no particular logic. Non-acoustic factors however, also suggest that 'acceptability' will be a function of the extent to which the rationale for the approach and the extent to which expectations are delivered upon. In other words use of auralisation and visualisation as a communication tool is not about defining a universally satisfactory outcome; rather it is about informing a management approach that is more acceptable.

The impact of non-acoustic factors on perception of sound seen in the experiment results does align with what would be expected considering the literature and case studies, which preceded it. The extent, to which the skewed visual stimuli impacted so variedly on perception of what was being heard however, was not hypothesised quite so specifically. Such findings and pontification can be applied to the recommendations to airports for a novel and effective engagement process that looks to improve environmental communications between themselves and their local communities; these recommendations are outlined in the following sections. Through the following concluding discussion, Objective 5 is addressed.

9.3 Research Critique and Further Lines of Enquiry

9.3.1 Benefit to Environmental Communications

This study has the potential to significantly help in Heathrow's respite challenge through adding visual stimuli to a similar experiment. The fundamental aim of this experiment is to identify whether an additional stimuli decreases the sound level change associated with the onset of discernibility. Whilst overall, the results have shown visual stimuli to have a significant impact on human perception of a sound being heard, many questions surrounding the robustness and therefore validity of results have been raised. This is not a negative result however, as it emphasises that, given the power of human perception on the exposure-response process of a sound, the strengths of auralisation and visualisation technology lie much more in quantitative experiments and usage overall.

Throughout the discussions chapter (Chapter 9) auralisation and visualisation has been explored as a research tool under a more quantitative approach. If this were the case, would such an approach help to build a more comprehensible situation than have currently been achievable? And if so, where might this be useful? Fundamentally, it is important to consider that rather than being used as a tool to support direct communication and engagement (i.e. more qualitatively), used as a means of establishing the human response to chances that can be illustrated in a controlled environment, SoundLab can help develop and expand an evidence base that can make for a more robust and credible justification for given noise management actions.

If SoundLab can be used to illustrate changes as a result of a new management option, this could increase transparency and comprehension and thus support more effective dialogue. This would be a qualitative application as the intention is to support understanding and utilise this to inform discussions about the value of proposed outcomes. The 2D limitations of SoundLab were discussed through Chapter 7 (Section 4) however, and may restrict such applications. Soundlab in its current form then, may be better used as a support tool to the evidence base for discussions rather than to support the dialogue process itself.

The improvements already made to the visualisation capacity by the researcher from the Respite Study to the experiment for this study however, has already served as an example of the scope to evolve these technologies. Further technologies already built such as Oculus Rift, Google Glass, and other such augmented reality technologies, are further prime examples for revitalising SoundLab and such applications to their qualitative potential.

Whether qualitative or quantitative in approach to the utilisation of auralisation and visualisation as a communication tool, a more *interactive*, approach – in the form of a two-way dialogue – is key. This would allow engaged participants to reach a point where they agree on what a particular situation looks like; further allowing for a more personal explanation of what it means for them, in the context of their everyday experience, and the affects such a change would have. Such an interactive approach would facilitate discussion around what they do and don't prefer, and what would work better.

As it has been highlighted through the thesis, there will always be 'winners' and 'losers' in varying operational decisions, particularly in the context of Heathrow Airport where it is surrounded by such heavily populated communities, on all sides. Such communication experiences however, could at least facilitate in community members understanding the rationale behind particular decisions, even if they are not particularly happy about it. It would be hoped that the interactive use of the auralisation and visualisation technology would enable communities to see that there is a much larger benefit than there is population losing out, even though it is them personally who is losing; the rationale for that can at least be explained and discussed. The challenges remaining would be how to deal with those who are seeing a dis-benefit to the change. This is not within the remit of this thesis – this is a part of the next stage for airports in their research. What is within the remit of this thesis, is the extent to which auralisation and visualisation can support interactions with communities that is seen as more credible and thus facilitate more acceptable outcomes; this is after all, not about convincing all stakeholders, as seen in Section 4.5.1 discussion the notion of NIMBYism, as this would be impossible.

From the conclusions outlined above, it is clear that this thesis has explored key findings from the literature, when investigating the three embedded case study stages, and indeed the empirical experiment. Issues captured within the literature review highlight the vast range of non-acoustic factors impacting human response to a sound, and identifies ways in which a deeper understanding and consideration of these factors can enhance aircraft noise impact management, beginning with a robust engagement process. This thesis has established real value in outlining such an engagement process, but it's true value can only be identified by taking people through using the totality of the approach within a communications package to establish whether or not they do comprehend the information being provided, and whether or not they do feel empowered in discussion; and indeed whether the process can create opportunities for that voice to be heard.

The two identified roles for SoundLab are:

- Limited application as a facilitator of understanding and consultation (due to 2D limitations) - providing qualitative insights to opinions and values implicit in personal decision-making
- Use as a means of establishing reactions to sound stimuli – i.e. onset of discernibility. These quantitative insights can be used to inform/justify noise management options and thereby add to their credibility

9.3.2 Benefit to Arup

With the review of visualisation issues through the evolution of the SoundLab as a communication tool, this thesis has provided a good measure of whether there is mileage in taking the SoundLab technology forward as a *combined* visualisation and auralisation tool, or whether the focus remains on the auralisation that the SoundLab provides.

The strength of the SoundLab's technology does indeed lie within the combined auralisation and visualisation technology, but only in the event that the visualisation technology is comprehensive and simulates as realistic an image as possible. There are of course limitations to the 2D, and single screen visual facility, which at the time of concluding this thesis has already been recognised and advanced. Arup's continued technological development, both in SoundLab and in the portable SoundBooths, is on a continuing trajectory with augmented reality headsets, for example. Indeed, the concept of the iLab is already being undertaken, which would see a room that multiple people were able to walk in to, much like the current SoundLab, but with walls and ceiling covered in screens (or technology providing 3D visual experience).

The main suggestion to Arup from this research, is to, where marketing the SoundLab and associated technologies, focus on the strengths it can provide through facilitating transparent and comprehensible language; from here resulting in effective stakeholder communications.

9.4 Contribution to Knowledge

This research is novel, and timely, given the current Future Airspace Strategy, and the opportunity this is providing for Heathrow Airport to explore flight path options for providing respite to it's surrounding communities. Furthermore, the recommendations made by the Airports' Commission that Heathrow must implement in their bid for backing of a third runway, have already seen a strong strategy for improving relations with their neighbours. This research facilitates the understanding by industry of what makes for a robust engagement process in order to make such improvements.

In order that both UK and global aviation can continue its growth and economic benefit, there is a need to maintain consideration of effected communities, and the environmental impacts to them; this needs to be instilled and developed indefinitely and not just through or in the run up to a time where support is needed. In short, full acknowledgement for more sustainable development in the context of sustainable aviation must be maintained, and implemented policy adhered to.

This is the only known study to have currently built on that of the Respite Working Group in consideration of Heathrow's respite research, and of course, Heathrow's campaign for a third runway in accordance with the Airports Commission recommendations. Whilst this study has highlighted strengths in the use of auralisation and visualisation for the RWG research, the subsequent experiment carried out by the researcher uncovered potential pitfalls, and gave recommendations for a more effective use of the technology in the context of aircraft noise communications, and improving environmental communications between airports and their surrounding communities.

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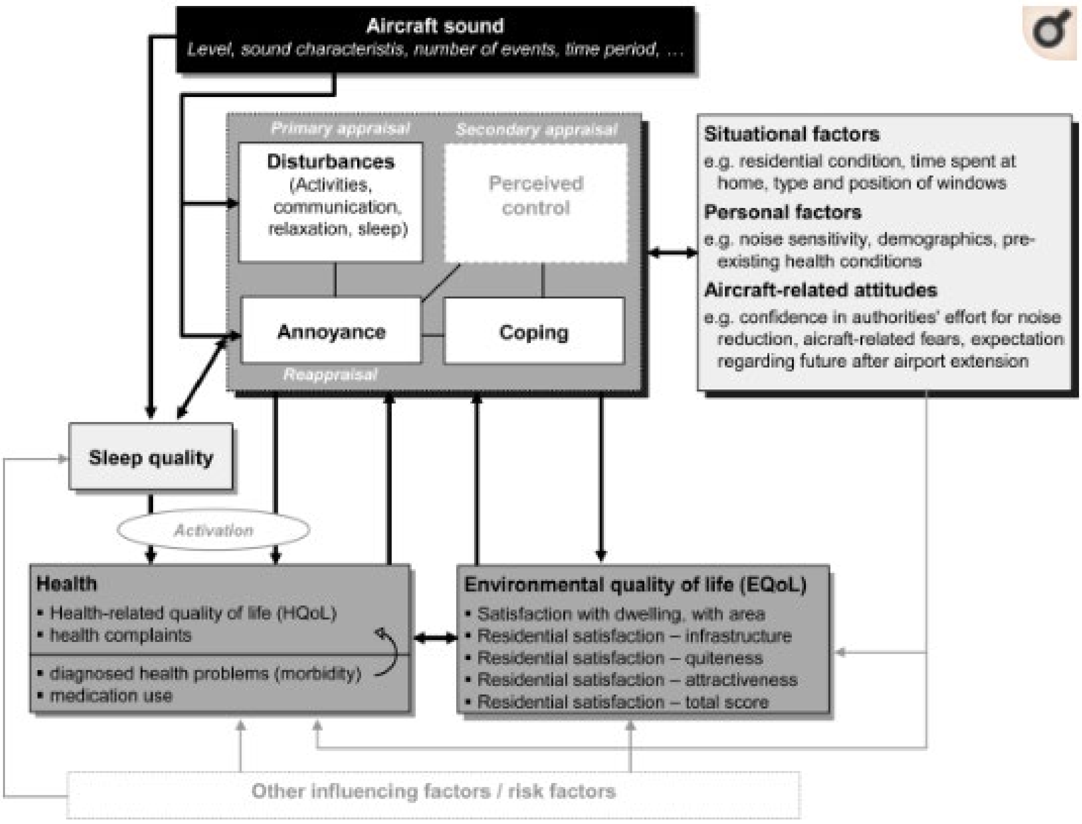
Appendices

Appendix 1.0 Conceptual Model of Aircraft Noise Effects



(Stallen, 1999, Adapted by Schreckenberg et al, 2010: 3386)

Appendix 2.0 Extended Footnotes

Effective Perceived Noise Level (EPNL)

The noise made by a passing aircraft is complicated by its motion, which causes its intensity and frequency composition to change with time. Much research into human perception of aircraft noise led to the conclusion that PNL [Perceived Noise Level] did not adequately reflect the true noisiness of a complete aircraft event unless account was also taken of the effects of both tones and duration. Sounds that exhibit distinct whistles and whines and/or have longer durations proved to be more annoying than simple PNL measures indicate. The modified scale developed to accommodate these parameters is EPNL, which continues to be used for setting the international noise standards by which the noise performance of jet (and most other large) aircraft is assessed in the process of noise certification.

The calculation of EPNL involves the measurement of a sequence of 1/3-octave band spectra at 1/2-second intervals during the noise event, that event being tightly controlled (for certification testing) through defined operating procedures and test conditions. Each individual spectrum is examined using a specified process for the presence of tones, identified by 'spikes', for which a tone-correction is computed.

(CAA, 2009:4)

Appendix 3.0 Experiment Material

Appendix 3.1 Invitation Email

PARTICIPATION REQUIRED FOR SOUNDLAB AIRCRAFT NOISE EXPERIMENT

Aim of Research: To help improve relations between airports and their surrounding communities

Research Topic: Aircraft noise and public understanding

Why Do I Need You? I am a PhD student sponsored by Arup Acoustics here at Piccadilly Place and need a wide variety of participants to provide their views on what they are experiencing

Where: Arup, 6th floor, 3 Piccadilly Place, M1 3BN

Time Required: 60 mins approx.

When: 21st May – 1st June, inclusive

Reward: £50 high street vouchers prize draw

How to Take Part: follow the link to Doodle and fill your name in on the slot you wish to attend, or simply reply to this email and let me know when you are available. All names and emails addresses are anonymised on the doodle poll so no one other than me can see your details.

More Info:

My name is Rebecca; I am a PhD Student at Manchester Metropolitan University, sponsored by Arup Acoustics.

As a pivotal part of my study I am conducting an experiment in the SoundLab at Arup. Below is a link to Arup's website providing a bit of information for anyone that hasn't heard of their innovative SoundLab.
https://www.arup.com/perspectives/themes/transport/soundlab

It really doesn't matter whether or not you know anything about aircraft noise or surrounding topics at all, I just need your thoughts and opinion on the information being presented to you. All answers will be anonymised.

As a thank you for your time, if you wish to provide your name and email address you will automatically be entered in to a prize drawer to win £50 of high street vouchers.

If you would like any further information please feel free to get in touch.

I look forward to hearing from you,

Rebecca Hudson

Appendix 3.2 Participation Information

Participant Information Sheet

STUDY TITLE

Aircraft Noise and Public Understanding – How to improve environmental communications

INVITATION PARAGRAPH

My name is Rebecca; I am a PhD Student at Manchester Metropolitan University, sponsored by Arup Acoustics.

I have invited you to take part in a research study. Before you decide, you need to understand why the research is being done and what it will involve for you. Please take time to listen to the following information carefully. Ask questions if anything is unclear or if you would like more information.

PURPOSE OF STUDY

The experiment you will be taking part in today is for the sole purpose of my PhD study and the findings from today will be used in a chapter of my research.

PARITICPANT SELECTION

Participation is voluntary: an invitation email was sent around to every employee of every business within 3 Piccadilly Place and 4 Piccadilly Place, and in the local surrounding remit. This was to draw upon a diverse and random population from the variety of companies and organisations within each building. All employees were also encouraged to extend the invitation to any friends or family they wished, so the pool of participants extends beyond the target employee groups.

The study will include 90 participants overall.

DO I HAVE TO TAKE PART?

This is entirely your choice. This information sheet describes the study and what will be asked of you. You will then be asked to read through and sign a consent form.

For any reason you suddenly feel uncomfortable during participation <u>*at any point*</u>, please feel free to stop. Details of how you exit will have been walked through and explained to you when you first arrived at Arup in case of a feeling of urgency to get out. Your answers will be null and void and all related details destroyed. If you feel that way after the event, please feel free to contact me at any point and once again, all answers will be removed from research and all details destroyed. Participation in this research is not intended to make anyone feel uncomfortable at any time.

PARTICIPATION PROCESS

Each session should last no longer than one hour and your participation is required only once.

The SoundLab is an anechoic chamber made up of a 16 speaker ambi-sonic sound, with a visual screen in front of you. You will be asked to sit with two other participants and me, the researcher, in Arup's SoundLab; all this means is that you're insulated form the outside world so that what you see and hear is that which is controlled in the SoundLab.

You will be provided with data recording sheets and asked to mark down your opinion of what you are seeing and hearing within each session.

There will be three sessions; each lasting just over 5 minutes each. Between each of these sessions we will have a short break, during which you will be asked to fill out a very brief demographics question sheet and will be provided with some contextual narrative.

After the three sessions there will be an opportunity to briefly discuss your experiences from today.

There are no right or wrong answers to any of what you will be asked; I am simply interested in your opinions, and any further comments you may wish to add.

CONFIDENTIALITY

All details and information, which is collected about you during the course of the research, will be kept strictly confidential and safeguarded during and after the study under the Data Protection Act, 1998. The Doodle that you filled out to get you to this point anonymised your details to other intending participants.

On each data recording form – including how I note down your opinions in the discussion at the end – you are referred to only as a participant ID. The only reason I give each person a unique ID is so that I maintain consistency of your opinions between each part of the experiment I take you through. I will keep a record of your participant ID against your name for up to and no longer than three months after the experiment is complete in case at any point you wish to withdraw your input I know exactly which answers to void from results and destroy. This name and ID correlation however, is *not* used in any analysis.

The only reason your name and email address will be kept on file at all is if you indicate to me that you wish to be entered in to the prize draw; even in this instance, all details will be destroyed once the draw is finished or after the three month period mentioned above, whichever is greater.

ORGANISATIONS AND SPONSORS OF THE STUDY

I am undertaking a sponsored PhD at Manchester Metropolitan University, part funded by Arup Acoustics and The Engineering and Physical Sciences Research Council [EPSRC].

CONTACT DETAILS

My email address is listed on the consent form that you will shortly be given to sign and take away in duplicate form, however if you wish to note it down now: **r.hudson@mmu.ac.uk**

Appendix 3.3 Consent Form

Consent Form

Title of Project: Aircraft noise and public understanding – how to improve environmental communications

Name of Researcher: Rebecca Hudson
Email Address of Researcher: r.hudson@mmu.ac.uk

Participant Identification Code for this project:

Please initial each box and then sign below*
**Please only participate if you are aged 18+*

1. I confirm that I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason to the named researcher. ☐

3. I understand that if I chose to withdraw my input after today, that I can contact the researcher named above and all answers will be removed from the study and details destroyed. ☐

4. I understand that my responses will be sound recorded and used for analysis for this research project. ☐

5. I understand that my responses will remain anonymous. ☐

6. I understand that at my request, a transcript of my interview and overall participation can be made available to me. ☐

7. I agree to take part in the above research study. ☐

________________________	________________	____________________
Name of Participant	Date	Signature
________________________	________________	____________________
Researcher	Date	Signature

Once this has been signed, you will receive a copy of your signed and dated consent form and information sheet by email.

Appendix 3.4 Discussion Guide

Discussion Guide: with SoundLab Participants

INTRODUCTION

My name is Rebecca; I am a PhD Student at Manchester Metropolitan University, sponsored by Arup Acoustics.

The experiment you will be taking part in today is for the sole purpose of my PhD study and the finding from today will be used in a chapter of my research.

There are no right or wrong answers here – I am just after your opinion. The session will be recorded, but all answers and feedback are covered by anonymity.

Arup's SoundLab is a state-of-the-art sound-proofed facility. You are seated near to the centre of a sphere of loudspeakers – on the ceiling, to each side and on the floor; controlled by sophisticated hardware and software.

Please stay in the marked rectangle on the floor, as this is the area for which the aircraft sounds are calibrated.

PART I: SOUND PAIR SESSION I

Please imagine yourself outdoors where you should be able to both hear and see overflying arrivals.

I will be presenting you with 3 sets of paired sounds [*5 pairs in each of the 3 sets*] and ask you questions about what you perceive to be different in the pairs of sounds. For each pair please then compare the *second* flyover with the first flyover; I would like you to know whether you thought the *second* aircraft was louder/the same/quieter than the first [*see record sheet*].

As it happens, all of these are arrival sounds, recorded from a West London street – not that this matters at all. I simply need your judgement of what you hear. Once again, there are no right or wrong answers, just tell me what you think.

You'll notice there is an 'observations' box on the data record sheet; if anything comes to mind, please feel free to write it down. It is however, entirely optional.

Also, you will see that at the top of your sheet there is a participant identification number; this is simply for my benefit in helping me keep a track of corresponding answers per person whilst keeping you anonymised.

As it is human nature to be influenced by other people's viewpoints, please would you turn to one side when you record your response to each pair?

[INTERVIEWER AID TO TICK OFF LIST AS STIMULI PRESENTED]:

1A:	1B:	4A:	4B:
2A:	2B:	5A:	5B:
3A:	3B:		

PART II: DEMOGRAPHIC GATHERING

I have provided you with a sheet of questions. Most require very brief answers.

I'm just trying to capture some anonymised information about all participants involved, I'd be grateful if you can complete this [*See demographics collection sheet*].

PART III: SOUND PAIR SESSION II

Once again, much the same as Part I.

So as a reminder, as before, you will be hearing pairs of sounds and asked to comment on the sounds you hear according to the record sheet you have in front of you.

And once again, please feel free to add any other observations on the form, and of course, as it is human nature to be influenced by other people's viewpoints, please would you turn to one side when you record your response to each pair.

Are you all clear about everything and do you have any questions?

[INTERVIEWER AID TO TICK OFF LIST AS STIMULI PRESENTED]:

1A:	1B:	4A:	4B:
2A:	2B:	5A:	5B:
3A:	3B:		

PART IV: RESPITE EXPERIMENT INFORMATION

I thought you would like a little bit of context to what and why you are here today.

A similar study was carried out last year by Heathrow that looked in to what constitutes respite: were people able to identify a change in sound level as a means of determining what people deem valuable as respite.

This revealed some really interesting outcomes, which I'm now trying to investigate further. Suffice to say, one of the key questions explored was, if we're going to offer some benefit from changing air traffic patterns, what sort of change would be regarded as constituting respite? i.e. duration of mode changes, how loud the sound change has to be.

I'm very grateful that you're here today; this is helping to gain a deeper understanding of some of those issues.

PART V: SOUND PAIR SESSION

Once again, much the same as Sound Pairs I and II [*run through **very** briefly if needed*].

Also, just a reminder to please turn to one side when you record your response to each pair to avoid any influencing of viewpoints.

Are you all clear about everything and do you have any questions?

[INTERVIEWER AID TO TICK OFF LIST AS STIMULI PRESENTED]:

1A:	1B:	4A:	4B:
2A:	2B:	5A:	5B:
3A:	3B:		

PART VI: SUMMARY/DEMO OF ACHIEVEMENT AIM

I'm going to show you a brief demonstration of the varying aircraft that you have seen and heard today.

As you will see, there are 7 different positions that the aircraft fly across the screen, and with each you will hear their associated noise level.

You have been listening to an A380 arriving in to Heathrow.

The 7 sounds come from a range of sound levels that the previous 'respite' study used [*explain 12 options*]. The A380 arrival mid-range sound level was chosen for a number of technical reasons, and then the sound levels were calibrated either side of this to +/- 3/6/9dB. The 3dB increments denote the onset of sound level change noticeability [*explain if needed*].

The visual was then designed to accurately illustrate this sound level change, the distance having been calculated to a logarithmic scale, either further or closer to the 60.4dB sounding aircraft (which of course will be the middle plane in the sequence).

In this demonstration I will toggle between the 7 aircraft sounds and their associated visuals so that you can both hear and see the increments in relation to each other.

Within your 3 sets of 5 sound pairs I asked you to listen to, you would always firstly hear what is known as the 'base' sound of 60.4dB and the visual always matched this. The second aircraft sound *and* visual you heard/saw of each pair, may have been either the same, or +/- 3/6dB different to the first.

PART VII: QUESTIONNAIRE

I want to talk to you about your experience of today; I am interested in what *you* felt. Please don't be influenced by others' opinions or feel your answer is of any less value – I'm interested in the thoughts of all of you.

Please also feel comfortable enough to let me know if there is anything else you'd like to know or don't understand.

[*Once the discussion group has finished, ensure they leave details if they wish to enter in to the prize draw. (Escort participants to reception*].

Thank you for your time

Appendix 3.5 Data Gathering Material

Data Record Sheet: SoundLab Participants

SOUND PAIR SESSION I

Of the 2 aircraft sounds you have just heard, was the *second aircraft* the same or different?

Please tick one answer per row/pair

	The 2nd aircraft was **much quieter** than the 1st	The 2nd aircraft was **a bit quieter** than the 1st	The 2nd aircraft was **no different** to the 1st	The 2nd aircraft was **a bit louder** than the 1st	The 2nd aircraft was **much louder** than the 1st
Pair A					
Pair B					
Pair C					
Pair D					
Pair E					

Comments and Observations: *(Optional)*

SOUND PAIR SESSION II

Of the 2 aircraft sounds you have just heard, was the *__second aircraft__* the same or different?

Please tick one answer per row/pair

	The 2nd aircraft was **much quieter** than the 1st	The 2nd aircraft was **a bit quieter** than the 1st	The 2nd aircraft was **no different** to the 1st	The 2nd aircraft was **a bit louder** than the 1st	The 2nd aircraft was **much louder** than the 1st
Pair A					
Pair B					
Pair C					
Pair D					
Pair E					

Comments and Observations: *(Optional)*

SOUND PAIR SESSION III

Of the 2 aircraft sounds you have just heard, was the *second aircraft* the same or different?

Please tick one answer per row/pair

	The 2nd aircraft was **much quieter** than the 1st	The 2nd aircraft was **a bit quieter** than the 1st	The 2nd aircraft was **no different** to the 1st	The 2nd aircraft was **a bit louder** than the 1st	The 2nd aircraft was **much louder** than the 1st
Pair A					
Pair B					
Pair C					
Pair D					
Pair E					

Comments and Observations: *(Optional)*

Appendix 3.6 Data Gathering Material

Questionnaire for SoundLab Participants

1. ABOUT YOU

1a: Please place a tick in the appropriate box to your age range:

18 - 24		25 - 39		40 - 54		55 - 69		70+	

1b: How would you describe your gender? *Please tick one:*

Male		Female		Other *Please specify if you wish*		I'd rather not say	

2. RESIDENTIAL/LOCATION

2a: Do you consider yourself to live close to an airport?

YES ☐ ☐ NO

2b: Do you consider yourself to live under a flight path?

YES ☐ ☐ NO

2c: Do you consider the area in which you live to be affected by aircraft noise?

Not at all affected		Not very affected		I do not have an opinion		A little bit affected		Very much affected	

2d: Do you have double-glazing in your home? *Please tick one:*

Yes, in all rooms		Yes, in some rooms		No	

2e: How long have you lived at your current home? *Please tick one:*

<1 year		1 – 4 years		4 – 11 years		11 – 20 years		20+	

2f: How would you categorise your residential area? *i.e. city centre/town/countryside …urban/rural*

Please specify: ____

3. TRAVEL

3a: How often do you fly (per year)? *i.e. holiday, work travel*

0		1 - 2		3 – 4		5+	

Thank you for your time.