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Developing a Sound, Noise and Health Conceptual Framework for fair and equitable dispersion of aircraft

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Agreed Fair and Equitable Dispersion of aircraft is an aspirational objective by many airports to alleviate the burden of noise from aircraft/airspace changes on affected communities and a hot topic in aviation generally. A workable definition of Fair and Equitable Dispersion would, in theory, enable airspace managers and aircraft operators to design solutions to deliver quicker, quieter and cleaner journeys and more capacity for the benefit of those who use and are affected by airspace. However, reaching consensus amongst stakeholders on an agreed definition of Fair and Equitable Dispersion is highly challenging and not just a technical issue due to the substantial acoustic, health, quality of life and non-acoustic factors affecting the human perceptual response to sound in context. This paper presents findings from an independent study in the United Kingdom aimed at developing a definition of an airport's Fair and Equitable Distribution of traffic and recommendations to inform stakeholder discussions as a stage process. To the best of the authors' knowledge, this was the first study of its kind in the UK with this aim. Using a mix of descriptive and exploratory qualitative research techniques, the study compiles findings from reviews of aviation noise metrics, policy and technology options; an updated evidence review of health effects of aircraft noise; and an overview of the impact of non-acoustic factors. The study proposed a transdisciplinary *Sound, Noise and Health Conceptual Framework and recommendations for implementation as a stage process* comprised of: *i* locally salient non-acoustic factors derived and mapped through stakeholder engagement, *ii* a Health Dashboard incorporating agreed combined environmental and health metrics, *iii* acoustic and psychoacoustic metrics building upon a perception-based engineering approach, *iv* operational indicators to be agreed with local and national stakeholders, within the international context. The study posits important considerations for future air transport policy and sound, noise and health research and sets a foundation for further ongoing studies to apply the proposed *Sound, Noise and Health Conceptual Framework*.

KEYWORDS

aviation, sound, noise and health, non-acoustic factors, stakeholder engagement, perception-driven, acoustic engineering, psychoacoustics, performance-based navigation

1 Introduction

Environmental noise is accepted as a public health issue and has significant impacts on physical health, mental health, and wellbeing (EEA, 2020). For example, in Europe policymakers found that 'over 20% of the population are exposed to long term unhealthy noise levels from transportation sources […] as defined by the Environmental Noise Directive (END); this figure increases to 30% when applying the stricter limit values recommended by the World Health Organization (WHO)' (EEA, 2024). Noise is a nonspecific stressor that affects both psychological and physiological health (Basner et al., 2014), the adverse effects of which from aviation have been extensively investigated and reported. The past two decades have seen an increase in evidence linking aircraft noise exposure to annoyance (Janssen et al., 2011; Guski et al., 2017), sleep disturbance (Elmenhorst et al., 2019; Basner and McGuire, 2018), cardiometabolic disorders (Van Kempen et al., 2018), children's learning (Clark et al., 2021b; Clark and Paunović, 2018a), and mental health (Clark et al., 2021b; Clark and Paunović, 2018b; Hegewald et al., 2020). Environmental noise can influence health, as it can trigger biological responses in an individual, such as increasing stress hormone levels and influencing risk factors for poorer cardiometabolic health such as blood pressure, blood sugar and blood fats (Münzel et al., 2024; Münzel et al., 2021). If these biological responses are triggered over a long period, they can lead to poorer mental health and diseases such as diabetes, heart attacks and strokes. These biological responses can also be triggered by annoyance and sleep disturbance associated with aircraft noise exposure (Basner and McGuire, 2018).

Annoyance is the most prevalent community response in a population exposed to environmental noise and is increasingly used to inform environmental impact assessments and policy to protect public health. The European Union (EU) Aviation Noise Impact Management through Novel Approaches (2024) (ANIMA) project reported that 'annoyance is the most prominent and immediate impact reaction to aviation noise'. Annoyance from noise is affected by both acoustic and non-acoustic factors (NAFs) wherein these separately account for approximately one-third each of the human response to sound (WHO, 2018; Guski, 1999). The Civil Aviation Authority (CAA) (2018, p. 44) in the United Kingdom (UK) describes NAFs as "all those factors other than noise level alone which contribute to annoyance". While variations exist this definition reflects broad agreement by experts (Guski, 1999; Fields, 1993; Job, 1988) as noted in the International Standard on non-acoustic factors ISO/TS 16755-1:2025 (ISO, 2025). Industry and policymakers recognise the importance of both the effects of noise on health and the impact of NAFs in building and maintaining public, community and stakeholder support to optimise aviation activities for the benefit of all (Bartels et al., 2022; Heyes et al., 2022; Leylekian et al., 2022; van Kamp and Woudenberg, 2025; Clark et al., 2025).

Against this backdrop, this paper presents an overview of an independent study, commissioned by a major airport (the Airport) in the UK (Torija et al., 2022; Lavia et al., 2023). As part of ongoing stakeholder engagement activities in relation to noise, other environmental impacts and national airspace change policy requirements (see "AMS/UK airspace" in Nomenclature), Fair and Equitable Distribution (FED) of aircraft was introduced as an aspirational objective by communities affected by noise from the Airport. However, reaching consensus on an agreed definition of FED is highly challenging and not just a technical issue due to the substantial acoustic, health and non-acoustic factors affecting the human perceptual response to sound in context. Summarising the challenge, a review by Gatwick Airport (2019), cited in Torija et al., 2022, p.8 noted that 'the complex issues underscoring FED require engagement of all relevant parties as early as possible in the decision-making processes. Specifically, they require an explanation of how change will be managed, and stakeholder alignment on what must, should and could be changed.' As a result, the Airport was seeking to develop a clear definition of FED to enable airspace managers and aircraft operators to design solutions to meet this aspirational objective. Therefore, this independent study was commissioned by the Airport's noise management engagement body including industry partners, communities, policymakers, and regulators with this aim. To the best of the authors' knowledge, this was the first study of its kind in the UK with the aim to develop a clear definition of FED (Torija et al., 2022). A subsequent study commissioned by the Airport built on the findings and recommendations of this study (Porter et al., 2024). This paper explicates key elements of the first study (FED1) and its impact in the context of the second study (FED2) and future research agendas. The usability of the findings are proferred by applying a *Sound, Noise and Health Conceptual Framework* to develop FED of aircraft generally and in relation to other transportation modes.

This paper is organised in sections as follows: the Introduction (s.1); Methods (s.2); summary of the Findings (s.3) from the study comprising Policy and Regulations (s.3.2), Technology and Procedures (s.3.3), Metrics for Aviation Noise (s.3.4), Evidence Review of Effects of Aircraft Noise on Health (s.3.5), and Non-Acoustic Factors and Developing an Effective Definition of FED (s.3.6); Recommendations (s.4); Summary and Further Work (s.5).

2 Methods

2.1 Project scope, aim and objectives

This independent study, commissioned by the Airport, took place in the UK between September 2021 and March 2022, led by the University of Salford, UK with City St George's, University of London, UK and the Noise Abatement Society, UK. As stated by Torija et al. (2022), p.6, the scope of this study was to 'Deliver an independent study to inform stakeholder discussions as a stage process during the development of potential [UK airspace proposals] for which the definition and quantification of [FED] of aircraft is useful.' The aim of the study was to 'develop a clear definition of FED of traffic that would enable airspace managers and aircraft operators to design solutions to deliver quicker, quieter and cleaner journeys and more capacity for the benefit of those who use and are affected by airspace in the UK' (Torija et al., 2022, p.2). To meet the aim of the study six objectives were developed. These objectives were delivered via a range of activities comprising a review of UK policies and regulations, as well as best practice and viable technology options; a review of the health effects of aviation noise; an overview of the role of non-acoustic factors; the views of policymakers, industry stakeholders and communities;

recommendations and areas for further research. The scope, aim and objectives of the study are shown in Figure 1, adapted from Torija et al. (2022), p.6.

2.2 Methodology

This independent study used a mix of descriptive and exploratory qualitative research techniques. Descriptive studies seek to "*describe* phenomena rather than explain them" (Ayton, 2023, para.3), for example, to present data and evidence about a topic rather than necessarily collect new evidence (Sandelowski and Barroso, 2003). Exploratory research considers preliminary analyses of existing/novel areas and may "propose new ideas or generate new hypotheses" (Swedberg, 2020, summ.). Combined, these approaches were suitable for this study because: *1* it was the first study of its kind of FED of aircraft in the UK and, as noted by Hauptvogel et al. (2021), p.11, overall "the empirical evidence is scarce" for FED of air traffic; *2* the complexities of the human health and perceptual response to sound in context due to the impact of *both* acoustic and non-acoustic factors (Bartels et al., 2022; Hahad et al., 2024; Münzel et al., 2024); *3* calls by experts for the *necessity* of the application of theory to practice for FED of aircraft based on *locally relevant* contextual determinants (Heyes et al., 2022; Hauptvogel et al., 2021). These components, together with the study frame 'to *inform* stakeholder discussions with the *aim* to develop a clear definition of FED of air traffic [for a specified local context]' (Torija et al., 2022, pp.2, 6, emphasis added), were considered by the project team building on the state of the evidence to propose a locally applicable conceptual framework with related interdependencies through which a *workable* definition and *route to consensus* of FED for the Airport could be achieved. The activities undertaken to meet the FED study objectives are shown in Figure 2, adapted from Torija et al. (2022), p.6. Aligned with descriptive and exploratory techniques, the FED study used desk-based research to collect, describe, and analyse data and evidence to conceptualise and propose a pathway to define FED for the Airport.

This paper presents a summarised version of the FED study structured in five sections as follows: Introduction (s.1); Methods (s.2); Findings (s.3); Recommendations (s.4); Summary and Further Work (s.5). The summaries in this paper of the FED study activities, findings, and recommendations are based on the timeframe of the study, with selected factual/syntax updates in this paper for accuracy (e.g., applicable policy references) and/or clarity (e.g., from 'noise' to 'sound and noise').

3 Findings

This section presents summaries of the findings from the FED study (Torija et al., 2022). The section is organised as follows: Background and Overview of Selected Findings from the Airport's Preliminary Work on FED of Aircraft and Stakeholder Engagement (s.3.1); Policy and Regulations (s.3.2); Technology and Procedures (s.3.3); Metrics for Aviation Noise (s.3.4); Evidence Review of the Effects of Aircraft Noise on Health (s.3.5); Non-Acoustic Factors and Developing an Effective Definition of FED (s.3.6).

3.1 Background and overview of selected findings from the airport's preliminary work on FED of aircraft and stakeholder engagement

This section provided an overview of selected findings from the Airport's preliminary work on FED of aircraft which led to the commissioning of the FED1 study and the rationale by the project team for the activities taken to meet this objective (Figure 1). An online workshop with community stakeholders to support the work carried out for this section was organised on the seventh of December 2021 for 2.5 h. The Airport invited representatives of communities who were members of their noise management engagement body to attend the workshop. Attendance was voluntary and community members who could not attend were also given the opportunity to respond via email or regularly scheduled meetings of the noise management engagement body. During this workshop the communities' representatives were invited to provide any views or objectives regarding:

- The concentration versus dispersal of aircraft (and thus aircraft noise); acoustic metrics to assess aircraft dispersion and their use in assessing FED.
- The health effects of aircraft noise and their relevance in assessing FED.
- Non-acoustic factors to consider as metrics to support FED.

The communities' views conveyed in this workshop, in addition to feedback and contributions from other stakeholders expressed to the Airport, through ongoing meetings of its noise management engagement body from industry partners, communities (who chose to provide feedback through this route), policymakers, and regulators, were also gathered and considered by the delivery team for the study recommendations and design of the *Sound, Noise and Health Conceptual Framework*.

All communities' representatives expressed a tendency towards an agreement that aircraft dispersal is preferred to concentration, so that the associated noise is shared in the fairest way possible recognising the constraints of the Airport location, runway orientation and the physical characteristics of aircraft operations. However, even with an agreement towards dispersal, communities' views varied on how that dispersal should be implemented. For instance, some communities were in favour of dispersing air traffic as much as possible (so no one is overflown more frequently than others), while other communities were in favour of dispersing traffic within areas that have historically been impacted by aircraft operations. The workshop participants [CRx] gave the following feedback as noted by Torija et al. (2022), p.33:

- [CR1] was in favour of dispersal of air traffic as much as possible, so no individual is overflown more frequently than others.
- [CR2] was in favour of dispersal of traffic *'within areas that have historically been impacted by aircraft'*. They also stated that *'[the] extent of dispersal should take account of historical circumstances [. . .].'*, and that *'[new] areas should not be overflown and material increases in concentration within areas previously overflown should be avoided'*. Furthermore, they stated that flying over new areas should be considered if

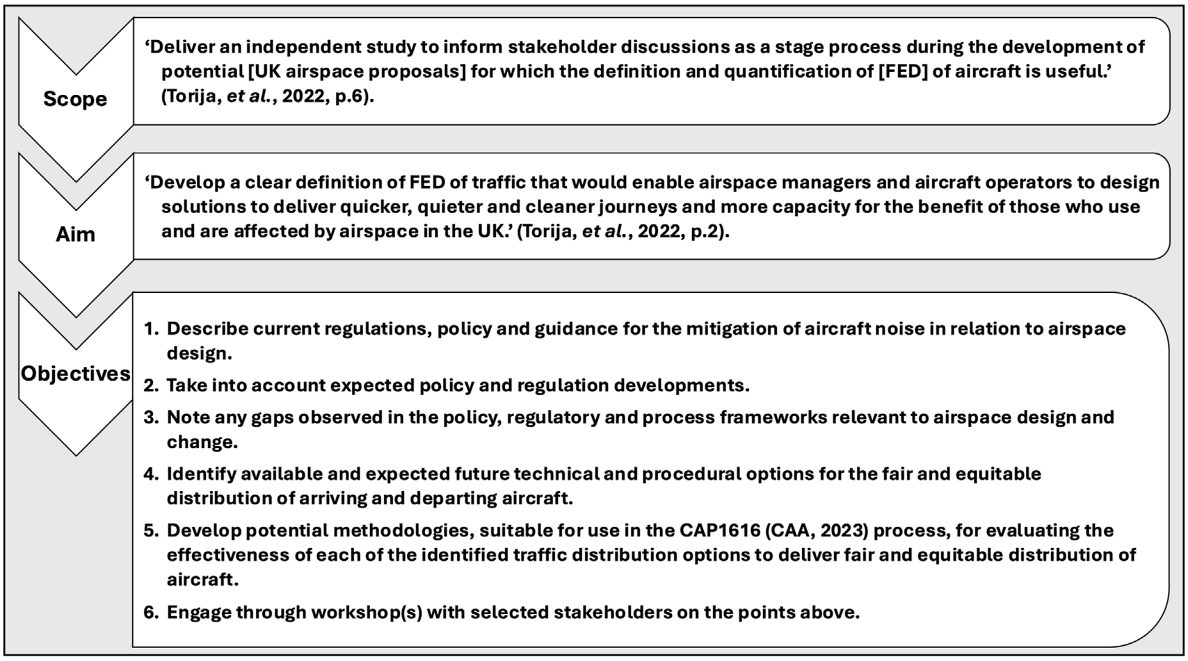

FIGURE 1
The scope, aim and objectives of the first independent study, to the best of the authors' knowledge, on Fair and Equitable Distribution (FED) of air traffic in the UK to inform an airport's UK airspace proposals, led by the University of Salford, UK with City St George's, University of London, UK and the Noise Abatement Society, UK. Adapted from Torija et al. (2022), p.6.

'currently impacted communities would suffer noise above the limits recommended by the WHO.'

- [CR3] stated that *'the concentration of air traffic has to be avoided, so that air traffic and the noise they generate can be widely dispersed and shared as equitably as possible [. . .].'* They also suggested monitoring the frequency of overflight with Number Above metrics.
- [CR4] stated that *'that departure flights should be dispersed and [. . .] concentration [of air traffic] avoided as much as possible'.* They recommended 'distribution of traffic on Noise Preferential Routing (NPR)' and more research to *'determine if random dispersal or pre-planned (time based) dispersal is preferable.'*

For community representatives who could not attend the workshop, views in writing were also invited and communicated to the delivery team. Those received reflected the views expressed during the workshop (noted above). One of the proposals extended the views already expressed on dispersion to 'optimal dispersal', which proposes to *'seek to reduce the harmful impact of aircraft noise, while minimising the number families that experience any significant noise disturbance.'*

Concerns were also expressed that current approaches do not provide a comprehensive approach to assessing the health impacts of aircraft noise such that the harmful effects of aircraft noise are minimised, while reducing the total number of people exposed to significant aircraft noise (based on Lowest Observed Adverse Effect Level [LOAEL] and Significant Observed Adverse Effect Level [SOAEL] values). Some community representatives viewed 'optimal dispersal' as a framework to address these inequities. Of course, the definition of 'optimal dispersal' must be developed with relevant stakeholders and communities around the Airport. In sum, the views of communities aligned with those expressed in numerous other studies regarding annoyance from aviation noise (Haubrich et al., 2019; Bartels et al., 2022).

3.2 Policy and regulations

This section included an overview of current regulations, policy and guidance relevant for the mitigation of community noise impact in relation to airspace design in the UK.

3.2.1 Policy review

This section presented an overview of current regulations, policy and guidance relevant for the mitigation of community noise impacts in relation to UK airspace design (CAA, 2025a), summarised from "Aviation Policy and Regulation Overview" of Gatwick Airport's Environmental Noise Directive - Noise Action Plan 2019-2014 (END NAP) (Gatwick Airport, 2019). The Airport's END NAP specifies three main levels of aircraft noise regulation in the UK: International, European and National.

Internationally, the International Civil Aviation Organization (ICAO, 2025a) is the intergovernmental body on aircraft noise, established to develop the principles and techniques of civil air navigation and support the planning and development of international air transport. ICAO establishes the international standards, and recommends best practice and technical information, including for aviation noise. Through the Balanced

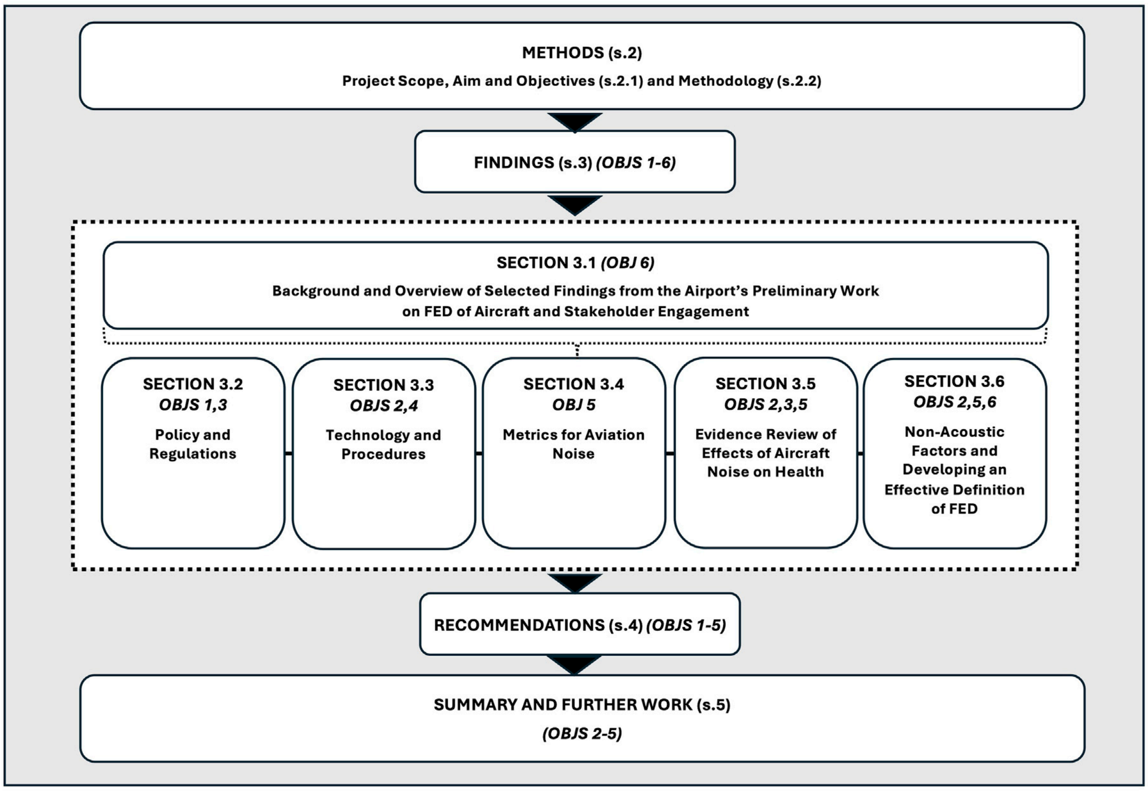

FIGURE 2
The framework of the first independent study, to the best of the authors' knowledge, on Fair and Equitable Distribution (FED) of air traffic in the UK to inform an airport's UK airspace proposals, led by the University of Salford, UK with City St George's, University of London, UK and the Noise Abatement Society, UK. The figure shows the study sections aligned to the objectives (Figure 1). Adapted from Torija et al. (2022), p.6.

Approach framework, ICAO (2004) encourages its member states to incorporate four noise control techniques: noise control at source, land use planning, operating procedures, and operational restrictions. The EU and UK have both adopted the Balanced Approach. European regulations are standardised through a common aviation policy approach to aircraft noise management. While the UK has fully left the EU, after the end of the UK/EU Agreement transitional period on 31 December 2020, the CAA (CAA, 2025e, para.1) confirmed "the law that applies to [EU] aviation rights and obligations is now all UK law and includes the retained EU Regulations, as amended by an increasing amount of UK law."

Regarding NAFs, both the Airports Council International (ACI) and the Civil Air Navigation Services Organization (CANSO) observed, in a presentation to the ICAO Assembly 40th Session Executive Committee ICAO (2019), ss.2.2–2.3, that despite the growing evidence base demonstrating the importance of NAFs in influencing communities' response to noise and levels of annoyance *"national government policy and aircraft noise management strategies to date have focused on measures to reduce noise exposure"*. Based on their analysis ACI and CANSO invited the Assembly to *"explore further the understanding of non-acoustic factors as a means to potentially support policy development which properly addresses community aircraft noise annoyance"* (ICAO, 2019, ES-B).

3.2.2 Gaps in existing UK policy

Nationally, gaps in UK law were identified pertaining to the impact of noise on health. CAP1616 (CAA, 2023) sets out that an airspace change process (ACP) appraisal must use the DfT's (2024b) TAG module for valuing the impacts of noise, including those from changes in aircraft noise, on health and quality of life. There are gaps in knowledge relating to TAG that are relevant to its use in airspace design and change. One gap is the lack of inclusion of additional health outcomes, which could be considered if a TAG+ approach to the analysis was taken. This would address community concerns about some health outcomes being omitted from TAG. Further concerns relate to the lack of more recent evidence informing the exposure-response relationships used in TAG. Another gap concerns the sensitivity of TAG for evaluating the impacts of airspace change over differing scales and types of geographical area, particularly smaller areas and communities and urban and rural areas. The scale of the assessment can make it difficult for communities to see themselves and their local area represented in a TAG assessment. Assessing the impact of the scheme as a whole limits understanding of changes in impacts at smaller geographical scales. And the focus on the total number of households facing increases or decreases in noise levels can leave communities feeling that the magnitude of the issues faced by those assessed as 'experiencing no change in exposure' is being overlooked. It is unclear how the magnitude of change in the total number of households informs the airspace change process. TAG presents results for time-averaged metrics ($L_{Aeq,16h}$; $L_{Aeq,8h}$) and does not include metrics such as Number Above (NA) or metrics for shorter-time periods which communities can feel better represents their exposure situations. TAG also does not consider populations exposed to levels below 51 dB $L_{Aeq,16h}$ and 45 dB $L_{Aeq,8h}$.

Finally, another gap concerns the inclusion of specific NAFs in policy. The CAA (2018), p.54 reviewed research on NAFs and recommended that: *"questions on trust in authorities and perceived fairness in air traffic related decisions should be included in future surveys [of communities], given the importance of these aspects to the annoyance response"*.

3.2.3 Summary of policy and regulations

After the description of the current regulations, policy and guidance relevant for aviation noise, two key aspects should be considered for the inclusion of FED objectives in the development of the Airport's airspace change proposals: *i* Environmental noise is a priority below 4,000 ft, where the objective in UK policy is to limit and, where possible, reduce the total adverse effects on people (DfT, 2017; DfT, 2024a); *ii* TAG as the tool for assessing airspace change proposals should be updated, in dialogue with policymakers to discuss how TAG+ and/or a health dashboard and NAFs analyses could additionally be taken into account in the decision making processes in line with the current and growing evidence base (CAA, 2025b; Schreckenberg et al., 2024).

3.3 Technology and procedures

This section described the noise related requirements to be addressed by airspace modernisation (AMS) related to airspace design concepts with the potential to offer noise mitigation that are drawn from UK CAA Guidance CAP1378 (CAA, 2016). This section introduced Performance Based Navigation (PBN) technologies and summarised how they can be used to either concentrate or accurately disperse traffic with the aim of reducing aircraft noise exposure. An overview of the findings of CAP1378 (CAA, 2016) was provided regarding the minimum lateral distance between routes to ensure meaningful changes in aircraft noise exposure on the ground.

3.3.1 Performance based navigation

The DfT (2017) Air Navigation Guidance (ANG) provides the CAA and wider aviation industry with statutory guidance on the environmental objectives that should be considered when conducting air navigation functions, including the development and regulation of Airspace Change Proposals (ACPs). The guidance lays out the altitude-based priorities that should be taken into account when considering the potential environmental impact of an airspace change. Change sponsors must satisfy these priorities when developing design options that seek to optimise the environmental performance of a portion of airspace.

The ICAO (2008) PBN Manual, Doc 9613 describes PBN specifications. Routes use a combination of satellite technology, ground systems and onboard avionics to improve aircraft track keeping accuracy. PBN routes can be designed with greater precision and flexibility than conventional alternatives, offering more options to mitigate the environmental impacts of aviation. However, the precision with which PBN routes are flown typically concentrates noise impacts as the general dispersion in flight paths following conventional routes is removed. Noise concentration linked to PBN has the potential to degrade the environmental performance of airspace if the positioning of the routes is not carefully managed. The expectation set out in the ANG (DfT, 2017, s.3.2) is that airspace changes limit and, where possible, reduce the number of people in the UK significantly affected by adverse impacts from aircraft noise. In this case the traffic concentration delivered by PBN routes is an asset in avoiding densely populated areas. However, the increased concentration of aircraft may come at the expense of increasing the intensity or frequency of aircraft operations over a smaller area which can negatively affect communities overflown.

For the purpose of assessing airspace changes, according to the ANG (DfT, 2017, fn.18), the UK government wishes the CAA to interpret this objective to mean that the total adverse effects on people as a result of aviation noise should be limited and, where possible, reduced, rather than the absolute number of people in any particular noise contour. Adverse effects are considered to be those related to health and quality of life. There is no threshold at which all individuals are significantly adversely affected by noise. It is possible to set a Lowest Observed Adverse Effect Level (LOAEL) that is regarded as the point at which adverse effects begin to be seen on a community basis (Defra, 2010, s.1.7).

3.3.2 Vectoring and lateral separation

Air traffic controllers often rely on vectoring (FAA, 2025) to manage the traffic using conventional routes as efficiently as possible. Flights are directed to follow a specific compass heading to a particular altitude or way point rather than fly the conventional route as designed. This practice further increases the dispersion of flight paths. The introduction of PBN routes is commonly accompanied by a significant reduction in the use of vectoring. The extent to which vectoring is reduced by the introduction of air traffic onto multiple PBN routes is a key determinant of noise concentration and therefore an important factor when considering the optimal approach to mitigating environmental impacts.

The degree of noise mitigation provided by the dispersion of air traffic onto PBN routes will significantly depend on the lateral separation between the routes (ICAO, 2012), the height of the aircraft and the degree of vectoring that is retained to deliver an efficient sequence of inbound traffic for landing. In CAP1378 (2016, Annex A, p.97; Annex B, p.100), the CAA's Environmental Research and Consultancy Department (ERCD) presented analysis of the relationship between route spacing, aircraft height and noise on the ground. A summary of these results shows the relationship between lateral spacing and noise level considering four broad thresholds: 'just perceptible' (3 dB difference), 'clearly perceptible' (5 dB difference), 'half as loud' (10 dB difference), and 'much quieter' (20 dB difference) (CAA, 2016; fig.A1). The results demonstrate that:

- *at 3,000 ft relief routes would need to be at least c.1 km away to be perceptibly quieter, c.2 km away to be half as loud and c.4 km away to be considered 'much quieter'.*

- *at 5,000 ft relief routes would need to be at least c. 1.8 km away to be perceptibly quieter, c.3 km away to be half as loud and over 5 km away to be considered 'much quieter'.*
- *at 7,000 ft+ relief routes would need to be at least c.2.5 km away to be perceptibly quieter, c.4 km away to be half as loud and well over 5 km away to be considered 'much quieter'.*

3.3.3 Summary of technology and procedures

The optimal position of routes included in an ACP is highly influenced by the local circumstances associated with each proposal (e.g., NAFs). Engagement and consultation with all stakeholders that may be affected by the change is essential for the sponsor to understand the features of an optimal solution regarding the positioning of routes. For this FED study, the process of optimisation assumed *a blank sheet approach that is not constrained by the treatment of existing noise abatement procedures*. At times, concentrating flight paths on a smaller number of routes away from densely populated areas may lead towards an optimal solution. In other circumstances, distributing the flight paths using multiple routes to achieve predictable/periods of noise relief and/or respite (see Nomenclature) for those on the ground may be preferrable. This section did not consider any limitation in the number of routes in PBN options with multiple routes. In line with CAA (2016) guidance, the specific number of routes will need to be carefully designed and implemented on the bases of safety considerations, but also accounting for the minimum lateral distance between routes to ensure a meaningful change in noise level on the ground.

3.4 Metrics for aviation noise

This section introduced the technical definitions of relevant objective acoustic metrics and their use in assessing the human response to aviation noise. Many variations of such metrics exist, but those most commonly defined within policy are addressed here. Reviewing the acoustic metrics is a fundamental framework needed to address the objective effects of aircraft noise on health, which is discussed in Section 3.5.

3.4.1 Time-averaged, discrete event, number above, and combined metrics

Time-averaged metrics are used to deal with the variation of sound pressure over time. They are metrics which give an average sound pressure level integrated over a specific period of time. With respect to aviation noise, time-averaged metrics quantify the average amount of physical aircraft noise over time by taking into account both the average sound level associated with each aircraft flyover event, and the average number of those events over defined time periods. These metrics do not quantify actual annoyance or disturbance (Flindell et al., 2021). A widely used time-averaged metric is the *equivalent continuous sound pressure level* (L_{eq}), which when corrected by the A-Weighting curve to be applied to aviation noise, is A-weighted L_{eq} (L_{Aeq}). Some benefits of using the L_{Aeq} for aviation noise is that it can represent the total aircraft noise exposure of a given period and may be used to show variations in sound level from contiguous time periods, for example, hourly. Some drawbacks of the L_{eq} metric are that the noise level at any given time within an encompassing time period is not represented. Average noise exposure metrics may yield similar results for one area with many quieter flight events, compared to another area with few(er) noisier flights, whereas the actual experience at the two locations will be different with one another. Also, as human response varies over a 24-h period, the heightened sensitivity to noise during the evening and night-time periods are not accounted for with the L_{Aeq}.

Sometimes it is beneficial to represent individual noise events with *discrete-event metrics*, such as the *maximum sound pressure level*, L_{Amax}. Discrete event metrics such as the sound exposure level, SEL or L_E represent the individual dose of an event, such as an aircraft fly-over, by representing the complete sound energy of the event normalised over 1 s. By adding up the individual SELs from a number of individual events, one can determine the L_{eq} over a time period, for example, a 16-h daytime period.

A commonly used group of noise descriptors in aviation noise is the *number above metric* (NA). A number above metric corresponds to the total number of aircraft sound events above a specific sound pressure level during a specified time period. Some examples are, N60 and N65, which represent the number of aircraft events above 60 dB [during a defined time period, typically the night-time, although some argue for its use for daytime operations (Yu and Hansman, 2019)] and 65 dB (during the daytime) respectively. The NA metric is usually based on single-event metrics such as SEL or L_{Amax}. The strengths of these metrics are in combining the single-event metrics with the number of aircraft operations and to give an indication as to how airport operations might affect human activities, such as awakenings during the night-time. The NA metrics might also show the frequency of disturbing aircraft flyover events during the daytime or night-time periods. A minor disadvantage to relying solely on this metric would be that it is not a specific indicator of individual level, just an indication of the number of events above a predetermined threshold.

Some attempts have been made to develop *combined metrics* which account for the issue of subjectivity in human noise perception. The most prominent metric of this class is the *Effective Perceived Noise Level* (EPNL), a derivative of the *Perceived Noise Level* (PNL) which was first defined in Kryter (1960). The EPNL went further in trying to quantify the annoyance effect from tonal components within aircraft sound in addition to the effects from the duration of the noise event. Furthermore, the *Noise and Number Index* (NNI) is another metric used to assess the subjective effects of numerous flights during a given time period (e.g., day or night). A difference of 10 NNI has the effect of quadrupling the number of flights during the integration period or increasing the PNL by 10 dB.

3.4.2 Other metrics

Many epidemiological studies and annoyance surveys have reviewed noise exposure expressed as equivalent continuous levels over longer time periods (e.g., L_{dn}, L_{den}, L_{night}, etc.). It has been repeatedly shown that these energy-based metrics (alone) are limited regarding annoyance or disturbance effects from noise Wunderli et al. (2016). The combined effects of overall energy with the temporal aspects of a given noise event are reviewed here.

In CAP1498 the CAA the defines *overflight* as an in-flight aircraft passing over an observer at an elevation angle greater than an agreed threshold and at an altitude below 7,000 ft. The elevation angle is the approximate angle between the horizon and the aircraft. These overflights accumulated over a specified period of time, form the *overflight metric*. Given this definition, further metrics such as onset rate can be used to describe the noise characteristics associated with defined overflights. An additional metric to those most common within aviation noise policy is the *onset rate*, which aims to quantify the effect of the increase in noise level associated with aircraft flyover. Typically, onset rates of commercial aircraft lie in the region of 10 dB increase in instantaneous sound pressure level per second (dB/s). Despite strong correlations between annoyance and onset rates at various SELs tested on humans both indoors and outdoors, the use of the metric is not often used within policy (Plotkin et al., 1991). Wunderli et al. (2016) conceptualised the *intermittency ratio* (IR) as a metric for describing the temporal variation of a series of noise events, particularly designed to be applied to highly intermittent traffic noise exposure situations, which means it is suitable for implementation in common aircraft noise prediction models. IR is defined as the proportion of acoustic energy from individual noise events above a defined threshold as a proportion of the overall sound energy. It is particularly aimed at addressing the effects of transportation noise on humans during the night, where acute physical reactions to noise during sleep occur. The probabilities of these reactions clearly correlate with maximum sound pressure level of noise events whereas average noise metrics usually fail to predict noise-induced sleep disturbances sufficiently.

3.4.3 Use of acoustic metrics for aviation

An important consideration is that the currently available metrics are only designed to quantify the aircraft noise and therefore should be used with caution if representing community annoyance and disturbance. At an individual level, there is a significant variability in the relationship between noise exposure and any associated annoyance effects. For this reason, the community impacts of aircraft noise are subject to considerable uncertainty. An example of this is the fact that overall reported annoyance around airports does not seem to be reduced in proportion to the important reductions in noise contour areas that have been achieved with the introduction of quieter aircraft and operational procedures (Guski et al., 2017). Flindell et al. (2021) summarise the sources of uncertainty in aircraft noise annoyance as:

- Sound levels measured (or modelled) might not be representative of the actual exposure to aircraft noise.
- The long-term averaged sounds, used for the derivation of exposure-response curves, are not necessarily representative of the actual noise exposure in a particular day, and are unable to account for the daily/weekly/monthly variability (especially important for noise respite schemes).
- The influence of non-acoustic factors are not appropriately factored in.
- The potential lack of representativeness in the way that community attitudes to aircraft noise is gathered, i.e., using standardised quantitative survey methods.

3.4.4 Summary of metrics for aviation noise

In sum, the most commonly studied aviation noise metrics have been reviewed within this section. Although time averaged metrics, such as $L_{Aeq,T}$ are widely studied, relatively simple to understand and are somewhat correlated to annoyance, other metrics such as NA, L_{Amax} and Intermittency Ratio can provide more accurate information about the number of overflights effectively contributing to the total aircraft noise exposure. Other acoustic and psychoacoustic metrics able to better account for short-term noise exposure and impacts associated with respite, relief or dispersal schemes need further investigation. Reviewing the acoustic metrics is a fundamental framework needed to address the objective effects of aircraft noise on health.

3.5 Evidence review of effects of aircraft noise on Health

This section provided an overview of the current evidence base for the effects of aviation noise on health and consideration of health as a metric for FED. This section identified up-to-date evidence for outcomes considered in the UK Department for Transport's (DfT) Transport Analysis Guidance (TAG) (DfT, 2024b), as well as identifying evidence for health outcomes not currently considered in TAG. This section also considered health metrics to measure and report noise impacts, as well as consideration of the evidence for health effects associated with change in aircraft noise exposure.

3.5.1 Levels of evidence

The effects of aircraft noise on health could provide further information or metrics to inform considerations of FED. However, the increasing number of individual studies examining the effects of aircraft noise on health in recent years has led to complexity and introduced uncertainty in understanding *1* whether aircraft noise is having a detrimental effect on a specific health outcome; and *2* the magnitude of any effect, as findings often vary across studies. Systematic reviews of the evidence have been undertaken to help stakeholders and policymakers understand the strength of the evidence across studies by statistically pooling estimates for effects of aircraft noise on a health outcome using meta-analysis. Narrative systematic reviews, which qualitatively compare findings, are also available where it is not possible to meta-analyse data. Typically, evidence from systematic reviews is considered more favourably than individual studies, but individual studies that are relevant to the Airport or UK context, and/or that examine novel exposures or health outcomes, and/or that are methodologically robust should also inform considerations of FED. Evidence from longitudinal studies that examine how aircraft noise exposure influences the development/incidence of disease is stronger than evidence from cross-sectional studies which examine exposure and health at one time-point. The following sections summarised evidence to inform discussions about using health as a metric of FED, regarding:

- Most recent evidence and/or exposure-response functions;
- Evidence assessing the effects of airspace change or operational changes; and
- Gaps in knowledge.

3.5.2 Annoyance

The term annoyance describes negative reactions to noise such as disturbance, irritation, dissatisfaction and nuisance (Guski, 1999). Exposure-response functions (ERFs) showing the 'percentage highly annoyed' (%HA), assessed following Technical Standard

(ISO/TS15666, 2021; ISO/TS15666, 2003), plotted against noise exposure increasingly inform policy, guidance and impact assessment.

However, predicting annoyance at any given sound level has uncertainty, with wide-ranging estimates of annoyance being found for the same sound level across studies (Guski et al., 2017; Guski et al., 2018). Uncertainty is associated with methodological differences in survey design (sampling, recruitment, population, range of exposure) but also in terms of how noise exposure is estimated; operational differences between airports (e.g., number of runways, night-flights, availability of respite) and non-acoustic factors (Clark et al., 2021a). There has been much debate about differences between recent annoyance surveys (Independent Commission on Civil Aviation Noise, 2019; Guski et al., 2019; Gjestland, 2018). The uncertainty assessment of annoyance should take a 'sensitivity' approach and examine impacts using estimates from different ERFs, and not rely solely on one ERF to estimate annoyance effects (the WHO recommends using a local ERF where available). ERFs can be derived either from pooling individual study ERFs across the evidence base (e.g., WHO) or from individual studies of a particular context (e.g., SoNA 2014). Both approaches have pros and cons and provide different or limited information on the uncertainties in the estimates. Studies rarely report uncertainties in the noise exposure assessment and pooled estimates, depending on the methodology employed, often cannot provide confidence intervals of the lowest and highest estimates for the annoyance relationship. The 'sensitivity' approach could take uncertainties into account when examining impacts, where known.

In terms of time-average metrics such as $L_{Aeq,16h}$ or L_{den} there are several ERFs from meta-analyses or individual studies that could be used to estimate aircraft annoyance within communities around the Airport: the World Health Organization Environmental Noise Guidelines Exposure Response Function (WHO ENG ERF) (Guski et al., 2017b), the Survey of Noise Attitudes (SoNA) 2014 ERF (Civil Aviation Authority, 2021), and the 2002 EU ERF (often referred to as the Miedema curve) (European Commission, 2002; Miedema and Oudshoorn, 2001).

The WHO ENG estimates a stronger relationship between aircraft noise and annoyance than the SoNA 2014 and 2002 EU ERFs. For example, the WHO ENG ERF suggests that 10% HA would occur at 45 dB L_{den}, whilst SoNA 2014 suggests that 10% HA would occur at 55 dB $L_{Aeq,16h}$. SoNA 2014 additionally provides an ERF for N65, suggesting an increase in annoyance responses between 50–99 events and 100–199 events for N65.

In considering how to undertake Health Impact Assessment (HIA), the WHO ENG set out that "*data and exposure–response curves derived in a local context should be applied whenever possible to assess the specific relationship between noise and annoyance in a given situation. If, however, local data are not available, general exposure–response relationships can be applied, assuming that the local annoyance follows the generalized average annoyance.*" (Section 5.5, page 109) (WHO, 2018). This would favour using the SoNA 2014 ERF. However, as previously described there has been much debate about differences between the WHO ENG and SoNA 2014 ERFs.

Another aircraft noise metric that could inform the consideration of FED is the intermittency ratio (IR) (Wunderli et al., 2016), which reflects whether the time-average noise exposure is made up of distinct or a high number of distinct pass-by events (a high IR) or constantly flowing events (a low IR) (Brink et al., 2019). The Swiss SiRENE study found that the ERF between aircraft noise exposure (L_{den}) and %HA varied slightly with the intermittency of the noise exposure (Brink et al., 2019), suggesting that annoyance was slightly higher for continuous compared with intermittent aircraft noise. To date, there are no annoyance ERFs for the UK context published that consider the IR. Similarly, there are no published ERFs for aircraft noise annoyance that consider how the annoyance response might vary between areas with different characteristics (e.g., urban, suburban, rural) or with differing levels of ambient noise. The lack of evidence makes it challenging to take these factors into account in any impact assessment.

The WHO ENG, SoNA 2014 and EU 2002 ERFs are steady-state relationships, reflecting the relationship between current noise exposure and annoyance. They do not reflect how people may respond to a change in exposure, which has led to criticism of their use in assessments dealing with airport expansion or airspace change including cost-benefit analyses such as TAG (Independent Commission on Civil Aviation Noise, 2019).

Several international studies examining change in aircraft noise exposure, including newly overflown communities, airspace change, and runway alternations, have found that there is an excess annoyance response in relation to the change in noise exposure, both for increases and decreases in exposure (Brown and van Kamp, 2017; Brink et al., 2008; Fidell et al., 2002; Nguyen et al., 2018; Quehl et al., 2017). This means that when noise exposure increases, the annoyance response is slightly higher than would be predicted from steady-state ERFs for the actual noise exposure. Studies from Switzerland and the Netherlands suggest that these excess-responses are not short-term but can endure for at least a couple of years, if not longer (Breugelmans et al., 2007; Brink et al., 2008).

A study of respite operational changes to the night-time curfew and redistribution of flights into the shoulder hours around Frankfurt airport also found that residents were poor at describing and perceiving changes in operations (Schreckenberg et al., 2015). Very few residents were aware of quite significant changes in sound levels, with residents experiencing reductions of 4–10 dB $L_{Aeq,1h}$ or increases of 1.5–4.5 dB $L_{Aeq,1h}$.

Taken as a whole, evidence suggests annoyance responses are likely to increase above that predicted by steady-state ERFs where there is an increase in aircraft noise exposure. However, there is little UK evidence to estimate the magnitude of the change effect so if used to inform the consideration of FED, it would be necessary to further review the international evidence to inform stakeholder discussions about modifications to the ERFs used in the assessment and any such estimates will have uncertainty and will need to be reviewed if more suitable evidence becomes available.

3.5.3 Sleep disturbance

Sleep disturbance is a key health outcome in relation to aircraft noise exposure. Humans continue to respond to sounds in the environment even when asleep and studies have shown that noise can affect sleep in terms of immediate effects (e.g., arousal responses, sleep state changes, awakenings, body movements, total wake time, autonomic responses), after-effects (e.g., sleepiness, daytime performance, cognitive function) and long-term effects (e.g., self-reported chronic sleep disturbance; cardiovascular effects such as increased blood pressure, heart attacks) (Basner and McGuire, 2018; Elmenhorst et al., 2019; Basner et al., 2006).

Two different and distinct types of sleep outcomes have been examined. Subjective (self-reported) sleep disturbance which is linked to external time-average metrics such as L_{night}; and objective sleep disturbance which uses polysomnography (PSG) to record biophysiological changes that occur during sleep and changes in sleep stages which has been linked to individual noise events such as indoor or outdoor L_{Asmax}. Reports between subjective sleep disturbance and objective sleep disturbance can differ as individuals are not always aware of or recall biological awakenings. Time-average metrics may not be best for assessing impacts on sleep disturbance, as night-time aircraft noise events are intermittent, which means that the same L_{night} value can result from differing numbers of events and maximum levels.

ERFs for aircraft noise effects on objective and subjective sleep disturbance were published to inform the WHO ENG 2018 (Basner and McGuire, 2018) and provide ERFs that could be used to estimate sleep disturbance in communities surrounding the Airport.

For example, the health protection scheme proposed by Basner et al. (2006) for the Leipzig/Halle airport in Germany to manage the risk of sleep disturbances associated with aircraft noise included the recommendation that on average there should be less than one additional EEG awakening induced by aircraft noise per night. This is an annualised metric, so there can be more than one additional EEG awakening per night if there are other nights when no additional EEG awakenings per night occur. The concept has been used to produce awakening contours for airports. This type of information could be used to inform considerations of FED.

However, the evidence for an impact of change in aircraft noise on subjective sleep disturbance is mixed, with some studies finding no change in self-reported sleep disturbance after operational changes (Nguyen et al., 2015; Yano et al., 2015; Breugelmans et al., 2007) and others suggesting that an increase or decrease in noise was associated with subjective sleep disturbance (Fidell et al., 2002). Given the mixed evidence it cannot be discounted that operational changes can cause subjective sleep disturbance.

3.5.4 Cardiometabolic diseases

Noise is hypothesised to increase risk factors for poorer cardiometabolic health such as blood pressure, blood sugar and blood fats which can lead to diabetes, heart attacks and strokes. (Münzel et al., 2018; Münzel et al., 2017). There are several ERFs for aircraft noise and cardiometabolic outcomes available which find statistically significant increases in risk for a range of cardiovascular outcomes including Acute Myocardial Infarction (AMI), coronary heart disease and cardiovascular disease (CVD), as well as on cardiovascular risk factors such as hypertension and diabetes (Cai et al., 2021; Basner et al., 2014; Van Kempen et al., 2018; Vienneau et al., 2019; Vienneau et al., 2015). There are also studies of populations around Heathrow Airport that could be used (Hansell et al., 2013; Jarup et al., 2008). A recent publication on the Swiss National Cohort has assessed the association of aircraft noise (L_{den}) with cardiovascular mortality over a 15 years period, finding an association with Myocardial Infarction (MI) but not with other cardiovascular mortality outcomes including CVD, ischaemic heart disease, and stroke (Vienneau et al., 2022). This study also found that intermittency of events during the night (assessed across three noise sources of road traffic, aircraft noise and railway noise) was associated with a range of cardiovascular mortality outcomes but that associations for number of events (also assessed across three noise sources) were only found for MI and stroke. This paper also provides age-specific estimates, as some of the associations with (CVD) mortality were stronger for younger (30-64 years) or older (65+) participants and the authors suggest this should be taken into account in HIA.

Few studies have examined the impact of a change in aircraft noise on cardiometabolic health. The NORAH study found that neither an increase or decrease in aircraft noise exposure influenced blood pressure over the course of 1 year (NORAH Knowledge No 11, 2011) but studies with a longer duration may be needed to show effects given the long developmental period for poor cardiometabolic health.

TAG estimates AMI based on the 2006 Babisch ERF (Babisch, 2006) and estimates hypertension and stroke based on the 2009 Babisch and van Kamp ERF for hypertension (Babisch and Kamp, 2009): this hypertension ERF informs calculations for effects on vascular dementia and stroke. Heathrow Expansion planned to additionally calculate the effects using the 2018 WHO ERF for stroke (Van Kempen et al., 2018) and the Vienneau ERF for AMI (Vienneau et al., 2015). Subsequent publications provide further ERFs that could be used (Vienneau et al., 2022).

3.5.5 Mental health, wellbeing and quality of life

Residents can report impacts of aircraft noise exposure on mental health, wellbeing and quality of life. Such responses could be the result of noise as a stressor but can also result from impacts of annoyance and sleep disturbance on stress hormones and mood. There is evidence for an effect of aircraft noise on a range of adult mental health, wellbeing and quality of life outcomes such as depression, but recent reviews highlight that the evidence does not consistently suggest an association (Clark et al., 2020; Clark and Paunović, 2018b; Hegewald et al., 2020). There is evidence for a small effect of aircraft noise exposure on children's hyperactivity symptoms (Clark et al., 2021b; Clark and Paunović, 2018b).

The NORAH study examined the health insurance data of over 655,000 individuals aged over 40 years living near Frankfurt Airport finding a relationship between aircraft noise exposure ($L_{Aeq,24h}$) in 2005 and new cases of clinical depression diagnosed between 2006 and 2010.

Odds for depression increased with aircraft noise exposure up to 55–60 dB $L_{Aeq,24h}$ but decreased and became non-significant at higher noise levels, which the authors speculated could have been due to noise mitigation at higher exposures or vulnerable people having moved out of the noisiest areas. The estimates of odds for depression across the 5 dB exposure bands (40–60 dB $L_{Aeq,24h}$) range from increases of 9%–23%. Similar associations were also found for night-time aircraft noise exposure. However, the study had limited statistical power to examine the relationship at the highest noise levels as only 11 individuals had depression in the 60 dB $L_{Aeq,24h}$ group, which is likely to be influencing the findings. The ERF from the NORAH study could be used to estimate effects of aircraft noise on mental health but the estimates above 60 dB $L_{Aeq,24h}$ are uncertain.

Analysis of the Swiss SAPALDIA study found longitudinal associations between transportation noise annoyance and noise sensitivity with health-related quality of life (assessed by the SF-36) over 8 years later (Cerletti et al., 2020). However, the study did not find associations between aircraft noise and later health-related quality of life (HRQoL). Further analyses also found an association between aircraft noise exposure and incidence of depression and transportation noise annoyance was also associated with higher risk of depression (Eze et al., 2020). Unfortunately, the SAPALDIA study did not examine aircraft noise annoyance *per se* and the findings are limited to transportation noise. However, considering recent evidence as a whole, there is support for an effect of aircraft noise on risk for depression and for transportation noise on quality of life.

Beghelli (2018) examined the impact of a flightpath change trial at Heathrow Airport in 2012–2013 on prescription medication. Linking monthly medication prescribing to noise exposure at GP practices during the trial, the study found that there were reductions in prescription spending on nervous and respiratory conditions for regions that experienced a drop in air traffic during the trial.

A recent paper has evaluated the influence of the 'Schiphol New Deal Policy' on depressive symptoms in over 1,700 older adults (aged 57–102 years) from the Dutch Longitudinal Aging Study Amsterdam (Li et al., 2021). The policy aimed to reduce noise levels by changing flight routes and influencing night-flights. However, the study found very small changes in noise levels before and after the policy was introduced and no change in depressive symptoms. The study also reports no change in life satisfaction, anxiety, sleep, cognition and loneliness but it is difficult to evaluate these findings as no details are provided as to how these outcomes were assessed. Overall, the study findings are potentially limited by the lack of change in exposure and the lack of detail about operational changes, as well as the focus on an older sub-group of the population.

TAG does not include mental health, wellbeing and quality of life outcomes. The recent paper by Clark et al. (2021b) provides an ERF for hyperactivity suitable for use in TAG that is also designed to inform HIAs.

3.5.6 Children's learning

A number of studies have found an association between aircraft noise exposure at school and children's cognitive abilities or learning outcomes (Clark et al., 2006; Klatte et al., 2016; Hygge et al., 2002). There is also evidence for effects of a range of different aircraft metrics on children's SATs test score including L_{Amax}, Number of Events above a threshold metrics (NA), and Time Above a threshold metrics (TA) (Sharp et al., 2014). There is evidence to suggest that becoming newly exposed to aircraft noise exposure impacts on children's reading test performance (Hygge et al., 2002). TAG does not include effects of noise on children's reading comprehension, as whilst published in 2005, the RANCH reading comprehension ERF (Clark et al., 2006; Stansfeld et al., 2005) does not use a dichotomous outcome suitable for monetising the effects of noise on reading comprehension. A recent meta-analysis has re-estimated the RANCH reading comprehension ERF pooling estimates across three studies carried out around Heathrow airport, with analyses additionally presented using a categorical assessment of reading comprehension (scoring well below or below average on the reading test) suitable for use in TAG (Clark et al., 2021b). Reading comprehension is a good marker for general cognitive ability.

3.5.7 Other health outcomes

Recent years have seen increasing expansion of the types of health outcomes examined in relation to environmental noise, with limited evidence emerging for effects of aircraft noise on birth outcomes, neurodegenerative outcomes and dementia (Nieuwenhuijsen et al., 2017; Clark et al., 2020), breast cancer (Hegewald et al., 2017), as well as effects on other risk factors for poor health including obesity (Pyko et al., 2017; Foraster et al., 2018). The ICCAN Rapid Evidence Review published in 2020 highlighted the lack of studies for aircraft noise specifically for neurodegenerative outcomes and dementia, birth outcomes and cancer (Natcen, 2020).

There will always be evidence from new systematic reviews, research studies, and on novel health outcomes that could inform Environmental Impact Assessment (EIA), and if health metrics are considered as part of FED, there will be a requirement to keep a watching-brief on the evidence-base to identify and agree potential updates and additions with stakeholders.

The evidence-base has evolved in recent years, both in terms of the number of studies and type of health outcomes examined. In 2019 the Department for Environment, Food and Rural Affairs (Defra) commissioned two evidence updates to inform a revision of the TAG methodology (Clark et al., 2020; van Kamp et al., 2020) which covered annoyance, sleep disturbance, cardiometabolic, mental health wellbeing, quality of life, cancer, dementia, birth, reproductive outcomes, and cognition.

3.5.8 Burden of disease

Impact Assessments and estimates of burden of disease tend to focus on a number of key health outcomes including annoyance, sleep disturbance, cardiometabolic and learning (World Health Organization, 2011; European Environment Agency, 2020). TAG does not consider learning. Assessments also differ in terms of which specific cardiometabolic outcomes they include.

In terms of the comprehensiveness of any assessment, current approaches treat each health outcome and noise source individually and there is little knowledge about how to combine effects (Houthuijs et al., 2018). There is debate about how burden of disease estimates can be added together to estimate total health effects due to the potential for double counting. Of particular relevance, is the double counting of health effects that are part of the same causal pathway, e.g., hypertension, AMI and Stroke are assessed as separate outcomes, yet hypertension can be on the earlier pathophysiological pathway to AMI and/or Stroke. Similarly, sleep disturbance can lead to greater annoyance and poorer cardiovascular health. Current methods do not take into account different effects on vulnerable groups within populations (e.g., the elderly, those with pre-existing disease) (see European Environment Agency (2020) for a discussion of the evidence for vulnerable groups). Another type of double counting that could be relevant relates to exposure to multiple noise sources, where effects for one noise source may be modified by the presence of another noise source. Uncertainty in assessments also comes from other data in the calculations, such as disability weights. Issues of double counting are methodologically challenging to resolve but should be acknowledged in assessments. Other issues of uncertainty in burden of disease calculations could be further elucidated using sensitivity analyses.

3.5.9 World Health Organization guidelines

The 2018 World Health Organization Environmental Noise Guidelines for the European Region (WHO ENG) provide recommendations for protecting human health from exposure to aircraft noise (World Health Organization, 2018). The 2018 WHO ENG partially superseded the WHO Community Noise Guidelines 1999 (World Health Organization, 2000) but do not supersede the Night Noise Guidelines, 2009 (World Health Organization, 2009) (WHO NNG).

Based on a series of systematic evidence reviews, the WHO recommended that, "For average noise exposure, the Guideline Development Group (GDG) strongly recommend reducing noise levels produced by aircraft below 45 dB L_{den}, as aircraft noise above this level is associated with health effects. For night noise exposure, the GDG strongly recommends reducing noise levels produced by aircraft during night-time below 40 dB L_{night}, as aircraft noise above this level is associated with adverse effects on sleep." These levels represent those at which 10% of the population will be 'highly annoyed' for L_{den} and at which 11% of the population would report being 'highly sleep disturbed' for L_{night}.

The night-time guideline of 40 dB L_{night} matches that in the 2009 WHO NNG which was set to protect the public, including the most vulnerable groups such as children, the chronically ill and the elderly. The WHO NNG additionally provided an interim target of 55 dB $L_{night, outside}$ "for the countries where the guidelines cannot be achieved in the short term for various reasons, and where policymakers choose to adopt a stepwise approach." The 2009 WHO NNG values represent a LOAEL value, identifying levels where there is no risk to health. The 2018 WHO ENG do not represent LOAEL values but "noise exposure levels above which the GDG is confident that there is an increased risk of adverse health effects" [see page 20 World Health Organization (2018)].

If health outcomes are used to inform FED, it will be important to assess effects across a wide-range of aircraft noise exposures (and metrics), including levels in the 40–49 dB range for day-time exposures.

3.6 Non-acoustic factors and developing an effective definition of FED

This section provided an overview of the role of NAFs in the human response to sound. The importance of NAFs regarding FED of aircraft was explored.

Generally, NAFs have been understood as *"all those factors other than noise level alone which contribute to noise annoyance and similar effects"* (Flindell and Witter, 1999). Recently a standardised definition of NAFs encompassing previous versions was published in ISO/TS 16755-1:2025 (p.1) as *"Specific factors, other than the objective, measured or modelled acoustic parameters, which influence the process of perceiving, experiencing, understanding and/or responding to an acoustic environment."* As noted by Woodland et al. (2024) this definition was informed by discussions with the International Commission on the Biological Effects of Noise (ICBEN) Team 6 Community Response to Noise and Annoyance (ICBEN, 2024). The CAA (2018) have defined NAFs as "All those factors other than noise level alone which contribute to annoyance." For ease and clarity at the time of the study, the CAA's definition of NAFs was used in alignment with current research and evidence regarding the human perceptual response to noise from aviation (Sparrow et al., 2019; Basner et al., 2017).

In the literature NAFs are confirmed as wide ranging and can include several categories, for example: *personal factors* (e.g., ability to cope, fear of the noise source, lack of trust in responsible authorities) (Flindell and Stallen, 1999; Schreckenberg et al., 2022; Bartels et al., 2022), *psychosocial factors* (e.g., perceived fairness, cultural norms, community benefits/disadvantages) (Flindell and Witter, 1999; Asensio et al., 2017; Hauptvogel et al., 2023), *local environmental factors* (e.g., quality of dwellings, access to valued restorative spaces, urban morphology) (Hao and Kang, 2014; Kroesen et al., 2010; Tammam et al., 2023), and *situational factors* (e.g., temporality, seasonality, effects on space and place based inter/actions and activity disturbance due to, for example, the timing, number and height of aircraft) [(Lavandier et al., 2011; Lefèvre et al., 2020; Memoli et al., 2018; Bartels et al., 2022); see also Figure 3, stage 1]. Synthesising the literature, in ISO/TS 16755-1 (2025, pp.2-3, emphasis added) NAFs were categorised into four dimensions comprising '*personal, social* (e.g., aligned with *psychosocial factors* as described)*, physical* (e.g., aligned with *local environmental factors* as described) *and situational factors'*. Potential permeability exists between NAFs categories and specific factors may interact. For example, the NAF of *perceived fairness* may be classified in the *personal* and/or *social* category/ies depending on whether it is 'linked to an individual's and/or a community perception' (ISO, 2025, p.3).

3.6.1 Non-acoustic factors and health

WHO (2018, p.13) reported that "Nonacoustic factors are an important possible confounder [. . .] between noise levels and critical health effects and the effects of acoustic interventions on health outcomes." Guski (1999), p.1 found that "In noise annoyance studies nonacoustic factors may explain up to 33% of the variance [of people's response to noise apart from the level]." Following the discussion in Section 3.5.5, the significance of NAFs and their potential strength of impact on human health, mental health, wellbeing and quality of life is well established (Basner et al., 2014; Benz et al., 2022; Clark et al., 2025; Hahad et al., 2024). How health impacts from NAFs related to FED of aircraft might be avoided, minimised and mitigated requires an effective understanding of locally salient NAFs (Figure 3, stage 1).

3.6.2 Perceived fairness

In a white paper for ICAO Schreckenberg et al. (2024), p.12 confirmed the 'consensus view [amongst experts is] that non-acoustical factors could prove useful in examining community response to [aircraft] noise.' Bartels et al. (2022), pp.198, 200, 204 emphasised the importance of gaining a better understanding of the influence of specific NAFs on annoyance from aviation noise including 'coping strategies and possibilities, and social aspects related to trust in authorities and perceived fairness'. Therefore, the impact of NAFs on the effective implementation of FED of aircraft requires understanding their contextual relevance. The NAF of *perceived fairness* has been consistently identified by experts as paramount to communities concerned about the distribution of aircraft noise (Hauptvogel et al., 2021; Liebe et al., 2020; CAA, 2018; ICCAN, 2021; Bartels et al., 2022;

Heyes et al., 2022; Schreckenberg et al., 2022). Central to the concept of perceived fairness in this context are the perceptions of *costs* (e.g., adverse effects of aircraft noise) versus *benefits* (e.g., the perception of a/the desired intervention/s to support the ability/capacity to cope with the effects of aircraft noise) as perceived, experienced and/or understood by individuals in context. Hauptvogel et al. (2021), pp.1-2,14 explored the concept of annoyance from aircraft noise through the frame of social justice research noting that 'improved perceived cost-benefit ratios could increase an individual's sense of perceived fairness'. They posited that these phenomena could be understood as functions of 'reduced adverse responses to noise through enhanced perceived capacity to cope'. Further, applying social justice theories to practice, Hauptvogel et al. (2021) presented a series of recommendations aimed at increasing individuals'/communities' sense of perceived fairness, and thereby coping capacity, relative to FED of aircraft and called for empirical research to explore the efficacy of the recommendations.

Bartels et al. (2022), pp.208–10 emphasised the importance of identifying specific locally relevant NAFs *as requisite* to designing and implementing a range of potential interventions to reduce annoyance from aircraft noise. Given the subjective nature and multi-dimensionality of NAFs, as outlined, what constitutes a *desired perceived cost-benefit ratio* may vary widely amongst individuals and communities and needs to be understood through the lens of all NAFs categories (Hauptvogel et al., 2023; Schreckenberg et al., 2022). Therefore, by extension, it can be theorised that solutions individuals and communities may perceive as *effective and desired* cost-benefit ratios for FED of aircraft need first to be informed by an understanding of contextually salient NAFs across these categories. Thus, following the work of, for example, Haubrich et al. (2020) and Hauptvogel et al. (2021), this study proposed the necessity of a stage to assess local NAFs as a basis to inform stakeholder discussions and engagement to develop a workable definition of FED of aircraft (Heyes et al., 2022; Asensio et al., 2017; Haubrich et al., 2019). This approach is presented in the study recommendations (s.4) as part of a *Sound, Noise and Health Conceptual Framework* (Lavia et al., 2023) (Figure 3). The Framework was designed to enhance transparency by bringing community concerns to the forefront of the consultation process and thus, ideally, the decisions and outcomes.

4 Recommendations

The aim of this study was to 'develop a clear definition of FED of air traffic [. . .] in the UK' (Torija et al., 2022, p.2) (s.2). The overviews presented in Section 3 were part of the study design to meet the aim by providing the basis for the study recommendations (s.4). First, the overviews summarised the current state of knowledge at the time of the study for aviation: policy (s.3.2), technology options and noise metrics (ss.3.3–4), health effects of noise (s.3.5), and non-acoustic factors (s.3.6). Drawing on the findings from Section 3, the concept of the 'fairness dilemma' from FED of aircraft explicated by Hauptvogel et al. (2021), pp.1–3 is paramount. As discussed, this challenge involves *balancing the perceived costs and benefits of changes and effects* of aircraft noise distribution on individuals and communities, and posits supporting/increasing their capacity to cope as a *benefit* (see s.3.6.1). As effects of noise are both acoustical and non-acoustical, perceived *benefits*, and thereby increased capacity to cope, can be gained from solutions in these areas. To this end, the findings from each overview were synthesised and conceptualised to develop a Framework (Figure 3) and recommendations for the study. These are set out in Sections 4.1–4.4.

4.1 Aviation noise metrics and technology options

This study recommended that the proposed *Sound, Noise and Health Conceptual Framework* (Figure 3), accounts for acoustic, psychoacoustic, non-acoustic and health factors to aid the formalisation of a FED consultation (and/or co-creation) process. This consultation process should take account of the wider communities around the Airport and the location of the runway, aircraft operating characteristics and safety regulations.

Technology options for managing aircraft to enable FED are well defined and available (see Section 3). After narrowing down to only feasible airspace design options, the proposed conceptual Framework can be used during a consultation process with relevant stakeholders and communities to develop the option(s) for FED.

This study recommended further work to understand the capabilities of available acoustic and psychoacoustic metrics, and to assess whether they are better able to account for short-term noise exposure and impacts with respite, relief or dispersal schemes (than $L_{Aeq,16h}$). Further research is therefore recommended to investigate the feasibility and performance of other acoustic metrics, that complement $L_{Aeq,16h}$, for a better assessment of FED initiatives. As described, the use of other metrics such as NA, L_{Amax}, and Intermittency Ratio can provide more accurate information about the number of overflights effectively contributing to the total aircraft noise exposure, the magnitude of aircraft noise events, and the temporal dynamics of the noise exposure respectively.

This study recommended further work to better understand the benefits of noise respite around the Airport, and options to improve an effective delivery of noise respite. As described by (Flindell et al., 2021), further research is needed to better understand the value of respite periods, and the sharing principle implicit in noise respite/relief schemes. Additionally, we recommend carrying out an in-depth investigation of the human response to noise exposure for newly overflown.

4.2 Health effects of aircraft noise

This study proposed that health outcomes could contribute to the evaluation of FED, in addition to the CAP1616 requirement to use TAG for airspace redesign. A health dashboard could be agreed between stakeholders, which could report the health impacts of key noise metrics for areas around the Airport. Further work would be needed to assess the geographical scale at which the data could be presented and there would need to be discussions between the Airport and stakeholders about which health data to present.

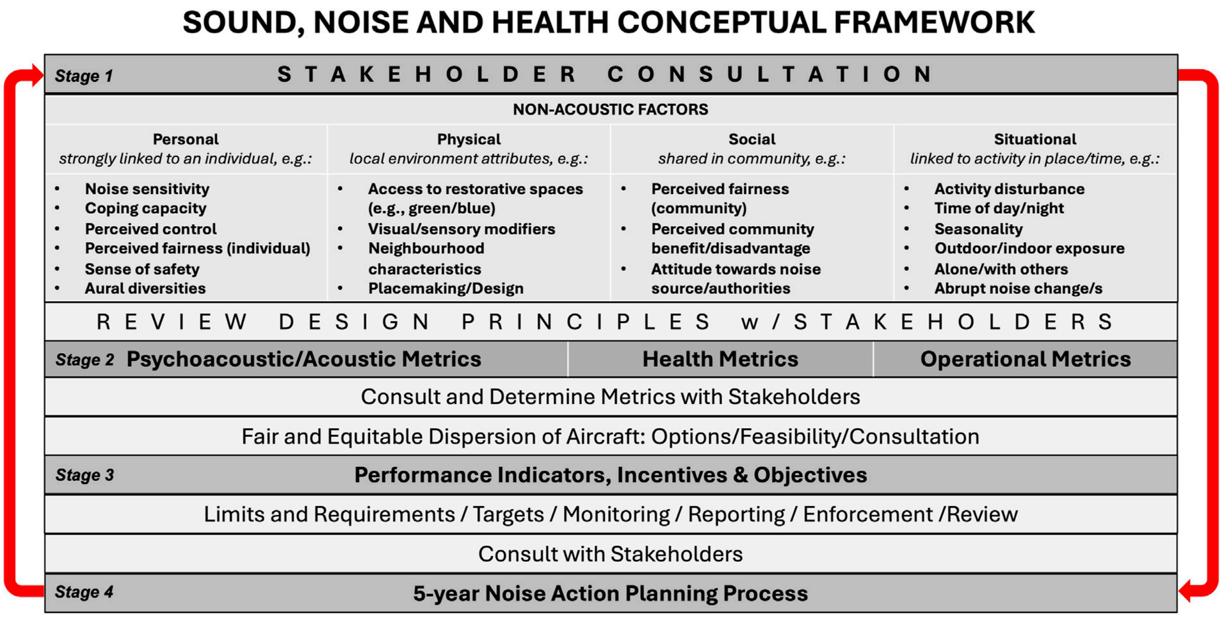

FIGURE 3
Sound, Noise and Health Conceptual Framework of the general stages recommended for operationalising the development of an agreed definition of Fair and Equitable Dispersion of air traffic. In Stage 1 of the Framework it is noted, according to ISO (2025), p.3, that potential permeability exists between NAFs categories and specific factors may interact. For example, the NAF of perceived fairness may be classified in the personal and/or social category/ies depending on whether it is 'linked to an individual's and/or a community perception'. Adapted from Torija et al. (2022), p.123; ISO (2025); HAL (2019); Lavia et al. (2023).

This study recommended that where health effects were assessed, sensitivity analyses were undertaken on the assessments where there was uncertainty in the evidence, using a number of exposure-response functions. This would ensure that stakeholders have estimates that take into account uncertainties that could exist in the evidence base (e.g., estimating annoyance with SoNA 2014 and the WHO ERFs). Further work would also be needed to develop an agreed process for 'new evidence' being added to the assessment.

This study recommended that the health effects were assessed across a wide-range of exposures, including populations exposed to lower levels, for example, <50 dB $L_{Aeq,16h}$. The Airport could consider setting LOAEL and SOAEL values for use in assessing the health impacts of airspace change. These values could be informed by precedence and discussions with stakeholders. Exposure above the SOAEL value is typically linked to the provision of mitigation.

This study recommended the expansion of the health outcomes included in TAG, via a TAG+ approach. This would require a dialogue between the Airport and regulators and all stakeholders in relation to the use of additional health data in statutory evaluations. There would need to be discussion about whether thresholds would be placed on some health estimates to inform FED, as well as discussions about who was impacted and mitigation. Ultimately, health impacts are not fair or equitable and there needs to be agreement with stakeholders about how effects are avoided, minimised, and mitigated going forward. Discussions should take account of health, mental health, wellbeing and quality of life outcomes (s.3.5.5), including the impact of NAFs (s.3.6) and how these impacts might be managed to provide for outcomes that are perceived to be fairer (s.3.6.2).

4.3 Non-acoustic factors assessment to agree a definition of FED

This study recommended the application of the Sound, Noise and Health Conceptual Framework in Figure 3 (Torija et al., 2022, p.123) to *i* aid the development of a FED consultation (or co-creation) process with the wider communities around the Airport; and *ii* the development of an agreed definition of FED. Effective sound planning necessitates accurately assessing the human response to sound in context. This requires the identification of context specific NAFs (Lavia et al., 2021). The Framework (Figure 3) proposed the general stages required for assessing NAFs and operationalising the development of an agreed definition of FED of aircraft. An overview of these stages is set out below.

4.4 Recommended implementation stages of the Sound, Noise and Health Conceptual Framework

4.4.1 Framework stage 1

Stage 1 of the *Sound, Noise and Health Conceptual Framework* (Figure 3) sets out the categories of NAFs based on ISO 16755-1 (2025) of *personal, social, physical and situational factors (see s.3.6)* and proposes a stakeholder consultation to determine the local contextually relevant NAFs for agreeing a definition of FED.

4.4.2 Framework stage 2

During *Framework Stage 2*, based on the NAFs derived from the *Framework Stage 1* data collection and analysis, the selection of acoustic (including psychoacoustic and technology) options, health, and operational metrics are consulted and determined with stakeholders based on the ability of the metrics to fit the design principles reviewed in *Stage 1*. For example,:

- *Acoustic, Psychoacoustic and Technology Options*–measure the acoustic features and levels of airport operations and flights. These might include the use of a combination of acoustic (e.g., N_{xx}, L_{Amax}, L_{Aeq}) and psychoacoustic metrics (e.g., Zwicker Loudness based on ISO, 2017).
- *Health, Wellbeing and Amenity Metrics*–measure the direct and indirect health effects from noise. These might include a selection from the range of health metrics discussed in Section 3.5. The recommended Health Dashboard (s.4.2) would be inclusive of agreed metrics, including operational and procedural actions (e.g., route changes, planned respite, runway alternation, etc.). The Framework sets out the requirement for all agreed project specific metrics to be measurable (i.e., Figure 3, Stage 3). In this case, ERFs included in the Health Dashboard could be quantified with existing mechanisms used in TAG, e.g., Disability Adjusted Life Years (DALYs; see Nomenclature), in TAG+.
- *Operational Metrics*–measure all metrics, apart from acoustics, psychoacoustics, technology and health. For example, these might consist of a combination of the new Low Noise Arrivals Metric/ Continuous Descent Operation (CDO) (CAA, 2022) with a 3° descent angle, planned and predictable respite, runway alternation, and preferential landing slots for quieter aircraft, as summarised in Sections 3.2–3.4.
- However, there is no 'one size fits all' approach for the selection of metrics in this stage. The most important consideration is that the selection of metrics is determined based on their ability to mitigate effects of noise [e.g., from distributional effects (s.3.3) and perceived fairness (s.3.6.2) associated with ACP] and/or enhance desired sounds (e.g., by improving local environmental quality) in line with the results from *Framework Stage 1* (Figure 3).

4.4.3 Framework stage 3

Framework Stage 3 consists of agreeing the Performance Indicators, Incentives and Objectives for the agreed suite of parameters and how these will be monitored, reported, enforced and reviewed. Once again, it is crucial that this stage is reviewed in consultation/co-creation with stakeholders.

4.4.4 Framework stage 4

Framework Stage 4 links the agreed suite of metrics (*Stage 2*) and parameters (*Stage 3*) with an airport's Noise Action Planning process agreed in consultation/co-creation with stakeholders. Finally, it is recommended that *Stages 1, 2 and 3* are reviewed with stakeholders during each round of Noise Action Planning, to ensure that the NAFs (*Stage 1*) and all subsequent metrics (*Stage 2*) and parameters (*Stage 3*) remain relevant to the local environment and stakeholders.

5 Summary and further work

This paper presented a summary of the findings of an independent study (FED1) (Torija et al., 2022) on Fair and Equitable Distribution of aircraft in the UK. This study:

- Was the first study of its kind in the UK, to the best of the authors' knowledge, with the scope to 'Deliver an independent study to inform stakeholder discussions as a stage process during the development of potential [UK airspace proposals] for which the definition and quantification of [FED] of aircraft is useful.' (Torija et al., 2022, p.6; Figure 1).
- Was set the aim to 'develop a clear definition of FED of traffic that would enable airspace managers and aircraft operators to design solutions to deliver quicker, quieter and cleaner journeys and more capacity for the benefit of those who use and are affected by airspace in the UK' (Torija et al., 2022, p.2; Figure 1).
- Explored how, as summarised in the findings (s.3), the impact of locally salient NAFs on stakeholders, especially communities, significantly affects perceptions of fairness (s.3.6.2). Therefore, the authors proposed a *Sound, Noise and Health Conceptual Framework* (Figure 3) to be applied in order to operationalise the development of an agreed definition of FED of aircraft. Stages to guide the implementation of the *Sound, Noise and Health Conceptual Framework* (Figure 3) were set out in Section 4.4. The Framework:
    - ○ Proposed *a non-acoustic factors assessment protocol* as a preliminary stakeholder consultation stage to provide a baseline to inform the subsequent stage of identifying and agreeing design principles with stakeholders for FED of aircraft.
    - ○ Proposed a *Health Dashboard* incorporating combined environmental and health metrics to be agreed with local and national stakeholders for FED of aircraft.
    - ○ Proposed *combined acoustic and psychoacoustic metrics* for measuring and assessing different options of FED of aircraft, based on human perception of sound and noise in context and a perception-driven engineering approach (Davies, 2018).

In sum, the FED study provided a robust theoretical foundation for further studies to operationalise the definition of FED and carry out objective assessments of different airspace changes/aviation activities. As noted, the *Sound, Noise and Health Conceptual Framework* (Figure 3) and recommendations (s.4), were designed to enhance transparency by bringing community concerns to the forefront of the consultation process and thus, ideally, the decisions and outcomes. The Framework conceptualised a mixed-disciplinary acoustics, psychoacoustics, technology, health and NAFs approach (Figure 3, stages 1,2) to agreeing a definition of FED supported by agreed management, assessment, and enforcement criteria in the context of policy requirements (Figure 3, stages 3,4).

The authors proposed the Framework (Figure 3) was applied in real-world aviation planning/ACP consultation scenarios, supported by the technical feasibility of any resulting design options. Applying the recommendations of the FED1 study (Torija et al., 2022), the Airport commissioned the FED2 study (CAA, 2025d, p.5; Porter et al., 2024) which explored 'perceptions of (un)fairness, selected metrics, and the risk of socially un/acceptable outcomes from ACP processes'. Thereby, the importance of the FED1 study was demonstrated by the implementation of its recommendations (s.4) in the FED2 study.

Finally, the work presented in this paper posits important considerations for future air transport policy in the context of the forecast growth in conventional aviation transport (IATA, 2024), Advanced Air Mobility (AAM) (Alonso et al., 2024), and the impacts of sound and noise on health (Münzel et al., 2024; Clark et al., 2025). The FED study Framework (Figure 3) and recommendations (s.4) are applicable for operationalising definitions of FED for growing noise sources, for example, from unmanned aerial vehicles (UAVs), or drones, and electric vertical take-off and landing aircraft (eVTOL) (Torija, 2025; CAA, 2025c). Building on the outputs from this study given the multiple dimensions and impacts of NAFs, air traffic modes and local contexts (ICAO, 2025b), applying the *Sound, Noise and Health Conceptual Framework* (Figure 3) *and recommendations (s.4)* in subsequent studies using a variety of mixed-methodologies (e.g., CAA, 2025d) is important. It is necessary to develop the evidence base, harmonise findings, deepen understanding and conduct meta-analyses. And to inform future aviation noise and health research and evidence (EEA, 2025), human perception of sound and noise in context, technology and perception-driven engineering.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

LL: Conceptualization, Formal Analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review and editing. CC: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Visualization, Writing – review and editing. AT: Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Visualization, Writing – review and editing.

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Conflict of interest

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The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Nomenclature

AAM Advanced Air Mobility

ACP Airspace Change Process. The procedures and guidance set out by the CAA (2023) for the development, making and consideration of an airspace change proposal in the UK.

Air Traffic/Traffic "The aircraft, or the number of aircraft, flying in an area or along a route." (Cambridge Dictionary, 2025a). Unless otherwise stated, in this paper "traffic" refers to "air traffic".

AMS/ UK airspace Airspace Modernisation Strategy in the UK is co-sponsored by the DfT and the CAA to update its structural design, change how the systems on which it runs work, and use new technology to improve how air traffic is integrated and managed. (UK Government, 2024).

ANIMA Aviation Noise Impact Management through Novel Approaches (2024) is a comprehensive research project, funded by the European Union, which addresses the critical issue of aviation noise for Europe.

CAA Civil Aviation Authority in the UK

CAP [X] Civil Aviation Publications (e.g., CAP1378; CAP1616) issued by the CAA, conveying UK aviation advice and guidance.

DALY/s According to the WHO (2021), "The burden of disease calculated using the disability-adjusted life year (DALY). One DALY represents the loss of the equivalent of 1 year of full health due to disease or a health condition".

DfT Department for Transport in the UK

EIA Environmental Impact Assessment

ERF Exposure Response Function

Equitable "Treating everyone fairly and in the same way. Fair to all parties as dictated by reason and conscience" (Cambridge Dictionary, 2025b).

Fairness "The quality of treating people equally or in a way that is right or reasonable" (Cambridge Dictionary, 2025c).

FED Fair and Equitable Dispersion/Distribution is defined as the "dispersion of [airborne] pollutants [including noise] and denotes the movement and distribution patterns of contaminants throughout the environment." Yang et al., 2024, p.2; Schwab, 2020; Welsh Government, 2024, part 2). E.g., in this study dispersion refers to the pollutant (i.e., noise) and the spread of exposure in a fair and equitable manner, whereas distribution refers to aircraft. Unless otherwise stated, FED is used in relation to aircraft/air traffic/traffic (e.g., FED of aircraft/air traffic/traffic, or simply FED) (see also "air traffic/traffic").

FED1 An independent study, commissioned by a major airport in the UK and led by the University of Salford, UK with City St George's, University of London, UK and the Noise Abatement Society, UK aimed at developing a clear definition of the Airport's Fair and Equitable Distribution of traffic that would enable airspace managers and aircraft operators to design solutions to deliver quicker, quieter and cleaner journeys and more capacity for the benefit of those who use and are affected by national airspace (Torija et al., 2022).

FED2 An application of the recommendations (s.4) and further work (s.5) from the FED1 study in a subsequent project published by the CAA (2025d) as CAP2971 to "understand how airspace design options influence those features that impact perception of fairness and equity to inform more socially acceptable airspace modernisation" (Porter et al., 2024, p.4).

Health Defined in this paper according to the World Health Organization (WHO, 2020, p.1): "Health is a state of complete physical, mental and social wellbeing and not merely the absence of disease or infirmity".

HIA Health Impact Assessment

ICAO International Civil Aviation Organization

NAF/s Referred to in this study as non-acoustic factor/s, defined as "all those factors other than noise level alone which contribute to annoyance" (CAA, 2018, p.44). Post study a standardised definition of NAFs encompassing previous versions (consistent with the one used in this study) was published in ISO/TS 16755-1: 2025 (p.1) as "Specific factors, other than the objective, measured or modelled acoustic parameters, which influence the process of perceiving, experiencing, understanding and/or responding to an acoustic environment."

PBN Performance Based Navigation (ICAO, 2008)

Relief A break from or a reduction in aircraft noise exposure (Porter et al., 2016).

Respite A scheduled relief from aircraft noise for a given period of time (Porter et al., 2016).

TAG/+ Transport Analysis Guidance provides information on the role of transport modelling and appraisal in the UK (DfT, 2024b).

Vectoring When flights are directed to follow a specific compass heading to a particular altitude or way point rather than fly the conventional route as designed. This practice further increases the dispersion of flight paths (FAA, 2025).