Before an Independent Hearings Panel
appointed by Christchurch City Council

under:	the Resource Management Act 1991
in the matter of:	the hearing of submissions on Plan Change 14 (Housing and Business Choice) to the Christchurch District Plan
and:	**Christchurch International Airport Limited** Submitter 852

Statement of Evidence of Laurel Smith (acoustics)

Dated: 20 September 2023

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STATEMENT OF EVIDENCE OF LAUREL SMITH

1 My full name is Laurel Jean Smith.

2 I am a consultant in the acoustical consulting practice of Marshall Day Acoustics Limited (*Marshall Day*). I hold the degree of Bachelor of Engineering from Auckland University. For the past 20 years I have worked in the field of acoustics, noise measurement and control in New Zealand. My work has included noise control engineering work for various industries in New Zealand.

3 I have undertaken noise prediction and provided consulting advice on over eight airports in New Zealand. My work has involved noise calculations, computer modelling, noise boundary development, assessment of noise effects, recommending airport noise rules, development of sound insulation packages and noise monitoring.

4 Marshall Day has been engaged by Christchurch International Airport Limited (*CIAL*) since 1992 to advise on various noise issues including:

4.1 preparation of the original noise contours to form the basis of the airport noise provisions in the Canterbury Regional Policy Statement (*CRPS*) and the Christchurch, Waimakariri and Selwyn District Plans;

4.2 preparation of the 2023 remodelled noise contours; and

4.3 on a number of specific land use consent applications and plan changes.

CODE OF CONDUCT

5 Although this is not an Environment Court hearing, I note that in preparing my evidence I have reviewed the Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note 2023. I have complied with it in preparing my evidence on technical matters. I confirm that the technical matters on which I give evidence are within my area of expertise, except where relying on the opinion or evidence of other witnesses. I have not omitted to consider material facts known to me that might alter or detract from my opinions expressed.

SCOPE OF EVIDENCE

6 I have been asked to comment on the relief sought by CIAL in relation to the proposed Plan Change 14 (Housing and Business Choice) to the Christchurch District Plan (*PC14*).

7 My evidence will address:

7.1 Airport noise management in New Zealand and the approach in Christchurch.

7.2 The recent air noise contours remodelling process and the resulting 2023 Remodelled 50 dB L_{dn} Outer Envelope Air Noise Contour (*Remodelled Contour*).

7.3 A review of recent international research and understanding of the community response to aircraft noise.

7.4 The assessment of noise effects relating to the Remodelled Contour.

7.5 Overview of the potential increase in noise effects and comparison with the latest World Health Organisation (*WHO*) guideline values for consideration in the context of PC14.

SUMMARY AND CONCLUSIONS

8 For PC14, aircraft noise exposure was identified as a Qualifying Matter in relation to residential intensification on land affected by future aircraft noise of 50 dB L_{dn} or greater.

9 The Remodelled Contour (finalised in May 2023) provides a technically robust and up-to-date identification of the location of future aircraft noise exposure at and above 50 dB L_{dn}. It was assessed and calculated in the same manner as the 2008 Noise Contour with respect to the northwest approach.

10 At the time PC14 was notified the air noise contour remodelling process for Christchurch International Airport (*Christchurch Airport / CIA*) was ongoing. Now it has been completed, PC14 can be updated to reflect the most accurate technical information.

11 The current planning framework for CIA was developed generally in accordance with NZS 6805 "*Airport Noise Management and Land Use Planning*" (the *Standard*) and with consideration of the existing land uses and existing aircraft noise protection at the time. Applying a Qualifying Matter in PC14 to land within the 50 dB L_{dn} contour maintains this level of protection for the benefit of both the community and CIA.

12 Recent research shows that the prevalence of annoyance relative to aircraft noise exposure (L_{dn}) has been increasing. Internationally other noise metrics such as L_{night} and Number Above are also being considered when assessing and planning around aircraft noise.

13 The 2018 WHO guidelines present the most comprehensive, evidence-based recommendations on assessing aircraft noise effects. The guideline values are generally considered low and achieving these retrospectively is most likely unrealistic. Nonetheless the guideline values can be used to inform decisionmakers to balance community health, amenity, airport efficiency and a range of other planning, economic and environmental matters. In my view, the guidelines aspirational limits are particularly relevant when considering land use planning decisions relating to greenfield and urban intensification situations where there is the opportunity to proactively limit the scale of future noise impacts on a population.

14 Managing the effects of aircraft noise relies on a multidimensional approach and land use planning is a key component. The scale of aircraft noise effects on a population is directly related to the size of the population exposed. As outlined in the Assessment of Noise Effects attached to this evidence at **Appendix 1**, the current planning framework for Canterbury enables the affected population to increase such that annoyance effects could increase by 35 – 50%. Allowing more residential intensification in areas subject to aircraft noise of 50 dB L_{dn} or greater could increase this further.

15 The Canterbury region is in the fortunate position to have controlled residential growth in areas affected by aircraft noise at or above 50 dB L_{dn} and most of the land within the 50 dB L_{dn} contour is low density or non-noise sensitive use. From a noise management perspective, I recommend that this approach continues, and applies to areas within the Remodelled Contour, to limit the scale of future noise effects.

OVERVIEW OF AIRPORT NOISE MANAGEMENT AND LAND USE PLANNING – NEW ZEALAND STANDARD NZS 6805

16 The Standard is the basis for the management of airport noise effects at the majority of airports in New Zealand. The Standard was published in 1992 with a view to providing a consistent approach to noise planning around New Zealand airports. Since publication, the principles of the Standard have been applied to more than 15 New Zealand airports.

17 The approach to airport noise management that the Standard provides for is to "*implement practical land use planning controls and airport management techniques to protect and conserve the health of people living near airports without unduly restricting the operation of airports*."

18 The Standard states that it provides the minimum requirement needed to protect people from adverse effects of aircraft noise. It

proposes that a local authority may determine a higher level of protection is appropriate in a particular locality[1].

19 The Standard uses the "Noise Boundary" concept as a mechanism for local authorities to:

19.1 "*establish compatible land use planning*" around an airport; and

19.2 "*set noise limits for the management of aircraft noise at airports*".

20 The Standard's recommended approach involves fixing an Outer Control Boundary (*OCB*) and a smaller Air Noise Boundary (*ANB*) around the airport and defining land use and noise controls within the boundaries.

21 The noise boundaries are based on a 24-hour noise metric, commonly used to quantify transportation noise, which is the night-weighted noise exposure (L_{dn}). L_{dn} is the sum of the sound energy from all aircraft noise events averaged over 24 hours with a weighting applied to night-time events. The night weighting means that aircraft noise events between 10pm and 7am are weighted by an additional 10 decibels to account for the heightened sensitivity to noise at night. International research correlates the L_{dn} and the similar L_{den} metrics with community annoyance to aircraft and other transportation noise. The Standard does not recommend a noise limit for individual aircraft events however it does recommend that night-time single event noise levels are considered when setting the location of the ANB.

22 When establishing the location of the noise boundaries, the Standard recommends calculating noise contours for a future projection of aircraft operations. It recommends a minimum 10-year period for the projection and also recommends that current and future runway capacity is considered in the projection[2]. The Standard sets out a number of other factors to be considered when establishing the location of the boundaries, including variation in airport operations within a year (e.g. due to seasonal effects), and the Standard recommends using the average L_{dn} over the busiest three months of the year when calculating the noise boundaries[3].

23 The Standard defines the OCB as an area outside the ANB within which there should be no new incompatible land uses, and that aircraft noise at or outside the OCB shall not exceed 55 dB L_{dn}.

[1] NZS 6805:1992 Section 1.1.4

[2] Section 1.4.3.2 of NZS 6805:1992.

[3] Section 1.4.3.5 of NZS 6805:1992.

24 The ANB is defined as an area around an airport within which aircraft noise is sufficiently high to require mitigation measures as well as prohibiting new incompatible land uses. The Standard states that aircraft noise shall not exceed 65 dB L_{dn} at the ANB. When establishing the ANB, the Standard also recommends that noise from night-time operations is considered. This is because, in some situations, the ANB based on L_{dn} may not be large enough to protect against high single event levels at night causing sleep disturbance. The Standard does not provide limits of acceptability for sleep disturbance, however historically in New Zealand a threshold of 95 dB L_{AE} has been used for managing the effects of night-time aircraft events.

25 The Standard suggests the Federal Aviation Administration (*FAA*) Integrated Noise Model (*INM*) or other appropriate models for calculating the projected noise contours. The INM was replaced by the Aviation Environmental Design Tool (*AEDT*) in 2015. The AEDT is now the mandated software in the United States for FAA CFR[4] Part 150 studies, and in Australia for airport noise forecasts. In New Zealand there is no national statutory requirement for modelling software.

26 Once the location of the noise boundaries has been established and agreed, the Standard recommends that the local authority incorporate the noise boundaries into the relevant District Plan maps and gives effect to the recommended land use controls summarised below. The airport operator is responsible for managing noise from aircraft operations to comply with limits set at the noise boundaries.

27 The Standard recommends that local authorities implement the following land use restrictions:

27.1 Inside the ANB:

(a) New noise sensitive uses (including residential) should be prohibited; and

(b) Existing residential buildings and subsequent alterations should have appropriate sound insulation;

27.2 Between the ANB and the OCB:

(a) New noise sensitive uses (including residential) should be prohibited unless a District Plan permits such use subject to appropriate sound insulation; and

[4] Federal Aviation Administration Code of Federal Regulations

(b) Alterations or additions to existing noise sensitive uses (including residential) should include appropriate sound insulation.

28 The combination of noise limits defined at the boundaries and land use controls inside the boundaries work together to control the extent of future aircraft noise effects on sensitive activities, thereby protecting health and amenity values of the community and the efficient operation of the airport.

IMPLEMENTATION OF THE STANDARD AT NEW ZEALAND AIRPORTS

29 The Standard provides the minimum requirement needed to protect people from adverse effects of aircraft noise. It states that a local authority may determine that a higher level of protection is appropriate in a particular locality. Throughout New Zealand the Standard has been adapted to suit the local situation taking account of the specific airport operational requirements and existing surrounding land uses. This has resulted in a range of varying noise boundaries and related rules. Few New Zealand airports have provisions that reflect the Standard precisely.

30 Whenever the Standard has been implemented throughout the country, the existing land use within the noise boundaries has influenced the application of airport noise land use controls. For example, it is easier for a local authority with an airport surrounded by non-noise sensitive land use to apply development constraints to maintain a high degree of protection for the community and the airport compared with an urban airport that is already surrounded by established residential zones. Landowners' expectations of established property rights and a higher demand for housing dictate less restrictive development controls in the urban situation. This is generally what has transpired throughout New Zealand as I will explain further.

31 In Canterbury, the Councils and CIAL have effectively maintained an area of low density or non-sensitive land use around the airport by implementing appropriate land use planning over many years including a policy of avoiding new noise sensitive activities within the 50 dB L_{dn} Air Noise Contour for CIA.

32 This is not the situation at many other New Zealand airports. In the cases of Auckland and Wellington, for example, the local authorities implemented more permissive land use planning rules during the adoption of the Standard into their district plans. This is because, in most cases, residential encroachment close to those airports had already occurred before the Standard arrived in 1992.

33 Wellington is the most significant example of this. It only has a 65 dB L_{dn} ANB within which new sensitive uses are classified as restricted discretionary and subject to acoustic insulation standards. Outside the ANB there are no controls on development. The residential neighbourhoods surrounding Wellington Airport were already well established in 1992. Wellington Airport operates according to a curfew from midnight to 6am for domestic flights and international departures, and from 1am to 6am for international arrivals.

34 Auckland is an example where the current and future shortage of residential land (and level of pre-existing development) in the Manukau area made a more rigorous approach to the OCB unfeasible. Development between the 60 to 65 dB L_{dn} contours is permitted subject to sound insulation and density controls. Development within the 65 dB L_{dn} contour is prohibited. There are no controls on development outside the 60 dB L_{dn} contour.

35 Queenstown adopted a more protective approach in its District Plan compared to Auckland. New residential development in rural zones is prohibited inside the 55 dB L_{dn} contour whereas the development rules in established residential zones are more permissive. This is an example of maintaining the existing land use and densities where feasible.

APPROACH AT CHRISTCHURCH INTERNATIONAL AIRPORT

36 My colleague, **Mr Christopher Day**, explains the historical approach to managing airport noise in Canterbury in greater detail including implementation of the Standard.

37 The noise management framework for CIA is based on the Standard and, like many New Zealand airports, it has been adapted rather than being implemented precisely. Like other airports, the existing land uses around CIA has influenced the degree of protection that was feasible when implemented. Furthermore, the CIA surrounds were already protected in the Waimairi section of the Christchurch District Transitional Plan using a 50 dB airport noise contour.

38 Marshall Day was engaged in 1993, together with a series of airport planning experts, to develop noise contours for CIA based on the approach in the Standard. In 2008 the noise boundaries were updated and referenced in the CRPS and subsequently implemented in the Selwyn, Waimakariri and Christchurch District Plans.

39 The future projected noise boundaries for CIA have been updated in 2023 and I will discuss this later in evidence. However, for this section I will describe the 2008 Noise Contours and the related operative rules in the planning framework.

40 Three airport noise boundaries are defined for CIA. The three noise boundaries are:

40.1 **Air Noise Boundary** defined by the outer extent of the projected 65 dB L_{dn} and 95 dB L_{AE} contours;

40.2 **55 dB L_{dn} Air Noise Contour;** and

40.3 **50 dB L_{dn} Air Noise Contour.**

41 The main departure from the Standard is the addition of the 50 dB L_{dn} air noise contour. The land use controls inside the 55 dB contour and the ANB reflect the minimum requirements from the Standard and function as the OCB and ANB in the that context. I will now describe how the 50 dB L_{dn} contour applies for land use management in Canterbury.

42 The CRPS Map A shows the 2008 50 dB L_{dn} Noise Contour. The CRPS policy 6.3.5 requires that the Waimakariri, Selwyn and Christchurch City District Plans include objectives, policies and rules to avoid noise sensitive activities within the 50 dB L_{dn} air noise contour for CIA with some specific exceptions. This applies to all land inside the 50 dB contour, including inside the 55 dB contour and the ANB. Accordingly, each District Plan includes the noise boundaries listed above and associated policies and land use controls.

43 Although the CRPS requires that new noise sensitive activities are avoided inside the 50 dB L_{dn} air noise contour, this does not mean they are prohibited. Rather, the District Plans give effect to policy 6.3.5 by including an avoidance policy[5] and maintaining existing zone densities within the 50 dB L_{dn} air noise contour. Within the 55 dB L_{dn} air noise contour, new noise sensitive activities are also subject to acoustic insulation standards. Within the Air Noise Boundary new noise sensitive activities are prohibited[6].

44 In summary, new noise sensitive activities are permitted in accordance with the zone rules existing at the time the 2008 Noise Contours were implemented in the planning framework, provided they are outside the ANB and comply with the acoustic insulation standards inside the 55 dB L_{dn} air noise contour.

45 In practice the avoidance policy that applies to land within the 50 dB contour has meant maintaining the existing land use and zone densities but selectively allowing intensification where other factors deem it necessary (e.g. the exceptions in Kaiapoi). There is a large

[5] CCC Policy 17.2.2.10, SDC Policy B2.1.28, WDC Policy 14.3.1.1.

[6] The ANB is located in the Christchurch District Plan only. Rule 6.1.7.1.6 prohibits new sensitive activities inside the ANB.

area of existing low density land use within the 2008 50 dB L_{dn} Noise Contour. The avoidance policy allows the authorities to take a measured approach to development in airport noise affected areas and promotes retaining the existing land use in order to preserve health and amenity values and protect efficient airport operations.

46 With respect to airport noise controls, CIA is located within Christchurch City; therefore the rules controlling noise from airport activities are included in the Christchurch District Plan only. In addition to the 65 dB L_{dn} noise limit for aircraft operations, there is a suite of rules related to managing and monitoring noise from all airport activities including engine testing. CIA has one of the more comprehensive airport noise management frameworks in New Zealand including an acoustic mitigation programme, annual reporting, noise monitoring and a community liaison committee.

CHRISTCHURCH INTERNATIONAL AIRPORT AIR NOISE CONTOUR REMODELLING

47 CIAL has undertaken a remodelling process to update the CIA Air Noise Contours which are used to manage aircraft noise and land use for the protection of community health and amenity.

48 Marshall Day was part of the CIAL expert team that prepared the updated air noise contours which were finalised in May 2023. The inputs, assumptions and methodologies used to produce two sets of updated contours are set out in the report '*2023 Updated Christchurch International Airport Noise Contours*' (*2023 Updated Contours Report*). In summary:

48.1 The updated contours were calculated on a future projection of aircraft activity based on the ultimate runway capacity for CIA including future runway extensions signalled in the airport's Master Plan.

48.2 The aircraft types in the future projection included current and anticipated future fleet based on available information at the time.

48.3 The updated contours were calculated in using AEDT version 3e software, the most contemporary software available at the time.

48.4 The flight track assumptions were derived from a rigorous analysis of recent radar data and advice from Airways Corporation NZ regarding likely future airspace management.

48.5 Two sets of updated noise contours were modelled based on two different approaches to runway utilisation (12 month or three month average usage). The two sets of contours are:

(a) **Outer Envelope** This approach takes account of the worst case 3-month runway usage for each runway by calculating four separate scenarios and taking the outer extent of these contours.

(b) **Annual Average** This approach avoids the variation in 3-month wind patterns by applying the annual average runway usage.

49 The technical modelling methodology and assumptions for both sets of updated contours have been endorsed by an independent peer review panel of experts appointed by Environment Canterbury as set out in the report '*Christchurch Airport Remodelled Contour Independent Expert Panel Report'*.

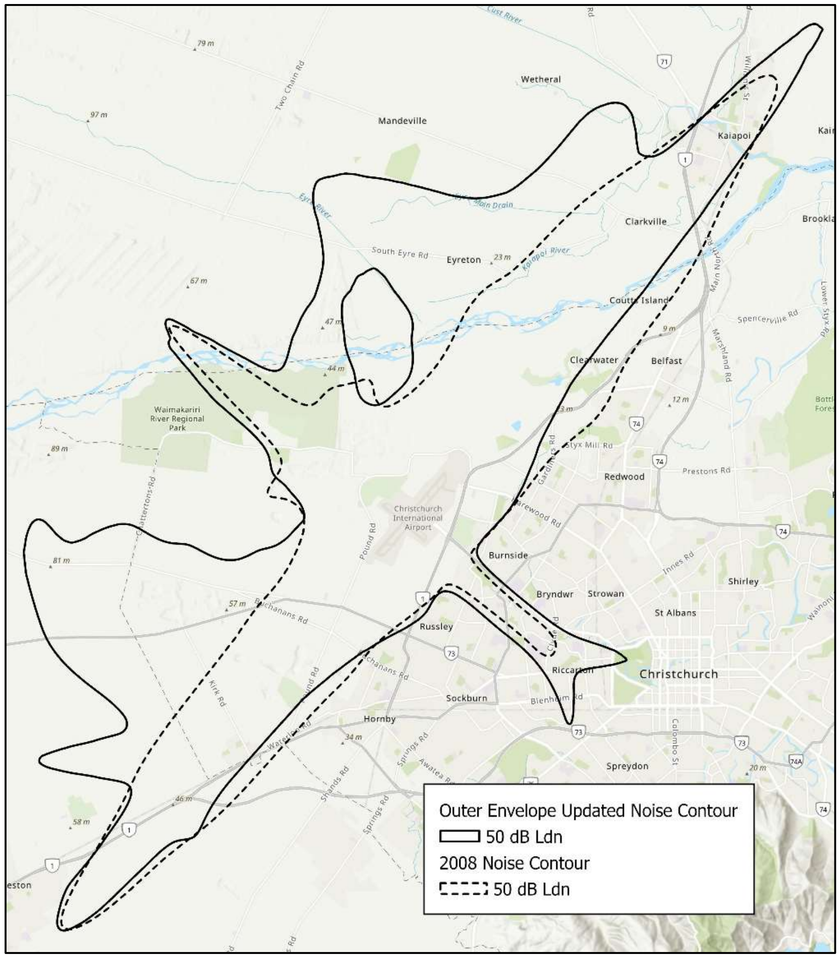
Updated Contours

50 As discussed, the 2023 Updated Contours Report provides two updated noise contour options for replacing the 2008 Noise Contours in the planning framework.

51 Which option will replace the 2008 Noise Contours is yet to be determined. The CIAL expert team and ECan's expert peer review panel were not tasked with making a recommendation as this is a planning matter that requires consideration of many factors outside the expertise of acoustic and aviation consultants.

52 For Christchurch City, the Outer Envelope option provides the most like-for-like replacement of the 2008 Noise Contours in terms of modelling approach and therefore aligns with the operative planning framework. The Outer Envelope and 2008 Noise contours are shown in Figure 1 below.

Figure 1: 2008 Noise Contour and Outer Envelope Updated Noise Contour



53 The current airport noise management framework, including the 2008 Noise Contours, controls noise from aircraft operations generally in accordance with the recommendations in the Standard. The Standard recommends that noise boundaries are based on the L_{dn} noise exposure averaged over three months or an alternative period as agreed by the airport operator and local authority.

54 The existing airport noise and land use framework for Christchurch City applies the three-month averaging period approach in two significant ways:

54.1 Noise from aircraft operations over the busiest three-month period is limited to 65 dB L_{dn} at the corresponding 65 dB contour mapped in the plan (Rule 6.1.6.2.5 (a)(i));

54.2 The 2008 Noise Contours were modelled to include the three-month seasonal noise exposure for the area of the contours extending southeast towards the city centre (i.e. for aircraft movements using the cross-wind runway[7]).

55 The area of the air noise contours associated with crosswind runway movements (i.e. the northwest approach), is particularly sensitive to the averaging as this runway is used more intensively during a three-month period when north westerly winds are more prevalent. Both the 2008 Noise Contours and the Outer Envelope Updated Contours take account of this seasonal increased activity in the modelling methodology, whereas the Annual Average Updated Contours do not.

56 The Outer Envelope 50 dB L_{dn} Updated Contour is more expansive than the 2008 50 dB L_{dn} Noise Contour over Christchurch City (refer Figure 1). The reasons for the change are described further in the 2023 Updated Contours Report (Volume 1 Executive Summary and Volume 5 pp 8, 9). In summary the difference in shape and size is due to a range of factors including:

56.1 Ultimate runway capacity forecast resulted in greater number of aircraft movements;

56.2 Greater proportion of wide body aircraft movements which are noisier than narrow body aircraft (although not all wide body aircraft can use the crosswind runway);

56.3 Crosswind runway usage is slightly greater due to detailed analysis of historical data and allowance for climate change;

56.4 Flight track changes including Required Navigational Performance (*RNP*) arrival tracks which influence the fishtail shape of the contour.

CIAL RELIEF SOUGHT

57 For PC14, aircraft noise exposure was identified as a Qualifying Matter in relation to residential intensification. The Qualifying Matter applies to land affected by future aircraft noise of 50 dB L_{dn} or greater. At the time PC14 was notified, the remodelling process was ongoing. The remodelling has now been completed and PC14 can be updated to reflect the most accurate technical information.

58 CIAL submitted the Remodelled Contour (the May 2023 Outer Envelope Contour (50 dB L_{dn})) to apply as the Airport Noise Influence Area Qualifying Matter notified in PC14. The notified Airport Noise Influence Area Qualifying Matter was based on the

[7] The 2008 Noise Contour was modelled using a 12 month averaging period for the main runway however for compliance purposes, a three-month averaging period applies.

draft Annual Average 50 dB L_{dn} contour prepared in 2021 by CIAL's expert team prior to the peer review process.

59 Through the peer review process, the modelling assumptions and inputs have been improved and both the Outer Envelope and Annual Average Contours have been recalculated. The draft 2021 contours have been superseded and should be replaced by the recalculated peer reviewed May 2023 contours.

60 In the context of the aircraft noise exposure Qualifying Matter for PC14, the Remodelled Contour provides technically robust and up-to-date identification of the location of future aircraft noise exposure above 50 dB L_{dn}. It was assessed in the same manner as the 2008 Noise Contours with respect to the northwest approach (refer paragraphs **52** – **56**).

61 In the following sections of evidence, I will present information that supports applying a Qualifying Matter in relation to residential intensification on land affected by future aircraft noise of 50 dB L_{dn} or greater.

COMMUNITY RESPONSE TO AIRCRAFT NOISE – UPDATED RESEARCH

62 Marshall Day recently undertook a review of available literature on community response to aircraft noise. This report is appended to my evidence at **Appendix 2**, and I will summarise the main conclusions below. I also note that my colleague, Mr Christopher Day, has also outlined a number of overseas studies that investigate community response to noise.

63 The literature review found research relating aircraft noise exposure to a range of effects including annoyance, sleep disturbance, cognitive impairment, and heart disease. Most studies relate to annoyance and sleep disturbance, and Marshall Day concentrated on these effects.

64 Recent literature on annoyance shows that annoyance levels have increased markedly compared with earlier research 20 years ago. The two largest studies conducted recently were the WHO[8] study in 2018 and FAA study in the USA in 2021.

65 The WHO 2018 noise guidelines recommend a limit for aircraft noise of 45 dB L_{dn} as the research indicates almost 10% of the population are highly annoyed at this level. This is 10 dB more stringent than the recommendations of the Standard which recommends prohibiting noise sensitive development within 55 dB L_{dn}.

[8] WHO European Region

66 Table 1 below is taken from the 2018 WHO guidelines and shows the predicted annoyance (% people highly annoyed) relative to aircraft noise exposure.

Table 1: 2018 WHO Guidelines Annoyance Response for Aircraft Noise

L_{den} (dB)	%HA
40	1.2
45	9.4
50	17.9
55	26.7
60	36.0
65	45.5
70	55.5

67 Applying this relationship to the CIA noise contours, we could expect 18 - 27% of people exposed to 50 - 55 dB L_{dn} to be highly annoyed. This increases to 27 - 46% between 55 and 65 dB L_{dn}.

68 The literature Marshall Day reviewed found there have been many sleep disturbance studies and dose response relationships developed over the last 30 years using a range of different metrics both indoors and outdoors. However, there is currently not an accepted approach in the literature to accurately assess the effects of aircraft noise on sleep disturbance. More research in this area is needed to determine a meaningful relationship and assessment methodology.

69 There are generally two types of approach using either energy equivalent metrics (i.e. average noise levels at night) or single event metrics.

70 The energy equivalent metric L_{night} is used in Europe to map night noise impacts from transportation sources including airports. The 2009 WHO Night Noise Guidelines set 40 dB L_{night} as an ideal target to avoid adverse sleep disturbance effects from aircraft and 55 dB L_{night} as a pragmatic interim target to avoid serious health effects from night-time noise where the lower target was not feasible in the short term. The 2018 WHO Guidelines just recommends a limit of 40 dB L_{night} to avoid adverse sleep disturbance effects from aircraft based on a predicted 11% of people being highly sleep disturbed at this level.

71 Table 2, taken from the 2018 WHO guidelines, shows the predicted percentage of people highly sleep disturbed (%HSD) at various L_{night} levels.

Table 2: 2018 WHO Guidelines Sleep Disturbance for Aircraft Noise

L_{night}	%HSD	95% CI
40	11.3	4.72–17.81
45	15.0	6.95–23.08
50	19.7	9.87–29.60
55	25.5	13.57–37.41
60	32.3	18.15–46.36
65	40.0	23.65–56.05

72 In Australia, Number Above contours using single event level of 60 dB L_{Amax} are used to understand night noise effects around airports although there are no mandated thresholds of acceptability.

73 In summary the 2018 WHO guidelines present the most comprehensive, evidence-based recommendations on assessing aircraft noise effects. Although further research is continuing, and many authors have reviewed and critiqued the 2018 WHO guidelines.

74 WHO published a report this year evaluating the uptake of the 2018 guidelines in the European region. Feedback from member states was that the consistent evidence-based methods for assessing noise effects are useful and being applied. But with respect to implementing noise limits aligned with the guidelines, the general feedback was that the recommended noise levels are unattainably low and that interim thresholds are needed.

75 Our literature review has guided my assessment of noise effects for the Outer Envelope Updated Noise Contours which I discuss next.

ASSESSMENT OF NOISE EFFECTS – OUTER ENVELOPE UPDATED CONTOUR

76 I have prepared an Assessment of Noise Effects (*ANE*) for the Remodelled Contour which is appended to this evidence at **Appendix 1**.

77 The ANE considers the impact of changes to the two factors influencing the scale of future aircraft noise effects on the surrounding population:

77.1 Change in aircraft noise planning environment (Remodelled Contour).

77.2 Change in the receiving environment (i.e. growth in residential activity enabled by operative land use controls).

78 I have assessed the change in the aircraft noise planning environment by comparing the scale of aircraft noise effects for the Remodelled Contour with the 2008 Noise Contours in the context of the existing housing stock.

79 I have assessed the change in the receiving environment by comparing the scale of aircraft noise effects for the existing housing stock with that for a potential future housing stock. The future housing stock is based on the maximum residential development enabled by the existing planning framework. For this analysis, I assumed the operative land use controls applying inside the 2008 Noise Contours as of March 2022, would also apply inside the Remodelled Contour.

80 I used four different methodologies to quantify the effects.

80.1 Number of houses inside L_{dn} contours;

80.2 Number of people highly annoyed using the 2018 WHO curve;

80.3 Number of existing houses with 5 dB L_{dn} or more increase due to the Remodelled Contours; and

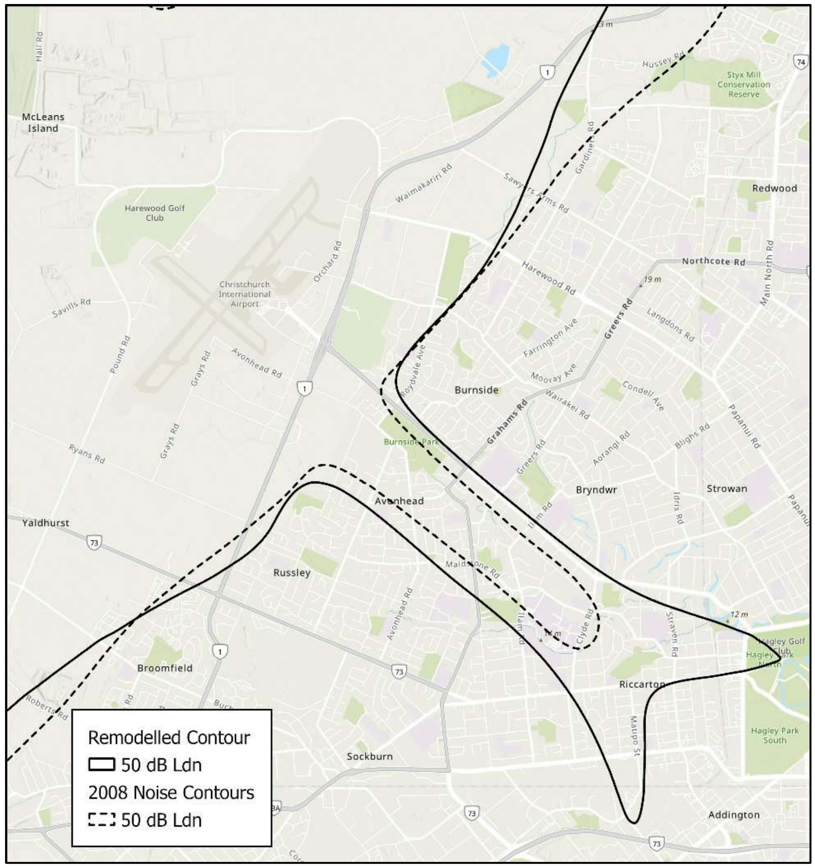
80.4 Number of people exposed to aircraft events above 70 dB L_{Amax}.

81 Night noise has also been considered by mapping night noise contours as recommended in the 2009 and 2018 WHO guidelines.

82 Since the Remodelled Contour represents the busiest three months for each runway direction, I have assessed the noise effects separately for each of the four busiest three-month scenarios. Further explanation on the four runway bias scenarios for the Remodelled Contour is in Appendix E of the ANE.

83 For PC14, the most relevant of these is the runway 29 bias scenario which includes the peak crosswind runway use during north westerly winds. In these wind conditions, arriving aircraft overfly urban areas in Christchurch and this scenario represents the busiest three-month period for noise impacts on Christchurch City. The figure below shows the spatial difference between the 2008 and Remodelled Contours.

Figure 3: 2008 Noise Contour and Remodelled Contour

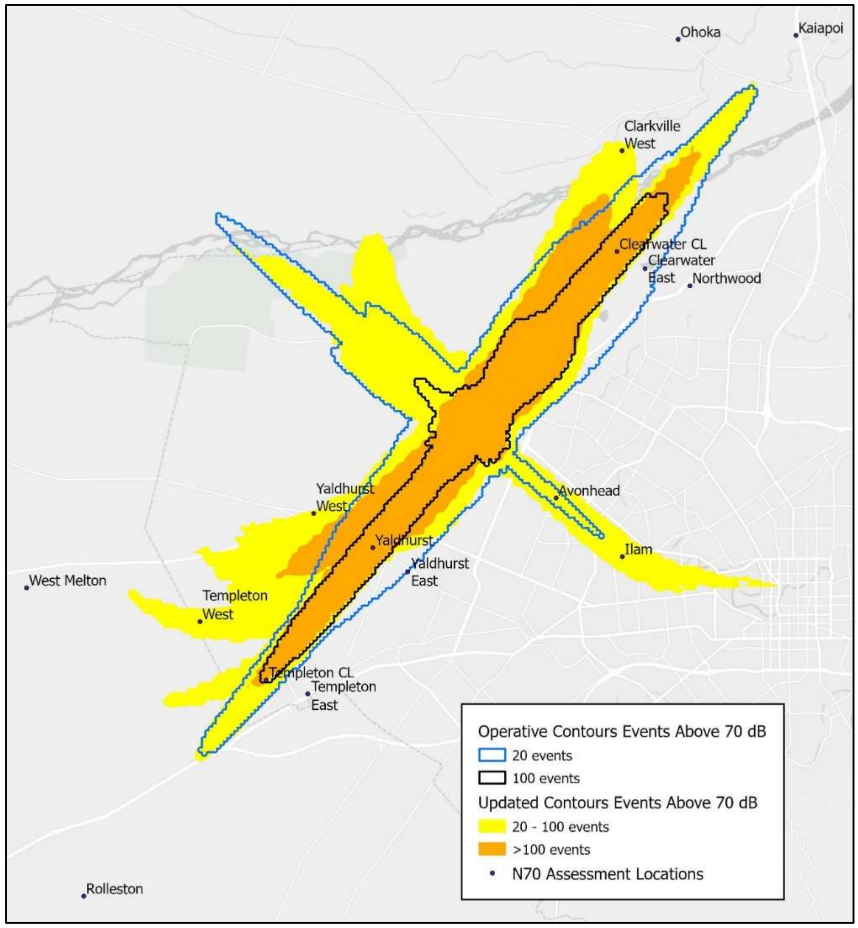


84 My assessment of the change in noise effects for the existing housing stock shows that, for the runway 29 bias scenario, there is a considerable increase in number of houses and people highly annoyed compared with the 2008 Noise Contours (20% and 24% respectively). Also, the number of people exposed to 10 or more aircraft events of 70 dB L_{Amax} or greater would increase by 70% compared with the 2008 Noise Contours. The Number Above 70 dB L_{Amax} metric (N70) is explained in section 6.5 of the ANE.

85 The change in N70 is demonstrated in Figure 4. For the Remodelled Contour, the shaded yellow area represents areas affected by 20 to 100 loud events[9] on average per day and the orange shaded contour represents more than 100 such events. The corresponding extent of this effect for the 2008 Noise Contours is shown as blue and black lines on the map. The extent of the 20 to 100 event area over Christchurch City is appreciably larger for the Remodelled Contour.

[9] Aircraft events being greater or equal to 70 dB L_{Amax} outdoors.

Figure 4: Change in N70 Contours – Number of Events above 70 dB L_{Amax}

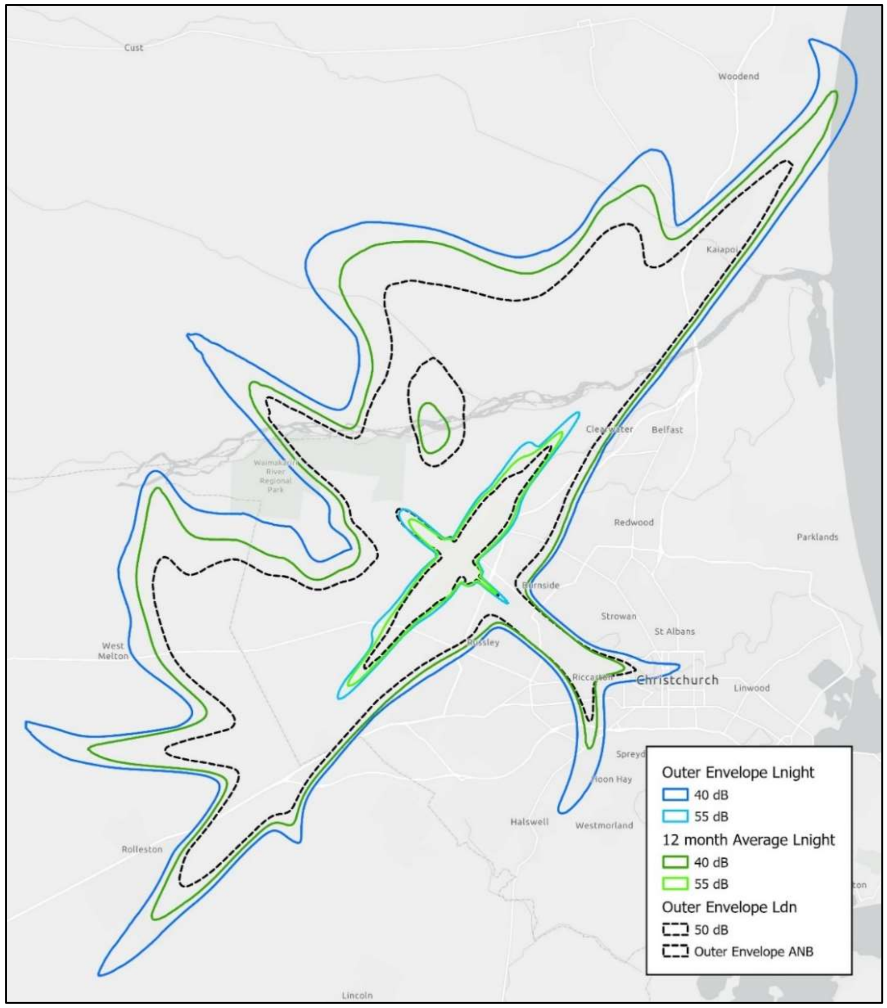


86 In the ANE report I have mapped the L_{night} contours for reference against the WHO guidelines for sleep disturbance effects. This is shown in Figure 5 below.

87 As previously discussed, the 2009 WHO Night Noise Guidelines set 40 dB L_{night} as an ideal target to avoid adverse sleep disturbance effects from aircraft and 55 dB L_{night} as a pragmatic interim target. The 2018 WHO guidelines rely on research that suggests 11% of the population are highly sleep disturbed (HSD) by aircraft noise at 40 dB L_{night}. The same relationship predicts 26% HSD at 55 dB L_{night}.

88 The guidelines refer to L_{night} as the 12-month average which I expect is due to the availability of 12-month average data through the European Environmental Noise Directive (END). Given the seasonal variability of operations at CIA, I have also mapped the Outer Envelope 3-month L_{night} for information.

Figure 5: Night Noise Contours and Remodelled Contour



89 The figure shows that both the 12-month and 3-month 40 dB L_{night} contours extend beyond the Remodelled Contour proposed by CIA as a Qualifying Matter for PC14.

90 The 40 dB L_{night} target defined by WHO is generally considered to be aspirational. I agree that in most situations it is not practicable to achieve this target. However, the PC14 Qualifying Matter relates to considering whether residential **intensification** inside areas affected by aircraft noise is appropriate.

91 From a noise effects perspective, consideration of the L_{night} contours in this context is prudent. Decision makers must balance the benefits of residential intensification against the consequential noise effects and an understanding of aspirational targets is appropriate.

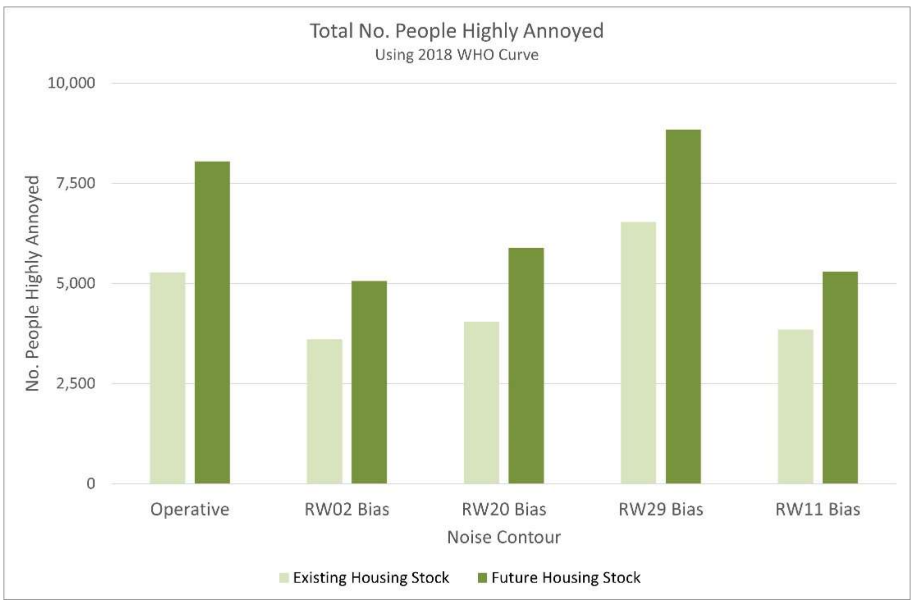
92 From a noise effects basis, the L_{night} contours support the case for applying a Qualifying Matter relating to residential intensification inside the Remodelled Contour.

93 For the ANE I assessed noise effects for the existing housing stock resulting from a change in aircraft noise, and I also considered the impacts resulting from a change in the receiving environment, relating to increased residential activity currently permitted in aircraft noise affected areas.

94 I carried out the same four method analysis as for the existing housing stock but using a hypothetical future housing stock which represents the theoretical residential capacity within the air noise contours based on the operative density controls.

95 This analysis suggests the currently permitted growth in residential activity, would result in a 35 - 50% increase in scale of noise impacts compared with the current population. Figure 6 below from the ANE shows the predicted number of people highly annoyed for the existing housing stock compared with the future housing stock.

Figure 6: Number of People Highly Annoyed Summary



96 This demonstrates the scale of noise impacts is heavily influenced by population density. It also shows the current planning framework allows an appreciable increase in affected population. This analysis emphasises that land use planning is a major contributor to the future scale of aircraft noise impacts.

97 For PC14, the runway 29 bias scenario is most relevant. Table 3 below taken from the ANE shows that for the runway 29 bias

scenario, if the operative permitted residential capacity is realised, this would result in a 35% increase in people highly annoyed.

Table 3: Increase in aircraft noise effects due to change in receiving environment

Noise Contour Scenario		# Houses	People HA	PEI (10^{-6})
2008		+57%	+53%	+52%
Updated	02 Bias	+41%	+40%	+52%
	20 Bias	+46%	+45%	+63%
	29 Bias	+37%	+35%	+36%
	11 Bias	+39%	+37%	+45%

98 If greater residential intensification is enabled inside the airport noise contours, the scale of airport noise effects on the surrounding population could increase even more significantly.

99 In summary, for the runway 29 bias scenario, the Remodelled Contour results in a 24% increase in aircraft noise annoyance effects compared with the 2008 Noise Contours. For the same scenario, the currently permitted residential density enables a 35% increase in aircraft noise annoyance effects compared with the current population. Enabling greater intensification could increase this further.

Laurel Smith

20 September 2023

APPENDIX 1 CHRISTCHURCH AIRPORT RECONTOURING ASSESSMENT OF NOISE EFFECTS

MARSHALL DAY Acoustics

CHRISTCHURCH AIRPORT RECONTOURING ASSESSMENT OF NOISE EFFECTS

Outer Envelope Updated Contours

Report No.005 | 20 September 2023

Project:	**CHRISTCHURCH AIRPORT RECONTOURING** **Assessment of Noise Effects – Outer Envelope Updated Contours**
Prepared for:	**Christchurch International Airport Limited** **PO Box 14001** **Christchurch Airport** **Christchurch 8544**
Attention:	**Christchurch Airport Environment and Planning Manager**
Report No.:	**Report No.005**

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1 INTRODUCTION

The Canterbury Regional Policy Statement (CRPS) and the three District Plans [1]contain the Christchurch International Airport Noise Contours that were produced in 2008 (the 2008 Noise Contours). The purpose of these contours is twofold – to apply land-use planning around Christchurch International Airport (CIA / the Airport) to avoid the effects of aircraft noise on future noise sensitive users and to set a 'noise envelope' for the airport to remain within. This process is explained in detail in the New Zealand Standard NZS 6805:1992 "*Airport Noise Management and Land Use Planning*" (**NZS6805**) and summarised in Appendix A of this report.

The 2008 Noise Contours were finalised following extensive interaction within an 'Expert Panel'. The Expert Panel was made up of experts in aviation forecasting, operational procedures (including flight tracks) and noise modelling. The basic premise behind the contours was that they were to be based on CIA operating at its 'long-term future capacity' and with future operational procedures.

The Expert Panel Report recommended that the 2008 Noise Contours (and the aviation assumptions they were based on) be updated in 10 years' time, which aligns with the general philosophy of updating District Plans every 10 years.

In 2018 Christchurch International Airport Limited (CIAL) began the process to update the 2008 Noise Contours. Airbiz and Marshall Day Acoustics (MDA) were engaged to prepare updated noise contours, with input from Airways New Zealand (Airways) and CIAL, for inclusion in the CRPS and District Plans. The new noise contours are referred to throughout this report as the "Updated Noise Contours". The details of this process are contained in a combined report by Airbiz, MDA, CIAL and Chapman Trip titled "*2023 Updated Christchurch International Airport Contours*" (the Update Report).

The outcome of the Update Report is that several input parameters for the Updated Noise Contours are different to those used in the 2008 Noise Contours. The resultant Updated Noise Contours are a different shape - being larger in some areas and smaller in others.

The purpose of this report is to provide an assessment of noise effects associated with:

1. The change in the future anticipated aircraft noise environment; and
2. The potential future change to the receiving environment.

Four different methodologies have been used to assess the effects. We've assessed the change to the future anticipated aircraft noise environment by comparing the 2008 Noise Contours with the Updated Noise Contours. We also examined the change to future receiving environment by comparing the numbers of existing houses in the noise contours with the potential future housing stock assuming maximum potential growth under the planning framework. Night noise effects have also been considered by mapping night noise contours.

To summarise our findings, the Updated Noise Contours generally represent a moderate increase in aircraft noise effects compared with the 2008 Noise Contours. For the worst-case usage of the cross-runway in the Updated Noise Contours, the increase in noise effects for urban Christchurch City is considerable. However, this is tempered by it being a short-term impact during seasonal north westerly wind conditions which is balanced by lesser effects during other times of the year.

Our analysis of the change in receiving environment shows that the potential increase in aircraft noise effects resulting from growth in residential activity currently permitted inside the Airport Noise Contours, is substantial and somewhat greater than the increase in effects due to the change in aircraft noise. If the land use controls applying inside the Airport Noise Contours (as of March 2022)

[1] Christchurch District Plan, Waimakariri District Plan, Selwyn District Plan

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were relaxed, the scale of airport noise effects on the surrounding population could increase even more significantly.

2 UPDATED NOISE CONTOURS – OUTER ENVELOPE

Details of the process and inputs to developing the Updated Noise Contours are contained in the Update Report. The Updated Noise Contours presented in this report are the Outer Envelope version which is explained further below. A brief summary of the modelling assumptions and a figure showing the 2008 and Updated Noise Contours is provided in Appendix C.

CIA effectively has four operational runways, two on the main runway and two on the shorter crosswind runway as follows:

- Runway 02 where aircraft land and take-off into a northerly wind.
- Runway 20 where aircraft land and take-off into a southerly wind.
- Runway 29 where aircraft land and take-off into a north-westerly wind.
- Runway 11 where aircraft land and take-off into a south-easterly wind.

Generally, each of these runways will be utilised when the wind is coming from the given direction. The runway usage in any given three-month period will vary significantly. For example, during the summer there are often periods when the north-westerly wind is dominant for several days (necessitating higher than normal usage of the north-west runway 29). The extent of this effect varies from year to year.

Aircraft need to be allocated to each runway in the noise modelling and there are two options for how runway usage is modelled in the Updated Noise Contours:

- The Outer Envelope future noise contour (composite of three month worst case runway usage for four wind directions)
- The Annual Average future noise contour (annual average runway usage)

NZS 6805 recommends that noise contours are based on noise over a three-month period (or such other period as agreed)[2].

The 2008 Noise Contours were based on a highest three month usage of runways 29 and 11 and an annual average usage of runways 02 and 20.

The Outer Envelope is a composite of four scenarios which represent the highest runway usage on each runway over a three-month period. We refer to these as the four **runway bias scenarios**. The highest runway usage is determined from a review of historic runway usage at CIA. The outer extent of these four noise contours overlaid, is taken to form the final Outer Envelope noise contour used for planning purposes.

These four scenarios would never occur simultaneously – they would occur in different three-month periods. This report therefore focuses on an assessment of the noise effects under each of these four individual runway bias scenarios separately. A detailed explanation of the four different runway biases is included as Appendix E.

[2] Clause 1.4.1.2 - New Zealand Standard NZS 6805:1992 "Airport Noise Management and Land Use Planning"

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3 ASSESSMENT OF NOISE EFFECTS - METHODOLOGY

Appropriate management of airport noise effects is a two-pronged approach involving aircraft noise management and land use management[3]. The scale of future noise effects is influenced by changes in both.

The Updated Noise Contours represent a change in the **aircraft noise planning environment** which we have assessed in this report by comparing with the 2008 Noise Contours.

We have also considered the impact of future changes to the **receiving environment** which is determined by land use planning controls. For this assessment, we have quantified the potential change in effects due to future growth of residential activity inside the Airport Noise Contours. This analysis is based on a hypothetical Future Housing Stock calculated to be the maximum residential development permitted under the operative District Plan land use controls.

The existing aircraft noise planning environment is the level of aircraft noise permitted and anticipated in the various operative District Plans and is defined by the 2008 Noise Contours. Replacing these with the Updated Noise Contours would result in changes to the permitted and anticipated aircraft noise levels in many areas. The purpose of our assessment is to quantify and describe these changes and their associated noise effects.

To quantify the change, we have used noise contours and Geographic Information System (GIS) software to calculate the change in noise at each existing residential property within the Airport Noise Contours. Then we have used this data to quantify and describe the change for the existing population overall.

The methods we have used to quantify and assess the change in noise environment by comparing the 2008 and Updated Noise Contours are:

1. Difference in number of houses within the contours;
2. Difference in number of people potentially highly annoyed;
3. Difference in future L_{dn} noise level – houses affected by a noticeable change;
4. Difference in number of people experiencing aircraft noise events above 70 dB L_{Amax}.

As well as considering what changes the Updated Contours mean for the existing housing stock, we have also quantified the potential change in effects due to future growth of residential activity inside the noise contours. The purpose of the Future Housing Stock analysis is to demonstrate the impact that changes to the receiving environment (i.e. land use planning) have on future outcomes.

In addition to the four methods listed above we have calculated night noise contours to demonstrate the extent of night-time aircraft noise and potential sleep disturbance effects.

3.1 Methodology - Existing and future housing stock assumptions

As described above, we have considered two different housing layers in our assessment. These are:

1. **Existing Housing Stock** - derived from Canterbury Maps Rating Units database[4];
2. **Future Housing Stock** - based on an estimate of the maximum residential development permitted under the existing planning framework[5].

[3] Refer to NZS 6805 summary in Appendix A and ICAO Balanced Approach summary in Appendix F

[4] Last updated 24 September 2021

[5] Operative in March 2022

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The Existing Housing Stock layer was derived using the ‘Rating units’ database from Canterbury Maps. The rating units layer contains information on land use and we simply removed rating units that are not residential related land use.

The Future Housing Stock layer was derived by calculating a theoretical maximum number of residential units permitted on land where residential activity is enabled in the various district plans. This is essentially the residential capacity around the Airport that may develop over time as properties are subdivided and the density of noise sensitive activities increases. Details of how the potential additional growth was calculated and the limitation of the analysis is provided in Appendix D.

For the Future Housing Stock analysis, we have assumed that the operative land use controls that applied inside the 2008 Noise Contours as of March 2022, would also apply inside the Updated Noise Contours. We have not made any assumptions about potential changes to the density controls occurring after March 2022.

Throughout this report the Existing and Future Housing Stock data has been used in our analysis. For the number of people highly annoyed analysis, the ‘sample area’ of properties was the outer extent of the 50 dB L_{dn} contours from the 2008 and Updated Noise Contours. We have assumed 2.5 persons per household when calculating the number of people affected. This number is from Statistics New Zealand Census data which provides an average number of people per household in Christchurch.

3.2 Method 1 - Difference in houses inside the contours

Replacing the 2008 Noise Contours with the Updated Noise Contours would mean a change in the number of existing houses included in the contours. This is a simple method to describe the change in planning environment for the Existing Housing Stock due to the Updated Noise Contours.

We have also calculated the potential future houses in each contour band using the Future Housing Stock to quantify the future impact resulting from changes to the receiving environment.

3.3 Method 2 - Difference in community annoyance

Over the last 40 years, a number of studies have been carried out in an attempt to determine the general relationship between aircraft noise and community annoyance. Most of these studies examine the relationship between annoyance and the day/night level (L_{dn}), or the day/evening/night level (L_{den}) as these metrics are shown to correlate well with annoyance.

L_{dn} is the metric recommended in NZS 6805:1992 to be used for defining aircraft noise contours and hence is the metric that defines the Airport’s noise contours. L_{dn} represents the cumulative noise energy (or noise exposure) over 24 hours with a 10-decibel penalty added to any night flights between 10pm and 7am. It is generally calculated over a three month or annual period which represents the long-term noise exposure. It takes into account both the number of aircraft noise events and the loudness of each event and is a measure of noise exposure.

The day/evening/night level (L_{den}) is similar to L_{dn} and applies a smaller weighting to noise during the evening period usually defined as 7pm – 11pm. For aircraft operations, L_{den} is usually only marginally higher than L_{dn} (0.6 dB). For simplicity we treat L_{dn} and L_{den} as being equivalent in this assessment.

The results of noise annoyance studies are normally plotted as a dose response curve – i.e. a graph of the number of people who report being ‘Highly Annoyed’ versus the noise level they experience (see Figure 1 below).

An early study carried out by Schultz in 1978 included various forms of transportation noise. In 2001 a comprehensive amalgamation of various airport noise studies was carried out by Miedema and

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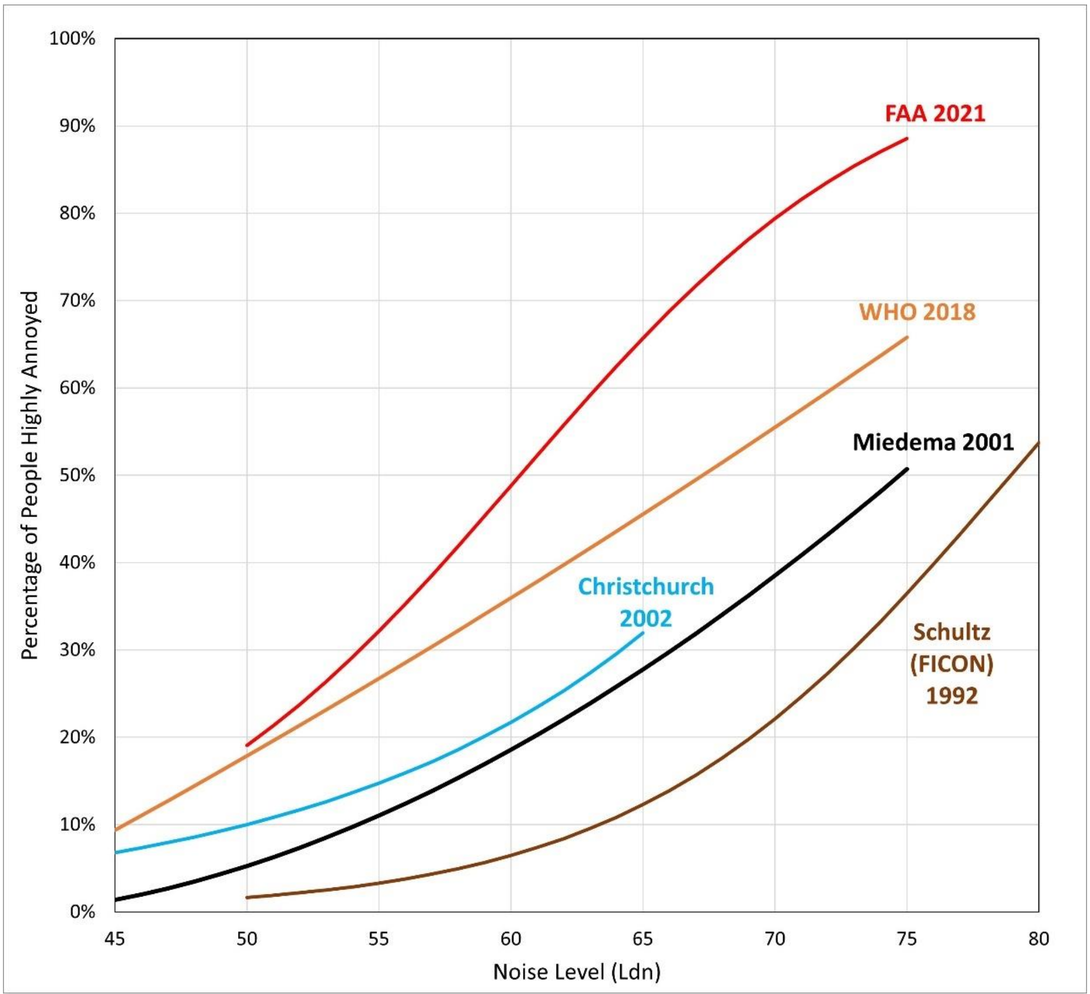
Oudshoorn[6]. This study produced a dose-response curve that has been used widely for many years (Figure 1).

Marshall Day Acoustics has recently carried out a literature review of the more recent studies into community annoyance due to aircraft noise. Our detailed literature review is presented in a separate report "*Christchurch Airport – Community Response to Aircraft Noise Literature Review*" dated 14 September 2023. In summary, the two most significant studies were by the World Health Organisation (WHO)[7] in 2018 which included 12 airports from around the world and the Federal Aviation Administration (FAA)[8] in 2021 which included 20 airports in the USA. Figure 1 compares a range of annoyance relationships using the L_{dn} metric (where L_{den} is taken to be equivalent to L_{dn}).

Figure 1: Community response to aircraft noise



The comparison in Figure 1 shows there is an appreciable variation between the curves making it difficult to predict the actual annoyance outcome with certainty. The general conclusion from Figure 1 is that community annoyance due to aircraft noise increases with noise level exposure (as expected), and overall has increased over time.

6 Miedema and Oudshoorn (2001); "Annoyance from Transportation Noise: Relationships with Exposure Metrics DNL and DENL and Their Confidence Intervals"

7 World Health Organisation (2018). Environmental noise guidelines for the European Region.

8 U.S Department of Transportation (FAA). (2021). *Analysis of the Neighbourhood Environmental Survey.*

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The dose-response relationships discussed above can be used to estimate the number of people likely to be highly annoyed at various levels of aircraft noise. For example, at 55 dB L_{dn}, 27% of the population are likely to be highly annoyed using the WHO curve.

Our assessment of effects, calculates the number of people in Christchurch predicted to be highly annoyed using the 2018 WHO curve for both the 2008 and Updated Noise Contours. We have calculated this for each of the four runway bias scenarios that make up the Updated Noise Contours and for both the Existing and Future Housing Stock.

To determine these numbers the Aviation Environmental Design Tool (AEDT) was used to calculate L_{dn} contours in 1 dB increments and then GIS software was used to count the number of houses within each 1 dB noise band (L_{dn}). The number of people in each band was then multiplied by the annoyance level from the WHO curve to give an overall number of people annoyed under each noise contour scenario. The sample area analysed is the 50 dB L_{dn} contour for the 2008 and Updated Noise Contours.

3.4 Method 3 - Difference in Ldn noise level

Replacing the 2008 Noise Contours with the Updated Noise Contours will mean a change in future aircraft noise at many properties. For some houses the future noise level would increase compared to the existing planning environment, and for others it would decrease.

The subjective response to a change in noise level is widely variable from individual to individual, and also varies for a change that occurs immediately compared with a change that occurs slowly over many years.

However, the following general response to an immediate change in noise is typical:

- An increase in noise level of 10 dB sounds subjectively about 'twice as loud';
- A change in noise level of 5 to 8 dB is regarded as noticeable;
- A change in noise level of 3 to 4 dB is just detectable;
- A change in noise level of 1 to 2 dB is not discernible.

Our assessment concentrates on existing houses impacted by a noticeable change of +/-5 dB L_{dn} or more between the 2008 and Updated Noise Contours. We have calculated this for each of the four runway bias scenarios that make up the Updated Noise Contours.

The change in L_{dn} level is most relevant to the Existing Housing Stock and has little relevance to the Future Housing Stock. Therefore, we have not completed this analysis for the Future Housing Stock.

This assessment is somewhat theoretical as residents do not currently experience the future aircraft noise level defined by the 2008 Contours and the future aircraft noise level defined by the Updated Contours would occur gradually over time. This means the change in noise would not be experienced the same as an immediate or short-term change. However, it is a method we can use to quantify the change in aircraft noise planning environment, using the subjective response to short-term changes to describe the severity of the difference.

3.5 Method 4 - Difference in houses exposed to aircraft noise events above 70 dB

In Australia, a noise effects assessment concept known as 'Number Above'[9] is used to describe the impacts that residents living near aircraft flight paths will experience in practice. The concept is simply based on the number of aircraft noise events that people experience. The Australian study states that the 'Number Above' concept is not meant to replace the noise exposure analysis, but rather to be used in conjunction with that analysis to assist with the communication of noise effects

[9] "Expanding Ways to Describe and Assess Aircraft Noise" Transport and Regional Services, Australia

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to the public. It is proposed that residents can more easily relate to a number of noise events experienced than a noise level expressed in dB L_{dn}.

The authors of the concept[10] submit that an aircraft is 'registered as a noise event' by receivers when it exceeds an external noise level of 70 dB L_{Amax}. Thus, for any one receiver, a noise event of 90 dB L_{Amax} is counted the same as an event of 71 dB L_{Amax}. Events below 70 dB L_{Amax} are not considered to be disruptive or particularly noticeable and therefore are not counted.

Using aircraft noise modelling software, it is possible to calculate the 'number of events above' 70 dB L_{Amax} at any given location for a given airport operations scenario. It is also possible to produce N70 contours to indicate where, for example, 20 aircraft events per day are experienced. This is referred to as an N70,20 contour.

We have calculated the N70 contours for the aircraft operations scenarios used in 2008 and Updated Noise Contours and used this data to calculate:

- The difference in number of events at representative locations surrounding the Airport;
- The number of people predicted to experience more than 10 events above 70 dB;
- The Person Event Index for 2008 and Updated Noise Contours.

We note the operating scenarios used for the N70 contours are an average day of aircraft operations. This means that inside an N70,10 contour, on average residents would experience 10 or more events over 70 dB L_{Amax} but on any given day this number could be greater or smaller.

We have also completed this analysis for both the Existing and Future Housing Stock.

3.6 Method 5 - Sleep disturbance effects

In our detailed literature review presented in a separate report "*Christchurch Airport – Community Response to Aircraft Noise Literature Review*" dated 14 September 2023, we found that there have been many sleep disturbance studies and dose response relationships developed over the last 30 years using a range of different metrics both indoors and outdoors. However, there is currently not an accepted approach in the literature to accurately assess the effects of aircraft noise on sleep disturbance. More research in this area is needed to determine a meaningful relationship and assessment methodology. In the meantime, we recommend that consideration of both equivalent exposure and single event levels would be appropriate.

The L_{dn} metric accounts for night-time noise with a 10 dB penalty between 10pm and 7am and in many cases the 65 dB L_{dn} contour sufficiently represents the extent of serious night noise effects. However, this is not always the case depending on particular airport operating scenarios. NZS 6805 recommends that individual event noise levels are also considered when setting the location of an ANB. For this reason, the existing noise management framework for CIA includes the 95 dB L_{AE} contour for single events at night as part of the ANB. The Updated Contours also include the relevant 95 dB L_{AE} contours as part of the ANB. This has been a common approach in New Zealand for protection against high single event noise from aircraft at night.

In addition to considering L_{dn} and L_{AE} metrics, we have calculated contours for night-time aircraft operations using the equivalent exposure level over the night-time period only (L_{night}). L_{night} is the equivalent noise exposure over a minimum eight-hour night-time period averaged over 12 months. For our calculations we have used the nine-hour night-time period from 10pm to 7am.

The L_{night} metric has been adopted by the European Union Environmental Noise Directive (END) which requires member states to regularly map L_{den} and L_{night} contours and quantify the number of people affected. The 2018 WHO Guidelines recommends a limit of 40 dB L_{night} to **avoid** adverse sleep

[10] David Southgate, Rob Aked, Nick Fisher and Greg Rhynehart

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disturbance effects from aircraft. An earlier recommendation in the WHO Night Noise Guidelines for Europe 2009 recognised 40 dB L_{night} as an aspirational target that may be difficult to achieve in practice. The 2009 guidelines defined a pragmatic interim target of 55 dB L_{night} to avoid serious health effects from night-time noise where the lower target was not feasible in the short term.

As concluded in our community response literature review, the energy equivalent metrics such as L_{night} are generally insensitive to sleep disturbance effects, however L_{night} is easily quantified and provides a broad overall understanding of sleep disturbance relative to the WHO guideline values. As such, we have mapped 40 and 55 dB L_{night} for the Updated Contours using both the busy three month outer envelope and 12 month average night time operations.

4 ASSESSMENT OF NOISE EFFECTS - RESULTS

4.1 Results 1 – Difference in number of houses inside the contours

Replacing the 2008 Noise Contours with the Updated Noise Contours would mean a change in the number of houses inside the contours. We have quantified the number of houses in noise level bands (i.e. 50 – 54 dB L_{dn} and so on) for the 2008 Contours and each of the four runway bias scenarios making up the Updated Contours.

Table 1 lists the results for the Existing Housing Stock and Table 2 lists the results for the Future Housing Stock.

Table 1: Number of houses in 2008 and Updated Noise Contours – Existing Housing Stock

	Number of Houses (Existing Housing Stock)				
L_{dn} Band	2008	Updated RW02 Bias	Updated RW20 Bias	Updated RW29 Bias	Updated RW11 Bias
50 – 54	8,188	5,874	6,768	9,392	6,067
55 – 59	1,236	571	418	1,738	747
60 – 64	90	100	105	277	100
>=65	18	29	29	24	28
Total	9,528	6,574	7,334	11,431	6,942

Table 2: Number of houses in 2008 and Updated Noise Contours – Future Housing Stock

	Number of Houses (Future Housing Stock)				
L_{dn} Band	2008	Updated RW02 Bias	Updated RW20 Bias	Updated RW29 Bias	Updated RW11 Bias
50 – 54	13,274	8,221	9,832	13,157	8,383
55 – 59	1,513	912	715	2,226	1,079
60 – 64	138	132	147	296	134
>65	18	29	29	24	28
Total	14,943	9,294	10,723	15,703	9,624

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To summarise the impact of the four runway bias scenarios in Table 1 compared with the 2008 Contours:

- Runway 02, 20 and 11 bias scenarios include fewer existing houses overall but have slightly more houses in the higher noise bands (>60 dB L_{dn}) compared with the 2008 Contours.
- Runway 29 bias scenario includes 20% more existing houses than the 2008 Contours. Runway 29 is used in north westerly wind conditions requiring aircraft to overfly the urban areas of Christchurch City meaning it naturally impacts more houses. For the Updated Contours we have used the historical worst-case three-month usage of runway 29 which is 14%, whereas the annual average usage is 5%. Because of the seasonal nature of the north westerly winds, this greater scale of impact is short term and balanced by less impact during the rest of the year.

The main runway (02 – 20) is used on average 95% of the time. Therefore, the runway 02 and runway 20 bias scenarios are most representative of the impact the majority of the time. For the Existing Housing Stock, these scenarios show a moderate increase in the number of houses affected by 60 dB L_{dn} or greater and an appreciable reduction in houses affected by 50 – 59 dB L_{dn}.

Table 1 shows that the number of existing houses impacted by the 65 dB L_{dn} contour will increase above the 18 currently affected by the 2008 Contours. The total number of existing houses within 65 dB L_{dn} for the Updated Contours is 29 however the analysis is based on the rating units by land parcel data rather than actual dwelling location, therefore 29 is an indicative number at this stage. We recommend that a detailed review is carried out to determine the location of existing dwellings within the Updated Contours 65 dB L_{dn}. CIAL administers an acoustic treatment programme to retrofit acoustic treatment to houses inside the operative 65 dB L_{dn} contour as recommended in NZS 6805. For existing dwellings exposed to greater than 70 dB L_{dn}, NZS 6805 recommends that consideration is given to purchasing these houses.

Comparing Table 1 and Table 2 we can see that the impact of the potential change in receiving environment (i.e. additional housing) would have a greater impact on the number of houses affected by aircraft noise than the change in aircraft noise planning environment would (i.e. the Updated Noise Contours).

The change in receiving environment is based on the assumption that the permitted density and subdivision controls that applied within the 2008 Noise Contours in March 2022 would also apply within the Updated Noise Contours. Any loosening of the current land use controls inside the airport noise contours would result in an even greater increase in affected residents.

4.2 Results 2 – Difference in number of people highly annoyed

The results above show the number of houses under the different scenarios without taking into account the difference in annoyance at the different noise levels. This section uses those house counts and the noise levels to calculate the number of people potentially highly annoyed for the 2008 Contours and each of the Updated Contours runway bias scenarios using the WHO 2018 dose-response curve. The methodology is described in Section 3.3. Table 3 shows the results for both the Existing Housing Stock and the Future Housing Stock.

Table 3: Number of people highly annoyed under the WHO curve

	2008	Runway 02 Bias	Runway 20 Bias	Runway 29 Bias	Runway 11 Bias
Existing housing stock	5,277	3,609	4,053	6,535	3,851
Future housing stock	8,050	5,063	5,897	8,843	5,295

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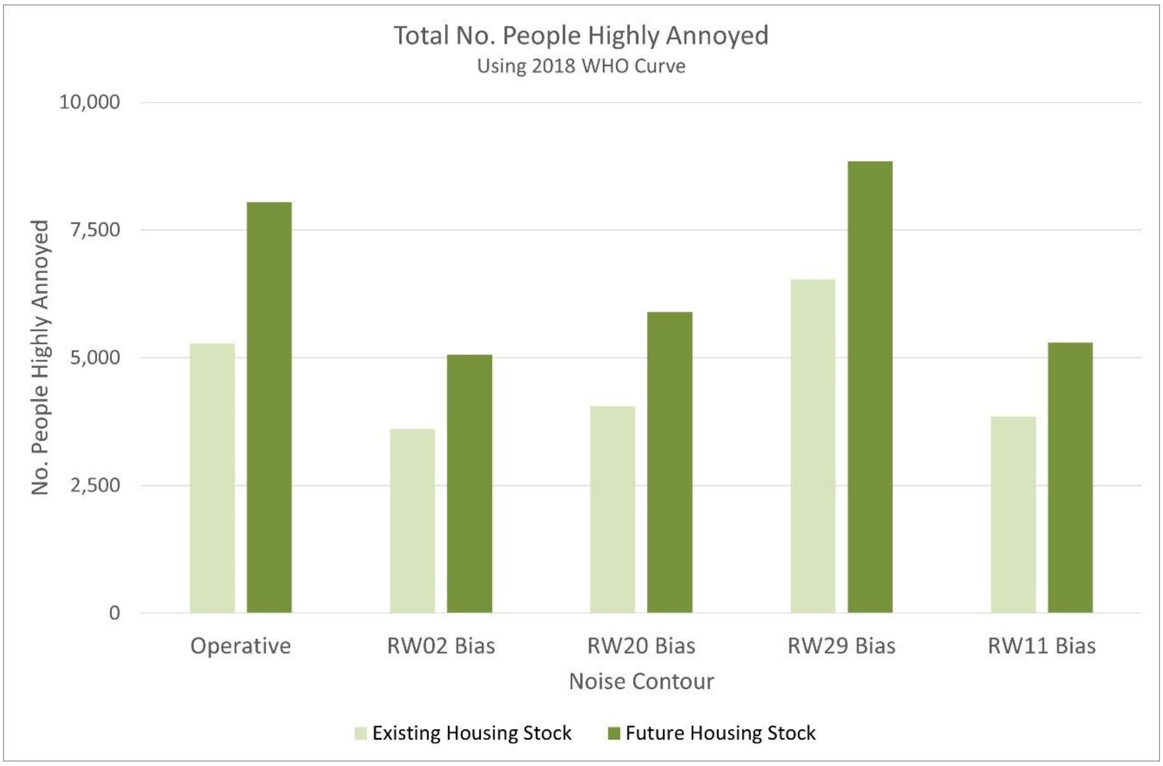
For the Existing Housing Stock, the number of people potentially highly annoyed for the runway 02, 20 and 11 bias scenarios would be fewer than for the 2008 Noise Contours, while the runway 29 bias scenario show a moderate increase.

The potential growth in residential development inside the airport noise contours presents a far greater increase in people potentially highly annoyed. There is a potential 35 - 50% increase in people highly annoyed should the currently permitted development density be realised. This data is also represented graphically in Figure 2.

Figure 2: Number of people highly annoyed 2008 and Updated Noise Contours using WHO Curve



Using an annoyance dose response relationship is useful for comparison purposes to evaluate the relative impacts of various scenarios. However as discussed in Section 3.3, there are various different annoyance curves available to use and it is difficult to predict the actual outcome with certainty. We have used the WHO 2018 curve which predicts approximately three times as many people being highly annoyed as the Miedema 2001 curve, which has historically been used in New Zealand.

4.3 Results 3 – Difference in Ldn noise level

Replacing the 2008 Noise Contours with the Updated Noise Contours would mean a change in the future anticipated L_{dn} noise level at properties surrounding the Airport. For some properties the difference is an increase and for others it is a decrease in aircraft noise.

An indicative map of the difference in noise level at properties within the Airport Noise Contours is shown in Figure 3. The map shows that larger increases occur in areas near West Melton and Mandeville between 50 and 55 dB L_{dn} for the Updated Contours. These areas are not inside the 2008 Contours but are in the Updated Contours due to changes in airspace management that have occurred since the 2008 Contours were developed in 2008.

To further understand the scale of the change across the population, we have counted the number of existing houses impacted by a noticeable change of +/-5 decibels or more. In our view, the significance of a change also depends on the absolute noise level, for example a 5 decibel increase from 45 to 50 dB L_{dn} is not as serious as an increase from 65 to 70 dB L_{dn}. Therefore, we've presented the results in L_{dn} contour bands.

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Table 4 below shows the number of houses in each contour band for the four runway bias scenarios where the anticipated increase is 5 dB L_{dn} or more.

Table 4: Number of existing houses with L_{dn} increase of 5 dB or greater

L_{dn} Band	RW02 Bias	RW20 Bias	RW29 Bias	RW11 Bias
50 – 54	383	384	2,187	359
55 – 59	28	35	19	25
60 – 64	0	22	1	0
>65	0	0	0	0
Total Houses with a 5 dB or greater increase in L_{dn}	411	441	2,207	384
Total Houses with a 5 dB or greater decrease in L_{dn}	448	1,761	532	471

Table 4 shows that the majority of houses affected by a noticeable increase is in the lower noise contour bands. The runway 29 bias scenario has the most houses affected by an increase particularly in the 50 to 54 dB L_{dn} bracket. The number of houses affected when the cross-runway is used is considerably greater than for the main runway because aircraft overfly the more populated urban areas of Christchurch. This is a short-term seasonal impact during north westerly wind conditions.

The last row in Table 4 lists the number of houses with a 5 dB or greater decrease in L_{dn} compared with the 2008 Noise Contours. The runway 20 bias scenario shows the largest number of houses with a decrease as this scenario does not include many movements on the cross-runway (11-29) reducing the impact on populated urban Christchurch.

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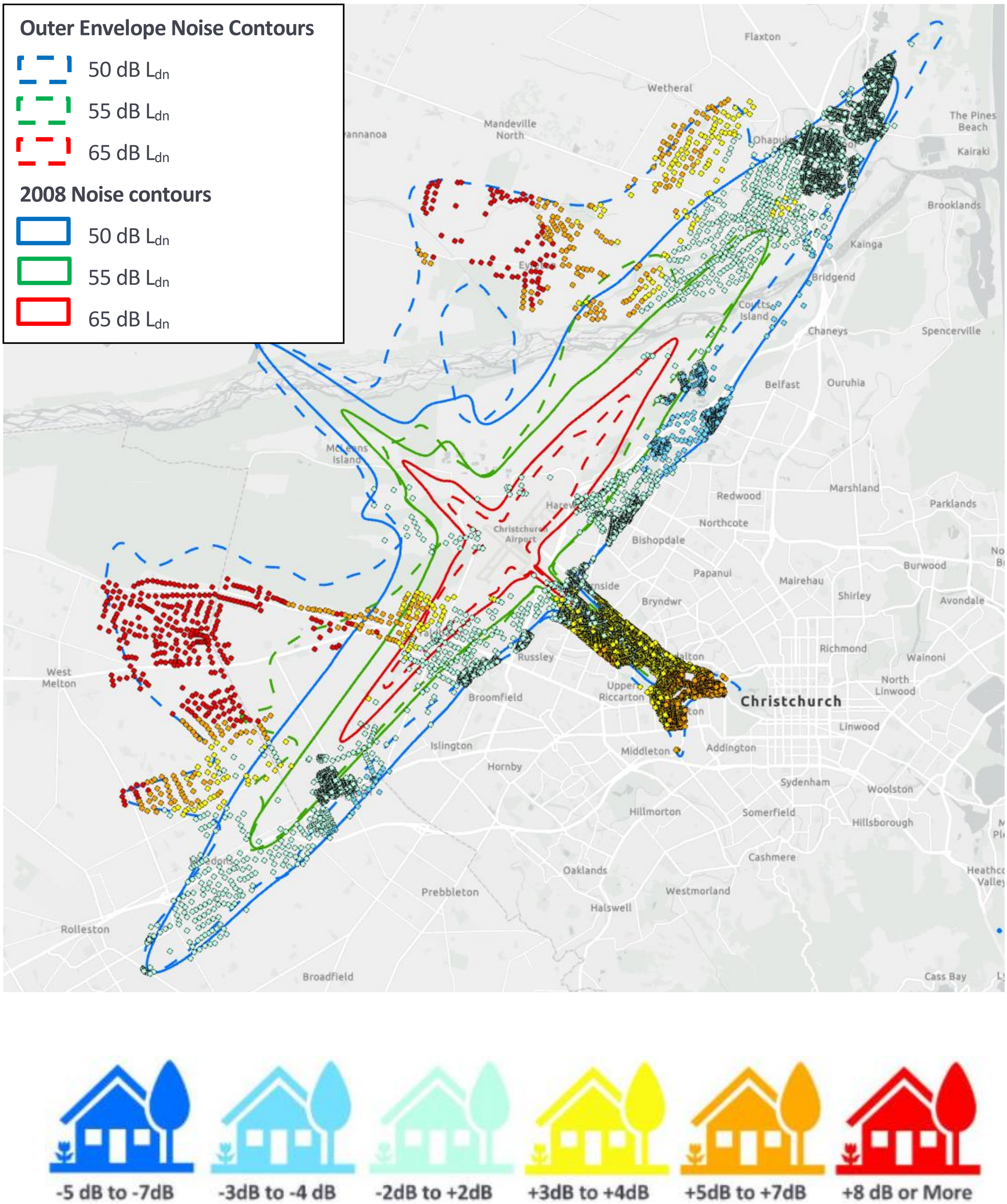
Figure 3: Difference in modelled airport noise level at each dwelling (relative to the 2008 Contours)

Note: This diagram is indicative only. The points are based on existing rating units in zones where residential activity may occur.



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4.4 Results 4 - Number of noise events above 70 dB

As discussed earlier, the N70 or 'Number Above' concept is aimed at identifying potential noise effects based on the number of aircraft noise events that people experience. The concept looks at the number of events above a specified noise level – L_{Amax} 70 dB, which is termed N70. Aircraft events above this level are considered to be noticeable whereas events below this level are treated as not particularly noticeable or disruptive and are not counted.

We have used N70 in three ways – Methods 4a, 4b and 4c.

4.4.1 Results 4a - Number of noise events above 70 dB experienced at representative locations

This method examines 16 representative locations and calculates the number of noise events experienced under the 2008 Contours and under the Updated Contours. Figure 4 below shows the 16 locations along with N70 contours for the 2008 and Updated Contours.

Figure 4: N70 contours and receiver locations for 'number above' analysis

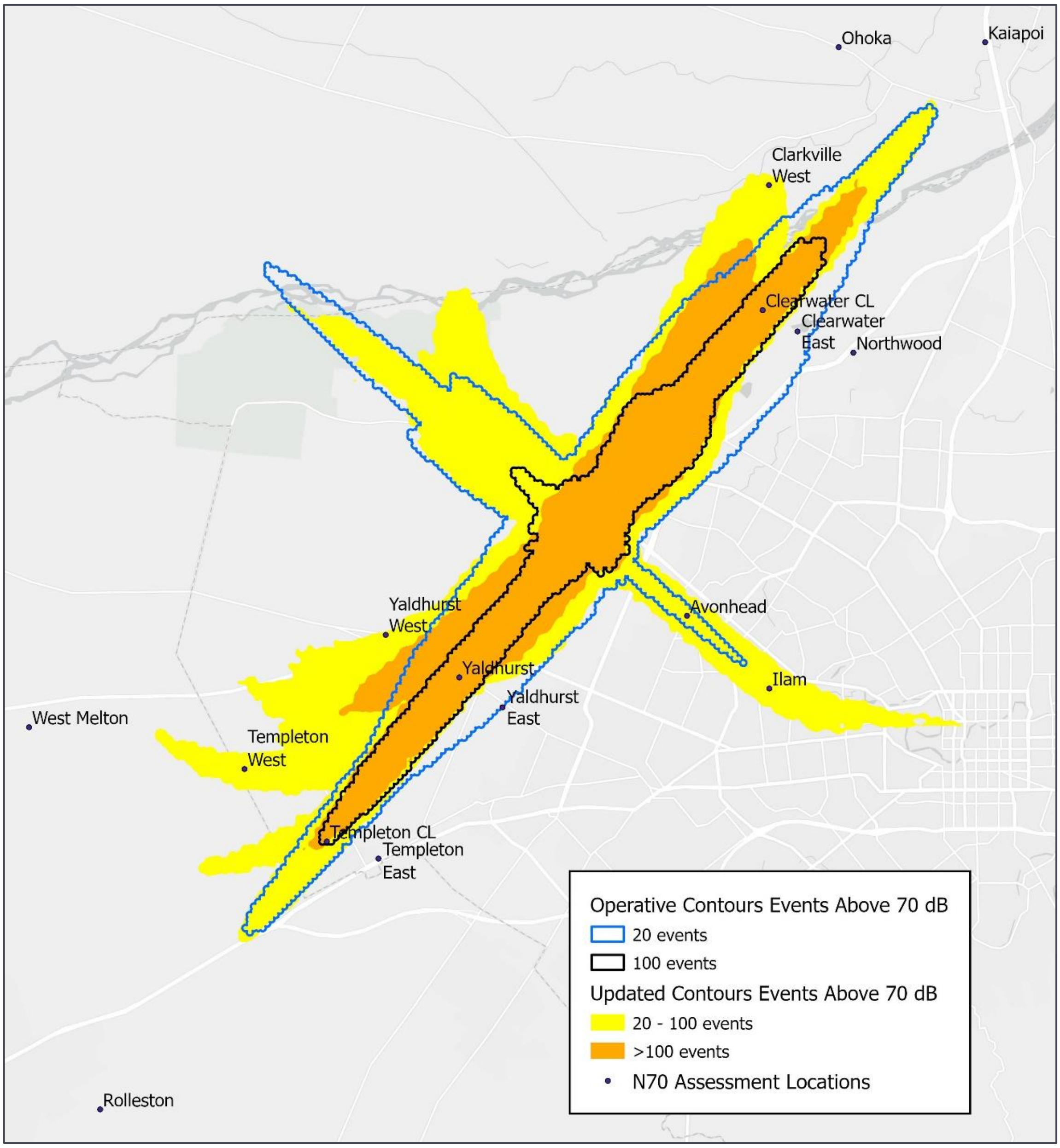

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Table 5 lists the number of noise events above 70 dB L_{Amax} at the 16 representative receiver locations.

Table 5: Number of noise events above 70 dB L_{Amax} per average day in each receiver location

Location	2008 Contours	Updated Contours	Change
Templeton East	4	< 1	Decrease
Clearwater East	38	3	
Northwood	14	< 1	
Yaldhurst East	14	2	
West Melton	< 1	< 1	No Change
Rolleston	< 1	< 1	
Ohoka	< 1	< 1	
Kaiapoi	< 1	< 1	
Yaldhurst West	3	28	Small to moderate increase, low number of events
Clarkville West	5	23	
Templeton West	3	43	Moderate increase, appreciable number of events
Ilam	15	56	
Avonhead	24	54	
Templeton Centreline	102	107	
Clearwater Centreline	138	192	
Yaldhurst	152	297	

Templeton East, Clearwater East, Northwood and Yaldhurst East all have fewer noticeable aircraft noise events under the Updated Noise Contours compared with the 2008 Noise Contours.

West Melton, Kaiapoi, Rolleston and Ohoka have a negligible number of noticeable aircraft noise events under both the Updated the 2008 Noise Contours.

Yaldhurst West and Clarkville West have more noticeable aircraft noise events under the Updated Noise Contours compared with the 2008 Noise Contours, but the numbers remain relatively low (less than 30 events per day).

Templeton West is a rural area situated under an arrival flight path. The predicted change is a moderate increase from 3 noticeable events in the 2008 Noise Contours to a moderate number of 43 events in the Updated Noise Contours.

Avonhead and Ilam are populated residential areas that experience overflights when the cross-runway (11-29) is used. The Updated Contours have over twice as many noticeable aircraft noise events in these areas relative to the 2008 Noise Contours. The Updated Noise Contours include the historical maximum usage of runway 29 over three months which influences this outcome. This scale of impact is short term during seasonal westerly wind conditions and is balanced by periods of reprieve for most other times of the year.

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Templeton, Clearwater and Yaldhurst are rural areas located on the extended runway centreline of the main runway (02-20). Being on centreline, these areas experience the greatest number of noticeable aircraft noise events. The Updated Noise Contours have more such events in these areas due to the updated operational capacity of the airport.

4.4.2 Results 4b – Overall number of people experiencing aircraft noise events above 70 dB

The number of events analysis in Section 4.4.1 is helpful for residents at a particular location to assess how many events they will experience in the future, but it does not show how many people are exposed to this number of events, or how the overall community is affected.

The N70 contours can also be analysed to determine the number of people that will experience a given number of aircraft events. We have used the N70 contours to calculate the number of houses and number of people[11] that will experience events over 70 dB L_{Amax} for the 2008 Noise Contours and the four runway bias scenarios for the Updated Noise Contours. Table 6 shows the results of this analysis for the Existing Housing Stock and Table 7 shows the results for the Future Housing Stock.

Table 6: Number of people experiencing aircraft noise events above 70 dB L_{Amax} (Existing Housing Stock)

	2008 Contours	RW02 Bias	RW20 Bias	RW29 Bias	RW11 Bias
10-20 Events	7,518	9,413	6,520	6,710	7,863
20-50 Events	2,258	2,818	588	7,518	5,373
50-100 Events	448	455	333	3,248	443
100+ Events	240	305	350	273	305
Total	**10,463**	**12,990**	**7,790**	**17,748**	**13,983**

Table 7: Number of people experiencing aircraft noise events above 70 dB L_{Amax} (Future Housing Stock)

	2008 Contours	RW02 Bias	RW20 Bias	RW29 Bias	RW11 Bias
10-20 Events	12,385	13,725	10,245	11,558	12,270
20-50 Events	2,783	3,653	1,048	10,108	6,513
50-100 Events	1,038	610	763	3,913	598
100+ Events	305	778	490	368	778
Total	**16,510**	**18,765**	**12,545**	**25,945**	**20,158**

Looking at the data in Table 6 we see that a similar number of people are impacted by 100 or more noticeable events in all scenarios (including the 2008 Noise Contours), and that the number of people is relatively low. This is because none of the scenarios have 100 or more noticeable events over urban Christchurch where greater numbers of people reside.

We can see in Figure 4 the orange and black N70,100 contours do not extend far from the Airport towards the city, and they are generally aligned with the main runway. The yellow and blue N70,20

[11] The number of people per house is based on data from Statistics NZ of 2.5 persons per household

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contours however do extend towards the city. This impact can also be seen in the second and third rows in Table 6 where the runway 29 bias scenario has significantly more people impacted than any other scenario.

The data is showing us that the number of people experiencing noticeable aircraft events for a given scenario is largely influenced by the number of aircraft using the cross-runway. The greater the number of flights on the cross-runway, the more people are impacted due to the greater population density of urban Christchurch. For example, the runway 20 bias scenario has only 1% of movements on the cross-runway compared with 5%, 14% and 9% for the runway 02, 29 and 11 biases respectively.

As discussed in previous sections, runway 29 is generally only used during north westerly winds which occur on average 5% of the time and the worst case three months being 14% of the time. Therefore, this greater scale of effects is short term and balanced by aircraft using the main runway (02-20) the majority of the time. Likewise, the scale of effects associated with runway 11 bias is very rare.

4.4.3 Results 4c – Person event index

The above analysis provides a useful comparison of the number of people that will experience various numbers of events. However, it does not differentiate between the people that experience 10 events per day (a small effect) and those that experience 100 events per day (a greater effect).

The Australian N70 study also developed a 'Person Event Index' ("PEI") which is a single value metric used to evaluate and compare the effects on a population as a whole. From the N70 contours the Person Event Index (PEI) can be calculated by multiplying the number of people in each N70 band by the number of events. For instance, if 50 people were exposed to 10 events per day or 5 people were exposed to 100 events per day, the PEI would be 500 in both cases (i.e., 50x10 and 5x100). The PEI gives a general indication of the magnitude of the noise impact for the overall population sample.

Only dwellings exposed to 10 events or more per day have been considered. The results from the PEI analysis for the Existing Housing Stock are shown in Table 8 and for the Future Housing Stock in Table 9.

Table 8: Person event index analysis for Existing Housing Stock (numbers reported in millions)

	2008 contours	RW02 Bias	RW20 Bias	RW29 Bias	RW11 Bias
10-20 Events	0.10	0.13	0.08	0.09	0.11
20-50 Events	0.06	0.07	0.02	0.24	0.13
50-100 Events	0.03	0.03	0.02	0.18	0.03
100+ Events	0.03	0.06	0.07	0.05	0.06
PEI ($x10^{-6}$)	**0.23**	**0.29**	**0.19**	**0.56**	**0.33**

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Table 9: Person event index analysis for Future Housing Stock (numbers reported in millions)

	2008 contours	RW02 Bias	RW20 Bias	RW29 Bias	RW11 Bias
10-20 Events	0.16	0.19	0.12	0.15	0.16
20-50 Events	0.07	0.09	0.03	0.32	0.16
50-100 Events	0.07	0.04	0.06	0.23	0.04
100+ Events	0.04	0.12	0.09	0.07	0.12
PEI ($x10^{-6}$)	**0.35**	**0.44**	**0.31**	**0.76**	**0.48**

We see the same trend in the PEI as we saw in method 4b in the previous section. The PEI for a given scenario is largely influenced by how much the cross-runway is used due to the greater impact on urban Christchurch.

The runway 29 bias scenario shows a considerable increase in PEI for the period of time this effect occurs (i.e. during seasonal north westerly wind conditions). Likewise, the runway 11 bias scenario has the next highest PEI but this scenario occurs rarely (<3% of the time).

The runway 02 and 20 runway bias scenarios show a moderate difference in PEI compared with the 2008 Noise Contours.

The results for the Future Housing Stock in Table 9 show the potential change to the receiving environment (i.e. increase in residential activity) would result in the PEI increasing by approximately 35 - 60% for the Updated Contours and 50% for the 2008 Noise Contours.

4.5 Results 5 - Night Noise Contours

The L_{night} noise contours for the 9-hour period from 10pm to 7am have been calculated for both the busy three-month scenario and the 12-month average scenario. The WHO guidelines refer to L_{night} as the 12-month average although this is likely due to the availability of 12-month average data through the European Environmental Noise Directive (END). Given the seasonal variability of operations at CIA, we have also mapped the Outer Envelope three-month L_{night} for information.

These contours illustrate the extent of night noise effects using the criteria recommended in the 2009 and 2018 WHO Guidelines. The current noise management framework for CIA or any other New Zealand airport does not include any mechanisms relating to L_{night} contours. However, this information may help inform land use planning decisions with respect to night noise effects in the context of WHO guidelines.

The 2009 WHO Night Noise Guidelines set 40 dB L_{night} as an ideal target to avoid adverse sleep disturbance effects from aircraft and 55 dB L_{night} as a pragmatic interim target to avoid serious health effects from night-time noise where the lower target was not feasible in the short term. The 2018 WHO Guidelines just recommends a limit of 40 dB L_{night} to avoid adverse sleep disturbance effects from aircraft based on a predicted 11% of people being highly sleep disturbed at this level.

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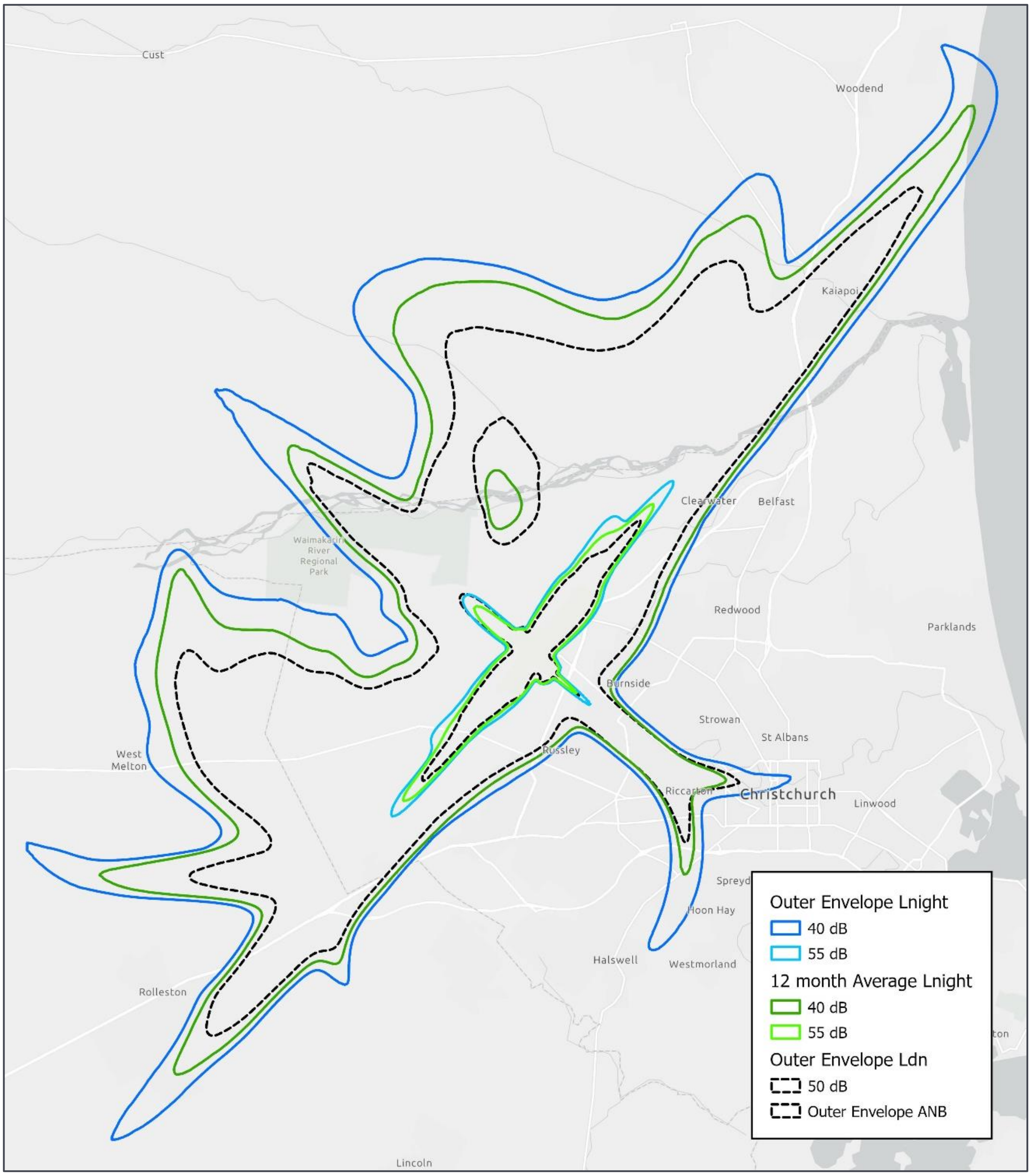
Figure 5: Updated Noise Contours Lnight



5 RELATIONSHIP BETWEEN COMPLAINTS AND EFFECTS

As discussed in our literature review ("*Christchurch Airport – Community Response to Aircraft Noise Literature Review*" dated 14 September 2023), annoyance is determined by the noise level experienced and also a number of non-acoustic factors such as personal and attitudinal factors that can make certain individuals more sensitive to noise. Complaints are considered one of many mechanisms that can be used to cope with the annoyance being experienced. However, complaining is only one way of coping with noise annoyance. Therefore, analysis of complaint data only gives us access to a small section of the population being annoyed by noise. Studies at Schiphol and Brisbane airports showed that not all people annoyed by noise complain. Only 19% and 34% of highly annoyed respondents complained about the noise at Schiphol and Brisbane airports respectively.

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Complaints data has been analysed in past studies to try and determine a relationship between noise levels, annoyance and complaints. However, no reliable correlation has been found to date. A paper by FICON in 1992 commented that "annoyance can exist without complaints, and conversely complaints may exist without annoyance" and it has long been thought that we therefore cannot use complaints data to accurately predict annoyance levels. This continues to be the finding of the latest research in this area. However, recent studies have shown that analysis of complaints data can show us other trends which may be helpful to understand.

A major reason for people not complaining about noise is when they perceive nothing can be done about the noise source. This explains why often most complaints received at airports are well outside the noise contours where there is scope to shift flight paths rather than close into the airport where flight paths are essentially fixed on extended runway centreline and cannot be shifted.

This occurred at Auckland Airport throughout the SMART trials, which were trials of new arrival paths into the airport. The trial proceeded unnoticed for the first 6 months and no complaints were received. It was then picked up by a local newspaper and complaints increased as the media coverage grew.

A large number of complaints were received during the yearlong trial that were well above historical complaint levels. These complaints were mainly from Mt Eden and Epsom (areas exposed to noise levels below 45 dB L_{dn}) whereas noise complaints from people living inside the noise contours were limited. In reality, the noise levels of the SMART flight paths in the Mt Eden and Epsom areas were not much different to the conventional flights paths that had flown over these areas for years.

The trial ceased after a year but interestingly the largest number of complaints received was in the week after the trial had stopped. There was also a very low correlation between people's complaints and the new flight tracks, with most people inadvertently complaining about conventional arrival and departure flight tracks thinking they were the new SMART flight tracks.

After the trial, a public consultation and review was completed, and the tracks were tweaked slightly and approved for permanent use. Complaints remained low during this period despite the tracks being used on a daily basis.

A similar scenario played out at Sydney airport and complaints from outside the noise contours resulted in a curfew being put on the airport. Similar trends are seen for complaints from CIA, with most complainants coming from people located outside the noise contours. Analysis of complaints data from 2017 to March 2022 shows that 75% of complainants were located outside the noise contours.

Another reason people may be more likely to complain is if there is a large upcoming change proposed at an airport, such as a new runway. Manchester Airport unveiled plans to construct a new runway in 1996 which caused public outcry and increased community complaint. Complaints in the years following decreased after this initial period to levels lower than those seen prior to 1996, even though the number of flights kept increasing over this time. The runway was eventually built in 2001 which again triggered another spike in complaints which were unrelated to the overall number of flight movements at the airport.

A study by Maziul in 2005 summarises that the following factors can lead people to/to not complain. As discussed above a large factor increasing people's likelihood to complaint is if they feel they can have some influence over an outcome. There are also things such as a person's socio-economic status or the ease in which someone can make a complaint which influences people's likelihood of complaining.

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Factors that enhance to lodge a complaint	Factors that rather keep from complaining
Knowledge of noise complaint service	Not knowing where to complain
Believe in the effectiveness of the complaint	Low expectancy of success or belief in having to 'put-up-with' the disturbance)
Confidence in one's ability, good socio - economic status (education, house ownership)	Low socio-economic status
Past complaint experience	Past complaint experience
Noises which people believe authorities can influence	Noises which people believe authorities cannot influence
Time of day that noise occurred	Time of day that noise occurred
Individual characteristics (e.g. susceptibility, individual threshold, coping mechanisms, willing to express criticisms, tendency to complain)	
Way different airports deal with noise complaints	
Concern about health, and fear of aircraft crashes.	Neither concern about health (in relation to noise) nor fear of crashes

In addition to the factors listed above, the noise level and time of an aircraft noise event can influence someone's likelihood of complaining. Hume 2003 did an analysis of complaints at Manchester Airport which showed that the louder the aircraft noise event, the more complaints that were generated. Also, night flights caused on average nearly five times more complaints than daytime flights. This study also found that more complaints were received in the busy season and that complaints tended to be lowest on Monday and highest on Sunday, increasing throughout the week.

Overall, we do not consider that complaints can be used as a reliable indicator of annoyance as they only represent a small proportion of people that are highly annoyed and are more likely to be from people living in lower noise environments. Complaints are also highly impacted by airport changes such a new runways or tracks being developed or public action against noise, which make them an unreliable source.

Analysis of complaints data over the years has not shown any reliable correlation to annoyance or overall noise levels. However, there are some trends that can be ascertained from looking at the data that can be helpful to understand the root cause of complaints and how an airport can best manage itself to avoid these.

6 REDUCING THE IMPACTS OF AIRCRAFT NOISE

It is widely accepted that reducing the impacts of aircraft noise requires a combined effort such that incremental improvements from many contributing factors can result in a meaningful reduction. It is important to differentiate between noise exposure and the resulting noise nuisance which is an outcome relating to the size of the population affected. If aviation services are important to a region, then the solution needs to be multi-dimensional rather than simply reducing aircraft noise by restricting operations. Responsible land use planning plays a significant role in reducing the impacts of aircraft noise.

The International Civil Aviation Organisation (ICAO) Balanced Approach framework sets out four fundamental principles for managing noise pollution around airports. The framework offers a 'balanced approach' across all parties affected by airports operations and aims to consider corrective actions that reduce noise annoyance on surrounding communities whilst limiting the affects to an airport's activities, allowing them to still operate in a way that is economically beneficial to all parties.

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The ICAO Balanced Approach reinforces the NZS 6805 approach to managing the effects of aircraft noise. Further information on the ICAO Balanced Approach framework is available in Appendix E.

The ICAO Balanced Approach is a helpful reference however it is not a complete solution to reducing the annoyance effects of aircraft noise. There is growing evidence and recognition that non-acoustical factors play a major part in the individual and community response to noise. Some of these factors are in the control of airport operators, for example open and responsive communication with the community. NZS 6805 also promotes these additional measures such as establishing noise committees and providing regular monitoring and reporting. CIA has a comprehensive noise management framework under the Christchurch District Plan that encompasses a suite of management, monitoring and mitigation measures.

7 ASSESSMENT OF NOISE EFFECTS - SUMMARY

NZS 6805:1992 is intended to *"ensure communities living close to the airport are properly protected from the effects of aircraft noise whilst recognising the need to be able to operate an airport efficiently"*. The Standard recommends doing this by applying a two-pronged approach that:

a. Manages aircraft noise emissions; and

b. Manages noise sensitive land use.

The current aircraft noise and land use controls for CIA are generally based on the NZS 6805 approach.

CIA's Airport Noise Contours are intended to be reviewed every 10 years as recommended by the Expert Panel in 2008. Accordingly, CIAL has commissioned the preparation of Updated Noise Contours to replace the 2008 Noise Contours.

This report considers the impact of changes to the two factors influencing the scale of aircraft noise effects on the surrounding population:

- **Change in aircraft noise planning environment** (Updated Noise Contours)
- **Change in the receiving environment** (i.e. growth in residential activity enabled by operative land use controls)

We have assessed the change in the aircraft noise planning environment by comparing the scale of aircraft noise effects for the Updated Noise Contours with the 2008 Noise Contours in the context of the Existing Housing Stock.

We have assessed the change in the receiving environment by comparing the scale of aircraft noise effects for the Existing Housing Stock with that for a potential Future Housing Stock. The Future Housing Stock is based on the maximum residential development enabled by the existing planning framework. For this analysis, we have assumed that the operative land use controls applying inside the 2008 Noise Contours as of March 2022, would also apply inside the Updated Noise Contours.

7.1 Outer Envelope Updated Noise Contours

The Updated Noise Contours are a composite of four operating scenarios that represent the historical worst case usage of each of the airport's four runways. We refer to these as the four runway bias scenarios:

- Runway 02 bias;
- Runway 20 bias;
- Runway 29 bias;
- Runway 11 bias;

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The highest runway usage over three months was determined from a review of historic runway usage at CIA. The outer extent of these four noise contours is taken to form the final Outer Envelope Updated Noise Contours.

These four scenarios would never occur simultaneously – they would occur in different three-month periods. This report therefore focuses on an assessment of the noise effects under each of these four individual runway bias scenarios separately.

For reference, the 2008 Noise Contours are based on an annual average usage of runways 02 and 20 and a highest three month usage of runways 29 and 11.

To provide context for the four runway bias scenarios, the main runway (02-20) is used on average 95% of the time. Therefore, the runway 02 and 20 bias scenarios are most representative of the impact occurring most of the time. Runway 11 is used very infrequently, less than 3% of the time as a worst case and less than 1% on average. Runway 29 is also used infrequently, approximately 5% of the time on average over a year but in a given three-month period it can be used up to 14% of the time due to seasonal north westerly winds. For reference, Appendix E lists the runway usage splits for each of the four runway bias scenarios and the annual average.

7.2 Change in aircraft noise planning environment

We have used four different methods to quantify the aircraft noise effects for the Existing Housing Stock:

1. Number of houses within the Airport Noise Contours (# Houses);
2. Number of people potentially highly annoyed (People HA);
3. Number of houses affected by a noticeable change in L_{dn} (# Houses >5dB Increase);
4. Number of people experiencing aircraft noise events above 70 dB L_{Amax} (PEI).

Table 10 summarises the difference between the Updated Contours (4 scenarios) and the 2008 Noise Contours for each of the metrics above.

Table 10: Updated Noise Contours change in aircraft noise effects for Existing Housing Stock

Runway Bias Scenario	# Houses	People HA	# Houses 5dB+ Increase in L_{dn}	PEI (10^{-6})
02 Bias	-31%	-32%	411	+26%
20 Bias	-23%	-23%	441	-17%
29 Bias	+20%	+24%	2,207	+143%
11 Bias	-27%	0%	384	+43%

As discussed, the main runway (02-20) is the predominant runway. On average 95% of aircraft movements over a year use runway 02 or 20. For these runway bias scenarios, our assessment shows a moderate change in the scale of effects predicted under all four assessment methods. This change reflects the revised operational capacity of the Airport used for modelling the Updated Noise Contours and our approach to use the historical worst case runway bias for the main runway.

The largest increase in aircraft noise effects occurs for the runway 29 bias scenario. Runway 29 is used in north westerly wind conditions requiring aircraft to overfly the urban areas of Christchurch City and naturally impacting more houses. For the runway 29 bias scenario we have used the historical worst-case three-month usage of runway 29 which is 14%, whereas the annual average usage is 5%. Because of the seasonal nature of the north westerly winds, the increased impact

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shown in Table 10 is short term and balanced by less impact during the rest of the year when the main runway is predominantly used.

The runway 11 bias scenario also shows an increase in scale of aircraft noise effects. We do not consider this change is material as runway 11 is used very infrequently, less than 3% of the time during the worst case three months and less than 1% on average over a year.

7.3 Change in receiving environment

We have compared the scale of aircraft noise effects for the Future Housing Stock with that for the Existing Housing Stock using three methods:

1. Number of houses within the Airport Noise Contours (# Houses);
2. Number of people potentially highly annoyed (People HA);
3. Number of people experiencing aircraft noise events above 70 dB L_{Amax} (PEI).

Table 11 summarises the increase in the scale of noise effects for the Future Housing Stock compared with the Existing Housing Stock for each of the metrics above.

Table 11: Increase in aircraft noise effects due to change in receiving environment

Noise Contour Scenario		# Houses	People HA	PEI (10^{-6})
2008		+57%	+53%	+52%
Updated	02 Bias	+41%	+40%	+52%
	20 Bias	+46%	+45%	+63%
	29 Bias	+37%	+35%	+36%
	11 Bias	+39%	+37%	+45%

Table 11 shows that under the operative land use controls (March 2022), the potential increase in residential activity within the Airport Noise Contours would result in a considerable increase in the scale of aircraft noise impact within the community.

For the change in receiving environment analysis, we have assumed that the permitted density and subdivision controls that apply within the 2008 Noise Contours (as of March 2022) would also apply within the Updated Noise Contours. Any loosening of the current land use controls inside the airport noise contours would result in an even greater increase in affected residents.

7.4 Conclusions

In summary, the Updated Noise Contours generally represent a moderate increase in aircraft noise effects compared with the 2008 Noise Contours. This is a result of the updated long term future operational capacity of the airport and the modelling approach to use the historical worst case runway usage for all four runways. Under the worst-case runway 29 bias scenario, the increase in noise effects for urban Christchurch City is considerable. This is tempered by being a short-term impact during seasonal north westerly wind conditions which is balanced by lesser effects during other times of the year.

As well as considering the impact of the change in aircraft noise environment, we assessed the impact of the potential change in receiving environment. Our analysis shows that the potential increase in aircraft noise effects resulting from worst case growth in residential activity currently permitted inside the Airport Noise Contours, is substantial and somewhat greater than the increase in effects due to the change in aircraft noise. If the land use controls applying inside the Airport

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Noise Contours (as of March 2022) are relaxed, the scale of airport noise effects on the surrounding population could increase even more significantly.

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APPENDIX A NEW ZEALAND STANDARD NZS6805

In 1992, the Standards Association of New Zealand published New Zealand Standard NZS 6805:1992 "*Airport Noise Management and Land Use Planning*" (the Standard) with a view to providing a consistent approach to noise around New Zealand airports. The Standard was finalised after several years of preparation and consultation and forms the consensus of opinion in 1991 of many different groups including the Ministry of Transport, the Department of Health, Airline representatives, Local Authorities, residents action groups, acoustic consultants and others including CIAL.

The Standard uses the "Noise Boundary" concept as a mechanism for local authorities to:

- "Establish compatible land use planning" around an airport; and
- "Set noise limits for the management of aircraft noise at airports"

The Noise Boundary concept involves fixing an Outer Control Boundary and a smaller, much closer Airnoise Boundary around the airport. Inside the Airnoise Boundary, new noise sensitive uses (including residential) are prohibited. Between the Airnoise Boundary and the Outer Control Boundary new noise sensitive uses should also ideally be prohibited (and of those that are required, all should be provided with sound insulation). The Airnoise Boundary is also the location for future compliance monitoring with a 65 dB L_{dn} limit.

The Standard is based on the Day/Night Sound Level (L_{dn}) which uses the cumulative 'noise energy' that is produced by all flights during a typical day with a 10-decibel penalty applied to night flights. L_{dn} is used extensively overseas for airport noise assessment, and it has been found to correlate reasonably well with community response to aircraft noise.

The location of the Airnoise Boundary is based upon the projected 65 dB L_{dn} contour, and the location of the Outer Control Boundary is generally based on the projected 55 dB L_{dn} contour. The Standard does however state in paragraph 1.4.3.8 that the local authority may show "the contours in a position further from or closer to the airport, if it considers it more reasonable to do so in the special circumstances of the case". The Canterbury Regional Council, and therefore Christchurch, Waimakariri and Selwyn Councils use the 50 dB L_{dn} contour for the location of the Outer Control Boundary.

The Standard recommends that the Airnoise Boundary and Outer Control Boundary are generally based on noise over a three-month period (or such other period as agreed). Airports in New Zealand mostly use a three-month average with Auckland Airport using an Annual Average. The Standard also recommends planning and management procedures be based on predicted noise contours (L_{dn}) for a future level of airport activity. The Standard (clause 1.4.3.1) recommends that a "minimum of a 10-year period be used as the basis of the projected contours."

It is important for a major international airport to plan for a period significantly longer than 10 years. At Auckland International Airport the original 1995 contours were based on a projection for the year 2030 (35 years ahead at the time). At Wellington International Airport the projections were based on the ultimate runway capacity. At Christchurch Airport they are based on ultimate runway capacity.

Clause 1.1.5(c) of the Standard recommends consideration of the noise from individual maximum noise events for night-time operations, and this is normally achieved by plotting the arrival and departure SEL 95 contours from the noisiest and most frequent night-time aircraft. If the SEL 95 contour extends beyond the 65 dB L_{dn} contour, then a composite of both contours forms the Airnoise Boundary. For Christchurch Airport the Airnoise Boundary used for land use planning is a composite of the 65 dB L_{dn} contour and the single event 95 dB SEL contour from an individual aircraft event.

Land Use Planning can be an effective way to minimise population exposure to noise around airports. Aircraft technology and flight management, although an important component in abating noise, will not be sufficient alone to eliminate or adequately control aircraft noise. Uncontrolled development of noise sensitive uses around an airport can unnecessarily expose additional people to high levels of noise and can constrain, by public pressure as a response to noise, the operation of the airport.

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Planning rules

The efficient use and development of Christchurch International Airport (CIA / the Airport) as a significant regional infrastructure resource is provided for in the Canterbury Regional Policy Statement (CRPS), in both Chapter 5 (Land use and Infrastructure) and Chapter 6 (Recovery and Rebuilding of Greater Christchurch).

The Airport is defined as "Regionally Significant Infrastructure" in the CRPS and is recognised across a number of policies and objectives. Policy 6.3.5 relevantly:

- provides for the continued safe, efficient and effective use of regionally significant infrastructure;
- provides for the provision for efficient and effectively functioning infrastructure;
- seeks to ensure that land use activities and new development are managed including avoiding activities that have the potential to limit the efficient and effective, "provision, operation, maintenance or upgrade of strategic infrastructure and freight hubs";
- expressly states that this includes "avoiding noise sensitive activities within the 50 dBA L_{dn} airport noise contour for Christchurch International Airport."

Policy 6.3.9(5) requires that the location and design of rural residential development avoid noise sensitive activities occurring within the 50 dB L_{dn} Air Noise Contour.

The Canterbury Regional Council and territorial authorities (Christchurch, Selwyn and Waimakariri District Councils) must give effect to the CRPS through their regional and district plans. This includes those provisions which direct the protection of strategic / regionally significant infrastructure.

The 50 dB L_{dn} Air Noise Contour has consistently been used as a basis for land use planning throughout Greater Christchurch. For example, in rural zones, noise sensitive land uses (including residential activities) are typically non-complying to give effect to Policy 6.3.9(5) of the CRPS. Sound insulation is also required for noise sensitive activities within 55 dB L_{dn}, which is reflected in relevant rules across all three district plans.

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APPENDIX B GLOSSARY OF TERMINOLOGY

Name	Description
AANC	Annual Aircraft Noise Contour. Prepared annually to determine compliance with the Air Noise Boundaries.
AEDT	Aviation Environmental Design Tool. A proprietary noise model created by the FAA used to calculate noise contours around an airport (replacement of the INM).
Airways New Zealand	The sole Air Traffic Service provider in New Zealand.
Ambient Noise	The totally encompassing sound in a given situation at a given time, from all sources near and far including the specific sound.
A-weighting	The process by which noise levels are corrected to account for the non-linear frequency response of the human ear.
CIAL	Christchurch International Airport Limited
Cross-runway	Refers collectively to Runway 11 and Runway 29.
CRPS	Canterbury Regional Policy Statement.
Current Fleet	Refers to the fleet mix provided by Airbiz that currently exists.
Current Runway Configuration	Refers to the currently existing main and cross-runway. Doesn't include any proposed extensions.
Daytime	Assumed to be from 7 am to 10 pm.
dB	Decibel. The unit of sound level. Expressed as a logarithmic ratio of sound pressure P relative to a reference pressure of Pr=20 mPa i.e. dB = 20 x log(P/Pr)
dBA	The unit of sound level which has its frequency characteristics modified by a filter (A-weighted) to more closely approximate the frequency bias of the human ear.
DMAPS	Divergent Missed Approach Protection System. Departure tracks that turn at an angle soon after take-off, instead of flying straight and then turning when instructed by Air Traffic Control.
DMAPS Tracks	Refers to the flight tracks currently in use, with RNP procedures in place and DMAPS departures.
Existing Aircraft Noise Planning Environment	The permitted and anticipated future aircraft noise environment defined by airport noise contours on the district planning maps.
Existing Housing Stock	Existing houses located inside the airport noise contours.
Expert Panel Report	Prepared in 2008 and outlines the assumptions and methodologies used to prepare the 2008 Plan Noise Contours

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FAA	The Federal Aviation Administration in the United States. The developer of the INM and the AEDT noise models.
Future Fleet	Refers to the fleet mix provided by Airbiz in the future. Includes new generation aircraft.
Future Housing Stock	The capacity of potential houses inside the airport noise contours based on the maximum density and subdivision permitted under the operative district plans as of March 2022.
Future Runway Configuration	Refers to the envisaged future main and cross-runway. Includes proposed extensions to runway 11 and 20.
ILS Approach	Instrument Landing System Approach. A type of approach that uses a precision runway approach aid based on two radio beams that provide vertical and horizontal guidance.
INM	The FAA's Integrated Noise Model. A proprietary noise model used to calculate noise contours around an airport.
L_{Amax}	The A-weighted maximum noise level. The highest noise level which occurs during the measurement period.
L_{dn}	The day-night noise level which is calculated from the 24-hour L_{Aeq} with a 10-dB penalty applied to the night-time (2200-0700 hours) L_{Aeq}.
Main Runway	Refers collectively to Runway 02 and Runway 20.
MDA	Marshall Day Acoustics.
Night-time	Assumed to be from 10 pm to 7 am.
Noise	A sound that is unwanted by or distracting to the receiver.
Noise Model	A programme used to model aircraft noise to produce the noise contours. The INM and the AEDT are types of noise model.
NZS 6805:1992	New Zealand Standard NZS 6805:1992 *"Airport Noise Management and Land Use Planning"*
2008 Plan Noise Contours	The Noise Contours Currently in the Canterbury Regional Policy Statement and Christchurch, Selwyn and Waimakariri District Plans.
Outer Envelope	The outer extent of multiple overlaid noise contours. The Updated Noise Contours are the Outer Envelope of four runway bias scenario contours.
RNP	Performance-Based Navigation. Encompasses a shift from ground-based navigation aids emitting signals to aircraft receivers, to 'in-aircraft' systems that receive satellite signals from sources such as the Global Positioning System (GPS).

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RNP Approach	Required Navigation Performance Approach. Is a type of RNP approach that allows an aircraft to fly a specific track between two 3-dimensionally defined points in space.
Receiving Environment	The environment affected by an external impact. In this case, the land within the airport noise contours.
Runway 02	Runway 02 is the main runway with aircraft landing and taking off in a northerly direction (heading 020 degrees magnetic)
Runway 11	Runway 11 is the cross-runway with aircraft landing and taking off in an easterly direction (heading 110 degrees magnetic)
Runway 20	Runway 20 is the main runway with aircraft landing and taking off in a southerly direction (heading 200 degrees magnetic)
Runway 29	Runway 29 is the cross-runway with aircraft landing and taking off in a westerly direction (heading 290 degrees magnetic)
Runway bias scenario	Four airport operating scenarios used for modelling the Outer Envelope Updated Noise Contours. Each runway bias scenario represents the highest historical three month usage for the runway vector (02, 20, 29 or 11).
SEL or L_{AE}	Sound Exposure Level. The sound level of one second duration which has the same amount of energy as the actual noise event measured. Usually used to measure the sound energy of a particular event, such as a train pass-by or an aircraft flyover
Updated Noise Contours	The updated noise contours to replace the 2008 Noise Contours, modelled by CIAL's experts and to be peer reviewed by a panel of experts before confirmation.
Visual Approach	An approach when either part or all an instrument approach procedure is not completed, and the approach is executed with visual reference to the terrain.

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APPENDIX C CALCULATED NOISE CONTOURS

A detailed explanation of the re-modelling process and outcomes is contained in the combined report by Airbiz, MDA, CIAL and Chapman Trip titled "*2023 Updated Christchurch International Airport Noise Contours*".

In summary, the inputs to the Updated Noise Contours differ from the 2008 Noise Contours in a number of aspects. The 2008 Contours were based on a different flight schedule, fleet mix, airspace management, runway configuration, runway usage and version of the noise model. These changes reflect progress in all these areas since 2008 when the 2008 Contours were developed. Table C1 below summarises the main differences in inputs between the 2008 and Updated Noise Contours.

C1 Differences in noise model inputs

INM Inputs	2008 Noise Contours	Updated Noise Contours
Movement Numbers	175k scheduled passenger 5 freight flights per week	201k scheduled passenger aircraft 15k freight aircraft 20k FBO/small commercial, airline/MRO) (Antarctic/military/govt excluded) 28k Helicopters/drones
Fleet mix	Older aircraft	Newer aircraft (A320 Neos etc) but more wide bodies
Runway Configuration	Current RWY 02/20 length. Extension on RW11/29	Runway extensions on 02/20 and 11/29
Flight Tracks	Conventional tracks (no DMAPS or RNP)	Updated airspace management including DMAPS for departures and RNP arrivals
Taxiing	Doesn't include	Does include
Runway Usage	Annual average with three month seasonal factor applied RW11/29	Outer envelope composite of three month worst case on each runway
Model version	INM v7.0	AEDT v3e

The resulting Updated Noise Contours are generally larger in most areas but smaller in some areas as shown in Figure C2. The 2008 Noise Contours are shown as dashed lines and labelled "2008 Expert Panel Noise Contours".

The updated flight tracks result in a change to shape of the outer noise contours. The tracks used for the 2008 Contours did not include RNP or DMAPS flight tracks and were predominantly straight (aligned with the runways) within the extent of the noise contours.

The Outer Envelope Updated Noise Contours also account for four different runway use scenarios. The various runway use factors applied in the model are detailed further in Appendix E.

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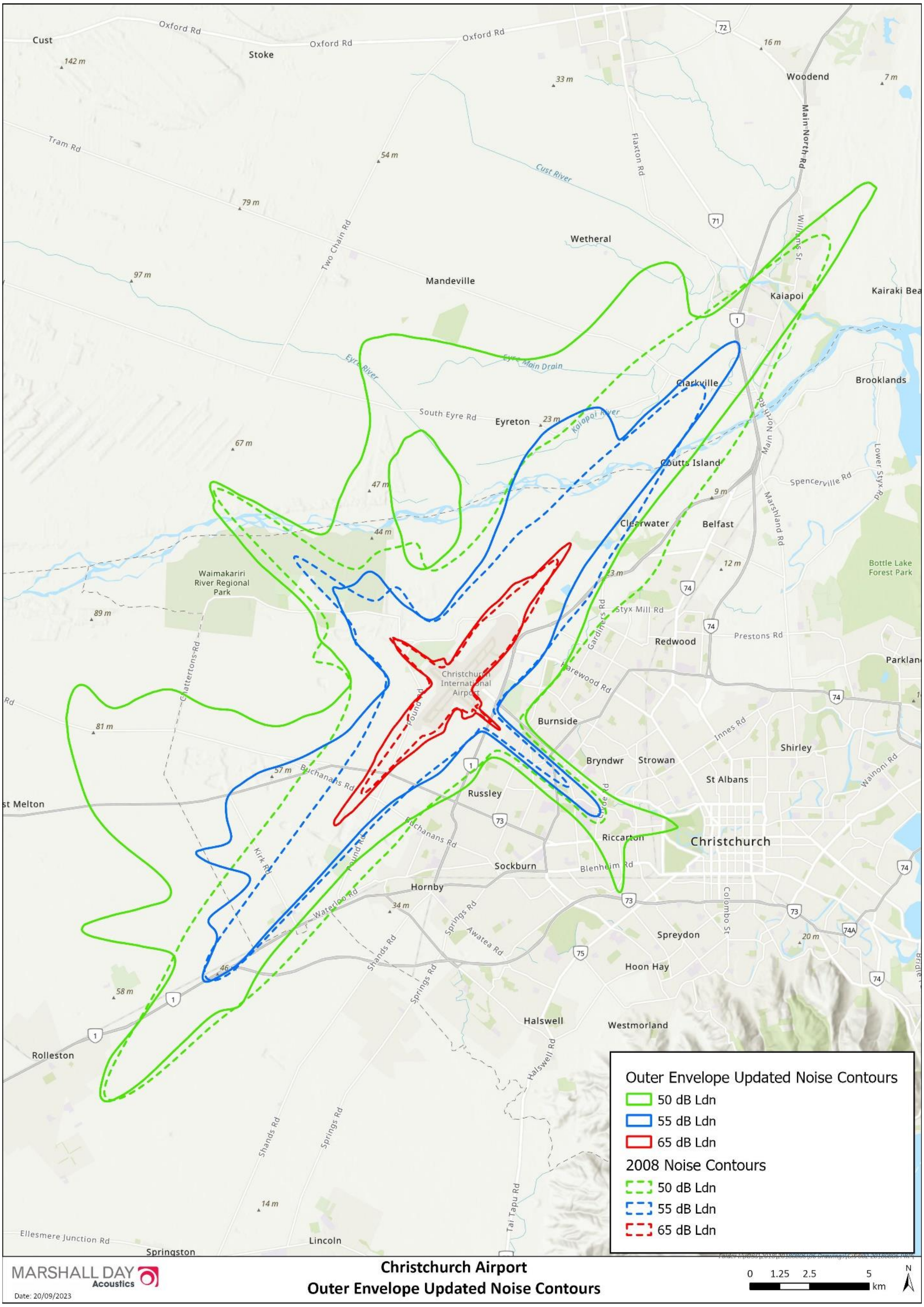
C2 2008 and Updated Noise Contours



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APPENDIX D DERIVATION OF POTENTIAL GROWTH IN RESIDENTIAL UNITS IN THE RECEIVING ENVIRONMENT

The analysis of the potential future growth of residential units within the airport noise contours was carried out jointly by CIAL, MDA and Chapman Tripp.

The Future Housing Stock was derived using parcel information from LINZ and the operative land use controls (as of March 2022) to estimate the development potential under the current planning framework.

The Operative District Plan land use controls from Selwyn, Waimakiriri and Christchurch City Councils were used to identify zones where residential activities could occur and at what density. Non-sensitive land uses such as industrial or commercial were excluded from our analysis.

The land area of each parcel was analysed to determine the development potential under the current planning rules taking into consideration the density controls applying to land within the 50 dB L_{dn} Airport Noise Contour. We have assumed that the same controls would continue to apply inside the Updated Noise Contours. No account was made for any change to density controls operative in March 2022.

The Future Housing Stock calculation **does not** account for how the following factors affect the potential number of residential units permitted on a given parcel:

- Shape of the parcel;
- Existing residential development on the land;
- Potential for combined development of adjoining parcels;
- Changes to the existing density controls and land use zones operative as of March 2022.

The calculation is simply based on parcel area and the permitted density.

Our analysis assumes no additional dwellings are permitted inside the Airnoise Boundary.

In summary, we have used available GIS information to prepare an estimate of the Existing and Future Housing Stock. The data contains inherent uncertainties and therefore the housing stock numbers presented in the report are an estimate only.

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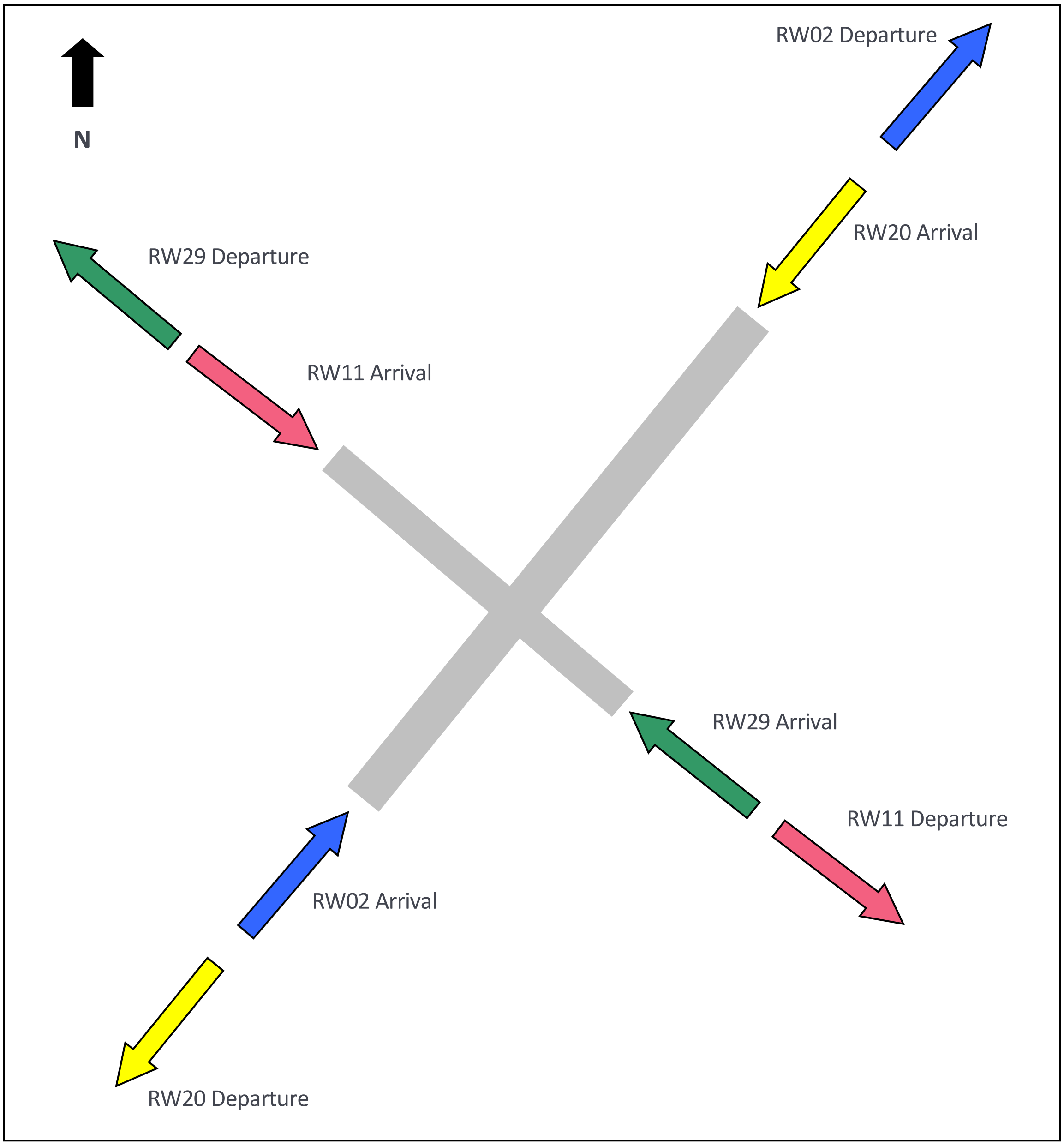
APPENDIX E RUNWAY BIAS

Runway 02 refers to operations using the main runway with a heading of 20 degrees from true north i.e. arrivals from the south west landing in a north easterly direction and departures towards the north east.

Runway 20 refers to operations using the main runway with a heading of 200 degrees from true north i.e. arrivals from the north-east landing in a south westerly direction and departures towards the south west.

Runway 11 refers to operations using the crosswind runway with a heading of 110 degrees from true north i.e. arrivals from the north-west landing in a south easterly direction and departures towards the south east.

Runway 29 refers to operations using the crosswind runway with a heading of 290 degrees from true north i.e. arrivals from the south-east landing in a north westerly direction and departures towards the north west.



Our aircraft noise contour modelling is based on an average day of aircraft movements which means we apply average runway usage percentages to assign aircraft movements to each runway. For Christchurch Airport the runway usage in any given three-month period will vary significantly due to seasonal wind conditions. For the Updated Noise Contours, we considered two options for modelling runway usage:

- The Outer Envelope future noise contour (composite of three month worst case runway usage for four wind directions)
- The Annual Average future noise contour (annual average runway usage)

Therefore, five different runway splits were initially used in developing the Updated Noise Contours. Four for the Outer Envelope and one for the Annual Average noise contour. This report presents the Outer Envelope option, but the Annual Average runway splits are provided to demonstrate how the seasonal fluctuations compare with runway usage over a year.

The runway splits given in Table E1 and E2 below are the overall runway splits that are not broken down for different aircraft types or operations. The more detailed runway splits given in Tables E3 – E7 below, reflect the fact that departures have not been allocated to runway 11 and slightly different runway splits apply for wide bodied jets which cannot use the cross-runway at all.

Outer Envelope

The Outer Envelope consists of four separate runs accounting for the busiest three-month runway usage recorded on each runway end between 1999 and 2019. We calculated the runway splits for each three-month period from 1999-2019 to find the highest recorded usage of each runway end. The runway usage for each period is given in Table E1. Although these runway splits represent the highest recorded usage on each runway, similar runway splits have been observed in other months/years and the numbers in Table E1 do not represent outliers in the data.

For the RW29 bias scenario, the worst case RW29 usage of 13% was increased to 14.3% to account for potential climate change effects on increasing the prevalence of north-westerly wind patterns. To balance out the increase on RW29, the usage on RW02 and RW20 was reduced equally for this scenario.

E1 Outer Envelope Runway Splits – Highest three month use for each runway end

Highest Usage of	Runway 02	Runway 20	Runway 11	Runway 29	Total
RW02	**71%**	24.5%	0.5%	4%	100%
RW20	49%	**50%**	0%	1%	100%
RW11	69%	23%	**2.5%**	5.5%	100%
RW29	55.35%	30.35%	0%	**14.3%**	100%

Annual Average

The Annual Average runway splits were determined by calculating the 12-month runway splits for each calendar year from 1999-2019 and then calculating the average 12-month split on each runway. These are shown in Table E2. For the modelling the splits differ slightly to those in Table E2 as RW29 usage was increased to 4.95% to account for potential climate change effects increasing the prevalence of north-westerly wind patterns. To balance this increase, the usage on RW02 and RW20 was reduced equally.

E2 Recorded Annual Average Runway Splits

Runway 02	Runway 20	Runway 11	Runway 29	Total
58.5%	36.7%	0.3%	4.5%	100%

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E3 Runway Splits – Highest Usage of Runway 02

	Runway 02	Runway 20	Runway 11	Runway 29	Total
Narrow bodied jet & Turboprop Arrivals	71%	24.5%	0.5%	4%	100%
Narrow bodied jet & Turboprop Departures	71%	24.5%	-	4.5%	100%
Wide bodied Jet Arrivals & Departures *(that can't use the cross-runway)*	74%	26%	-	-	100%

E4 Runway Splits – Highest Usage of Runway 20

	Runway 02	Runway 20	Runway 11	Runway 29	Total
Narrow bodied jet & Turboprop Arrivals	49%	50%	0%	1%	100%
Jet & Turboprop Departures	49%	50%	-	1%	100%
Wide bodied Jet Arrivals & Departures *(that can't use the cross-runway)*	49%	51%	-	-	100%

E5 Runway Splits – Highest Usage of Runway 11

	Runway 02	Runway 20	Runway 11	Runway 29	Total
Narrow bodied jet & Turboprop Arrivals	69%	23%	2.5%	5.5%	100%
Narrow bodied jet & Turboprop Departures	69%	23%	-	8.0%	100%
Wide bodied Jet Arrivals & Departures *(that can't use the cross-runway)*	75%	25%	-	-	100%

E6 Runway Splits – Highest Usage of Runway 29

	Runway 02	Runway 20	Runway 11	Runway 29	Total
Narrow bodied jet & Turboprop Arrivals	55.35%	30.35%	0%	14.3%	100%
Narrow bodied jet & Turboprop Departures	55.35%	30.35%	-	14.3%	100%
Wide bodied Jet Arrivals & Departures *(that can't use the cross-runway)*	64.0%	36.0%	-	-	100%

E7 Runway Splits– Historical Annual Average

	Runway 02	Runway 20	Runway 11	Runway 29	Total
Narrow bodied jet & Turboprop Arrivals	58.275%	36.475%	0.3%	4.95%	100%
Narrow bodied jet & Turboprop Departures	58.275%	36.475%	-	5.25%	100%
Wide bodied Jet Arrivals & Departures *(that can't use the cross-runway)*	61.0%	39.0%			100%

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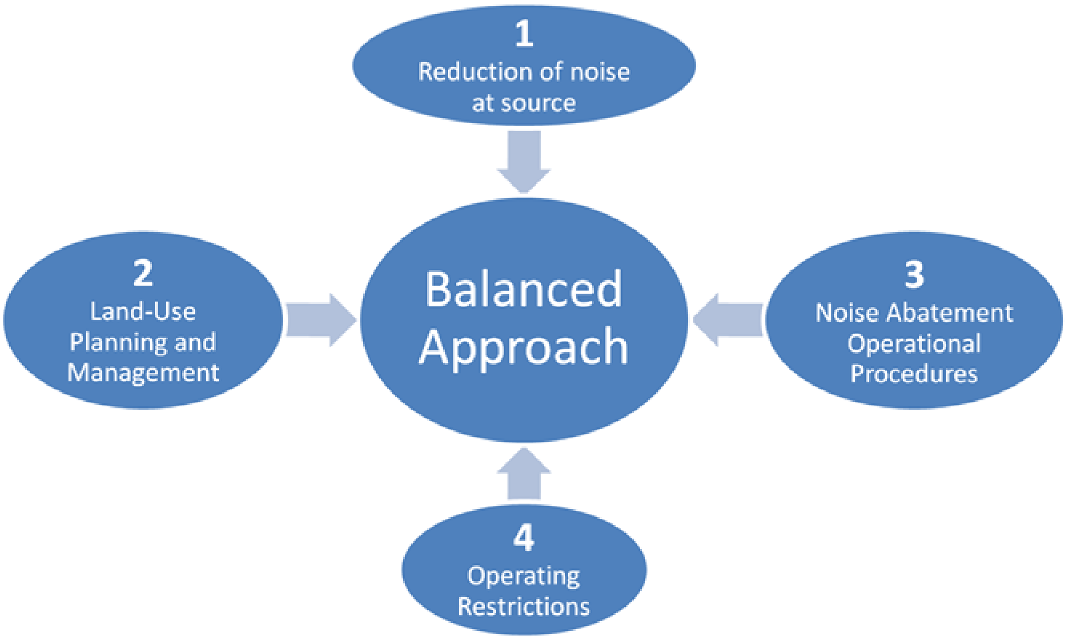
APPENDIX F ICAO BALANCED APPROACH POLICY

The ICAO Balanced Approach (BA) policy on aircraft noise was introduced by the ICAO Assembly in its 33rd Session in 2001 and reaffirmed in all subsequent Assembly Sessions. ICAO Resolution A41-20 states that "ICAO has accepted full responsibility for pursuing a course aimed at achieving maximum compatibility between the safe, economically effective and orderly development of civil aviation and the quality of the environment and is actively pursuing the concept of a 'Balanced Approach' for the reduction of aircraft noise and guidance on how states might apply such an approach".

The balanced approach to noise management developed by the ICAO consists of identifying a noise problem at an airport and then analysing different measures available to reduce noise through four basic principles; reduction of noise at source, land-use planning and management, noise abatement operational procedures and operating restrictions, with the goal of addressing the noise problem whilst considering the effects to all parties involved.

This summary outlines each of the four elements in the ICAO BA guidelines and gives references to case studies from airports around the world that have implemented some or all the frameworks.



1) REDUCTION OF NOISE AT SOURCE

Reduction of aircraft noise at source is fundamental and a strategically important part of the BA framework. The principal factors defining the sound level of an aircraft overflight are the noise radiating from acoustic sources on the aircraft, engines, airframe, etc. And the local topography and atmospheric/weather conditions during the event. The only factors that can be controlled with the aim of reducing noise at source are the principal elements of acoustic radiation from the aircraft such as, airframe, engine type, engine installation and the aerodynamic configuration of the aircraft such as flap configuration and airspeed.

Noise from a single aircraft is primarily produced by the engine. Introduction of the ICAO Annex 16 standards, chapters 2, 3 and 4 in 1998 has resulted in noise levels from separate flyovers at airports worldwide to decrease. As a result, modelled noise contours of 65 dB L_{dn} at airports have typically decreased since the 1970s regardless of the rise in total movements due to the replacement of noisy ICAO chapter 1 and 2 aircraft with much quieter chapter 3 and 4 aircraft.

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2) LAND-USE PLANNING AND MANAGEMENT

The goal of the second pillar of the BA, land-use planning and management, is to minimise the population affected by aircraft noise by introducing specific land-use zoning around airports. It is a necessary means to ensure that human activities nearby airports are consistent with aviation activities.

Residential areas near airports are normally generating most of the complaints and reverse sensitivity issues for air traffic operations. Intensification of such development in high noise areas will increase complainants and may put capacity constraints on airports and significantly increase the cost of providing transportation services.

An example of this situation is Schiphol Airport. Under directive from the Netherlands government Schiphol Airport has to reduce the number of houses inside the 58 dB L_{den} contour by 20% and the number of houses within the 48 dB L_{night} contour by 15% (12,766 houses in total) by November 2024. To achieve this, Schiphol Airport has worked through the BA framework and set targets to achieve their new restrictions, this includes reducing their operating capacity from 500,000 movements per year to 440,000 movements per year. Due to the short timeframe, land-use planning and management measures are not achievable and therefore the proposed measures are all related to operational restrictions. The total costs of each measure have been assessed and the table below shows the outcome of this analysis. The proposed measures will not quite achieve the target reduction of houses inside specific contours. The table below, lists the measures, the predicted reduction in affected houses and the cost effectiveness (i.e. the total cost of the measures apportioned per house removed from contours). The costs are estimated at approximately 600 – 700 thousand Euro per house.

Table 8.1 Effect on noise and cost-effectiveness of the combination to be notified

	Impact on target				Cost effectiveness (cost per reduced unit in EUR)			
Objective:	-20%	-20%	-15%	-15%				
Combination of measures	Houses within 58dB L_{den}	Highly annoyed people withinin 48dB L_{den}	Houses within 48dB L_{night}	People experiencing severe sleep disturbance 40dB L_{night}	Houses within 58dB L_{den}	Highly annoyed people withinin 48dB L_{den}	Houses within 48dB L_{night}	People experiencing severe sleep disturbance 40dB L_{night}
1. Use of quieter aircraft during nighttime period 2. Reduction of the usage of the secondary runways 3. Reduction of the capacity at night to 28,700 flights 4. Reduction of the capacity to 452,500 flights in total	-17.3%	-15.9%	-18.9%	-15.0%	-623,062	-42,160	-710,361	-208,840

Source: Notification Document European Commission notification Balanced Approach procedure for Schiphol September 2023

The Balanced Approach procedure recommends that an operating restriction should be a last resort. Proper land-use planning and management should be used to limit the possibility of reverse sensitivity effects on the airport, potentially limiting its operations, and therefore increasing the cost of providing services.

3) NOISE ABATEMENT OPERATIONAL PROCEDURES

Applying noise abatement operational procedures is a key pillar of the BA, allowing the airport to manage operational procedures to provide locally effective noise reduction to communities active in the airport's surroundings, from both arriving and departing aircraft.

ICAO Pans-Ops Volume 1 contains general guidance for airports around the developments of noise abatement departure procedures. By ICAO guidance all noise abatement departure procedures terminate at 1000m altitude, however there may be noise reduction benefits above this.

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Changing the operational procedures in accordance with ICAO guidance has the potential to make an immediate improvement in the environmental impact of aviation around an airport. Procedures in use today can be categorised into three broad components: noise abatement flight procedures, spatial management, and ground movement management.

ICAO BA also offers the following guiding principles that should be adopted when considering operational changes to reduce noise.

- Safety must not be negatively affected.
- Operational procedures should be developed in accordance with relevant ICAO provisions or regulatory guidance, while allowing for implementation of new procedures as that guidance evolves.
- Change to operational procedures must consider aircraft and operator capabilities and limitations with appropriate approval by the regulator.
- Appropriate assessment tools and metrics to support decision making and post-implementation review of conformance should be maintained.
- Interdependencies should be considered between other environmental and non-environmental impacts and disproportionate trade-offs should be avoided.

4) OPERATING RESTRICTIONS

Operating restrictions are defined in ICAO's BA guidance as "any noise-related action that limits or reduces an aircraft's access to an airport". The BA recommends considering the exposure reduction to be obtained from the other three BA elements ahead of applying operating constraints to eliminate noise exposure i.e. reduction of noise at source, land-use planning and management and noise abatement operational procedures.

To date hundreds of airports worldwide are implementing aircraft operational restriction for noise management purposes and many of them fall into the four categories below

- Global restrictions adopted worldwide or inside large regions to be applied at any airport. An example of this is the ICAO and EU decisions on Chapter 2 aircraft phase-out.
- Local restrictions adopted by airport operator or by the regulator to eliminate the operation of noisy aircraft types, for example Chapter 3 aircraft.
- Aircraft-specific restrictions based on individual aircraft noise performance, usually a specific route of departure or arrival at airport.
- Partial restrictions applied for specific flight directions and/or for certain runways at the airport, during noise-sensitive time periods (evening and night), or on specific days of the week (weekend).
- Progressive restrictions which provide for a gradual decrease in the maximum level of traffic or noise energy used to define a limit over a period of time, for example a quota for night-time movements at an airport.

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APPENDIX 2 COMMUNITY RESPONSE TO AIRCRAFT NOISE LITERATURE REVIEW

MARSHALL DAY Acoustics

CHRISTCHURCH AIRPORT
COMMUNITY RESPONSE TO AIRCRAFT NOISE
LITERATURE REVIEW

Rp 001 20201126 | 14 September 2023

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Attention:	**Christchurch Airport Environment and Planning Manager**
Report No.:	**Rp 001 20201126**

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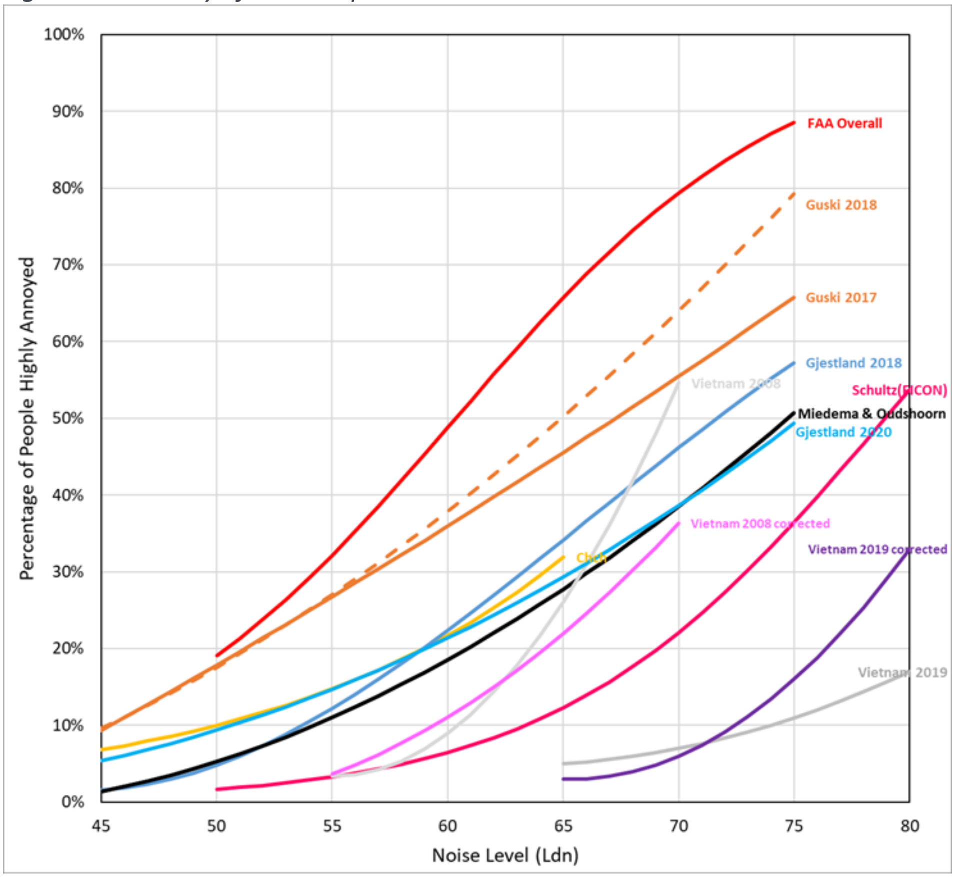
Cover Photo: Simon Eugster and Sergey Kustov

SUMMARY

Marshall Day Acoustics was engaged by CIAL to carry out a literature review of the research into community response to aircraft noise since 2001. A total of 57 studies have been reviewed and this report summarises the 14 most significant. Figure 1 below shows the dose-response curves from the studies reviewed which reflect the percentage of people highly annoyed by aircraft noise. A 'dose-response curve' is the graphed results of the percentage of people highly annoyed based on the noise level (L_{dn}[1]) they experience. With regards to community noise annoyance over time, six studies reported an increase, one reported a decrease, four reported no change and three did not provide comment on a change.

Figure 1: Summary of Dose-response curves



Summary of annoyance studies reviewed

A summary of our findings is broken down into four main regions: Europe, United States, Asia and New Zealand.

Europe Studies

In Europe, the Miedema and Oudshoorn 2001 dose-response curve is currently used. This shows that 10% of people were highly annoyed by aircraft noise at approximately 55 dB L_{dn}.

In 2017, the WHO commissioned a synthesis of studies that found the level of noise annoyance to be much higher; 10% of people highly annoyed at 45 dB L_{dn}. This conclusion informed the 2018 WHO Noise Guidelines, which recommends reducing noise from aircraft to 45 dB L_{dn}. International bodies around the world are considering whether to update their policies, and the WHO Noise Guidelines could provide the latest scientific knowledge.

[1] The various studies and dose-response relationships use either L_{dn} or L_{den} metrics. In general, L_{den} for aircraft activity is approximately 0.6 dB higher than L_{dn} therefore in this literature review, we use these terms interchangeably.

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United States Studies

The FAA currently use the Schultz 1978 dose-response curve, which is based on older data that includes all forms of transportation (aircraft, road, rail).

The FAA has since conducted a 20 airport study, which demonstrates the highest levels of annoyance out of all the studies reviewed. The study only considers noise from 50 dB Ldn and above. The level of annoyance at 50 dB Ldn is around 19% compared to 5% for the Miedema and Oudshoorn 2001 curve.

The FAA has not commented on whether this will be used to justify moving away from the Schultz curve. While there is no published literature critiquing the findings of this study yet, we consider it to be extremely robust and worth consideration.

Asian Studies

Our review is limited with regards to airports in Asia. We assess results from a Vietnam-specific study which is of relevance to Christchurch. However, in our opinion this should not hold much weight as culture and attitudes towards airport noise may be quite different.
There are Asian airports included in the WHO study along with airports in Europe so results from this region have been included in the overall data.

New Zealand Studies

New Zealand has use the Miedema and Oudshoorn 2001 dose-response curve in the past.

There are very few community response studies in New Zealand – we are only aware of the Taylor Baines study (which showed 10% of people highly annoyed at 50 dB L_{dn}) conducted for Christchurch Airport in 2002, and a recent road and rail noise study conducted by NZTA in 2019.

The NZTA study only looked at road and rail noise. Whilst this study did not consider aircraft noise, we have included it as it gives a basis for noise annoyance in New Zealand and shows that noise annoyance is higher in New Zealand when compared to the Miedema and Oudshoorn 2001 curves for road and rail.

However, the NZTA study had several short comings (some identified by the authors) including the issue that the noise annoyance questions were not masked. For these reasons we are of the opinion that little weight should be placed on the results.

Method of calculating annoyance dose-response curves

Most of the studies we have reviewed use the conventional method of predicting dose-response curves for noise annoyance. This method is not based on a set shape, but rather a 'best fit' based on the data contained in the survey.

Another possible approach is looking at the Community Tolerance Level (CTL). CTL is based on the assumption that the shape of the dose-response curve generally follows a set sigmoidal relationship, but that the onset of noise annoyance (i.e. the position of the curve relative to the noise axis) depends on non-acoustic factors. Most other studies fit a dose-response curve that is not a set shape but is a best fit based on the data contained in the survey or synthesis of surveys. This approach has been critiqued as actual dose-response curves are a different shape for different airports and often deviate from the standard sigmoidal shape assumed by CTL.

There has also been investigation into reasons why annoyance levels may have increased over time. Things such as the year of the study, the type of contact (phone, postal, face to face etc), the response rate and the annoyance scale (5-point vs 11-point scale) were investigated to see if they has some impact on the results.

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Of these factors, statistically only the scale (5 point vs 11 point) could account for the trend of increased annoyance in more recent studies. Although other studies which have investigated this further have ruled it out as a satisfactory explanation.

Sleep Disturbance

Literature on sleep disturbance research over the past 30 years has been reviewed to determine its relationship to aircraft noise. We conclude that energy equivalent metrics such as L_{night} are insensitive in respect to sleep disturbance. Metrics that consider the noise level of single aircraft events have been researched and cumulative indices have been developed that look at the effects of multiple night-time events. However, the complex assumptions and methodology that underpins these types of methods have not been evidenced with confidence.

We conclude that there is currently not an accepted approach in the literature to accurately assess the effects of aircraft noise on sleep disturbance. More research in this area is needed to determine a meaningful relationship and assessment methodology.

Non-acoustic factors

Non-acoustic factors are those, other than the noise level itself, which contribute to annoyance. Non-acoustic factors moderate an individual's sensitivity to noise, which is. subjective and can be influenced by elements such as age, gender and the attitude of the noise receiver. The resulting annoyance may influence behaviour in terms of how people live and whether they take action against noise.

The literature highlights that these play a potentially significant part in determining the level of annoyance in the community. However, we acknowledge that more research is needed to quantify the effect each of these factors has on noise annoyance.

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1.0 HISTORICAL COMMUNITY RESPONSE STUDIES

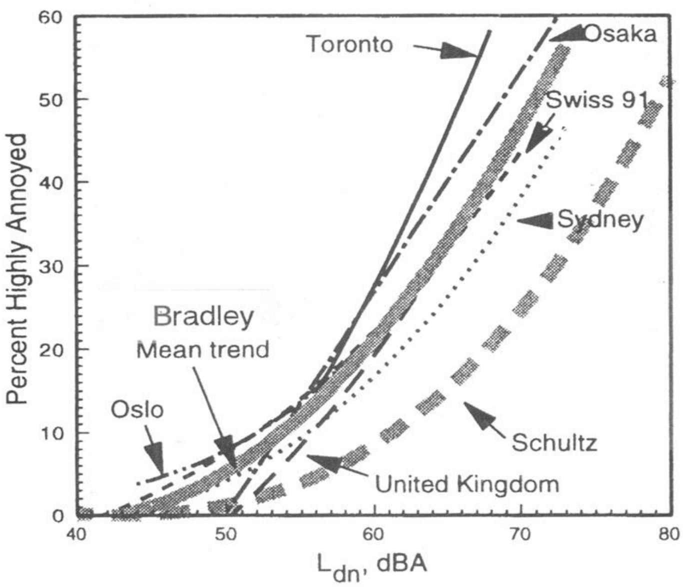
1.1 Introduction

A large number of overseas studies have been carried out over time to investigate community response to environmental noise. The general approach of these studies is to question residents (verbally or in writing) as to their level of annoyance to a particular noise source. The noise level at the respondent's location is then determined by either measuring it or by using calculated noise contours. 'Noise levels' are normally measured/calculated as L_{dn} – the day/night level which involves a summation of the noise energy over 24 hours with a 10 dB penalty for noise at night. Analysis of these widely varying results allows a 'dose-response curve' to be prepared showing the percentage of people highly annoyed versus the level of noise they are exposed to. Many studies in Europe use L_{den} as opposed to L_{dn}. L_{dn} includes only a 10 decibel weighting for night-time events between 10pm and 7am. L_{den} adds an additional weighting for flights in the evening period from 7pm of 5 decibels. The difference between these two metrics has been demonstrated to be around 0.5dB only and thus we use the terms L_{dn} and L_{den} interchangeably through this report.

Schultz 1978 provided the first synthesis of various studies into community response to transportation noise. The results were combined into a single dose-response curve that showed the community annoyance increasing with noise level (the Schultz curve is shown below in Figure 1). It is important to note that the Schultz 1978 curve was meant to represent noise from all forms of transportation (air, road and rail). Later studies noted differences in levels of annoyance between different sources of noise and separated out the dose-response curves.

In the 1990's, Bradley combined the results of a number of specific aircraft noise studies, to provide a relationship for community response to airport noise. The resulting graph (Figure 1 below), shows the various individual airport studies and the overall 'Bradley Mean Trend' for all studies (along with the Schultz curve).

Figure 1: Dose-Response Curves – Schultz 1978 & various others



Source: Bradley 1996

Use of the Bradley study came under specific scrutiny during a previous Environment Court hearing. In Gargiulo v Christchurch City Council (Unreported, C137/00, Environment Court at Christchurch, 17/8/2000, Jackson J) paragraph [29] the decision states.

> *"Consequently we accept his [Mr Day's] evidence in its entirety including his opinion that the figure as to community response to noise was accurate and could be relied on because it derived from Mr Bradley".*

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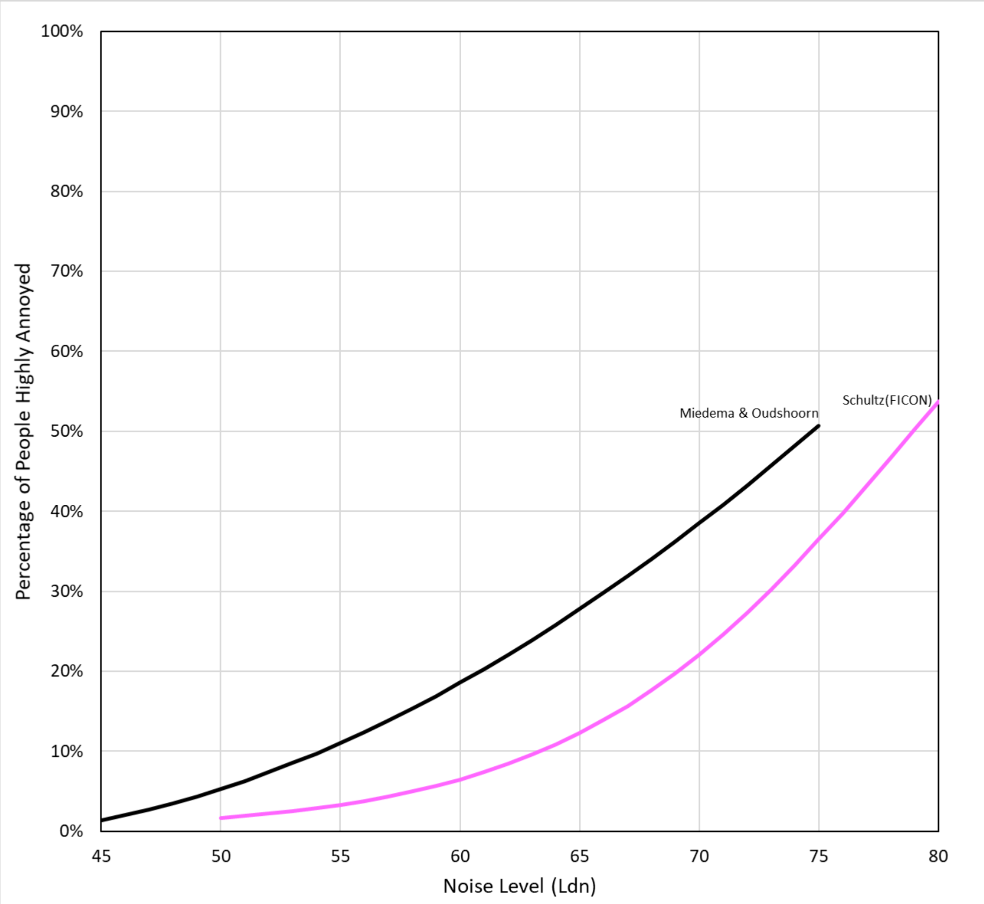
1.2 Miedema & Oudshoorn 2001 Synthesis of Studies

In 2001 Miedema and Oudshoorn examined studies from additional airports and used improved methods for establishing the regression curves. Their aircraft noise dose-response curve was based on 20 studies from around the world which include over 40 airports (some studies looked at multiple airports) with 34,214 respondents. The years of the surveys ranged from the 1960s to the 1990s with most studies in the earlier years.

Europe and New Zealand have adopted the dose-response curves from the Miedema and Oudshoorn study in 2001. This 2001 curve has generally replaced the earlier Schultz 1978 and Bradley 1996 curves apart from in the United States which still uses the Schultz 1978 curve.

Figure 2 compares the dose-response curves from Schultz 1978 with Miedema and Oudshoorn 2001.

Figure 2: Dose-Response Curves – Miedema and Oudshoorn 2001 vs Schultz 1978



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1.3 The Taylor Baines Christchurch Study 2002

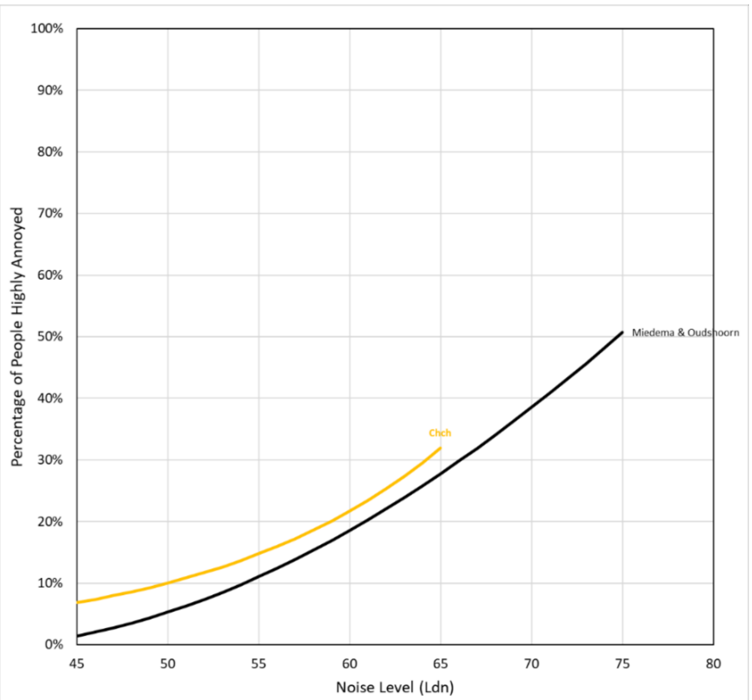
1.3.1 Study Summary

In 2001, Taylor Baines & Associates and Marshall Day Acoustics were engaged to conduct a noise annoyance survey in Christchurch. The study was conducted to investigate how the Christchurch community responded to environmental noise when compared to the previous overseas studies (Schultz, Bradley and Miedema). The Christchurch Study examined aircraft noise, road traffic noise and industrial noise in separate sub-groups. This review looks at the results from the airport noise study group only (498 responses).

Figure 3 compares the Taylor Baines dose-response curve with the Miedema and Oudshoorn 2001 curve. The resulting curve shows the Christchurch community experiences a higher level of annoyance (particularly at lower noise levels) than the Miedema & Oudshoorn 2001 study.

The study surveyed in five sample areas and was a masked survey which asked about other things in people's neighbourhood (parks, industry etc). Physical details of the dwelling were also asked along with respondent details and household composition. A total of 498 responses were received. The responses contained more responses from females and older people than the proportions shown in the 1996 Census.

Figure 3: Taylor Baines Study 2002 vs Miedema and Oudshoorn 2001



1.3.2 Study Design

Five sample areas were chosen to represent areas that were inside the current District Plan 50 dB L_{dn} contour and which would likely be in the future District Plan 50 dB L_{dn} noise contour. The Council provided a list of all the known addresses of residences within each sample area. For each sample area a random proportionate sample of separate residential addresses (sufficient to allow for non-responses) was drawn from all the known addresses within the specified geographical area.

The survey used masked questions and asked about other things in people's neighbourhood (parks, industry etc). Physical details of the dwelling were also asked along with respondent details and household composition. Two mail outs in March 2002 were required to achieve the agreed level of responses. These occurred a week apart from each other.

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2.0 COMMUNITY RESPONSE STUDIES SINCE 2001

Marshall Day Acoustics was engaged by CIAL to carry out a literature review of the international research into community response to noise carried out since 2001. A total of 57 studies have been reviewed and this report summarises the most significant 14 studies. A full bibliography is attached as Appendix B.

2.1 Summary of all Studies

Table 1 gives a summary of the 14 studies:

- 6 reported an increase in noise annoyance over time (FAA, Guski x3, WHO, Janssen and Vos)
- 1 reported a decrease (Vietnam)
- 4 reported no change (Gjestland x 2, Fidell, Gelderblom)
- 3 did not report on a change (NZTA, Brink, Gjestland 2021

Figure 4 shows the dose-response curves for each study. It appears that the difference in opinion exists between two main groups. Guski et al (includes Brink, Jannsen and Vos) and Gjestland et al (includes Fidell). We feel upon review of the literature that the evidence from Guski et al has more weight due to the fact that it was adopted by the WHO and also includes backing from Henk Vos who was the original author of the Miedema and Vos 1998 study which formed the basis of the Miedema and Oudshoorn 2001 dose-response curves.

Also, there appears to be no other literature out there from different authors critiquing the WHO 2018 noise guidelines and the issues raised form Gjestland et al have been refuted by Guski et al by reanalyzing the data to show no or little change in the dose-response curves from the original 2017 analysis. On this basis it seems appropriate to adopt the findings of the Guski 2017 study and resultant dose-response curves.

Table 1: Summary of Studies

Study	Increase/Decrease in Annoyance	Suggested Limit (if any)	No. Surveys	No. Responses	% HA @ 50 Ldn	% HA @ 65 Ldn	Results Challenged
			Historical Studies				
Schultz 1978	-	-	11	Unknown	1%	15%	-
Bradley	-	-	Unknown	Unknown	5%	35%	-
Miedema 2001	-	-	20	34,214	5%	28%	-
Taylor Baines 2002	Increase	50 Ldn	1	498	10%	32%	-

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Study	Increase/Decrease in Annoyance	Suggested Limit (if any)	No. Surveys	No. Responses	% HA @ 50 Ldn	% HA @ 65 Ldn	Results Challenged
			Studies Since 2001				
FAA 2021	Increase	-	20	10,328	**19%**	66%	N
NZTA 2019	-	-	3	801	5-8%	25-32%	Y
Vietnam 2009	Decrease	-	1	880	-	20%	N
Vietnam 2019	Decrease	-	1	502	-	3%	N
Guski 2017	Increase	45 Ldn	12	17,094	**18%**	46%	Y
Guski 2018	Increase	45 Ldn	19	39,309	**18%**	50%	Y
Gjestland 2018	No change	53 Ldn	18	16,047	5%	34%	Y
Guski 2019	Increase	45 Ldn	12	17,094	**18%**	46%	Y
Gjestland 2020	No change	-	65	93,000	9%	29%	Y
Brink 2020	-	-	-	-	-	-	Y
Gjestland 2021	-	-	-	-	-	-	Y
Fidell 2011	No change	-	43	76,000	5%	29%	Y
Gelderblom 2017	No change	-	62	58,867	-	-	Y
Janssen and Vos	Increase	-	41	48,369	-	-	N

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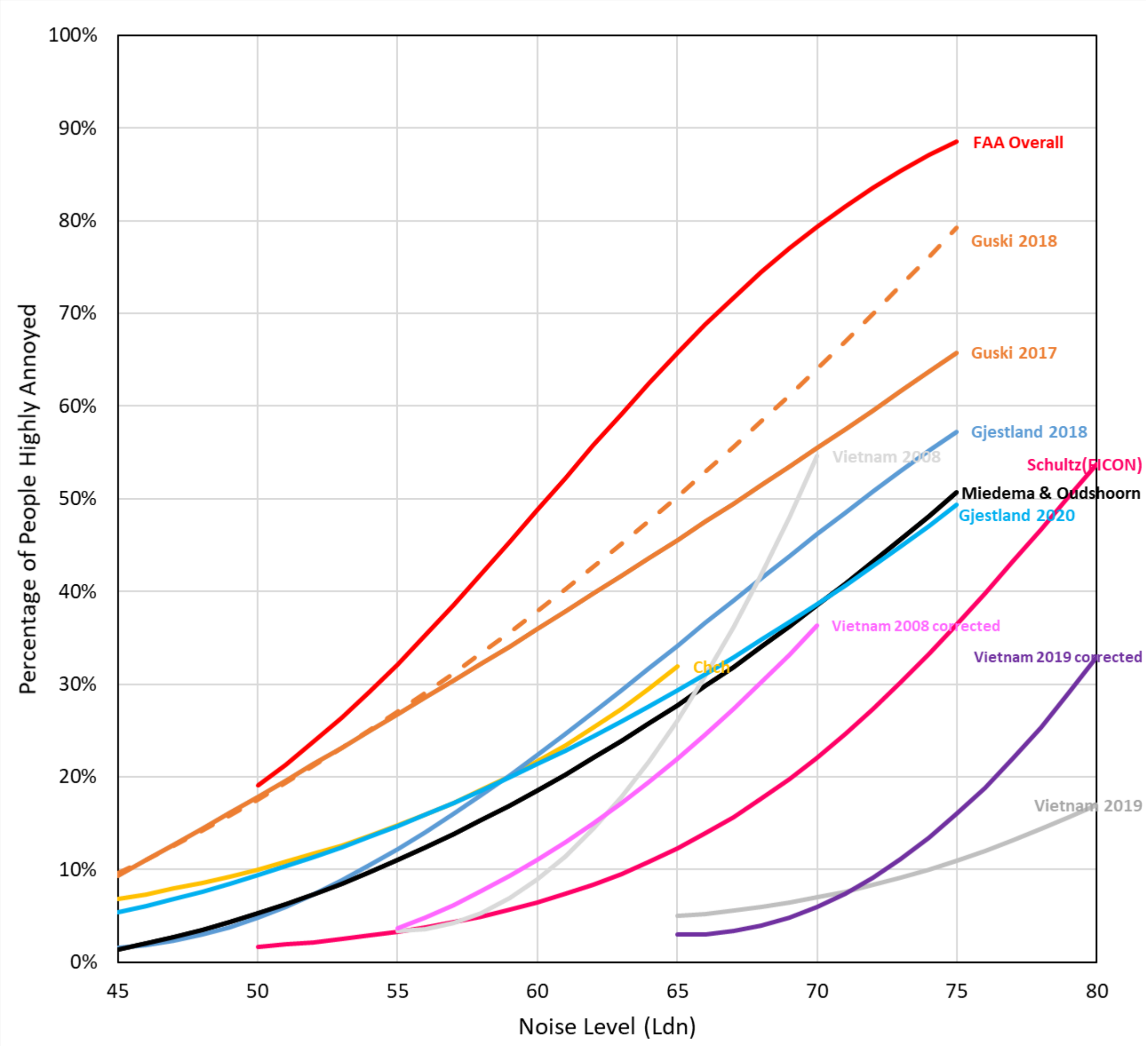
Figure 4: Summary of Dose-Response Curves



2.2 The FAA Study 2021

2.2.1 Study Summary

The US Department of Transportation conducted the Neighbourhood Environmental Survey (FAA Study) in 2021. The FAA conducted the study to Investigate whether the Schultz 1978 curve, which is used in the Unites States, needs to be updated.

The study included twenty airports and over 10,000 respondents. The study used the logistic regression model used to create the Miedema and Oudshoorn 2001 curve.

The resulting curves show much higher levels of annoyance than the Miedema & Oudshoorn 2001 curve and result in a trebling of the number of people predicted to be highly annoyed at most noise levels.

Figure 5 compares the dose-response curves from the FAA study with the Schultz 1978 and Miedema and Oudshoorn 2001 curves.

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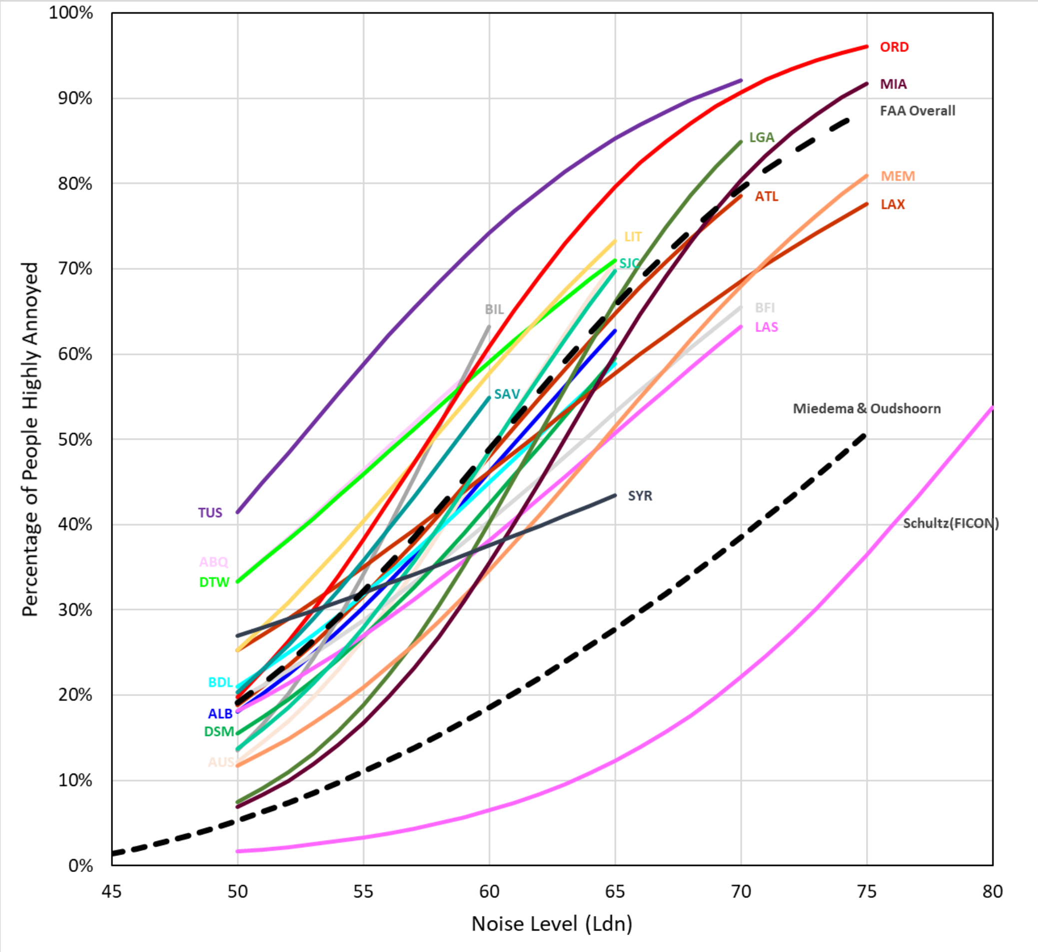
Figure 5: Dose-Response Curves – FAA Study 2021 vs Miedema and Oudshoorn 2001



2.2.2 Survey Design

This study used an initial mail out survey along with a follow up telephone survey to canvas more detailed questions such as respondents' opinions on noise, exposure to aircraft noise, relationship to the airport, concerns about aircraft operations, views on airport community relations, among others. The survey used masked questions and asked about other things in people's neighbourhood (parks, industry etc)

The study considered other survey forms such as web and in person surveys, but these were not used because:

- In person surveys were too costly
- Web based surveys were unlikely to provide adequate coverage of those with no access to the internet.

Hybrid survey forms were considered (using web and mail etc) but this was rejected as such approaches are shown to depress response rates.

The ACRP 02-35 research study published by Miller in 2014 required sample sizes of 500 respondents per airport to provide an adequate sample size.

The main annoyance questions in the survey were based on recommendations by ICBEN[2]. Demographic questions were asked but studies show that demographics do not impact noise

[2] International Commission of Environmental Effects

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annoyance. Selected attitudes such as fear of noise, distrust of the noise maker etc have an impact however and these were investigated further on the longer phone surveys.

The ACRP 02-35 study recommended the mail survey results be used to update the dose-response curve for the following reasons:

- The ACRP project's telephone survey had a response rate of only 12 percent compared to the mail survey's 35 percent
- Mail surveys have fewer coverage issues compared to telephone
- Most mail survey households adhered to the respondent selection protocol, providing evidence against the concern that those most annoyed would self-select into the survey
- The mail survey respondents were closer to Census figures on demographic variables collected
- While acknowledging small sample sizes, there is no evidence that there was a difference in annoyance between respondents to the mail survey and respondents to the telephone survey.
- Further, considering the above reasons, if any differences in annoyance existed, it could indicate improved data on the mail survey due to a more robust representation of the population.

2.2.3 Selection of Airports

A sampling frame criteria identified 95 airports that could be eligible for this study based on the following criteria:

- Located within the contiguous US
- Have at least 100 average daily jet operations
- Have at least 100 people exposed to greater than or equal to 65 dB L_{dn}
- Have at least 100 people exposed to noise levels between 60 dB L_{dn} and 65 dB L_{dn}

Of these 95 eligible airports, 20 airports were selected for the study. Three international airports were included automatically with the remaining 17 selected using a range of balancing factors to get a representative sample. These balancing factors were:

- Location
- Temperature
- Percentage night-time operations
- Number of flights
- Fleet mix ratio
- Population within 5 miles

2.2.4 Selection of Addresses

The target was to get 500 responses from each airport (10,000 in total). It was assumed that the response rate would be around 40%. Therefore, 1,300 houses at each airport (26,000 in total) would need to be sent a survey to meet the response target.

The study considered houses exposed to noise levels above 50 dB $L_{dn.}$ The 1,300 sample at each airport was broken down evenly into bands (stratum) from 50-55, 55-60, 60-65, 65-70 and 70+ $L_{dn.}$ This meant there were around 250 surveys sent out to a random sample of houses at each airport in each noise band. Noise bands that contained no houses had their sample transferred evenly into the other bands to ensure the overall sample size was still 1,300 for each airport.

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Surveys were sent out over a year long period to account for seasonal differences. To ensure that the first wave was a representative subsample of the initial sample, it was formed by sorting the initial sample within each airport noise stratum by county, census tract, block group, and block; then selecting an equal probability systematic sample within each airport noise stratum. Waves 2 through 6 were formed by randomly assigning the remaining addresses to five approximately equal-sized waves.

2.2.5 Calculation of Noise Levels

Noise levels at each site were calculated in the INM[3] for the annual average day for 2015 at each of the selected airports. Movements were allocated to the different runways and tracks based on radar data captured.

2.3 The NZTA Study 2019

2.3.1 Study Summary

The 2019 NZTA[4] study investigated noise annoyance from road and rail. Whilst this study did not consider aircraft noise, we have included it as it gives a basis for noise annoyance in New Zealand.

The main conclusion from the study was:

> *"The analysis suggests that the New Zealand population is more sensitive to noise as the onset of significant community response occurs at lower sound levels, approximately 13 dB lower for rail and 6 dB lower for road, when compared with Miedema and Vos."*

A total of two roads (557 responses) and one rail corridor (224 responses) were included in the study and dose-response curves were developed for the road and rail sources separately. The resulting curves show higher levels of annoyance than the Miedema and Oudshoorn 2001 curves, particularly at higher noise levels. **Figure 6** compares the dose-response curves from the NZTA study with the Miedema and Oudshoorn 2001 road and rail curves.

[3] Integrated Noise Model

[4] The New Zealand Transport Agency (Waka Kotahi)

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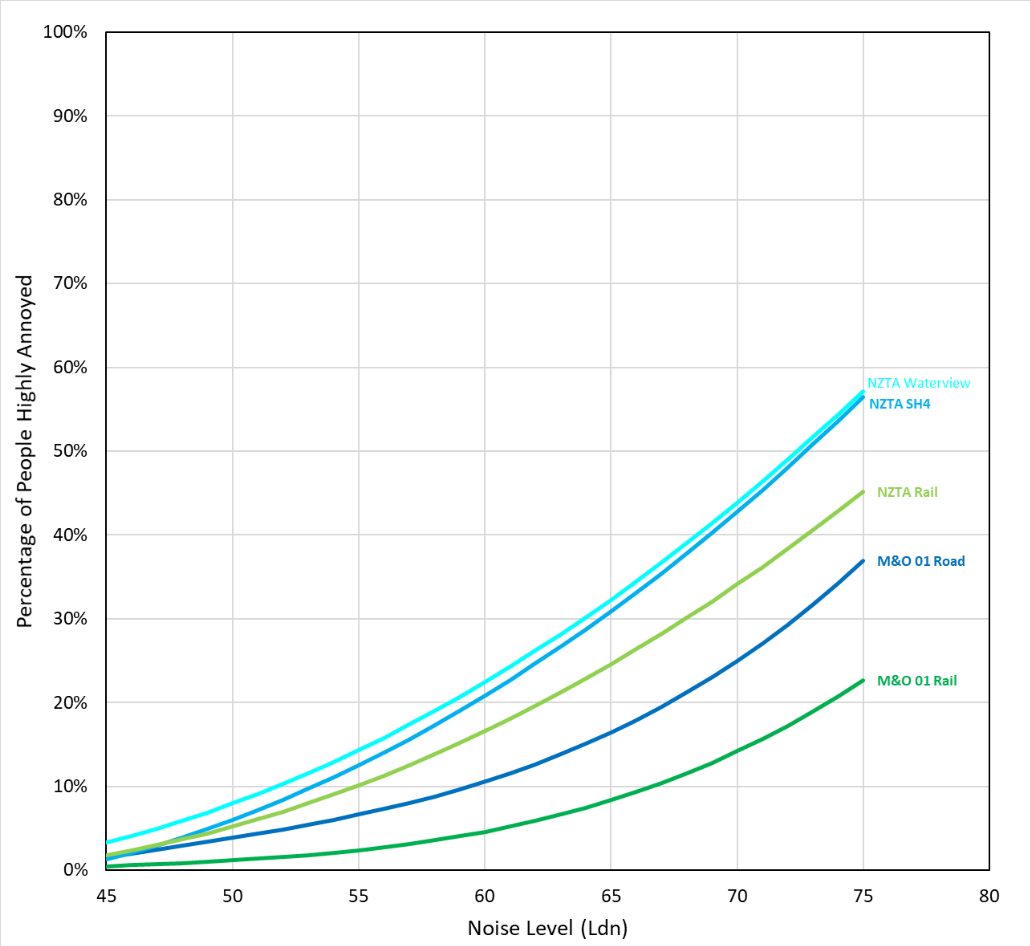
Figure 6: Dose-Response Curves – NZTA Study 2021 vs Miedema and Oudshoorn 2001



2.3.2 Survey Design

The survey was designed initially as a phone survey (for the SH1 Survey) and then was converted to an online survey tool (for the Waterview and the rail study). The survey did not use masking and the purpose of the survey (noise annoyance) was known to participants. Demographic details were also recorded. The survey was designed around ISO/TS 15666: 2003[5]. This standard has subsequently been updated in 2021.

A letter was sent out to households a week before and then a phone call was made. Only houses with phone numbers available were able to be included in the phone surveys. For the Waterview and rail survey areas the number of houses within the sample area was low and the phone surveys were converted to a mail survey to try and boost numbers.

This study had several short comings (some identified by the authors) including the issue that the noise annoyance questions were not masked. In a letter to the NZTA the authors identify the following issues with the study:

- The population size sampled was small and could have been increased by conducting more surveys on different roads/rail corridors to boost the number or respondents
- The calculated noise levels were based on a generalised noise model and could have been improved with better data inputs and calculation methodology

[5] ISO/TS 15666:2003 *Acoustics — Assessment of noise annoyance by means of social and socio-acoustic surveys*

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- The choice to use landlines as the primary survey technique likely reduced the number of potential respondents
- The study did not allow for atypical noise sources in the annoyance questions and therefore it is uncertain whether the respondents were basing their responses on the overall noise environment, or their responses were biased towards these events.
- The survey did not include questions about the time-of-day noise annoyance occurred

Compared with the Auckland 2013 census data the sample across each study area has a greater proportion of older individuals and a lower number of individuals in employment. Age has been demonstrated as a factor that influences annoyance with annoyance peaking at 45 years old. This could account for the higher annoyance levels measured

For these reasons we are of the opinion that little weight should be placed on the results. NZTA is currently undertaking a new community response to noise study.

2.3.3 Selection of Sites

The aim of the study was to assess dose-response relationships for annoyance from a new or altered road, existing road and existing rail site.

- 18 roads were evaluated for their suitability (12 new, 6 existing)
- 11 rail corridors were evaluated for their suitability (6 passenger, 5 freight).

The number of receivers within 500m of the road/rail route was assessed for each site. The number and spread of receivers was the main factor for site selection along with preference for high traffic flows and recently opened roads. The target response size was 400 for each site.

State Highway 1 – South Auckland and Auckland's southern rail corridor were selected for the existing sites based on the above criteria. Roads of National Significance were then looked at to pick the 'new or altered' road site. Of these projects five were investigated more closely. The final project chosen was Waterview.

2.3.4 Selection of Addresses

The target was to get 400 responses from each study area. The following number of houses were invited to take the survey for each site:

- State Highway 1 – 2000 invited / 400 completed (phone)
- Waterview - 1,771 invited / 157 completed
- Rail – 1,657 invited / 244 completed

The study considered houses exposed to noise levels above 46-48 dB $L_{Aeq(24hr)}$ for roads and 44.5 dB $L_{Aeq(24hr)}$ for rail. The samples were broken down into three categories of low, medium, and high noise as shown below to ensure an even distribution over various noise levels as much as possible.

Table 4.1 Noise level groupings ratings for the three study sites

Noise level band	$L_{Aeq\,(24h)}$ / dB		
	SH1	Waterview	Rail
Low	<48.5	<46.0	<44.5
Medium	48.5-53.0	46.0-50.3	44.5-50.3
High	>53.0	>50.3	>50.3

The State Highway 1 study area had surveys completed in September 2016. The Waterview and the rail corridor followed in October 2016 and March 2017. Th mail surveys to top up the phone surveys for Waterview and the rail project were sent out in April 2017.

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The noise level groupings for the responses are given below:

Table 5.3 Noise level grouping

Noise level band	Total	Rail	SH 1 south	Waterview
	%	%	%	%
Low	39	22	48	41
Medium	26	39	16	30
High	35	39	35	29

Table 5.4 Noise level ranges within study areas

Noise level band	$L_{Aeq(24h)}$ dB		
	Rail	SH 1 south	Waterview
Low	35-43	40-49	32-46
Medium	45-50	49-53	46-50
High	50-64	53-72	50-64

2.3.5 Calculation of Noise Levels

Noise levels were calculated in CadnaA[6] using the most recent traffic flow and rail movement data. The study used traffic data and train movements (from sources such as Mobile Road, Auckland Transport and Kiwirail. The data used was not as detailed as what would normally be required to model a new road but was considered to be sufficient for establishing noise exposure.

More detailed noise models would have been beneficial to allow calculation at building façades rather than an the centre of the parcel.

2.4 The Vietnam Study 2020

2.4.1 Study Summary

The Vietnam Study summarises two community response studies done in 2008 and 2019 at Vietnam's main international airport Tan Son Nhat. The main conclusion is that:

> *"The L_{den} –% HA relationship of the 2019 survey is lower than that of the 2008 survey and different from the relationship established in the European Union Position study (Miedema & Oudshoorn curve)"*

Figure 7 compares the dose-response curves for the 2008 and 2019 studies with the Miedema and Oudshoorn 2001 curve.

A total of 880 and 502 responses were obtained in the 2008 and 2019 surveys, respectively. Flights have tripled from 2008 to 2019 with noise levels found to increase markedly at most sites.

The initial dose-response curves (in grey) produced did not account for non-acoustic factors. When these were accounted for the resulting dose-response curves are quite different as shown in Figure 7 in pink and purple.

The dose-response curves that account for the non-acoustic factors show lower levels of annoyance that the Miedema and Oudshoorn curves.

[6] Computer Aided Noise Abatement

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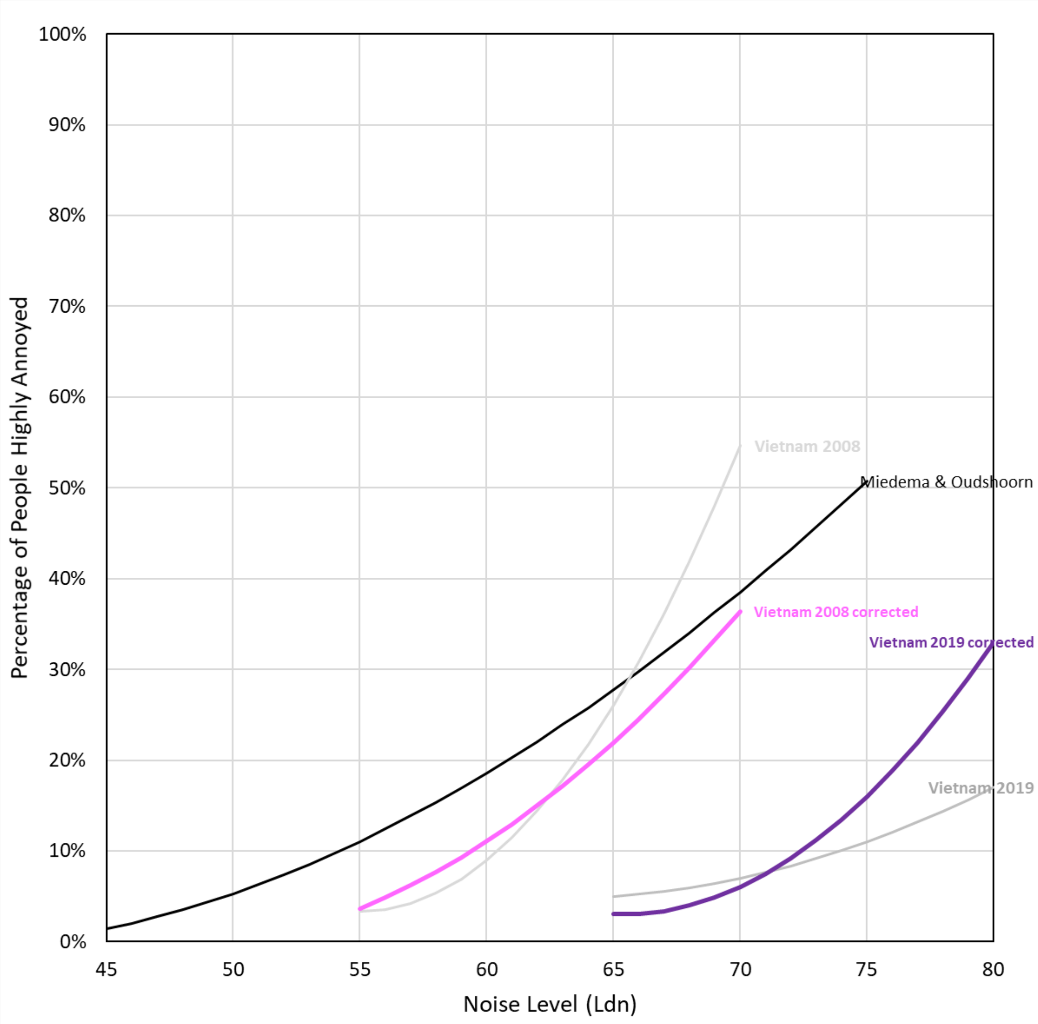
Figure 7: Dose-Response Curves – Vietnam Study 2020 vs Miedema and Oudshoorn 2001



2.4.2 2008 Study Design

For the 2008 study ten residential areas were selected around Tan Son Nhat airport. These include eight areas that were directly underneath the flight paths. The site selection was meant to represent noise exposure at a range of different distances from the airport.

The original 2008 survey was conducted using face to face interviews. The survey included a balance of genders and ages and only included those over 18 years old. The questionnaire was designed to follow the Technical Specification of ISO/TS 15666: 2003 and was a masked survey which included questions about the general environment as well as noise. Both the 5- and 11-point scales were used to assess noise annoyance as per the ICBEN guidelines. This standard has subsequently been updated in 2021.

Field measurements in Ho Chi Min city were used to quantify the noise exposure in each area and a week of noise data was recorded and analysed. Flight operation data was also collected for the same period.

2.4.3 2019 Study Design

The 2019 study looked at the same ten areas in the 2008 survey. Two new areas were added to act as control areas as they were not impacted by aircraft noise. Face to face interviews were used again in this survey and the same questions were used as the previous survey. Data on the health status of residents was also collected to investigate the effects of noise around the airport.

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The noise levels were quantified using weeklong measurements, as occurred in the 2008 study. Flight operation data was also collected for the same period.

2.4.4 Results

A total of 880 and 502 responses were obtained in the 2008 and 2019 surveys, respectively. The response rate in the 2008 study was higher and contained a lower proportion of older people.

The number of flights at the airport has increased markedly (3.3 times) from 200 per day in 2008 to 720 per day in 2019. Night-time flights in the 2019 survey experienced an even larger (4.3 times) increase.

Noise levels were found to increase between 2008 and 2019 with noise levels found to increase by 10 dB or more at four of the sites with the remaining sites experiencing a change in noise level ranging from 2-7 dB.

The initial analysis showed there was a general decrease oi noise annoyance between 2008 and 2019 with the exception of 2 sites. A marked decrease of over 35% was observed at sites 5, 6 and 7.

The study was refined further to consider the following non-acoustic factors:

- noise sensitivity
- length of residence
- total floor area of the house
- the frequency of opening windows
- the area preference
- evaluation of the surrounding quietness

A significant difference between surveys was found for noise sensitivity, length of residence, and area preference. Noise sensitivity had the greatest effect on the results. The corrected dose-response curves that account for these factors are shown in the graph in Section 2.4.1 along with the original uncorrected curves. The graph shows a narrowing between the dose-response curves when corrected for non-acoustic factors with the 2019 study showing slightly higher levels of annoyance than previously.

2.5 Guski 2017 Synthesis of Studies (to inform WHO 2018 noise guidelines)

The Guski 2017 study is a synthesis of more recent dose-response studies from 2001-2014 and supports the claim that noise annoyance has increased when compared to the Miedema and Oudshoorn 2001 dose-response curve. This study informed the 2018 WHO noise guidelines.

This study concludes that:

> *"The increase of %HA in newer studies of aircraft, road and railway noise at comparable L_{den} levels of earlier studies point to the necessity of adjusting noise limit recommendations"*

The aircraft noise dose-response curve in this study is based on 12 surveys from around the world and over 17,000 responses. The years of the surveys ranged from the 2001 to 2014. The dose-response curve is significantly higher than the Miedema and Oudshoorn 2001 Curve.

Figure 8 compares the dose-response curves from this study with the dose-response curves from Miedema and Oudshoorn 2001.

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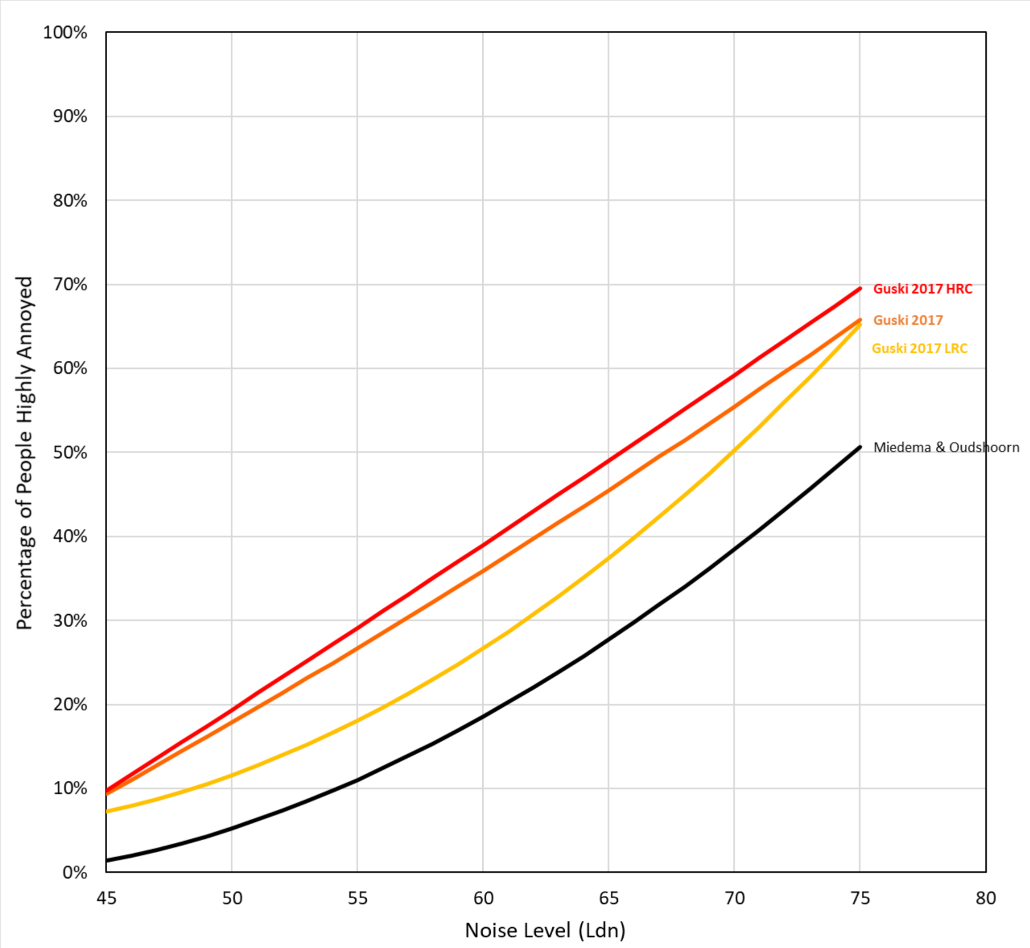
Figure 8: Dose-Response Curves – Guski 2017 vs Miedema and Oudshoorn 2001



Some studies have suggested that the increase in noise annoyance levels shown in more recent studies is due to most modern airports having a high rate of change (HRC) in flight movements than the earlier studies which happened to include mainly airports with a low rate of change (LRC).

This study considers whether some of the change in the number of people highly annoyed could be explained by airports that have a HRC in flights vs a low LRC.

A HRC airport is defined as one that has experienced an abrupt change in the number of flights defined by a significant deviation in the trend of aircraft movements from the trend typical for the airport. HRC airports also include those that have had public discussion about operational plans within three years of when the survey was conducted.

From the twelve studies considered, five were considered HRC, five LRC and two unclassified. Figure 8 show the HRC and LRC dose-response curves in relation to the overall curve. The two dose-response curves overlap at the highest and lowest noise levels, but the LRC curve shows lower annoyance levels overall.

However, the LRC dose-response curve still shows 5-15% higher annoyance levels than the Miedema and Oudshoorn 2001 curve. This finding may be seen to confirm the conclusions of other studies in saying that noise annoyance has increased over time.

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2.6 WHO 2018 Environmental Noise Guidelines

The WHO noise guidelines published in 2018 (ref Figure 9) recommend reducing aircraft noise levels to below 45 dB L_{den}. This is a 10 dB reduction from the 55 dB L_{dn} limits specified in NSZ6805:1992. The rules are copied below.

These recommendations are based on the results of the Guski 2017 synthesis of studies which shows a level of 10% of people highly annoyed at 45 dB L_{den}. In the past 10% has generally been used as the threshold where limits are set. The Miedema and Oudshoorn 2001 curve has 10% of people highly annoyed at around 55 dB L_{dn}.

Figure 9: WHO 2018 noise guidelines

3.3 Aircraft noise

Recommendations

For average noise exposure, the GDG **strongly** recommends reducing noise levels produced by aircraft below **45 dB** L_{den}, as aircraft noise above this level is associated with adverse 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.

To reduce health effects, the GDG strongly recommends that policy-makers implement suitable measures to reduce noise exposure from aircraft in the population exposed to levels above the guideline values for average and night noise exposure. For specific interventions the GDG recommends implementing suitable changes in infrastructure.

2.7 Uptake and Impact of the WHO Environmental Noise Guidelines

In 2023 the WHO in conjunction with the European Environment Agency released a policy brief examining the uptake, impact and experiences of European member states in relation to the 1999 and 2018 WHO environmental noise guidelines [58].

The assessment methodology was split into three main steps:

1. A workshop in 2019 with representatives of several member states.
2. A survey conducted in 2022 on the implementation status of the guidelines in member states.
3. In 2023 several survey respondents were asked for more detailed information and context.

The assessment results show that the guidelines have already had an influence on several member states of the WHO European Region. The guidelines have helped policymakers to take a harmonised and consistent approach when estimating the health effects and disease burden from environmental noise. However, there were some main challenges and barriers to the implementation of national noise limits aligned with the 2018 guidelines that were identified by this assessment.

- One of the main points was that the recommended noise levels were regarded to be unattainably low and, therefore, not feasible. The gap between current national noise limits and the guidelines' recommended exposure levels is too wide and that interim targets are needed.
- The economic costs of implementing noise limits aligned with the guideline exposure levels are too great.

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- Improvement in the guidelines for assessing the health effect of environmental noise, the current WHO guidelines set out L_{den} and L_{night} metrics. It has been suggested that the guidelines should consider additional acoustic parameters that account for variability in environmental noise sources, such as, intermittency measures and impulse, or single event indictors.
- The fine point of improvement in the assessment was a general need to increase the size and quality of the evidence base, further research on environmental noise and health is needed to close the current gaps in the knowledge base.

In conclusion, there is more guidance, information, products and tools required to implement the more ambitious noise limits set out in the WHO guidelines. Whilst the framework has provided a good standardised system for assess environmental noise affect across different nations, the current suggested noise limits and tools set out in the guidelines need to be updated to allow continued adoption.

2.8 Gjestland 2018 Synthesis of Studies (Updated from 2017)

The Gjestland 2018 study critiques the Guski 2017 study which informed the new WHO 2018 noise guidelines. The study investigates another selection of other 21st century studies (16,000 responses) and yields a different result.

The main conclusion from the study is:

> *"The moderate quality evidence report (Guski 2017) was used by the WHO Guidelines Development Group to strongly recommend a limit of L_{den} 45 dB to avoid adverse health effects from aircraft noise.*
>
> *A separate dataset has been compiled from 18 post-2000 aircraft noise surveys…The results of this effort indicate that the recommended exposure limit to avoid adverse health effects from aircraft noise should be L_{den} 53 dB."*

Figure 10 compares the dose-response curves from the Miedema and Oudshoorn 2001. Curves have also been plotted for HRC/LRC airports.

The calculated dose-response curve is much closer to the Miedema and Oudshoorn curve than what the Guski 2017 study showed with values only differing by 3 dB. Based on this the study could not conclude whether the two curves are statistically different.

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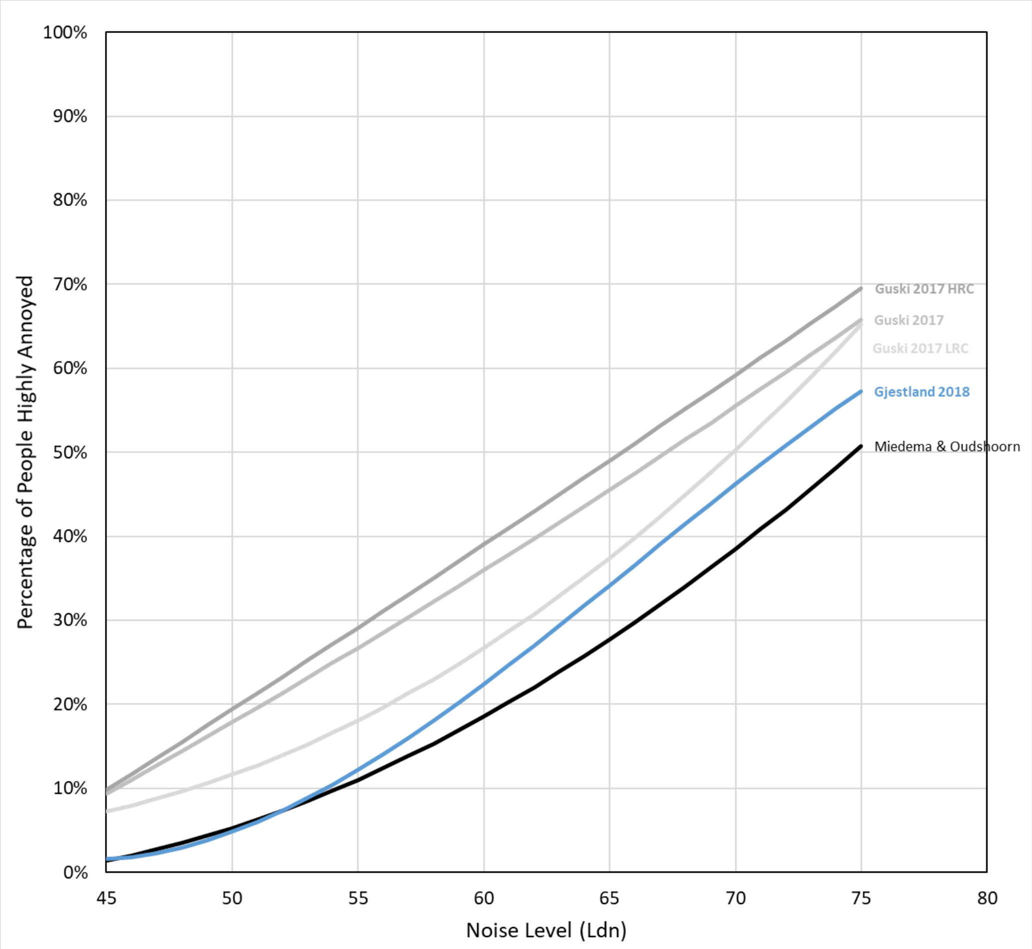
Figure 10: Dose-Response Curves – Gjestland 2018 vs Miedema and Oudshoorn 2001



This study calculated a dose-response curve for 18 post 2000 studies that the authors felt were a better selection than those included in the Guski 2017 study. Only six of these studies were included in the Guski 2017 study which informed the WHO 2018 noise guidelines. This synthesis of studies included 16,047 participants with half of the airports HRC and half LRC.

The Guski 2017 curve includes results from the HYENA study in Germany which only surveyed residents from 45-70 years of age. van Gerven 2009 has shown that age has been demonstrated as a factor that influences annoyance with annoyance peaking at 45 years old.

The Miedema and Oudshoorn dose-response curve included studies that looked at all ages. As the HYENA dataset comprises 28% of the total respondents in the synthesis of studies, it would have an impact on the results. The HYENA study also asked specific questions about night-time and daytime noise which was not included in the other studies and does not conform to the standard ICBEN questions.

Moreover, two airports in the HYENA study which experienced recent airplane crashes were included in the data even when the authors of the HYENA study excluded them from the analysis. Overall, all these factors could add to the higher level of annoyance measured.

Gjestland also asserts that the Guski 2017 study does not account for the numbers of survey respondents in the dose-response curve and that over 40% of the dataset for instance is from Amsterdam airport which would skew the results. Gjestland states that:

> *"Any specific non-dose factor that may be present at this airport will therefore have a prominent and disproportionate influence on the final exposure–response function."*

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Gjestland concurs with the assessment that LRC airports have lower annoyance levels than HRC ones. A study by Gelderblom in 2017 assesses that there is a 9 dB difference between LRC and HRC airports. Guski 2017 states that this gap is 6 dB.

2.9 Guski 2018 Synthesis of Studies (Updated)

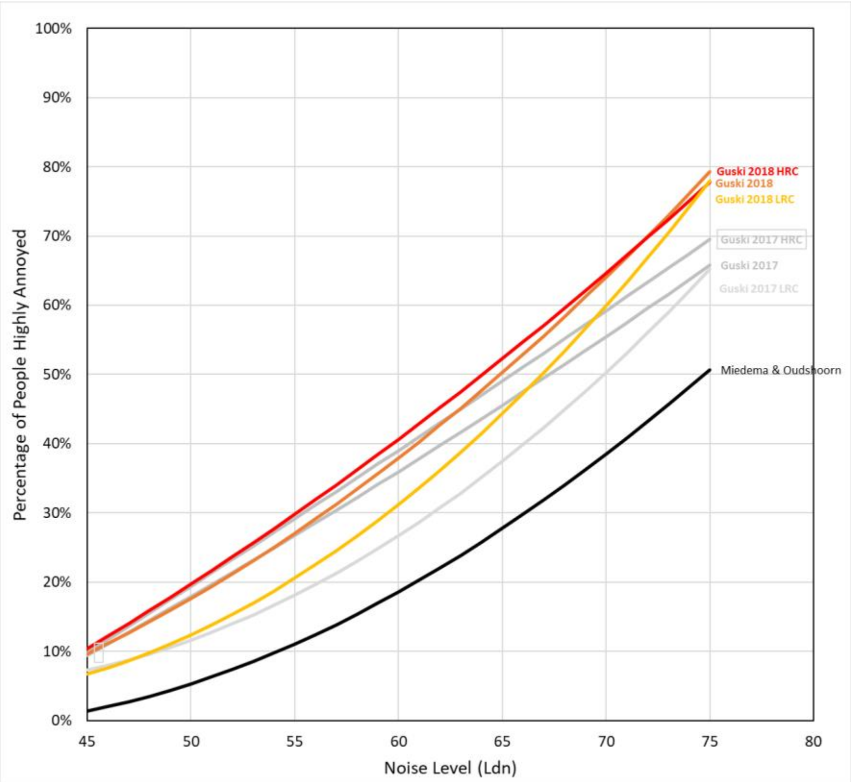
The Guski 2018 study is a follow up to the Guski 2017 study and a response to the Gjestland 2018 study discussed in Section 2.8. The study adds seven more airport surveys to the mix to give a total of 19 and a total of over 39,000 responses. This study supports the claim that noise annoyance has increased when compared to the Miedema and Oudshoorn 2001 curve.

The main conclusion from the study was:

> *"Recent publications found a considerably higher percentage of highly annoyed residents as compared to the so-called EU standard curve for aircraft noise. This is partly due to the rate of change of the airports under study. However, even in relatively stable conditions, an increase of the %HA at comparable continuous sound levels can be observed."*

Figure 11 compares the dose-response curves with the Miedema and Oudshoorn 2001 curve. The curve is significantly higher than the Miedema and Oudshoorn 2001 curve with 10% people Highly Annoyed at 45 dB L_{dn} versus 55 dB L_{dn}. The results show higher levels of annoyance at higher noise levels than what was presented in the Guski 2017 study.

Figure 11: Dose-Response Curves – Guski 2018 vs Miedema and Oudshoorn 2001



This study goes on to describe three reasons which might explain the differences in the results we see from the earlier Miedema and Oudshoorn 2001 synthesis of studies and this study. As summarised below.

Methodological differences (sample size, response rate, calculation methods)

- Meta-analysis of different studies has determined that:
    - Face to face surveys and telephone surveys have lower annoyance than postal surveys (older surveys generally face to face)

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  - Higher response rates significantly associated with a decrease in reported annoyance (higher response in older surveys)
  - Annoyance judgments higher on the 11 points scale than the 5-point scale, maybe not statistically significant though (5-point scale used in older surveys mainly)
- Older surveys mainly used sampling strategies that looked at very high and very low noise levels leaving out the mid-range whereas newer surveys look at all noise levels. Comparison of the older ANIS study and newer ANAISE British aircraft noise studies which used these two types of stratification show that higher annoyance levels were observed in a more stratified sample as occurs today.
- Prediction of noise level on the ground has improved significantly for newer surveys with better availability of data on movement numbers and flight paths. Also, the calculation software algorithms have changed over time generally resulting in smaller noise contours meaning noise level at larger distances from the airport are calculated to be lower.

Situational differences (rate of change, fleet mix changes)

- Some studies have claimed that older studies generally looked at stable airports that had a LRC and that newer studies mainly looked at airports that had a HRC (as defined previously in Guski 2017).
- The Guski 2017 and Guski 2018 studies showed that HRC airports do have slightly higher levels of annoyance than the LRC airports (7-10%), but that even the LRC dose-response curves are still significantly above the Miedema and Oudshoorn 2001 curve.

Societal changes (change in values/expectations)

- People may have become more attentive to environmental dangers and to their individual health and wellbeing as their standard of living has increased.
- There is no indication in past noise surveys that personal noise sensitivity has increased over time. However, this could be a factor to explore in more depth.

2.10 Guski 2019 (response to Gjestland 2018)

The Guski 2019 study is a response paper to the Gjestland 2018 study which critiqued the previous Guski 2017 synthesis of studies. The Guski 2017 study informed the WHO 2018 noise guidelines.

The main conclusion from this paper is:

> *"There were no specific flaws, faults, or inaccuracies in the analysis of the available evidence in the bespoke systematic review. We are convinced that the WHO Guideline Development Group did not come to false conclusions and that their recommended guideline value for aircraft noise is not unjustifiably"*

One of Gjestland 2018 critiques of the Guski 2017 study was that it included the HYENA study which only surveyed residents from 45-70 years of age. Gjestland 2018 asserts that age has been demonstrated as a factor that influences annoyance with annoyance peaking at 45 years old and that therefore the dataset should not be included.

Guski 2019 responds by saying that more recent evidence shows that age is not so much of a factor on annoyance and points towards the NORAH study which reports a weak non-linear effect of age. A study by Brink 2019 shows the same findings.

Gjestland 2018 critiques the fact that the Guski 2017 study did not apply weightings to the different studies for the number of survey respondents and that over 40% of the dataset for instance is from Amsterdam airport which would skew the results. Guski 2019 concurs that weighting can induce bias instead of reducing it.

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In response to this Guski 2019 has undertaken a weighting of the original dataset based on the square root of the sample size which is a commonly used procedure. This weighting is non-linear which reduces the impact of the absolute sample size for larger samples. The overall effect of this weighting is minimal as shown in Figure 12 below especially for level around 50 dB L_{dn} where there is little change.

Figure 12: Weighted (red) vs non-weighted (black) dose-response curves

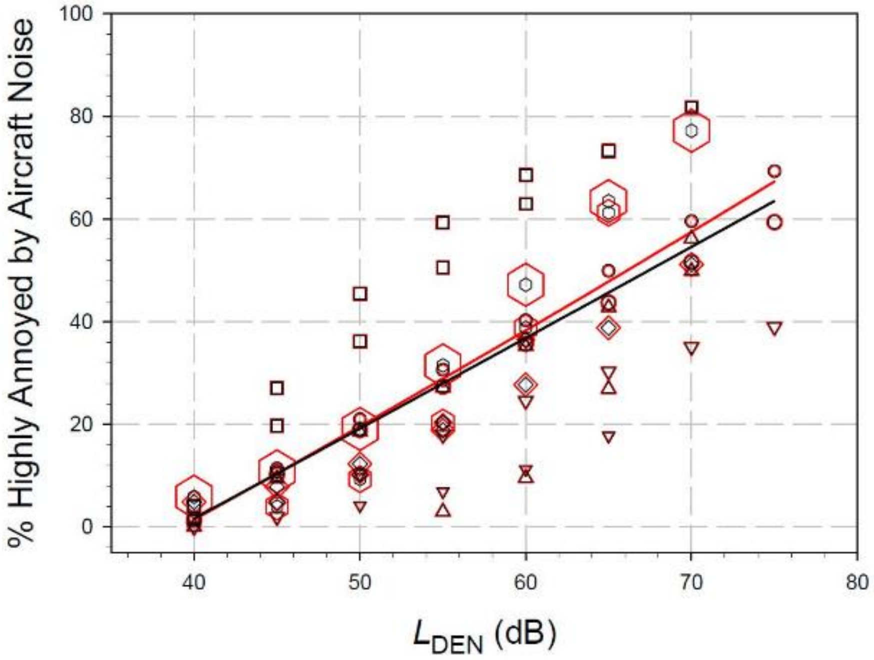

Figure 1. Exposure–response curves for aircraft noise annoyance responses in the WHO dataset [2]. "Highly annoyed" refers to respondents using ≥73% of the annoyance response scale. The red data points and regression line refer to study size weighting according to sample size; the black data points and curve refer to the same dataset without study size weighting.

The Gjestland 2018 study proposes CTL should be used to define and analyse community response to noise at different airports. This allows you to set a noise annoyance curve at each airport. Guski 2019 states a few issues with the CTL approach. Firstly, that CTL curves are based on a set sigmoidal curve form and slope which assumed the exposure-response function is the same at all airports.

Guski 2019 asserts that this is contrary to their findings where the dose-response curve shape for different airports varies quite a bit as shown in Figure 13 below. Guski 2019 is doubtful that a single curve shape can be derived at all due to the variability of the shape of different dose-response curves and that therefore CTL is not necessarily a more reliable method of defining a dose-response relationship.

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Figure 13: Dose-response curve shapes for different airports in the Guski 2017 study

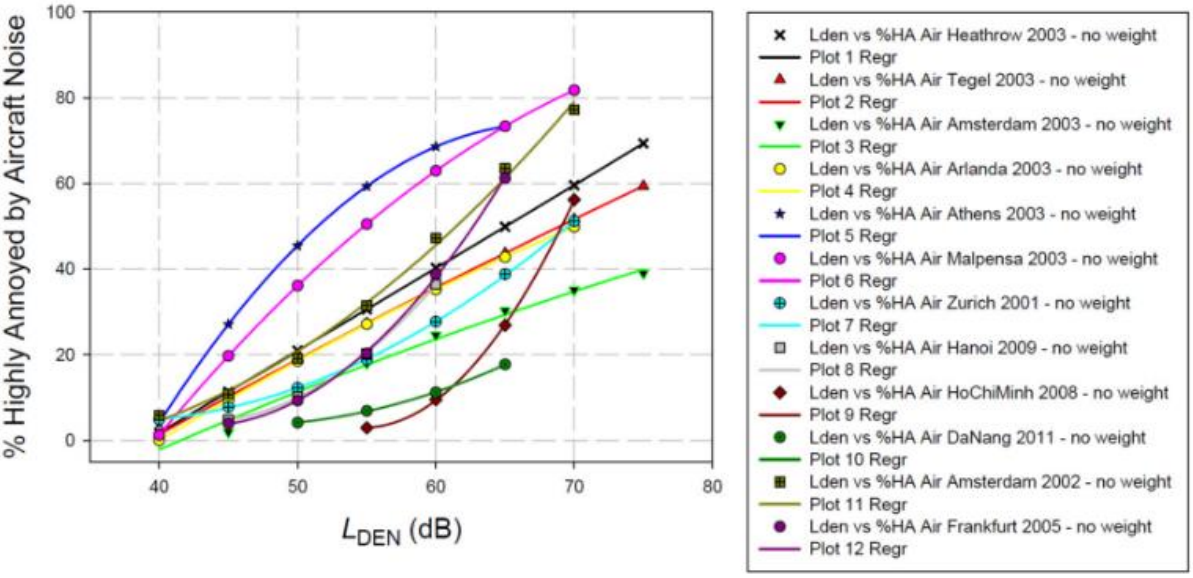

Figure 2. Individual exposure–response curves for aircraft noise annoyance responses in the 12 studies of the full WHO dataset [2]. % Highly Annoyed (%HA) refers to respondents using ≥73% of the annoyance response scale (same definition as in Figure 1). No weighting according to sample size is applied here.

2.11 Gjestland 2020 Synthesis of Studies (1961-2014)

The Gjestland 2020 study critiques the new WHO 2018 noise guidelines and the Guski 2017 study which informed them. The study investigates a number of studies since the 1960s (93,000 respondents) and gives a dose-response curve based on analysis of these.

The main conclusion from this study was:

> *"A re-analysis of a larger and more representative selection of studies that relies on standard procedures shows that no meaningful changes in prevalence rates of high annoyance with aircraft noise have occurred and that existing evidence does not support WHO's revised recommendations."*

The study looks at 65 surveys completed between 1961 and 2015. The surveys from the HYENA study have not been included due to the study only including older respondents over 45 years of age as discussed previously in Gjestland 2018.

As there are some questions around the validity of older datasets, the study splits the data up into three datasets (1961-2015, 1961-2000 and 2000-2015) and plots regression curves for each. The number of respondents in the pre and post 2000 period was around 69,000 and 24,000 respectively.

The dose-response curves for each time period vary little and are generally similar to the Miedema and Oudshoorn 2001 curve. However, the curve for post 2000 study is slightly higher (about 5%) where 10% of people become highly annoyed at around 50 dB L_{dn}.

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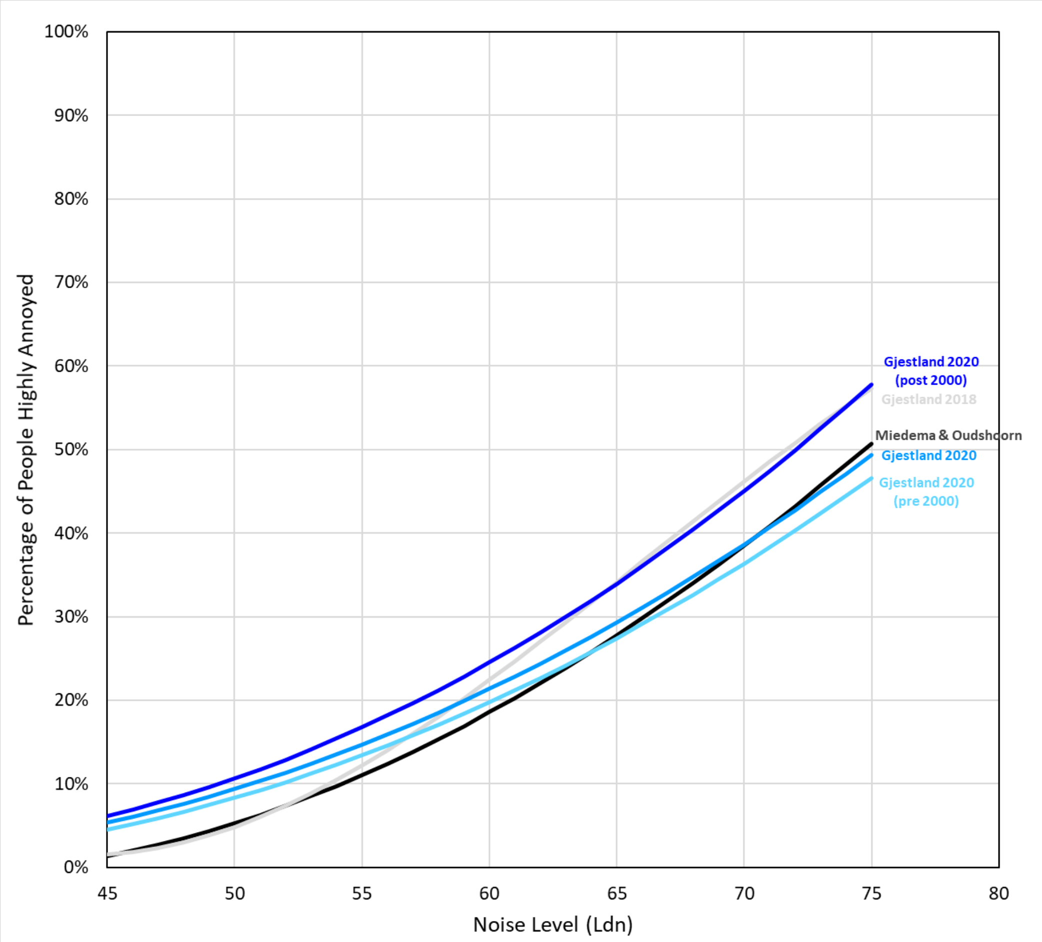
Figure 14: Dose-Response Curves – Gjestland Study 2020 vs Miedema and Oudshoorn 2001



A multi-step analysis procedure, the same as that used in the Guski 2017 study, was applied to this data to derive the dose-response curve. Gjestland 2020 critiques the multi-step analysis procedure used by Guski 2017 and states that the procedure used overestimates noise levels, but that it was used in this case to enable a fair comparison.

He applies the multi-step analysis procedure used in the Guski 2017 study to the original Miedema and Oudshoorn 2001 datasets to show how the Guski method alters the curve. Figure 15 shows the original Miedema and Oudshoorn 2001 curve as a solid blue line and the modified Miedema and Oudshoorn 2001 curve using the Guski 2017 multi-step analysis (dotted blue line). The Guski 2017 method overestimates noise at lower noise levels mainly because the Guski method does not include a bottom out of the curve at 42 dB as occurred in the Miedema and Oudshoorn 2001.

Based on this finding Gjestland 2020 concludes that the Guski 2017 curve should not be used as it does not use the correct approach to determine the regression curves. However, even in we concede to using the multi-step analysis procedure used by Guski 2017 the level of 45 dB L_{den} is still considered too low as a better selection of studies as discussed by Gjestland 2020 gives a level of 50 dB L_{dn} for 10% of people highly annoyed instead of 45 dB L_{dn}.

Reading back on the original Miedema and Vos 1998 paper it was initially decided to exclude results below 45 dB L_{dn}. But it turned out that the air, road, and rail curves all reached 0 at around 42 dB L_{dn} anyway, so the curves were altered to bottom out at 42 dB L_{dn} based on the underlying data.

On balance, in our view it would be wrong to apply the 42 dB bottoming out approach to new datasets coming through as the level at which the dataset bottoms out should be determined by looking at the underlying data for the dataset at hand rather than assumptions from previous studies.

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Also, the change this makes to the Miedema and Oudshoorn 2001 curve is not large with the percentage of people highly annoyed at 55 dB L_{dn} going from about 11% in the original dataset to around 9% when the assumption of bottoming out at 42 dB is removed. At 45 dB L_{dn} it goes from around 3% to 2%.

Figure 15: Miedema & Oudshoorn 2001 curve: Original (solid blue) vs without bottoming out at 42 dB (dashed blue).

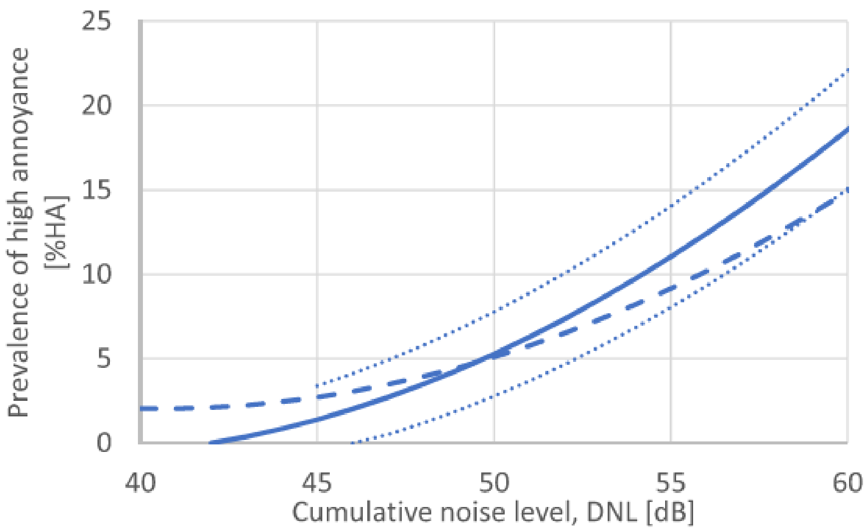

FIG. 7. (Color online) The lower end of the EU reference curve for aircraft noise annoyance (solid line) with its flanking 95% confidence intervals (dotted lines). A similar ERF is shown for an identical dataset with the method used by Guski *et al.* (2017) (dashed line).

2.12 Brink 2020 (response to Gjestland 2020)

The Brink 2020 study is a response paper to the Gjestland 2020 study which critiques a previous synthesis of studies done by Guski 2017. The Guski 2017 study informed the WHO 2018 noise guidelines.

The main conclusion from the paper is that:

> *"As long as the question of whether aircraft noise annoyance has increased or not over the last decades is not addressed by means of a sound meta-analysis, which is driven by a clearly formulated research question, including the disclosure of criteria for study selection and description of data extraction, we will not know. (1) if air-craft noise annoyance has increased or remained stable over the last decades, and (2) if the WHO guideline value for air-craft noise is appropriate or not. Gjestland's article cannot answer these questions."*

Brink 2020 asserts that Gjestland 2020 provides little information about the study objective, data sources and data extraction methods making it has to review his findings.

The study selection process was not defined and the criteria for inclusion/exclusion is not disclosed making it hard to critique the studies selected.

In addition, the Gjestland 2020 study looks at surveys from 1961-2014 in contrast to the Guski 2017 study which looks at studies from 2000-2014. Brink 2020 asserts the early studies (1960s/1970s) are questionable as there was a lack of standardised study measures and questionnaires meaning the results from these earlier studies could differ widely with surveys done in the 2000s.

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However, the Gjestland 2020 study does break the dataset down into studies from 2000-2015 and plots a regression curve for this which is similar to the curve for the whole dataset, so this critique seems ill-founded.

2.13 Gjestland 2021 (response to Brink 2020)

The Gjestland 2021 study is a response paper to the Brink 2020 study which critiques a previous paper by Gjestland 2020.

Broadly, Gjestland 2021 disagrees with Brink 2020s assessment that older studies should not be included in the analysis and contends that many older studies used very similar survey techniques as are used now and thus the data is still valid.

He also refutes that assertion by Brink 2020 that Gjestland 2020 provides little information about the study objective, data sources and data extraction methods making it hard to review his findings saying that:

> *"Little imagination is needed to restate the title of the Gjestland article ("Recent World Health Organization regulatory recommendations are not supported by existing evidence") as a formal research question"*

As a final conclusion Gjestland 2021 states that even the WHO 2018 noise guidelines state that the evidence used to justify a level of 10% high annoyance at 45 dB L_{den} is of moderate quality which brings into questions the validity of the guidelines.

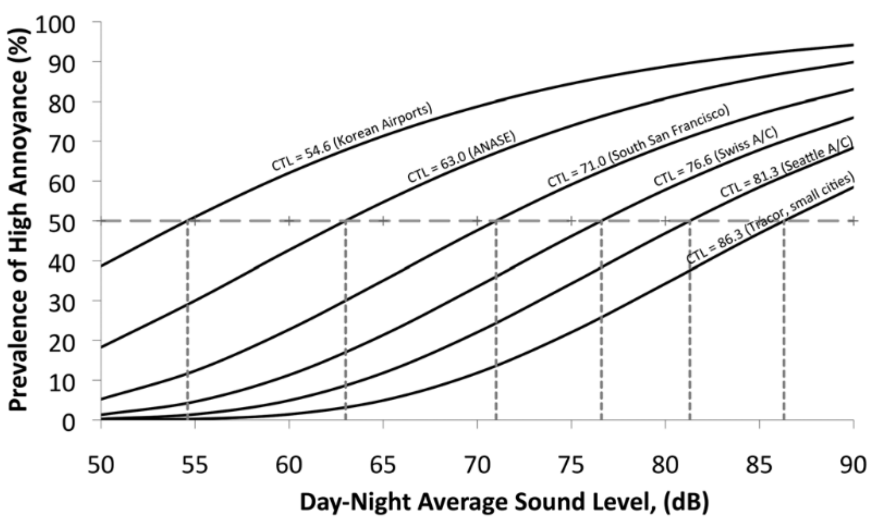
2.14 Fidell Study 2011 – Community Tolerance Level

The Fidell 2011 study suggests a different approach to assessing the level of annoyance in the community by using the Community Tolerance Level (CTL). CTL is based on the assumption that the shape of the dose-response curve generally follows a set sigmoidal relationship but that the onset of noise annoyance (i.e., the position of the curve relative to the noise axis) depends on non-acoustic factors.

The graph below shows an example of CTL curves for various airports. A set sigmoidal CTL curve is plotted and then slid left and right along the X-axis to fit the survey data for each airport. The CTL value is then obtained by reading off the noise level where 50% of people are highly annoyed (an arbitrary anchor point).

This study plotted CTL curves for 43 airport studies that contained 76,000 respondents. Figure 16 shows a selection of six airport CTL curves from this study. As you can see, each airport has a different curve.

Figure 16: Examples of CTL



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The mean CTL for all 43 studies considered was 73.3. Table 2 shows the predicted annoyance levels at 55, 60 and 65 dB L_{dn} for the mean CTL and for 1 standard deviation either side which is thought to approximate annoyance in two thirds of communities.

For the mean CTL, the levels of annoyance correspond well to those found in the Miedema and Oudshoorn 2001 dose-response curve. However, there is a large variance from airport to airport which shows that a bespoke dose-response curve for each airport using CTL may be better to approximate noise annoyance in specific communities.

Table 2: Predicted Annoyance Levels

TABLE III. Predicted annoyance prevalence rates for three levels of noise exposure and three degrees of community tolerance for noise exposure.

DNL	%HA FOR $L_{ct} = 73.3$ dB	%HA FOR $L_{ct} = 66.3$ dB	%HA FOR $L_{ct} = 80.3$ dB
55 dB	8.6%	1.9%	22.0%
60 dB	17.6%	6.0%	34.3%
65 dB	29.3%	13.6%	46.9%

2.15 Gelderblom 2017 Synthesis of Studies

The Gelderblom 2017 study uses the Community Tolerance Level (CTL) method as described in Section 2.14 to determine whether noise annoyance has changed over time. Specifically in relation to LRC and HRC airports and whether HRC airports yield higher annoyance levels than LRC airports.

The overall conclusion from this study was that:

> *"No evidence was found for a large enough temporal trend in aircraft noise-induced annoyance prevalence rates to justify updating existing exposure-response curves"*

This study calculated CTL values for 62 studies in total between 1961 and 2015 (top left graph) and concluded initially that people's tolerance for aircraft noise is about 8dB lower that it was in the 1960s and 4.5 dB lower for the 1970s. This is less than half the difference found by Guski 2017 as shown in the top left graph of Figure 17.

It was hypothesised that the increase in noise annoyance over time could potentially be explained by the differences in the types of airports being surveys in more modern surveys. More modern surveys seemed to contain airports that were classified as having a high rate of change (HRC) whereas older studies contained mainly studies that included airports with a low rate of change (LRC). HRC airports have been documents to increase levels of annoyance in communities.

The top right graph of Figure 17 shows the results split out into HRC and LRC airports. The graph shows that there are no significant trends in the data when aggregated by HRC/LRC. Moreover, it was deemed that improvements in survey techniques meant that estimations from studies more than 30-40 years old were more uncertain. Due to this a cut-off of 1978 was implemented and the data analysed again for all surveys in this period (not split by LRC/HRC). This updated analysis (bottom graph) showed no significant trends in the data and supports the conclusion that there has been no change in noise annoyance over time.

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Figure 17: Results from the initial analysis (top left) and further refined results when aggregating by LRC/HRC airports (top right) and surveys conducted post 1978 (bottom)

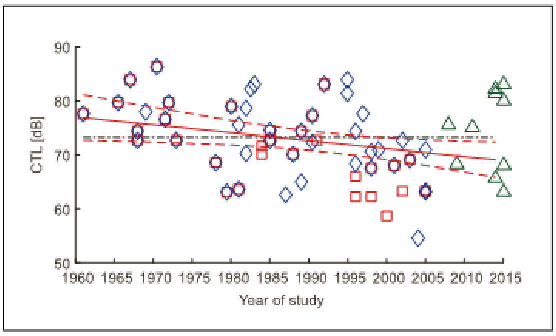

Figure 1. (Colour online) CTL values for 62 aircraft noise annoyance studies conducted between 1961 and 2015 (diamonds: Janssen and Guski, squares: Fidell *et al.*, triangles: Vietnam and Norway. The solid line (R^2 = 0.09) shows the linear fit of all data, including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 dB for comparison with the EU guideline.

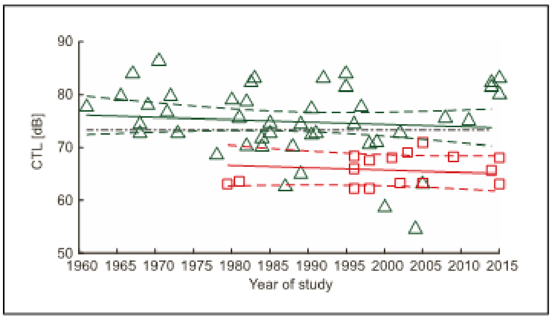

Figure 2. (Colour online) CTL values for 62 aircraft noise annoyance studies conducted between 1961 and 2015 categorized by HRC (squares) or LRC (triangles) (see text). The solid upper and lower lines show their respective linear fits (R^2 = 0.33), including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 dB for comparison with the EU standard curve.

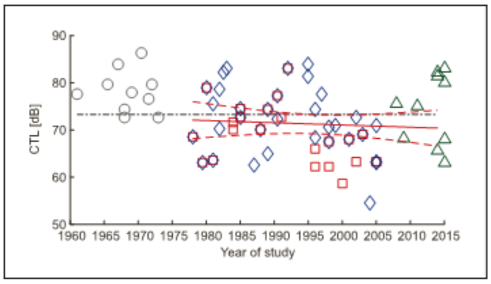

Figure 3. (Colour online) CTL values for 52 aircraft noise annoyance studies conducted between 1978 and 2015 (diamonds: Janssen and Guski, squares: Fidell *et al.*, triangles: Vietnam and Norway). The circles indicate excluded studies. The solid line shows the linear fit of all data (R^2 = 0.005), including confidence intervals (dashed lines). The dash-dot line shows a constant CTL of 73.3 dB for comparison with the EU standard curve.

2.16 Janssen and Vos 2011 Synthesis of Studies

The Janssen and Vos 2011 study analysed results from 34 studies from 1967 to 2005 many of which were included in the original Miedema and Oudshoorn 2001 dose-response curve. Seven newer studies were also analysed to bring the total number of respondents to 48,369.

The main conclusion from the study was that:

> *"A significant increase over the years was observed in expected annoyance at a given level of aircraft noise exposure. Several study characteristics can be put forward as possible explanatory factors on the basis of the present analysis. Of these factors, only the (annoyance) scale could account for the trend of increased annoyance in more recent studies. Although other studies which have investigated this further have ruled it out as a satisfactory explanation."*

A significant increase was observed in annoyance over the years at a given level of aircraft noise exposure. Data from each study was analysed to determine whether certain factors could explain these trends.

These factors included the year of the study, the type of contact (phone, postal, face to face etc), the response rate and the annoyance scale used (5pt vs 11pt).

Figure 18 shows that higher annoyance is predicted in later studies. Also, higher annoyance is predicted in those with postal surveys, those with low response rates and those with larger scales

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(11-point vs 5 point). All these characteristics are commonly found in more recent surveys with the older surveys using face to face surveys, having high response rates, and using 5-point scales.

Of these factors, statistically only the scale could account for the trend of increased annoyance in more recent studies. Although other studies which have investigated this further have ruled it out as a satisfactory explanation. The other factors could not statistically account for the change. This suggests that there could be increased annoyance in the population which cannot be attributed to other factors.

Figure 18: Annoyance vs study characteristics

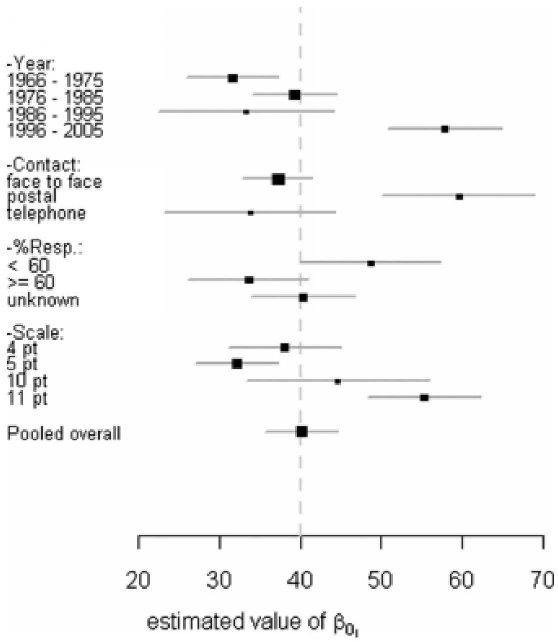


FIG. 2. The estimated mean annoyance on a 100-point scale (β_{0i}) at the overall mean exposure level plotted against study characteristics, with associated 95% confidence intervals and with size of the data-points proportional to the inverse variance (SE_i^2) in β_{0i}.

3.0 SLEEP DISTURBANCE

Literature on sleep disturbance research over the past 30 years has been reviewed to determine its relationship to aircraft noise.

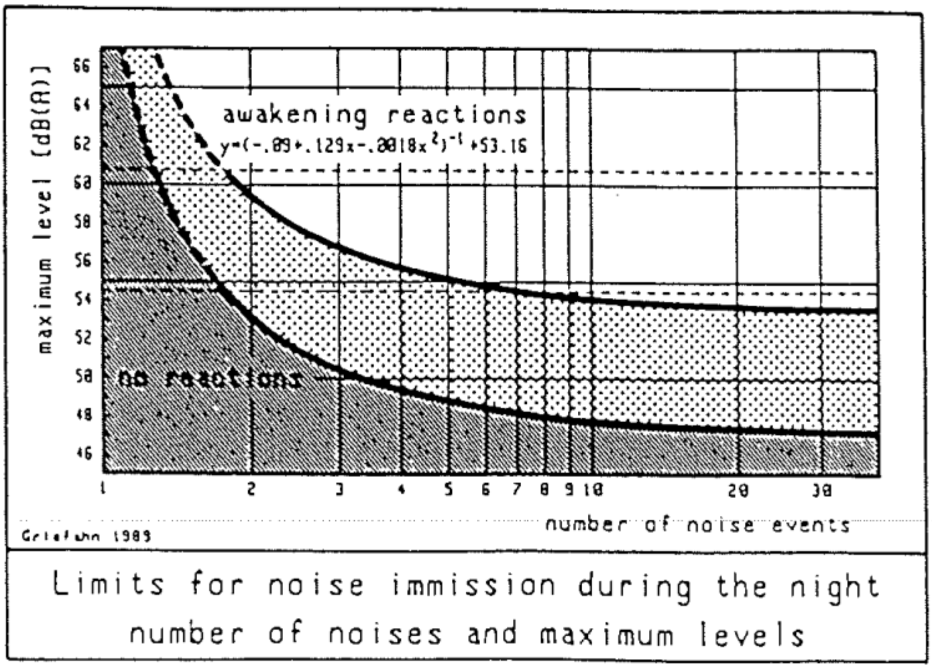
There have been many studies on the effects of noise on sleep carried out both in the laboratory and in the field. The term sleep disturbance itself has various connotations and can include a range of aspects from awakening to affecting the depth of sleep in various stages and creating difficulty with falling asleep.

The findings of relevant studies typically relate sleep disturbance effects to either the SEL or L_{AFmax} noise metric, but in more recent times there has been attempts to provide robust dose response relationships using cumulative noise exposure metrics. Several of the key studies and papers we discuss in the following sections.

3.1 Griefahn 1992 Probability of Awakenings

Some of the earliest work on the topic of sleep disturbance was reviewed in 1992 by a major contributor to the topic of sleep disturbance, Barbara Griefahn [50]. Griefahn identified that there was a need for further research in the field of environmental noise and sleep disturbance, but nonetheless published a relationship between maximum indoor noise level and the number of noise events occurring during the night, thus providing limits for noise emissions during the night in terms of risk of awakening reactions (Figure 19).

Figure 19: Indoor limits for noise emission during the night, based on the number of single events and maximum level of each event (Griefahn 1992)



The analysis of awakening reactions took into account the results of previous experimental studies, which were pooled and recalculated, and a new study in which a range of participants were exposed to up to 32 short term noises (≤ 40 seconds duration) each night. Various types of aircraft noises were trialled, along with pink noise, truck noise and other impulsive sounds.

Griefahn recognised that sleep disturbance was linked to the number of noise events occurring throughout the night, as well as the noise level of each disturbance. On Figure 19, the lower curve (labelled no reactions) illustrates where zero awakening reactions were expected, while the upper curve (labelled awakening reactions) represents the upper admissible risk of awakening for a single night. The lower curve provides the preventive goal, which should be realised if possible, while the upper curve should not be exceeded in order to avoid long term effects on health. Each point on the upper curve represents the same risk of awakening. According to Figure 19, the admissible sound pressure level (L_{AFmax}) of each event decreases considerably from one to five noise events. Thereafter it approaches gradually to 53 dB L_{AFmax}.

3.2 FICAN Dose Response Relationship

In 1992, FICAN (known at the time as Federal Interagency Committee on Noise (FICON)) recommended a dose-response curve that linked the percentage of awakenings to the sound exposure level (SEL) of a single aircraft noise event [51]. The study was based on laboratory testing of peoples awakening responses.

Between 1992 and 1997 additional research led to FICAN reviewing their dose-response curve [52]. Laboratory sleep studies had been found to result in greater responses compared to equivalent studies undertaken in people's homes. The novelty of a laboratory environment was thought to affect sleep, such that the results of sleep studies were exaggerated. Accordingly, in 1997, FICAN revised their dose-response curve to reflect that people in their own homes were likely to be less affected by sound exposure than had been suggested in 1992.

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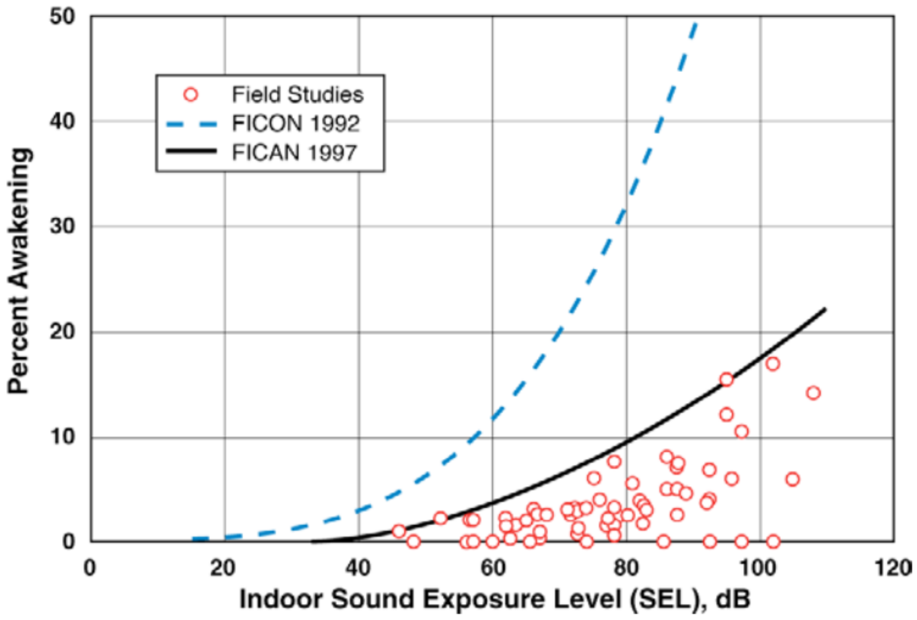
The relationship developed in 1997 by FICAN[7] (shown in Figure 20) predicts the maximum percentage of an exposed population[8] expected to be behaviourally awakened for a given indoor SEL.

Figure 20: FICAN Sleep Disturbance Dose-Response Relationship



We note that the limitation of the FICAN Dose Response Relationship is that it is a curve for predicting the maximum likelihood of behavioural awakening from a *single* aircraft noise event. No distinction is made between one such event occurring or multiple events occurring on any given night. Indeed, the 1992 FICAN report acknowledged that "single event metrics are of limited use in predicting and interpreting cumulative noise exposure impacts". For this reason, FICAN is not considered helpful in terms of assessing the noise effects from multiple events.

To counter this, throughout the years, researchers have endeavoured to improve understanding of the way in which multiple night-time events interact cumulatively, and in independence.

3.3 ANSI/ASA S12.9-2008/Part 6

In 2008, the American National Standards Institute (ANSI) issued ANSI/ASA S12.9-2008/Part 6 "*Quantities and Procedures for Description and Measurement of Environmental Sound – Part 6: Methods for Estimation of Awakenings Associated with Outdoor Noise Events Heard in Homes [53].* The standard was based on an array of sleep studies and was specifically aimed to address noise experienced in residential bedrooms.

The ANSI standard provided a methodology to calculate the probability of awakening at least once from a full night of aircraft operations. The probability of awakening could then be used to estimate the percentage or number of people awakened across a given area.

Subsequent to the release of the 2008 ANSI standard outlined above, FICAN ceased use of their dose-response curve and recommended adoption of the ANSI standard methodology (FICAN, 2008). Compared to the dose-response curve, the probability of awakening from a single noise event was lower in the ANSI standard, but the ANSI standard took into account the cumulative noise effects of a full night of disturbance, which the dose-response curve was insensitive to.

[7] Federal Inter-agency Committee on Aviation Noise (1997). *"Effects of Aviation Noise on Awakenings from Sleep"*.

[8] The study recommends that this relationship applies to adults residing in aircraft noise affected areas.

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At the time, the ANSI standard detailed the most comprehensive way to quantify sleep disturbance effects based on the number of noise events and their noise level.

However, in 2016, an Acoustical Society of America working group made the decision to withdraw ANSI/ASA S12.9-2008/Part 6 "*Quantities and Procedures for Description and Measurement of Environmental Sound – Part 6: Methods for Estimation of Awakenings Associated with Outdoor Noise Events Heard in Homes*. The working group believed that the methodology described in the standard would lead to overestimations of the number of people awakened (for example, because it did not take into account habituation to noise), and that the limitations of the standard outweighed its usefulness. While the 2008 standard was informed by a body of research, by 2016 the inconsistent results of additional research led to a high level of uncertainty, and a lack of confidence that the application of the standard would result in representative outputs.

The working group concluded that a revision of the standard would not be possible until a substantial amount of new research was undertaken to inform an alternate awakening prediction methodology.

3.4 WHO Night Noise Guidelines 2009

In 1999, the World Health Organisation (WHO) "Guidelines for Community Noise" had recommended night-time noise targets to protect from sleep disturbance (from all noise sources) [46]:

- Outside façades should not exceed 45 dB $L_{Aeq,8hr}$ and 60 dB L_{Amax}
- Inside bedrooms should not exceed 30 dB $L_{Aeq,8hr}$ and 45 dB L_{Amax} for single sound events.

In 2009, the WHO prepared the "Night Noise Guidelines for Europe" (NNG) with updated energy equivalent guidelines to control night-time noise to minimise adverse effects on sleep [54]. While specified as European guidelines, the hope was that the guidelines would be utilised worldwide. The metric included in the guidelines was the $L_{night, outside}$ which was defined as an average night-time noise level over 12 months. A target level 'Night Noise Guideline' of 40 dB was recommended for $L_{night,outside}$ to protect the community. For countries where 40 dB would be a significant change from their current night-time noise levels, the WHO proposed 55 dB as an 'Interim target' until 40 dB could be achieved.

Of the target level of 40 dB L_{night}, the WHO NNG states in Table 5.34 "*However, even in the worst cases the effects seem modest. L_{night} outside is equivalent to the Lowest Observable Adverse Effect Level*".

Criticism of the NNG that followed publication suggested that the NNG were aspirational targets, hard to achieve in practice in existing situations. There was a real risk the NNG could be sidelined entirely for being unachievable in practice.

It is noted that whilst it may be desirable for none of the adverse effects of sleep disturbance to occur, this could only be achieved if noise impacts are considered in isolation without considering the planning, social, cultural, economic and health consequences of such an approach.

3.5 WHO Night Noise Guidelines 2018

In 2018, the World Health Organisation (WHO) updated its European night noise guidelines [55]. As per the 2009 guidance, the WHO continued with an outdoor noise metric (to be measured at the most exposed façade of a building).

The night-time aircraft guidelines were based on a key response metric of "percentage of the population highly sleep-disturbed", with a benchmark of 11% of the population highly affected as an acceptable threshold. The 11% benchmark was determined to be set at 40 dB L_{night} (with night typically being the 8-hour period from 11pm to 7am, averaged over twelve months).

The World Health Organisation did not provide guidance on noise levels from individual events, or their timing or frequency.

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3.6 Basner 2018, 2019

Basner *et al*. (2018) conducted a review of environmental noise and its effects on sleep, taking into account the energy equivalent guidance provided by the WHO [56]. They stated that a large body of research had been undertaken that focused on energy equivalent metrics, and hence these metrics were often incorporated into policy and legislation. However, there was evidence that average noise level metrics provided limited information about the effects of noise on sleep, as scenarios with different sleep consequences could result in the same equivalent noise level (i.e. few loud events can have the same equivalent noise level as many quieter events, or a several loud events can result in the same average as one continuous noise level).

This limitation was illustrated with an example where 2% of a study population experienced sleep disturbance as a result of 40 dB L_{night} road and rail noise, but 10% of the population experienced sleep disturbance at the same equivalent level of aircraft noise. Basner *et al*. (2018) concluded that sleep disturbance was better reflected by metrics that took into account the number and acoustic properties (e.g. SEL or L_{max}) of each individual noise event.

Following on from their 2018 review, in 2019 Basner *et al [57]*. published the results of a pilot study to investigate sleep disturbance from aircraft noise around Philadelphia International Airport. The pilot study was based on 2,375 aircraft noise events, with noise levels from each event measured inside and outside of the participants bedrooms. While the study was caveated by its small sample size, it nonetheless revealed a significant relationship between the maximum sound pressure level (L_{ASmax}) of an aircraft noise event and the awakening probability of the participant (as inferred from heart rate and body movement). Additional positive correlations were identified between the probability of awakening and the time from sleep onset (i.e. participants were more likely to wake up if the aircraft noise event occurred later into their sleep period).

A 2019 review of the state of the science of aviation noise impacts, by Sparrow *et al*., furthered support for the Basner *et al.* (2019) individual event analysis, and the analyses undertaken by previous studies outlined above:

> *"While energy equivalent metrics often correlated with sleep disturbance, the number and acoustic properties of the individual noise events better reflected the degree of sleep disturbance experienced by those living near airports."*

Sparrow *et al*. (2019) acknowledged that human responses to aircraft noise are highly variable, resulting in difficulty when trying to set limits.

> *"There does not appear to be a specific value (across any metric) where people switch from being 'not-disturbed' to 'disturbed'. As a result, noise limits and metrics differ widely in policy and legislation around the world as each country accepts a compromise between society health and economic/infrastructure development."*

3.7 Recent and Upcoming Research

In 2019 a pilot field study on the Effects of Aircraft Noise on Sleep Around Atlanta International Airport [32] was conducted. The pilot study aimed to assess the viability of a wider national field study across the whole of the United States. The authors developed test methodology using electrocardiography (ECG) and actigraphy with electrodes that can be easily applied by the study participants themselves to monitor the sleep of participants.

The study focused on the feasibility of an unattended field study on the physiological effects of aircraft noise on sleep. Although the authors found several ways to improve data quantity and quality, overall, the approach was found to be feasible.

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In 2023 a study on noise and sleep disturbance around four major United Kingdom (UK) airports was conducted [33]. The study used a large sample size of 105,773 participants living around four major airports in the UK. The authors concluded no significant association between night-time aircraft noise and self-reported sleeplessness or sleep duration. However, the study was noted to have limitations, such as the potential for misclassification of noise levels and biases in self-reported and altimetric sleep outcomes.

4.0 NON-ACOUSTIC FACTORS

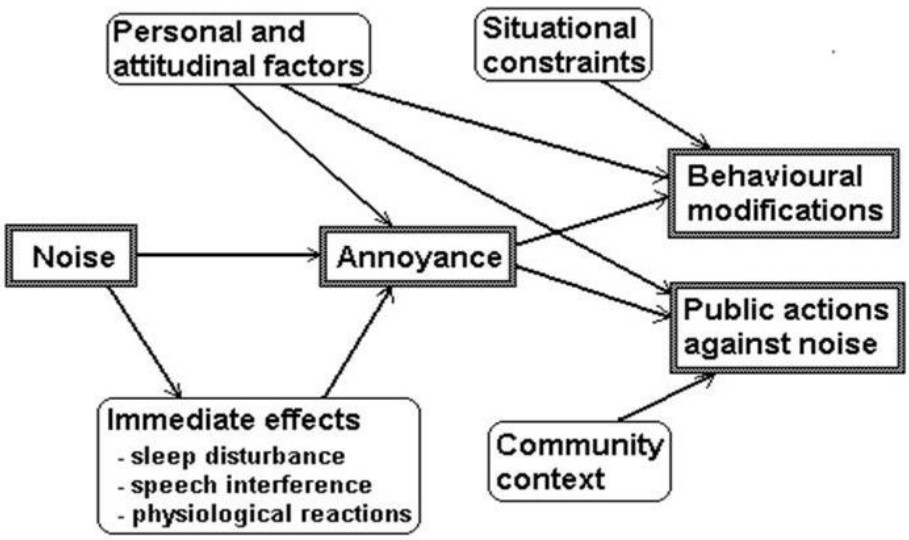
The research literature acknowledges that non-acoustic factors play a potentially significant part in determining the level of annoyance in the community. Non-acoustic factors are those factors other than the noise level which contribute to annoyance. Both Schultz and Miedema note in their papers that non-acoustic factors are thought to be a significant contributor to noise annoyance. There are reports that non-acoustic factors could potentially account for more than 2/3 of the variance in the data.

Non-acoustic factors moderate an individual's sensitivity to noise which in turn can affect their level of annoyance. Figure 21 show the various factors that can impact noise annoyance. These include 'acoustic factors' such as the noise level and its immediate effect on sleep disturbance and speech interference. The diagram also shows non-acoustic attitudinal factors which influence annoyance and subjective response. These include things such as:

- Age
- Gender
- Socioeconomic status
- Attitude of the noise receiver to aviation
- Attitude of the noise producer to the receiver

The resultant annoyance can then translate into behavioural modifications in terms of how people live and can also result in public actions against noise depending on the community context.

Figure 21: Noise Annoyance and Non-acoustic Factors



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There are a number of papers that have been published in recent years which have tried to determine the relationship between various non-acoustic factors and annoyance. Miedema and Vos in 1998 surmised that the differences observed between air, road and rail annoyance curves (annoyance is less for road/rail sources) could be due to a fear of aircraft crashes and other non-acoustical factors that did not exist for road/rail sources.

Similar findings were reported in a paper published by Van den Burg in 2018 which looks and the relationship between worry and annoyance at Schiphol airport. This paper showed a strong correlation between worry/fear about living underneath or near a flight path/airport with the level of annoyance experienced with those more worries experiencing significantly higher levels of annoyance. This paper also found that females, those above 35 years of age and those having a high risk for anxiety/depression or being in bad health had increased levels of worry and thus increased levels of annoyance.

A paper by Clark investigated the results from the National Noise Attitude Survey in 2012 in the UK and found that noise sensitivity was more strongly associated with sociodemographic factors than with dwelling or geographic factors. The main findings were that higher noise sensitivity was recorded for:

- Older respondents (40+)
- Females
- People who had a mortgage
- People without children in the house
- Those not working full time (excluded retired people which had a lower noise sensitivity)
- Those with a higher social class

Bauer in 2014 published a paper which looked at results from the COSMA study which was a study of three European airports. This study identified factors which appeared to increase/decrease noise annoyance which include:

Factors that increase annoyance:

- Night/early flights
- Disturbed work or relaxation
- Noise felt as a health hazard
- Noise that required coping mechanisms to be implemented
- Personal noise sensitivity

Factors that decrease annoyance

- Feeling fairly treated by the airport
- Belief that you can get used to aircraft noise
- Belief that the airport is economically important
- Satisfaction with noise insulation
- Satisfaction with residential area

This report summarises that at one of the airports, the non-acoustical factors were found to account for 55% of the variance in the data. This variance it thought to vary from airport to airport which confirms the assumptions of the CTL approach.

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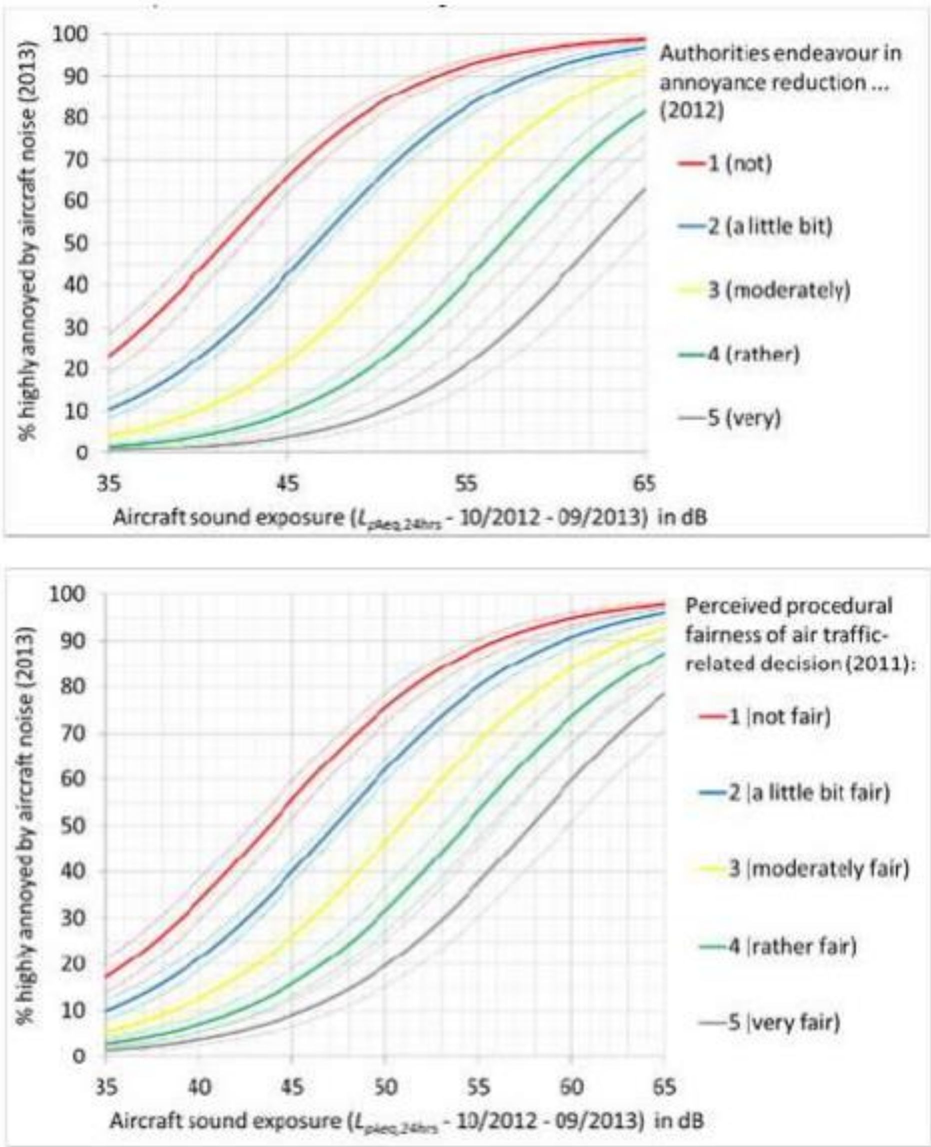
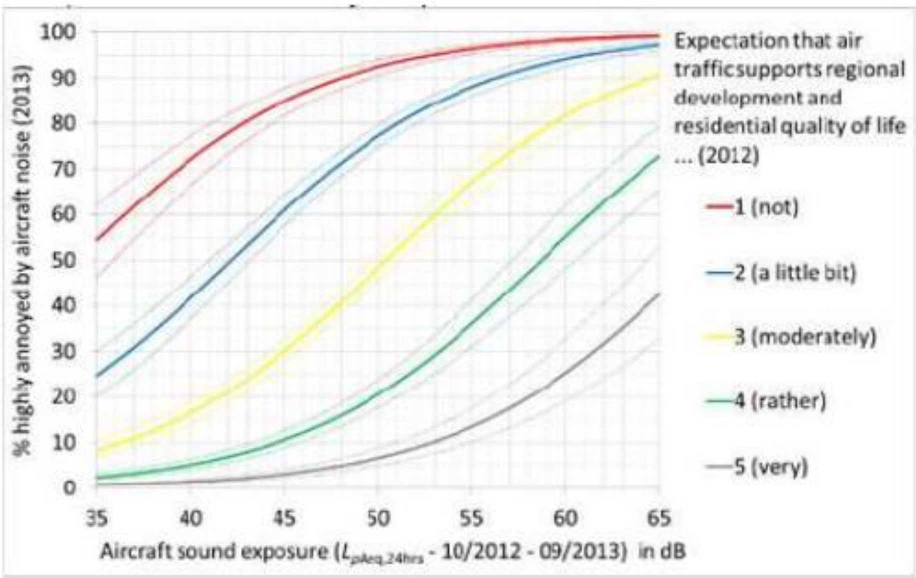
Schreckenburg published a paper in 2017 which looked at the results from the NORAH study. He looked at things such as whether trust in authorities to endeavour to reduce annoyance, perceived procedural fairness and expectation that air traffic supports regional development could account for variance in the data.

The Figures below show the dose-response curves from the NORAH study split out into the different responses. The graphs show a large variance between respondents who trust the airport, think the airport has procedural fairness and believe that air traffic has a positive effect on regional development to those that do not believe this.

The graphs show that for the same noise level, agreeing/not agreeing with these statements has a large impact of the level of annoyance. For example, those that have a high level of trust in the airport authority report a level of annoyance of around 15% at 55 dB $L_{Aeq\,(24hr)}$), whereas those who rate their trust in the airport authority at low report level of annoyance at around 95% at 55 dB $L_{Aeq\,(24hr)}$.

Figure 22: NORAH Study – Levels of annoyance





5.0 CONCLUSIONS

Aircraft noise can result in adverse effects on communities including annoyance and sleep disturbance effects. A literature review has been undertaken to determine the latest research in these areas.

5.1 Annoyance

Recent literature on annoyance shows that annoyance levels have increased markedly compared to the 2001 Miedema study. The two largest studies conducted recently were the World Health Organisation (WHO) study in 2018 and the Federal Aviation Administration (FAA) study in the US in 2021. The WHO 2018 noise guidelines now recommend noise limits for aircraft noise of 45 dB L_{dn} as a result of this research. This is 10 dB more stringent than the recommendations of NZS 6805 which recommends prohibiting noise sensitive development within 55 dB L_{dn}.

International bodies around the world are considering whether to update their policies, and the WHO Noise Guidelines could provide the latest scientific knowledge. We consider that the WHO curve represents the latest research in this area internationally and should replace the Miedema curve for assessing the effects of aircraft noise on communities.

Whilst the FAA study is also valid, this study only considers the annoyance response from one country whereas the WHO curve is an amalgamation of data from European and Asian cities.

The research showed that non acoustic factors play a potentially significant part in determining the level of annoyance in the communities. More research is needed in this area to quantify the effect each of these factors has on noise annoyance. However, the research clearly highlights that good management of an airport, transparency and positive engagement with communities in relation to aircraft noise and overflights can significantly lower annoyance levels. These things should not be seen as a 'nice to have' but rather as critical part of managing annoyance around airports.

5.2 Sleep Disturbance

There have been a number of studies on sleep disturbance from aircraft noise over the past 30 years. There is currently not an accepted approach in the literature to accurately assess the effects of aircraft noise on sleep disturbance.

The literature shows that energy equivalent metrics such as L_{night} are generally insensitive in respect to sleep disturbance. Metrics that consider the noise level of single aircraft events have also been widely researched and cumulative indices have been developed that look at the effects of multiple

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night-time events. However, the complex assumptions and methodology that underpins these types of methods have not been evidenced with confidence.

More research in this area is needed to determine a meaningful relationship and assessment methodology. In the meantime, consideration of both equivalent exposure and single event levels would be appropriate for the following reasons. The use of L_{night} is desirable because it accords with the direction of international policy, is easily quantified and provides a broad overall understanding of sleep disturbance. However there remains evidence that this metric provides limited information about the significance of effects of noise on sleep. As shown in some studies, individual noise events better reflect the degree or significance of sleep disturbance experienced by people living near airports and as result single event metrics should also be considered.

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APPENDIX A GLOSSARY OF TERMINOLOGY

Noise	A sound that is unwanted by, or distracting to, the receiver.
dB	Decibel The unit of sound level. Expressed as a logarithmic ratio of sound pressure P relative to a reference pressure of Pr=20 μPa i.e. dB = 20 x log(P/Pr)
dBA	The unit of sound level which has its frequency characteristics modified by a filter (A-weighted) so as to more closely approximate the frequency bias of the human ear.
A-weighting	The process by which noise levels are corrected to account for the non-linear frequency response of the human ear.
L_{dn}	The day night noise level which is calculated from the 24-hour L_{Aeq} with a 10 dB penalty applied to the night-time (2200-0700 hours) L_{Aeq}.
L_{den}	The day evening night noise level which is calculated from the 24-hour L_{Aeq} with a 5-decibel penalty applied to the evening (1800-2200 hours) L_{Aeq} and a 10-decibel penalty applied to the night-time (2200-0700 hours) L_{Aeq}.
Noise dose-response curve	A dose–response relationship is the magnitude of the response (in this case annoyance) of a person to a certain dose of a stimulus or stressor (in this case noise). Dose–response relationships can be described by dose–response curves. Dose-response curves are created by graphing the magnitude of the response (level of annoyance) for each individual against the dose (noise level) and performing a statistical analysis on this data to create a single dose-response curve for the population.
Air Noise Contours	The noise contours published in the District Plan (50 L_{dn} | 55 L_{dn} | 65 L_{dn}).

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