Project NAPKIN - Noise

AN ASSESSMENT OF THE NOISE IMPACT OF ZERO EMISSION REGIONAL HYDROGEN AIRCRAFT AND THEIR OPERATION.

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CONTENTS

1 INTRODUCTION

The noise study within NAPKIN analysed noise implications of H2 aircraft at three levels:

1. Comparative noise performance of individual aircraft concept designs.
2. Implications for airport noise.
3. Implications for overall UK aviation noise.

In order to model the noise emissions of individual designs the known noise performance of the corresponding baseline aircraft is used as a starting point and the variation in the main noise sources is estimated. While such a methodology is limited it captures the major variation in noise due to changes in existing (dominant) noise sources through both design and operation.

Given the approach used there is always a risk that new noise sources are introduced that are not accounted for, although for the NAPKIN aircraft concepts this is considered a low risk. Equally, the noise analysis assumes that technology used in concept aircraft is broadly equivalent to that of the baseline aircraft and this has the effect of over-estimating noise – for example, improved propeller design may lower noise compared to baseline aircraft.

Whilst the noise analysis starts with estimating concept aircraft noise with respect to that of the corresponding baseline aircraft it should be recognised that this in itself does not give a complete or true indication of resultant noise impact. Changes in passenger capacity and mission characteristics of the aircraft need to be taken into account – especially when considering airport noise.

In terms of the individual concept aircraft noise performance this is found to improve broadly in line with what would be expected from historical trends of conventional equivalents. However, take-off noise has a larger improvement than approach noise implying a change in overall noise distribution.

Generally, the lower passenger capacity (and sometimes range) of the NAPKIN fleet means that their introduction is not simply a matter of one for one replacement. Given the assumed penetration rates of the NAPKIN fleet this has a slight implication for noise around smaller airports but generally does not affect overall UK aviation noise which is dominated by larger aircraft.

The following sections of this appendix discuss these matters in more detail.

2 BACKGROUND

Noise is an unwanted aspect of aircraft operation and affects many people living close to airports. As the volume of air traffic grows it is therefore necessary that steps be taken to ensure that noise emissions from the operation individual aircraft decreases. To this end, all new aircraft must meet certain noise certification standards (set by ICAO) that have become more stringent over time (Figure 1: Aircraft Noise Certification Standards Easa.europa.eu. 2021. Figures and Tables | European Aviation Environmental Report. [online] Available at: https://www.easa.europa.eu/eaer/topics/technology-and-design/figures-and-tables).

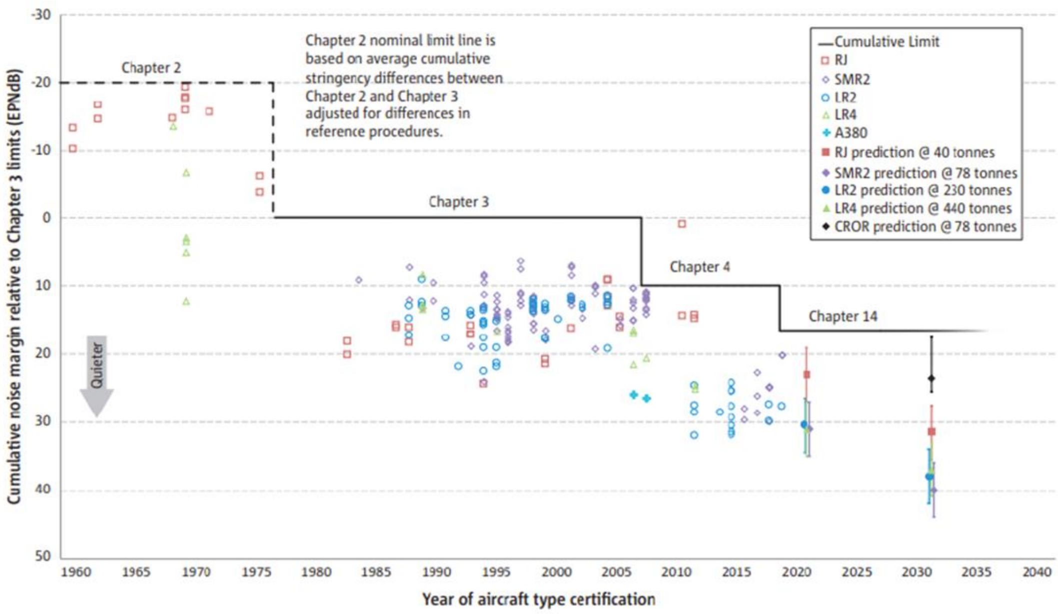


Figure 1: Aircraft Noise Certification Standards Easa.europa.eu. 2021. Figures and Tables | European Aviation Environmental Report. [online] Available at: https://www.easa.europa.eu/eaer/topics/technology-and-design/figures-and-tables

The levels quoted in Figure 1: Aircraft Noise Certification Standards Easa.europa.eu. 2021. Figures and Tables | European Aviation Environmental Report. [online] Available at: https://www.easa.europa.eu/eaer/topics/technology-and-design/figures-and-tables are the arithmetic sum (known as the cumulative value) of the EPNL dB levels measured at three certification points (see next Section).

Certification points:

Noise certification limits for the NAPKIN concepts are set by the ICAO Annex 16 (1). Due to the size variation of the concepts ranging from small propeller driven aircraft to regional turboprops and turbofan powered engines, certification limits are addressed within one the following Chapter of the Annex:

- Chapter 6: (Propeller-driven aeroplanes not exceeding 8,618 kg — Application for Type Certificate submitted before 17 November 1988)

Tests to demonstrate compliance with the maximum noise levels consist of a series of level flights overhead the measuring station at a height of 300 +10, -30 m. The aeroplane shall pass over the measuring point within ±10° from the vertical.

- Chapter 10: (Propeller-driven aeroplanes not exceeding 8,618 kg — Application for Type Certificate or certification of Derived Version submitted on or after 17 November 1988)

  The take-off reference noise measurement point is the point on the extended centre line of the runway at a distance of 2,500 m from the start of take-off roll.

  Note: Figure Figure 2: (Left) Aircraft certification points from: European Civil Aviation Conference (ECAC) CEAC Doc 29 .(Right) Comparison of Chapter 6 and Chapter 10 certification point limits. illustrates the difference in the certification levels specified under Chapter 6 and Chapter 10. Concepts based on the B-N 2 Islander will be compared to Chapter 6 as this is the Chapter under which the Islander is certified. However, the new concepts would be certified under Chapter 10 a (green line).

- Chapter 14: (Subsonic jet aeroplanes and propeller-driven aeroplanes with maximum certificated take-off mass 55,000 kg and over -- Subsonic jet aeroplanes with maximum certificated take-off mass less than 55,000 kg -- Propeller-driven aeroplanes with maximum certificated take-off mass over 8,618 kg and less than 55,000 kg)

  - **lateral full-power reference noise measurement point:** 1) for jet-powered aeroplanes: the point on a line parallel to and 450 m from the runway centre line, where the noise level is a maximum during take-off; 2) for propeller-driven aeroplanes: the point on the extended centre line of the runway 650 m vertically below the climb-out flight path at full take-off power, or 1) shall alternatively be permitted.

  - **flyover reference noise measurement point:** the point on the extended centre line of the runway and at a distance of 6.5 km from the start of roll

  - **approach reference noise measurement point:** the point on the ground, on the extended centre line of the runway, 2,000 m from the threshold. On level ground this corresponds to a position 120 m vertically below the 3° descent path originating from a point 300 m beyond the threshold.

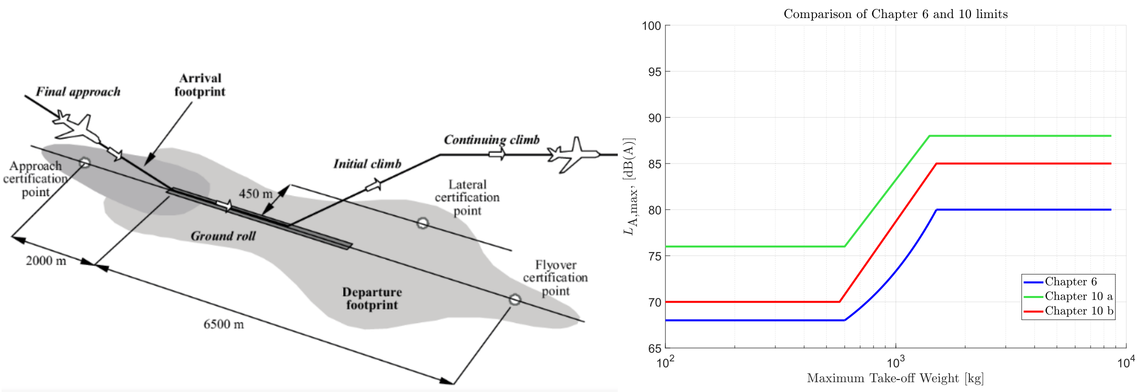


Figure 2: (Left) Aircraft certification points from: European Civil Aviation Conference (ECAC) CEAC Doc 29 (34).(Right) Comparison of Chapter 6 and Chapter 10 certification point limits.

Whilst aircraft noise certification drives individual aircraft noise downwards this does not necessarily reflect the experience of communities near airports where multiply flight operations occur. To assess this latter, noise exposure metrics are used which "average" the total noise from all aircraft operations over a given time – typically a whole day. These equivalent exposure metrics (L_{eq}) are normally reported in the form of contour diagrams. The aim of the noise modelling work within NAPKIN is to develop the necessary tools to make realistic estimations of these contours for a number of scenarios where electric and hydrogen aircraft are introduced.

<u>Definitions of acoustic terms and metrics:</u>

- <u>Slant distance [m]:</u> Shortest distance from an observation point to a flight path.
- <u>SEL [dB]:</u> Single event **S**ound **E**xposure **L**evel. Defined as the one-second-long steady level containing equivalent total acoustic energy as the actual fluctuating noise.
- $L_{A,max}$ [dBA]: Maximum sound-level during an event. The A subscript denotes an A-weighting applied in an effort to account for the relative loudness perceived by the human ear. Used as the standard noise metric in Chapters 6 and 10 of the ICAO noise certification Annex 16.
- <u>EPNL [EPNdB]:</u> **E**ffective **P**erceived **N**oise **L**evel. It is a function of both frequency and level and rates aircraft noise in terms of human perceived noisiness. Additionally accounts for the duration and bell-shaped time history of an aircraft noise event. It has units of EPNdB and is a common aircraft noise annoyance indicator. Used as the standard noise metric in Chapter 14 of the ICAO noise certification Annex 16.
- <u>Cumulative noise level [EPNdB]:</u> Cumulative noise levels are defined as the arithmetic sum of the certification levels at each of the three certification points (concerns only aircraft certified under Chapter 14, where three points are required).
- <u>Noise margins:</u> Margins are defined as the arithmetic difference in noise levels between the aircraft actual noise measured and the limit set at that certification point by any of the certification rules/chapters.

- Noise exposure footprint: Footprints are the collection of locations that experience the same noise exposure level as a result of single aircraft operation. Footprints may be generated for a series of noise metrics with the most common one being SEL.
- Noise exposure contour: Contours are the collection of locations that experience the same cumulative noise exposure level as a result of multiple aircraft operations over a period of time. Contours may be generated for a series of noise metrics with the most common one being $L_{A,eq,T}$, where the time period T may vary between applications (16h is used in this report).

Noise-Power-Distance curves and flyover noise:

Noise-Power-Distance (NPD) data define, for steady straight flight at a reference speed in specified reference atmospheric conditions and in a specified flight configuration, the received sound event levels, both maximum and time integrated, directly beneath the aircraft as a function of distance.

Sound intensity and therefore aircraft sound power at any given time is represented by a noise-related power parameter. For fixed wing subsonic aircraft, the parameter generally used is corrected net thrust. Baseline event levels determined from the database are adjusted to account for i. differences between actual (i.e. modelled) and reference atmospheric conditions and (in the case of sound exposure levels) ii. aircraft speed, iii. for receiver points that are not directly beneath the aircraft, differences between downwards and laterally radiated noise. This latter difference is due to lateral directivity (engine installation effects) and lateral attenuation. But the event levels so adjusted still apply only to the total noise from the aircraft in steady level flight. The typical flyover procedure follows the diagram in Figure 3:. (Left) Diagram illustrating the flyover typically used to produce NPD curves and data. for the generation of the baseline event levels, while an example of a NPD data set for a DHC-6 Twin Otter is also shown.

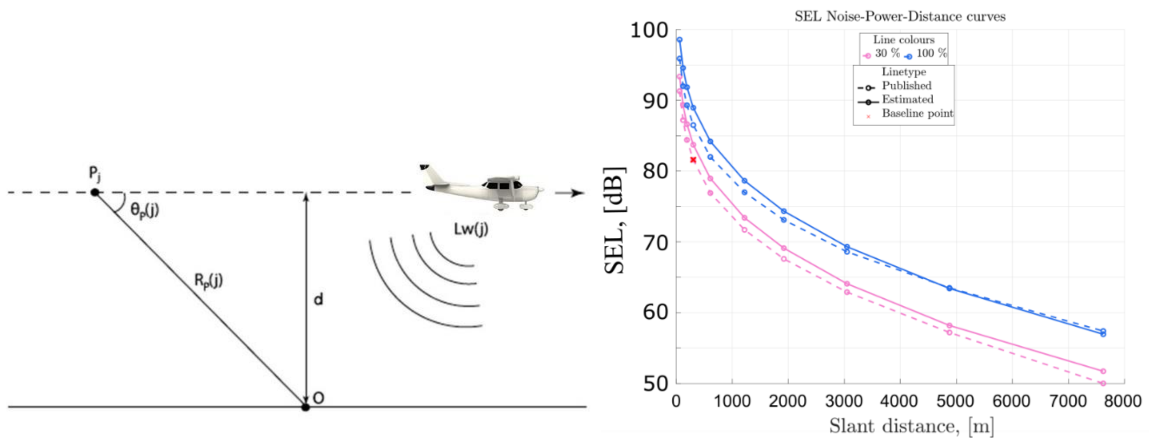


Figure 3:. (Left) Diagram illustrating the flyover typically used to produce NPD curves and data. (Right) Example Noise-Power-Distance curves for a take-off operation of a DHC-6 Twin Otter.

NPD data is the primary input for airport noise models that follow the ECAC CEAC Doc29 contour modelling methodology. The publicly available aircraft noise and performance (ANP) database is a primary source of NPD data for the purpose of generating noise exposure contours for current fixed-wing aircraft.

When a new design of aircraft is offered by manufacturers to enter service it goes through a noise certification process. This entails measuring the noise of the aircraft during a number of carefully managed flight procedures which ensure it meets the ICAO standards. In addition, the procedures and measurements generate the NPD curves of the aircraft which are then published. As alluded to above, these NPD curves allow for the prediction of aircraft noise within an operation setting. Within the UK such curves are used, by for instance the CAA, to predict likely noise exposure contours around airports.

3 METHODOLOGY

3.1 NOISE SOURCE MODEL

Within NAPKIN, the UoS has developed a noise source model for novel aircraft which allows the prediction of NPD curves. The method requires the main noise sources of the aircraft to be identified and the likely noise of each to be determined by reference to the baseline aircraft with any new sources also being estimated. Unlike previous methods noise directivity is included – something of importance to smaller aircraft that are likely to be propeller driven. A flow diagram of the overall methodology is shown in Figure 4: Flow diagram of the noise source & airport noise prediction model methodology used by the ISVR tools..

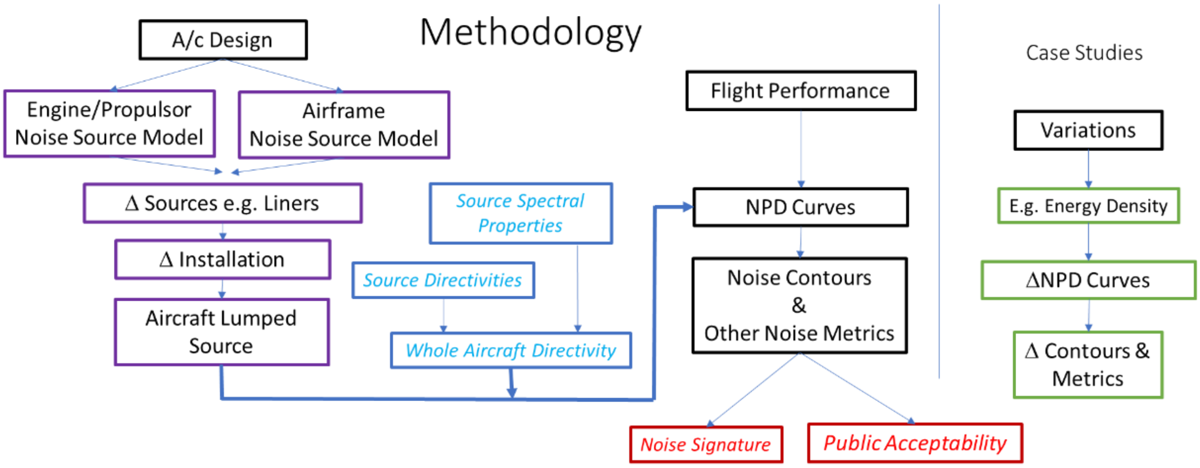


Figure 4: Flow diagram of the noise source & airport noise prediction model methodology used by the ISVR tools.

When combined these individual sources comprise a lumped source model that allows prediction of aircraft NPD curves and subsequently the certification values and operation noise. Once this is done, an individual aircraft can be integrated into a fleet model allowing airport noise contours to be predicted.

3.1.1 Lumped Source Model

Each concept is represented as a noise source using a lumped source model. This lumped source is characterised by the total acoustic power radiated by the aircraft W_j, (subscript j denotes the aircraft power setting) and a directivity factor D that determines the directions in which this acoustic is radiated. The Sound Pressure Level (SPL) at an observer location at distance r and direction (θ, φ) due to a lumped source is given by:

$$L_p(r, \theta, \varphi) = 10 \log \left[\frac{W_j D(\theta, \varphi)}{r^2} C \right]$$

where $C = \rho c / (4\pi p_{ref}^2)$ is a constant.

The total Sound Power Level of the lumped source is determined by the sum of the contributions of the individual noise source mechanisms,

$$W_{tot,j} = \sum_{i=1}^{n} W_i$$

with W_i being the acoustic power of source i out of the total number of contributing sources n. This addition assumes incoherent aircraft noise sources due to the random relative phases between the individual sources. The total lumped source directivity is then defined as the weighted average of the individual source directivities D_i,

$$D(\theta,\varphi) = \frac{\sum_{i=1}^{s} W_i D_i(\theta,\varphi)}{\sum_{i=1}^{s} W_i}$$

The individual source directivities used for this study may be seen in Figure 5: Individual source directivity for Turboprop and Turbofan aircraft., for propeller and ducted fan configurations.

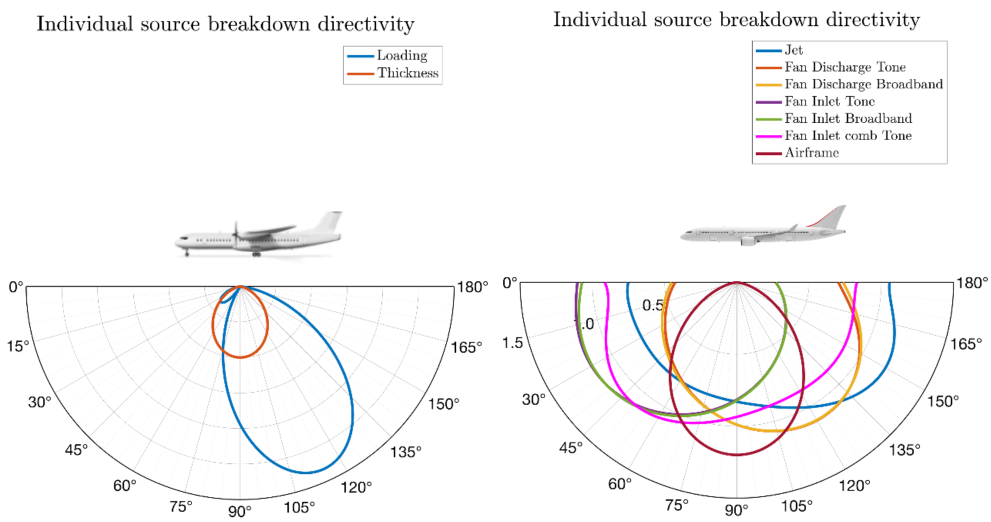


Figure 5: Individual source directivity for Turboprop and Turbofan aircraft.

Instead of calculating the absolute values W_i, the SyNoPoD framework (2) (3) and accompanying tools of the ISVR (4) estimate changes in the contributions of the individual sources and relate it to a baseline scenario. The baseline scenario/aircraft is chosen to be representative of current generation technologies where the noise levels are known or may be estimated. Variation in the noise due to technological and operational changes are related to that of the baseline to give the noise impact of the concept under study.

Specifically, given the Sound Power Level (PWL) of the baseline scenario $L_{w,0}$, and the estimated changes to the individual sources ΔW_s, the PWL of the concept may be expressed as,

$$L_w = L_{w,0} + 10\log\left(1 + \frac{\sum_{s=1}^{n} \Delta W_s}{\sum_{s=1}^{n} W_s}\right)$$

The baseline aircraft PWL, $L_{w,0}$ is given by the publicly available NPD curves from the ANP database. The level corresponding to the chosen NPD point is back-propagated to the source, accounting for atmospheric attenuation, spherical spreading, A-weighting and the position at which $L_{A.max}$ occurs.

The change in individual noise source levels ΔW_s are calculated using component level predictions models for each source separately. If method M predicts the noise levels of source s which are a function f of parameters $\eta_{1,0}, \eta_{2,0}, \dots, \eta_{m,0}$ where m is the total number of influencing parameters, the change in PWL between a baseline scenario denoted by subscript 0 and the concept is approximated by,

$$\Delta L_{w,s} = 10 \log \left(\frac{f(\eta_1, \eta_{2,0}, \dots, \eta_m)}{f(\eta_{1,0}, \eta_{2,0}, \dots, \eta_{m,0})} \right)$$

Once the lumped source has been fully characterised, numerical flyovers are performed in order to generate the required NPD curves.

3.1.2 Individual Noise sources

Noise sources on aircraft are generally categorised into engine noise sources and airframe noise sources. In addition to the sources that fit in into that classification, interaction noise sources are also present whereby, aerodynamic effects of the flow or potential fields from the engine interact with a solid boundary (e.g. wing) of the airframe, or vice versa, to generate new sources of noise. The major source of engine noise in conventional aircraft are the fan and jet, with compressor, combustion and turbine noise contributing to a lesser extent. In the case of propeller aircraft, the propeller itself is the dominating source of noise, effectively masking the contributions of the engine/gas turbine powering it.

Airframe noise can be attributed to the interaction of the oncoming flow with the aircraft airframe. Specifically, components of the airframe that contribute most to overall noise are: high-lift devices, landing gear and fuselage and wing self-noise.

The principal aircraft noise sources considered for the estimation of the NAPKIN concept NPD data are the fan and jet components of engine noise for a ducted fan configuration, propeller steady loading noise for reciprocating engine and turboprop configurations, and airframe noise. More specifically, the components of noise, the specific parameters that determine the noise emission and the models used are listed below:

- Ducted fan / turbofan engine
    - Fan (F_N, BPR, d_f, V_0, V_j, V_{BP}, N1), Heidmann model (5)
    - Jet (F_N, A_m, V_0, V_m), Stone model (6)
- Propeller (Hanson frequency domain model (7) (8))
    - Steady loading noise (F_N, d_p, RPM, V_0, V_m, blade geometry)
    - Thickness noise (d_p, RPM, V_0, V_m, blade geometry)
- Airframe (Fink model (9))
    - High-lift devices (δ_f, V_0)
    - Fuselage + wing (F_N, V_0, D)
    - Landing gear (F_N, V_0, D)

The selection of these particular individual sources and respective models has been made following the results of total aircraft noise breakdowns such as the one presented in Figure 6: Noise source breakdown for Dash 8 – Q400 aircraft [Reference - Turboprop Aircraft Noise – Advancements and comparison with flyover data Aeronautical Journal – New Series – May 2015 Antonio Filippone]. for conventional turboprop aircraft. The propeller noise source dominates all airframe and other engine components and gives the final shape to the OASPL time history. References (10) (11) provide source breakdowns for conventional turbofan engines and identify the dominant sources.

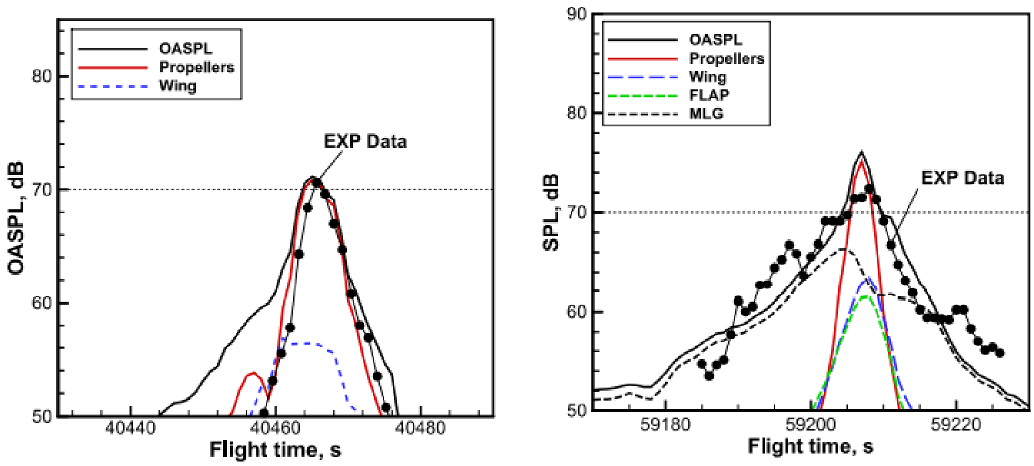


Figure 6: Noise source breakdown for Dash 8 – Q400 aircraft [Reference - Turboprop Aircraft Noise – Advancements and comparison with flyover data Aeronautical Journal – New Series – May 2015 Antonio Filippone].

Furthermore, interaction sources are hard to characterise at the conceptual/preliminary design stage, as exact geometry and operating conditions are not fully defined.

3.1.2.1 Corrections Installation effects

Installation effects can be broadly separated into two categories, effects that alter the directivity of the aircraft and redistribute the already existing sound power. These are typically shielding and reflection effects. The second category are the installation effects that contribute additional sound power to the overall system and are noise generating mechanisms themselves. Reference (12) provides a review of installation effects present on conventional tube and wing aircraft.

Analytical methods have been developed and could provide details insight on the effects fan tone scattering and reflection by the fuselage have on the far-field noise, as well as noise due to installed open-rotors (13) (14) (15). Recent studies on propeller-wing interactions quantify the source balance of such set-ups (16) (17) (18).

In this study, installation effects are accounted for empirically using a correction $\Delta\ dB$ to the appropriate noise sources and the direction in which they take effect. References (2) and (19) detail the methodology of applying such corrections.

Table 1: Installation effect corrections for individual noise sources

Installation effect	Correction (dB)	Direction (polar angle, θ)	Reference
Under-wing mounted engine flap noise	-2 +2	$0^{\circ} < \theta < 45^{\circ}$ $140^{\circ} < \theta < 180^{\circ}$	(20)
Underwing mounted engine jet / turbomachinery flap noise	-3	$0^{\circ} < \theta < 180^{\circ}$	(21) (22)
Underwing mounted engine fan forward arc reflection	+2	$0^{\circ} < \theta < 90^{\circ}$	(23) (24) (25) (26)
Underwing mounted engine fan rear arc reflection	+2	$90^{\circ} < \theta < 180^{\circ}$	(23) (24) (25) (26)
Fuselage tail mounted engine.	-3	$0^{\circ} < \theta < 90^{\circ}$	(27)

3.1.2.2 Noise prediction risks

It is important to identify potential additional sources of noise that are unique to the hydrogen concepts discussed herein, and that could have potential of dominating the sound profile under specific operating conditions if care is not taken.

In addition to the risks of additional sources, the noise prediction methodology used does not account for noise abatement design choices implemented or planned for the concept aircraft. Examples of such design choices could be the use of fan intake liners or the use of novel propeller/fan design for quiet operation.

Table 2: Potential unaccounted for noise sources. summarises the risks associated with unaccounted for noise sources.

Table 2: Potential unaccounted for noise sources.

Source Mechanism	Description
Rotor Stator interaction	Interaction of periodic velocity fluctuations with downstream outlet guide vanes (stator) produces discrete frequency noise or pure tones. Increasing the strength of the interaction or increasing the efficiency with which the source radiates acoustic waves. Correct choice of blade/vane count ratio and vane location.
Multiple propulsor interaction	Interaction of individual propulsor potential fields, as well as wake/tip-vortex interaction with or without the interference of the propulsor structure itself.
Propulsor-airframe interaction	Interaction of airframe component potential fields with the propulsor field causing unsteady effects on noise generating mechanisms. Propulsor wakes interacting with the airframe structure and vice-versa.
Fuselage Scoop/Intake noise	Flow over open cavities or cut-outs in the surfaces of aircraft often produces intense pressure oscillations in the cavity which radiates discrete noise.
Hydrogen combustion noise	Flame attachment due to high reactivity of H2 has a significant effect on how low-swirl injectors respond to self-excited flame oscillations. This leads to significantly higher acoustic driving due to the compact shape of the flame and its flame folding dynamics. Mitigation of flame attachment

	and/or deferring the formation of the outer shear layer is needed to avoid such noise generation dynamic mechanisms.
Electric motor	The dominant source of noise in electric motors comes from the interaction of a rotor and stator that induces vibration of the motor frame. Preliminary research shows that levels are expected to be low compared to other propulsion noise sources like the fan, however, it is possible that a portion of a flyover during approach will include motor noise depending on the motor installation.

3.2 RANE: AIRPORT NOISE TOOL

Given the NPD curves for the NAPKIN, any airport noise tool that is developed under the standard ECAC Doc29 methodology such

The airport noise tool RANE (Rapid Airport Noise Evaluator) uses the concept of pre-integrated noise surfaces that surround the discretised aircraft flight trajectory (Figure 7: (Left) Discretised aircraft trajectory characterised by straight line segments and way-point (WP) that carry each segment input parameters. (Right) Illustration of the noise surface modelling technique implemented by RANE. The intersection of the noise surface and the airport ground plane give the noise exposure contour location on the ground.), with the footprints and contours being calculated as the intersection with the ground. Only two general inputs are required NPDs and noise source directivity. Aircraft performance data and NPD curves are obtained by publicly available databases (e.g., ECAC and ICAO ANP, Eurocontrol BADA). The capabilities of RANE to produce single event footprints and fleet contours has been benchmarked against public domain methods and producing near identical results.

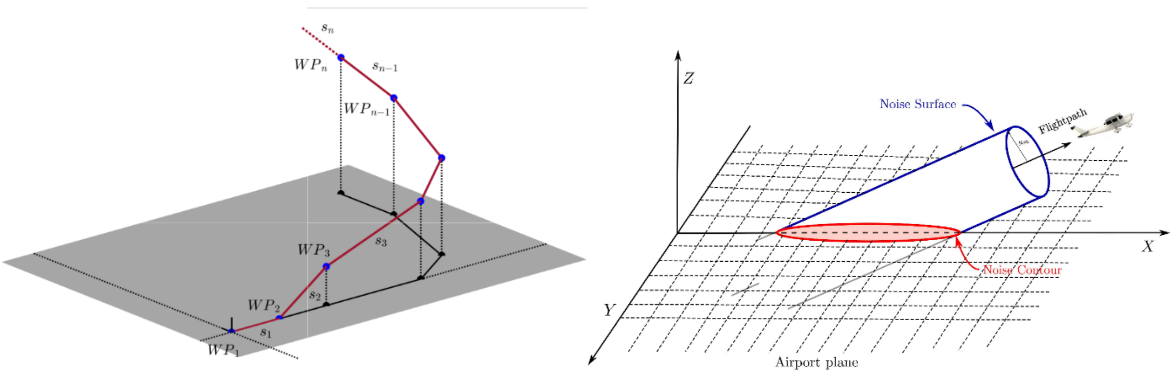


Figure 7: (Left) Discretised aircraft trajectory characterised by straight line segments and way-point (WP) that carry each segment input parameters. (Right) Illustration of the noise surface modelling technique implemented by RANE. The intersection of the noise surface and the airport ground plane give the noise exposure contour location on the ground.

4 NAPKIN CONCEPT AIRCRAFT

4.1 CONCEPT DESIGN SPECIFICATION

Given the multiplicity of concepts studied it would be cumbersome to reference to each concept from each manufacturer with the uniquely specified name. This Appendix uses a name code for each concept based on the reference aircraft that was used during the design. The code names may be seen in Tables Table 3: Design and performance parameter overview for NAPKIN concepts developed by CAeS. to Table 5: Design and performance parameter overview for NAPKIN concepts developed by Rolls-Royce plc. along with reference aircraft and characteristic design and operation parameters for each concept.

4.1.1 Cranfield Aerospace Solutions (CAeS) concept aircraft

Cranfield Aerospace Solutions (CAeS) developed a series of small regional concepts using i. a retrofit approach, where the novel hydrogen propulsion system of choice was fitted into the airframe of an existing aircraft while aiming to replicate the performance at the same time; ii. A clean sheet approach, where the performance characteristics of the reference current generation aircraft were used to drive the preliminary sizing of new optimised for the implementation of the hydrogen propulsion systems. A summary of the concepts is seen in Table 3: Design and performance parameter overview for NAPKIN concepts developed by CAeS. The concepts are based on the mission and performance characteristics of three current generation small propeller powered aircraft: the Britten Norman B-N 2 Islander, the de Havilland Canada DHC-6 Twin Otter and the Jetstream 3100 series.

Table 3: Design and performance parameter overview for NAPKIN concepts developed by CAeS.

Concepts	Noise Code Name	Noise Chapter	Reference Aircraft	Propulsion System Configuration	MTOW (kg)	Range (km)	PAX	Max Static Thrust (kN)	Net Take-off Thrust (kN)
A	A1	6	B-N 2 Islander	Gaseous Hydrogen/Fuel Cell Electric Propulsion	2,994	236	7	4.77	3.90
B	B1	10	DHC-6	Gaseous Hydrogen/Fuel Cell Electric Propulsion	5,626	214	11	8.48	7.98
C	A2	6	B-N 2 Islander	Gaseous Hydrogen/Fuel Cell Electric Propulsion	3,233	240	9	4.60	3.76

D	B2	10	DHC-6	Liquid Hydrogen/Fuel Cell Electric Propulsion	5,664	532	13	8.48	7.98
E	B3	10	DHC-6	Liquid Hydrogen Supply to Gas Turbine Engines	5,670	280	19	8.48	7.98
F	B4	10	DHC-6	Liquid Hydrogen/Fuel Cell Electric Propulsion	6,311	1,151	19	5.08	3.20
G	B5	10	DHC-6	Gaseous Hydrogen/Fuel Cell Electric Propulsion	7,376	795	19	5.08	3.20
H	G1	10	DHC-6	Liquid Hydrogen/Fuel Cell Electric Propulsion	8,470	1,102	19	11.67	11.49
I	G2	10	DHC-6	Liquid Hydrogen/Fuel Cell Electric Propulsion	8,539	1,122	19	11.64	11.44
J	G3	10	DHC-6	Liquid Hydrogen/Gas Turbine Propulsion	5,959	1,050	19	8.24	7.82

4.1.2 GKN Aerospace concept aircraft

GKN Aerospace developed regional concepts for two different classes of aircraft, the 19-PAX small regional size and a 40-PAX medium regional aircraft. Three different configurations were assessed for the 19-PAX category with the results informing the sizing procedure for the larger 40-PAX aircraft as well. All iterations of the concept are clean sheet designs with mission and performance characteristics based on the DHC-6 Twin Otter for the 19-PAX and the ATR42-600 for the 40-PAX. A summary of the concepts is seen in Table 4: Design and performance parameter overview for NAPKIN concepts developed by GKN Aerospace. All concepts feature a liquid hydrogen (LH2) fuel cell combination as the propulsion system with electric motors driving a ducted fan or open propeller.

Table 4: Design and performance parameter overview for NAPKIN concepts developed by GKN Aerospace.

Concepts	Noise Code Name	Noise Chapter	Reference Aircraft	Propulsion System Configuration	MTOW (kg)	Range (km)	PAX	Max Static Thrust (kN)	Net Take-off Thrust (kN)
First 19-PAX	B6	14	DHC-6	Liquid Hydrogen/Fuel Cell Electric Propulsion	10,000	550	19	14.90	9.697
Second 19-PAX	B7	14	DHC-6	Liquid Hydrogen/Fuel Cell Electric Propulsion	10,000	550	19	14.90	9.697
Third 19-PAX	B8	14	DHC-6	Liquid Hydrogen/Fuel Cell Electric Propulsion	10,000	550	19	14.90	9.697
40-PAX	D1	14	ATR42-600	Liquid Hydrogen/Fuel Cell Electric Propulsion	19,055	1,148	40	-	-

4.1.3 Rolls-Royce concept aircraft

Rolls-Royce plc as a part of project NAPKIN developed three concept aircraft. The concepts range from medium to large regional aircraft utilising turboprop and turbofan configurations. A summary of the concepts is seen in Table 5: Design and performance parameter overview for NAPKIN concepts developed by Rolls-Royce plc.. Concepts E1 and Z1 are designs based on the current airframes of the ATR72-600 and the Airbus A220-100, with modifications to the propulsion and energy storage systems to accommodate LH2 gas turbine operation. Concept E2 is a 50-PAX clean sheet design with external LH2 storage tanks, lower internal volume wings and distributed propulsion.

Table 5: Design and performance parameter overview for NAPKIN concepts developed by Rolls-Royce plc.

Concepts	Noise Code Name	Noise Chapter	Reference Aircraft	Propulsion System Configuration	MTOW (kg)	Range (km)	PAX	Max Static Thrust (kN)	Net Take-off Thrust (kN)
ATR72-600 LH2 GT	E1	14	ATR72-600	Liquid Hydrogen/Gas Turbine Propulsion	19,600	1,963	48	21.4	19.5
50-Seat LH2 GT	E2	14	ATR42-600	Liquid Hydrogen/Gas Turbine Propulsion	16,000	1,111	50	-	-
Airbus A220-100 LH2	Z1	14	A220-100	Liquid Hydrogen/Gas Turbine Propulsion	48,222	2,654	90	-	-

A complete analysis for the 50-PAX clean sheet concept has not been undertaken due to time constraints. The discussion section following provides some indication on the acoustic performance as a result of the design decisions that have been implemented.

4.2 NOISE-POWER-DISTANCE CURVES

4.2.1 Take-off / Departure NPDs

Figures Figure 8: Concept A1 departure $L_{A,max}$ and SEL NPD curves. to Figure 23: Concept Z1 departure $L_{A,max}$ and SEL NPD curves. show the predicted departure $L_{A,max}$ and SEL NPD curves for the NAPKIN concepts.

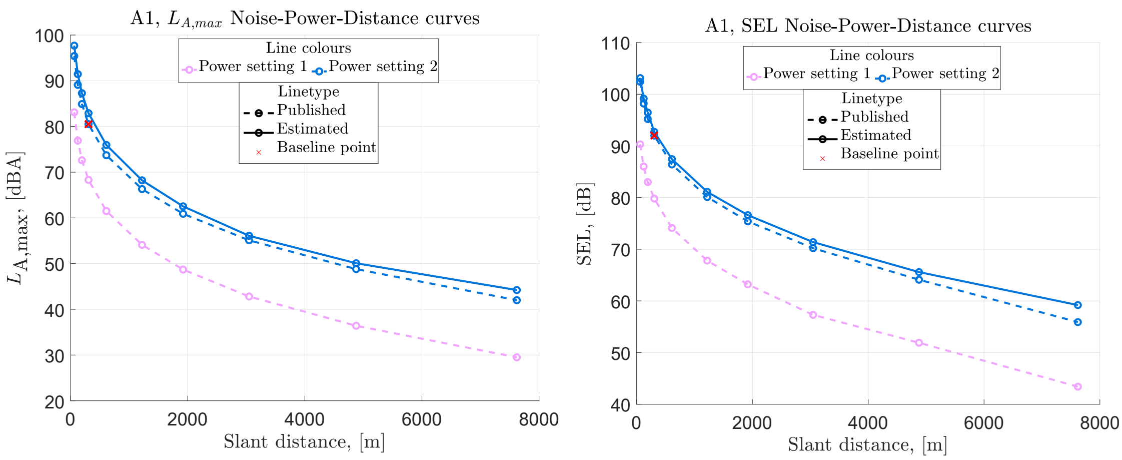


Figure 8: Concept A1 departure $L_{A,max}$ and SEL NPD curves.

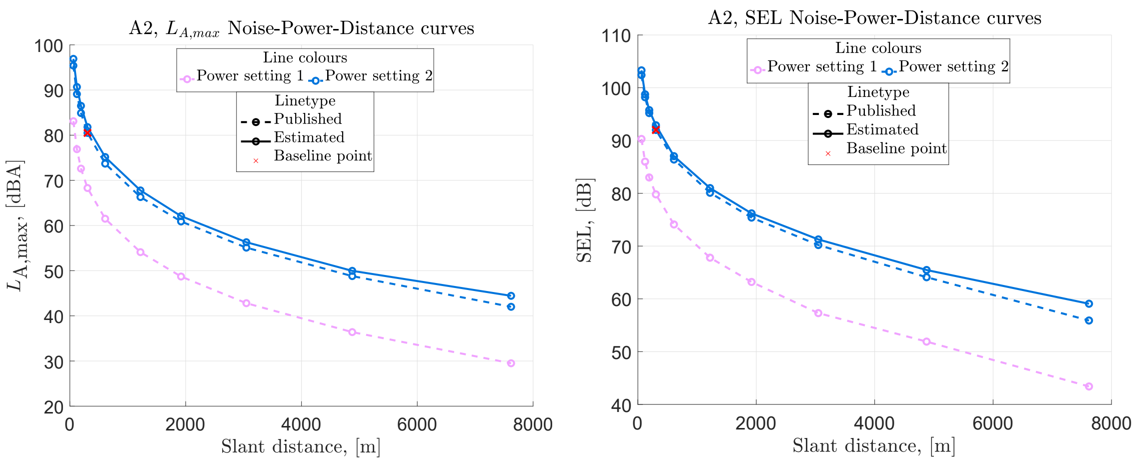


Figure 9: Concept A2 departure $L_{A,max}$ and SEL NPD curves.

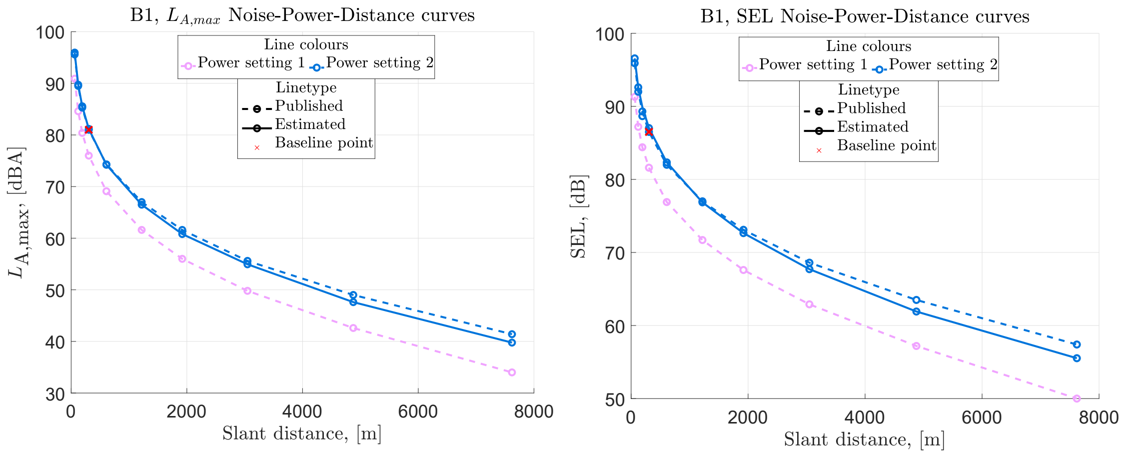


Figure 10: Concept B1 departure $L_{A,max}$ and SEL NPD curves.

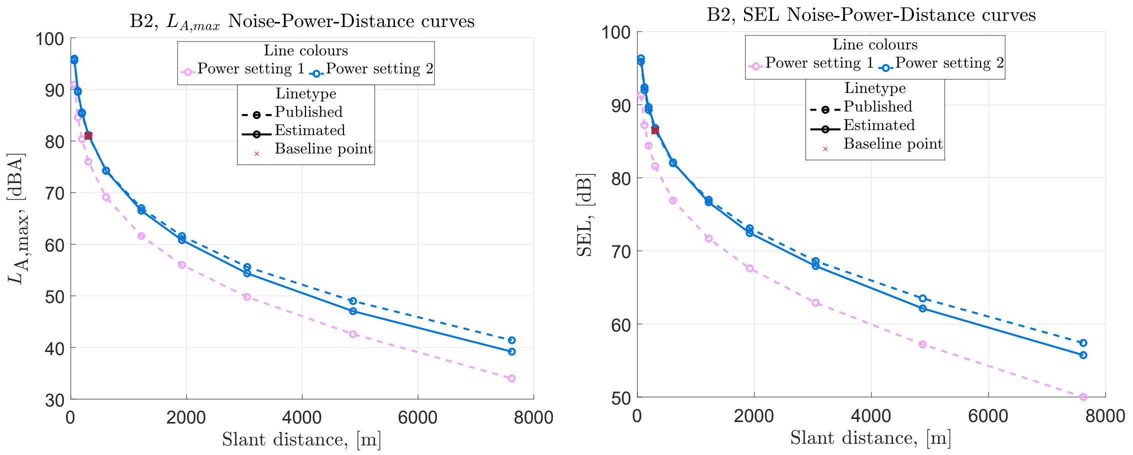


Figure 11: Concept B2 departure $L_{A,max}$ and SEL NPD curves.

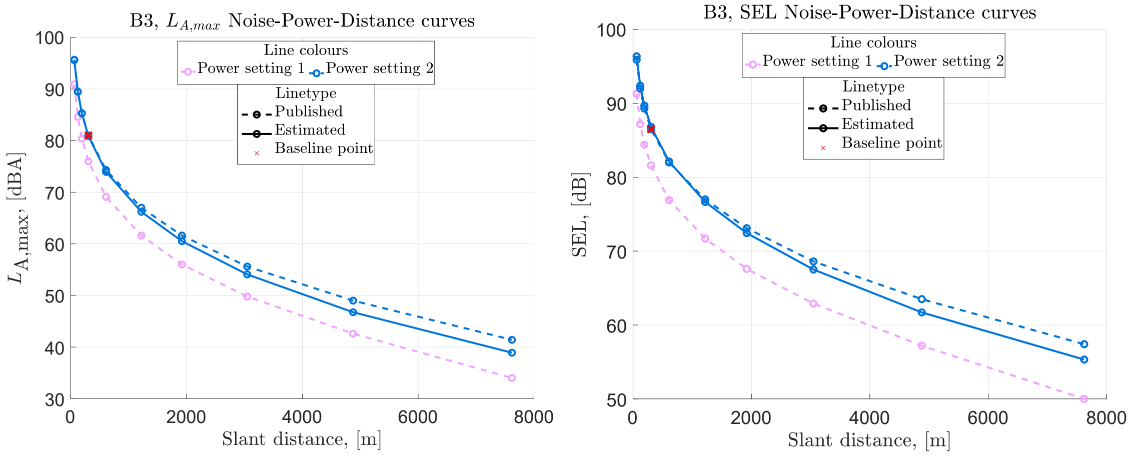


Figure 12: Concept B3 departure $L_{A,max}$ and SEL NPD curves.

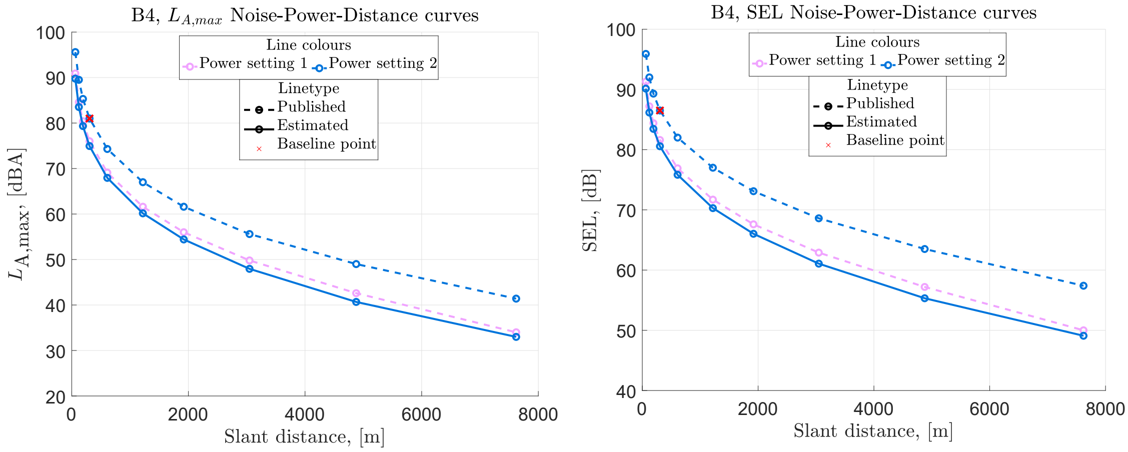


Figure 13: Concept B4 departure $L_{A,max}$ and SEL NPD curves.

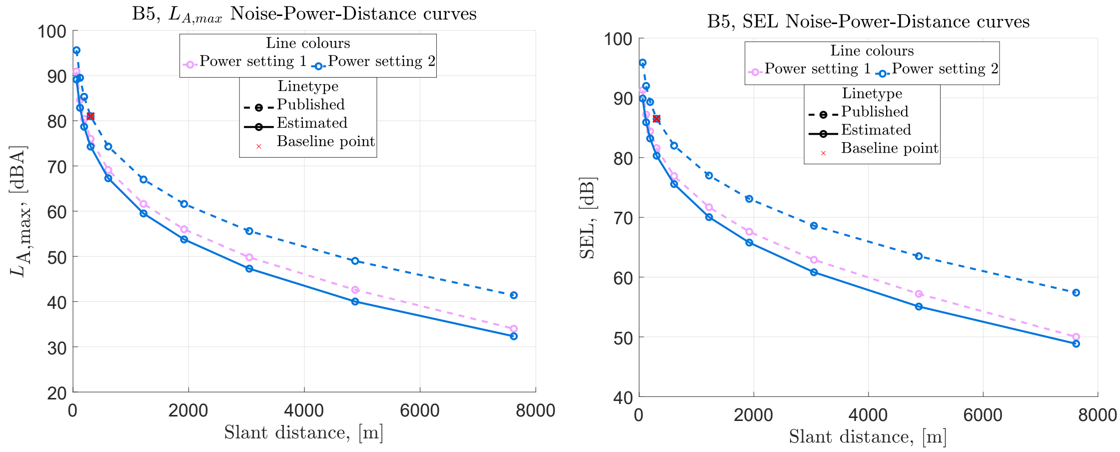


Figure 14: Concept B5 departure $L_{A,max}$ and SEL NPD curves.

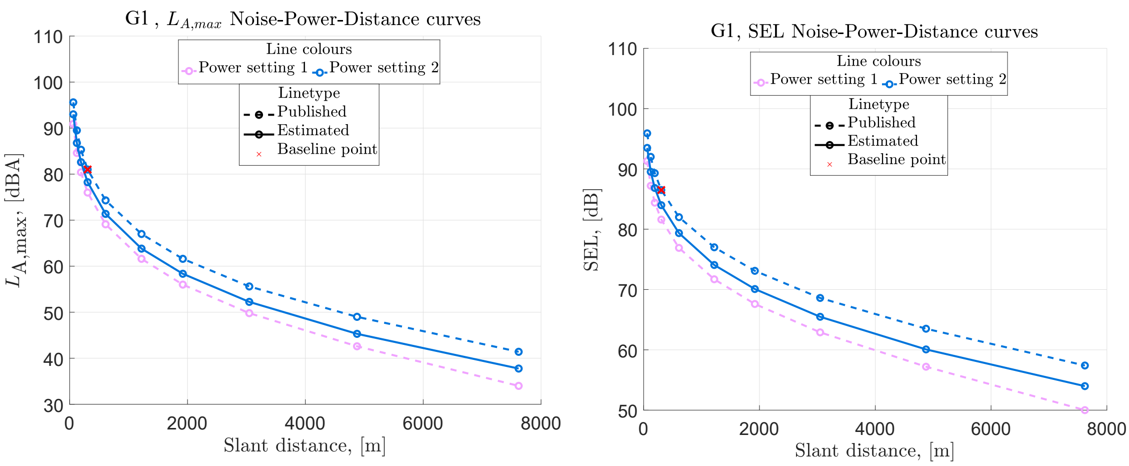


Figure 15: Concept G1 departure $L_{A,max}$ and SEL NPD curves.

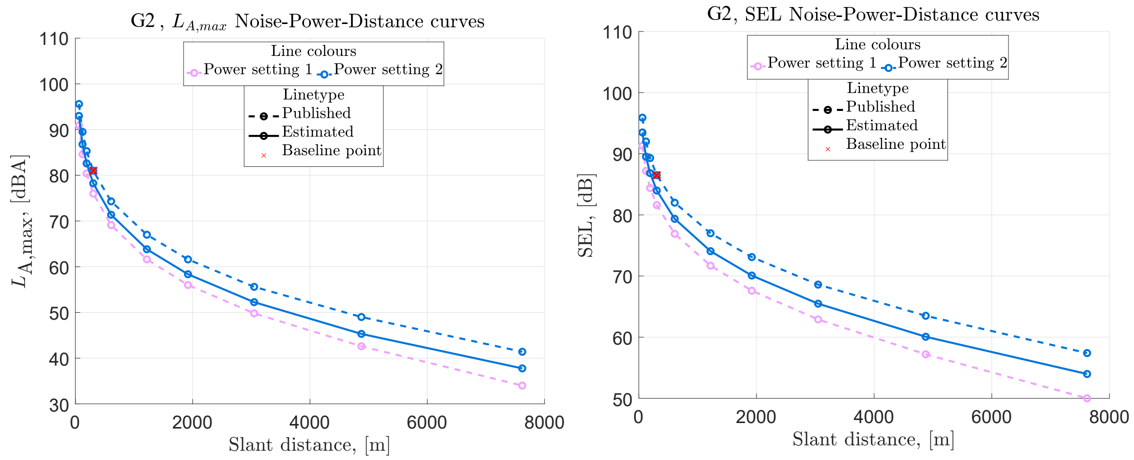


Figure 16: Concept G2 departure $L_{A,max}$ and SEL NPD curves.

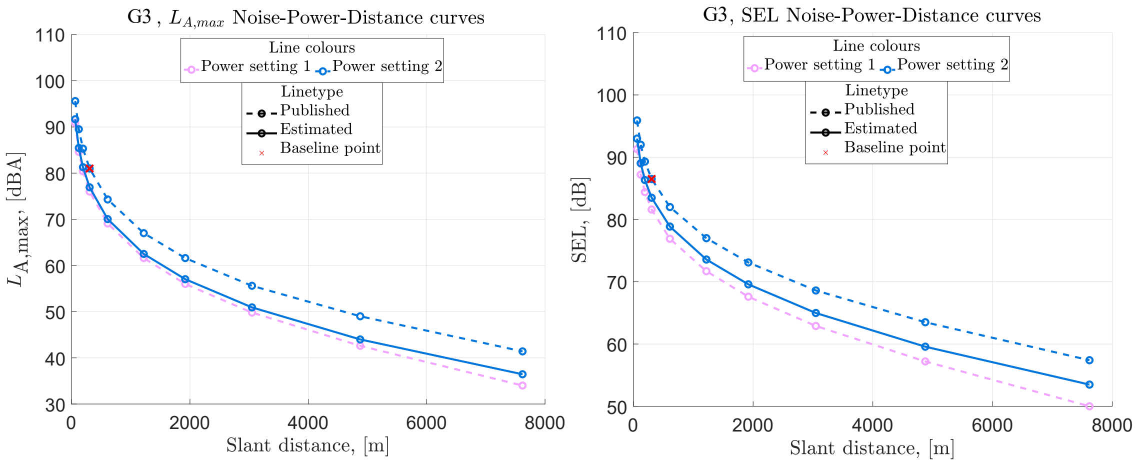


Figure 17: Concept G3 departure $L_{A,max}$ and SEL NPD curves.

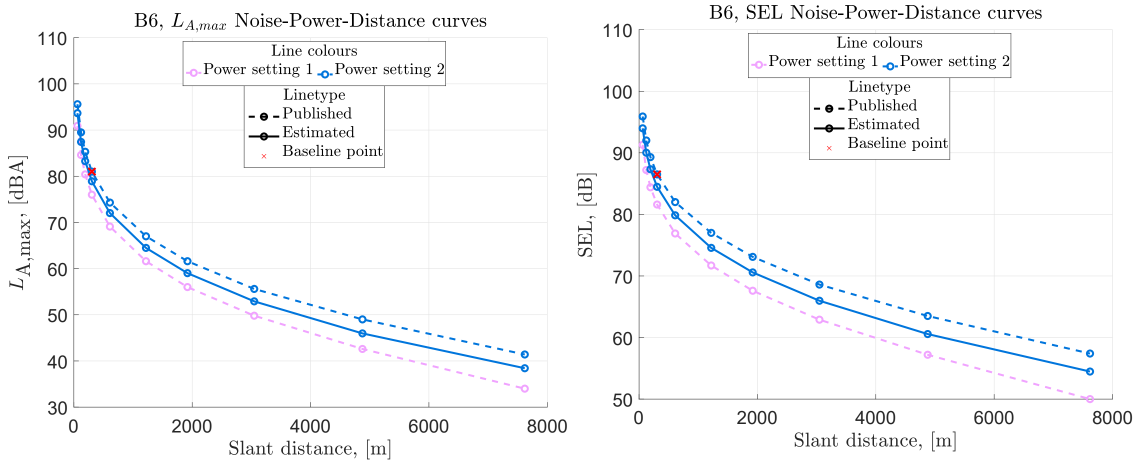


Figure 18: Concept B6 departure $L_{A,max}$ and SEL NPD curves.

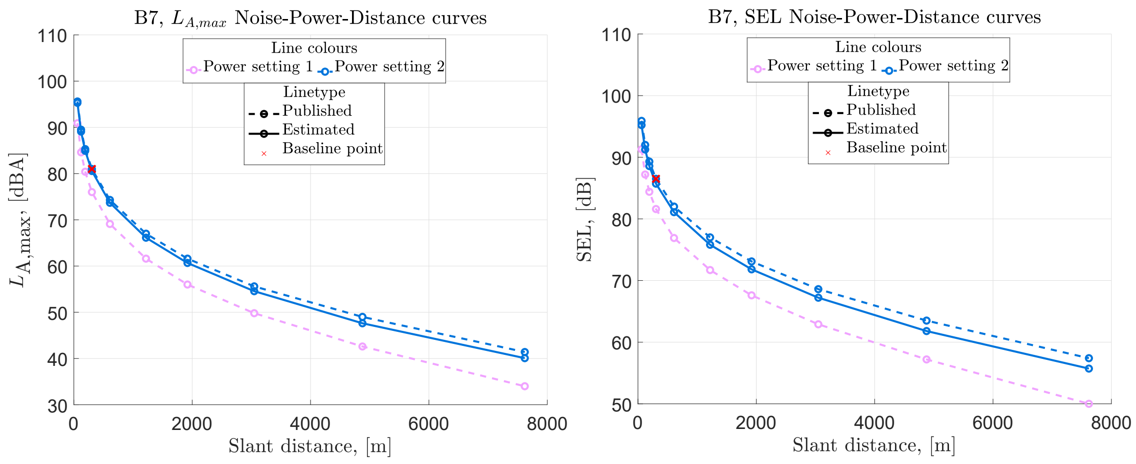


Figure 19: Concept B7 departure $L_{A,max}$ and SEL NPD curves.

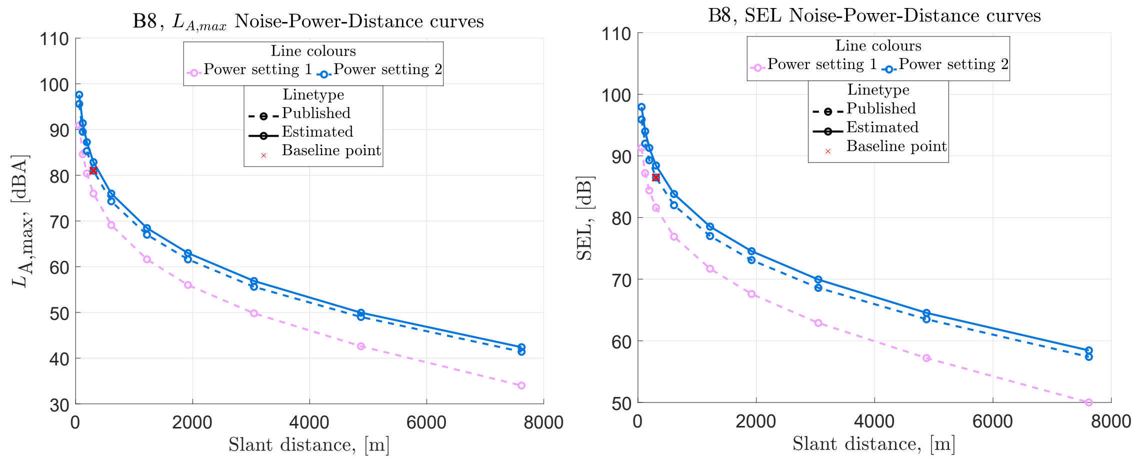


Figure 20: Concept B8 departure $L_{A,max}$ and SEL NPD curves.

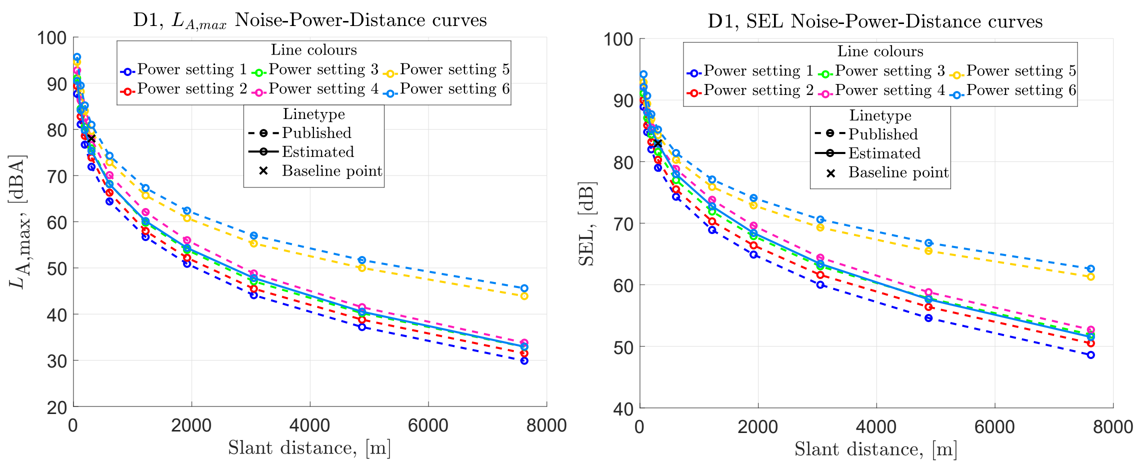


Figure 21: Concept D1 departure $L_{A,max}$ and SEL NPD curves.

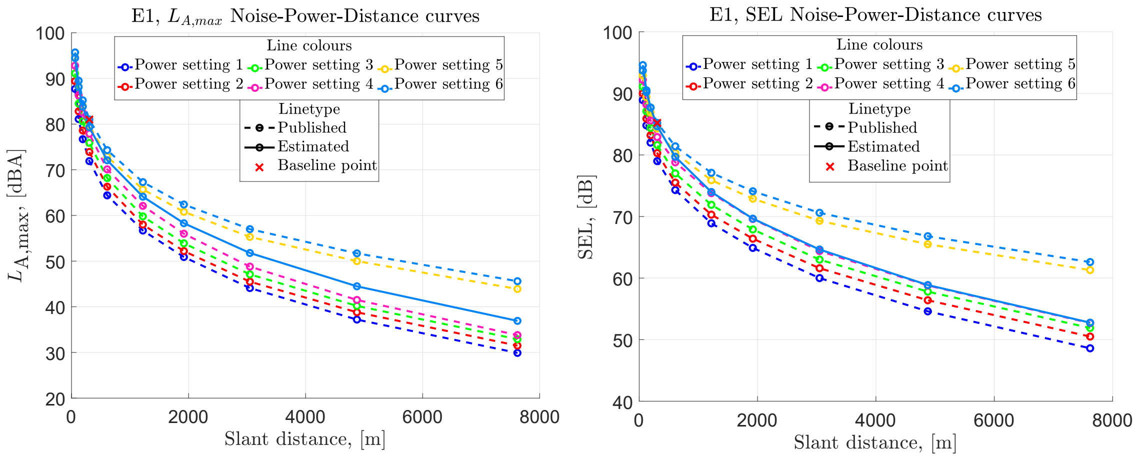


Figure 22: Concept E1 departure $L_{A,max}$ and SEL NPD curves.

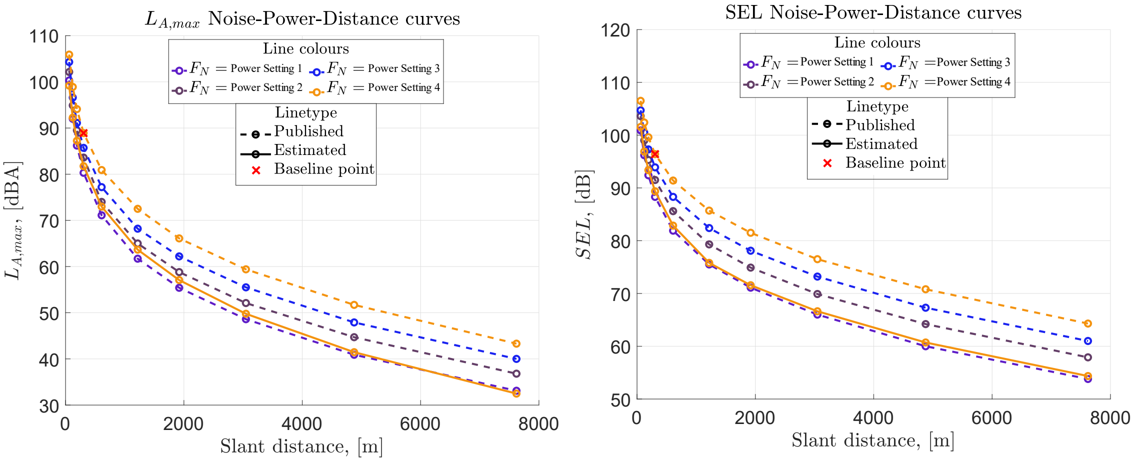


Figure 23: Concept Z1 departure $L_{A,max}$ and SEL NPD curves.

4.2.2 Approach / Landing NPDs

Figures Figure 24: Concept A1 approach $L_{A,max}$ and SEL NPD curves. to Figure 39: Concept Z1 approach $L_{A,max}$ and SEL NPD curves. show the predicted approach $L_{A,max}$ and SEL NPD curves for the NAPKIN concepts.

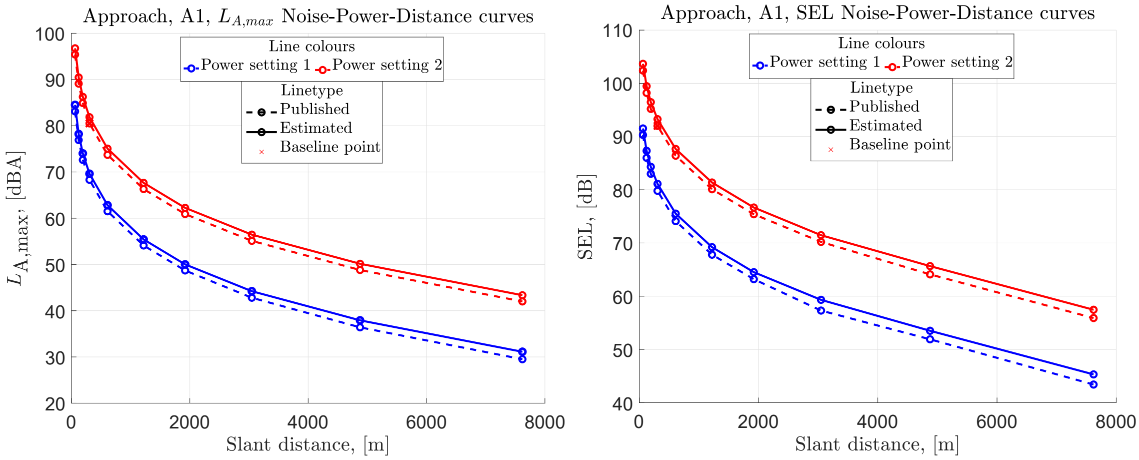


Figure 24: Concept A1 approach $L_{A,max}$ and SEL NPD curves.

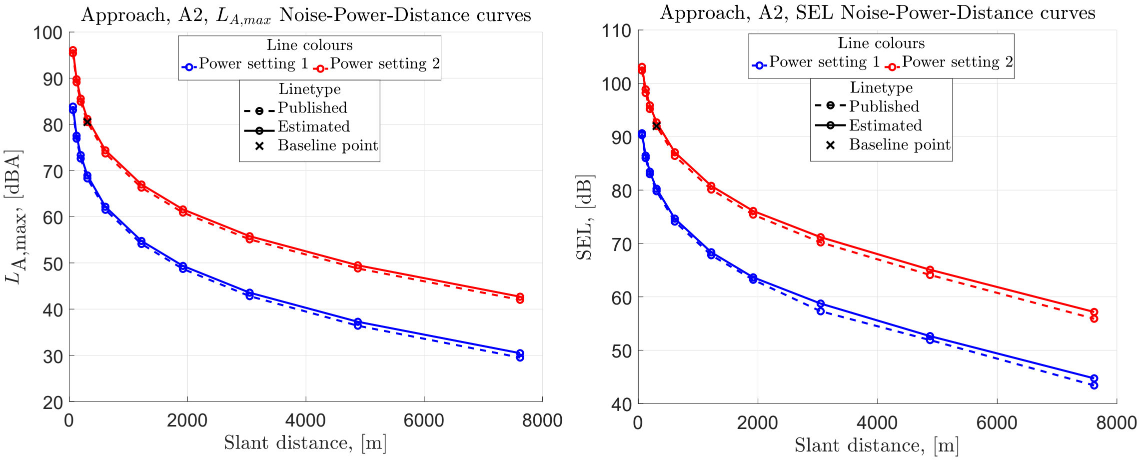


Figure 25: Concept A2 approach $L_{A,max}$ and SEL NPD curves.

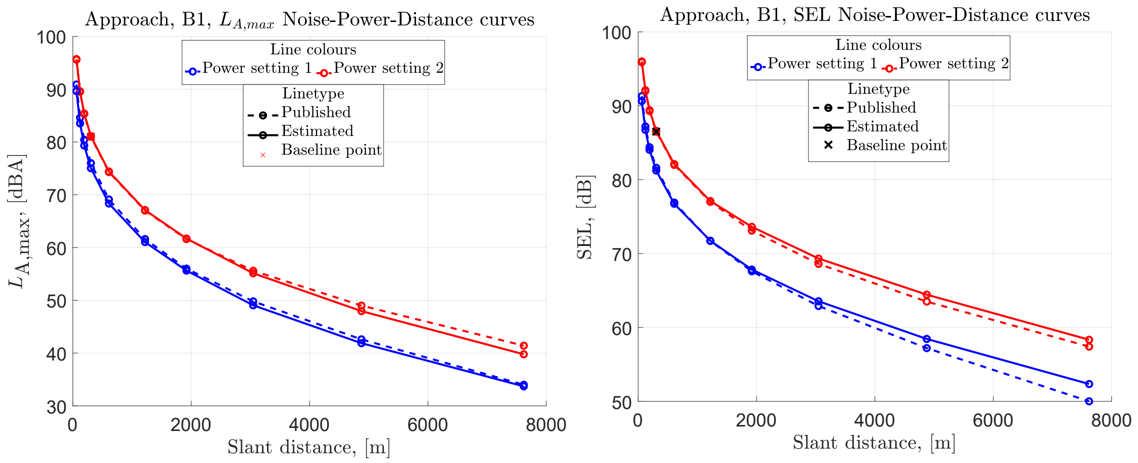


Figure 26: Concept B1 approach $L_{A,max}$ and SEL NPD curves.

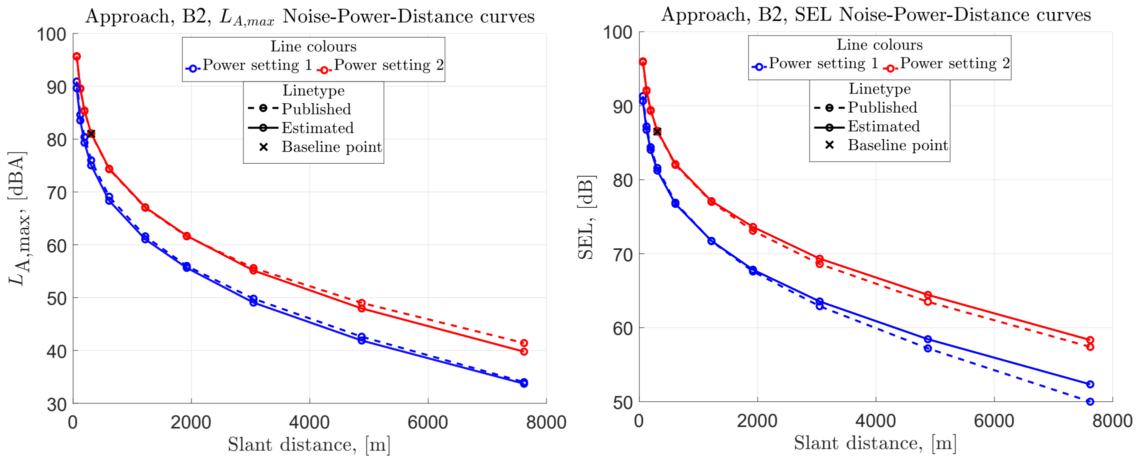


Figure 27: Concept B2 approach $L_{A,max}$ and SEL NPD curves.

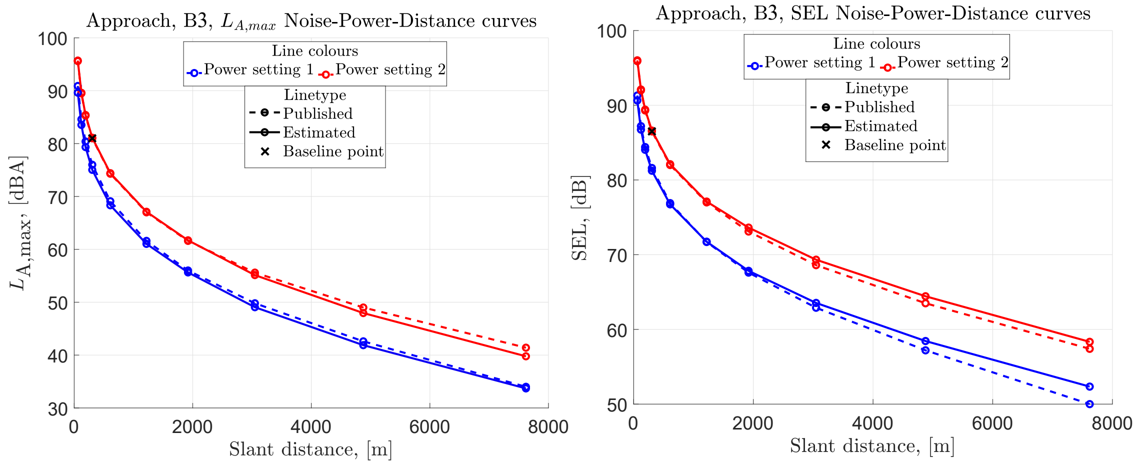


Figure 28: Concept B3 approach $L_{A,max}$ and SEL NPD curves.

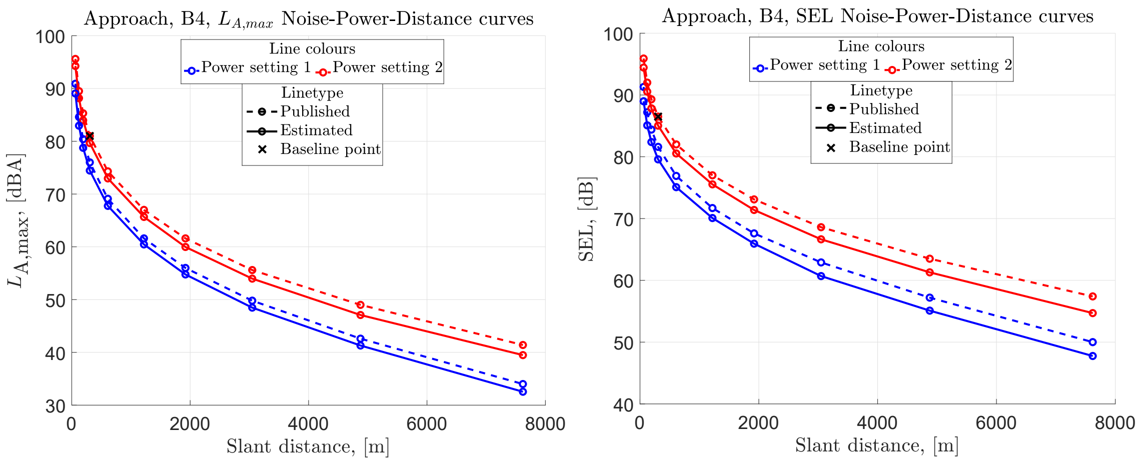


Figure 29: Concept B4 approach $L_{A,max}$ and SEL NPD curves.

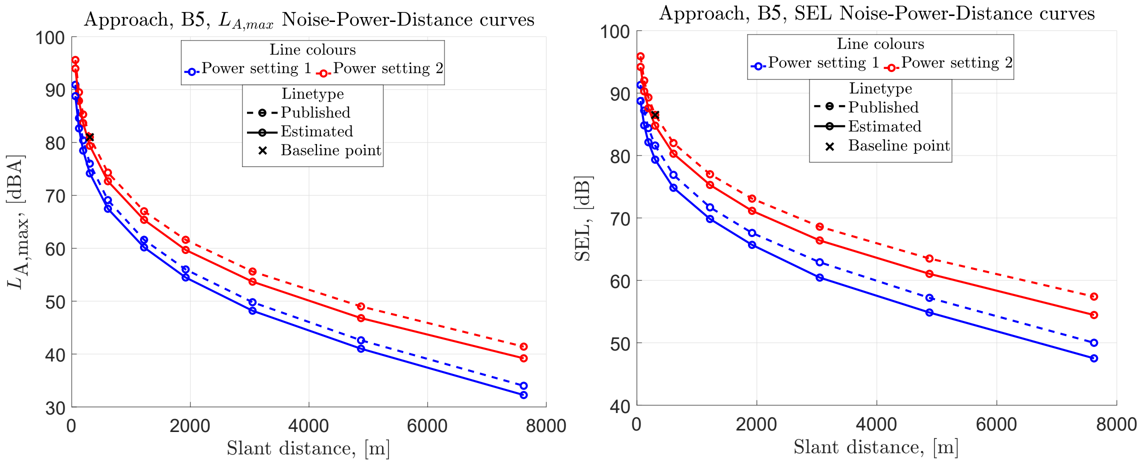


Figure 30: Concept B5 approach $L_{A,max}$ and SEL NPD curves.

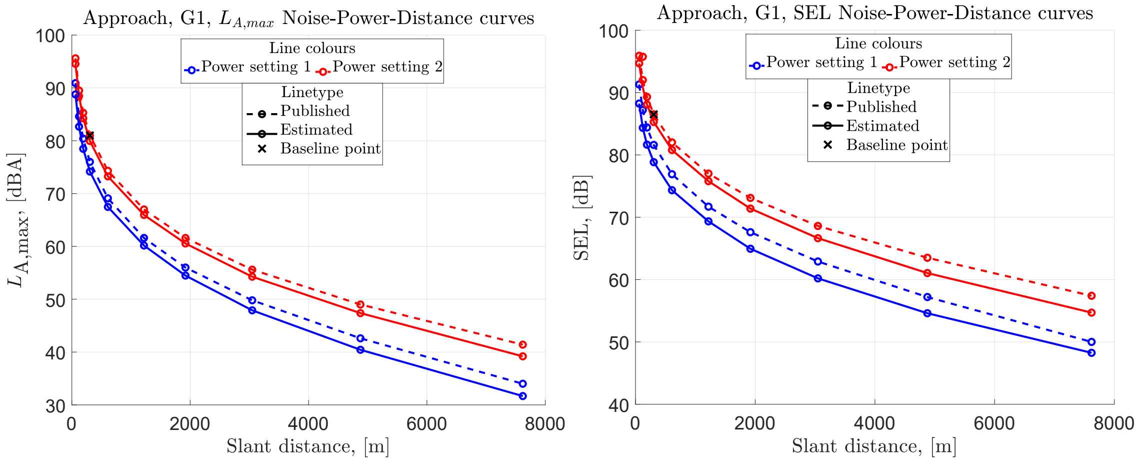


Figure 31: Concept G1 approach $L_{A,max}$ and SEL NPD curves.

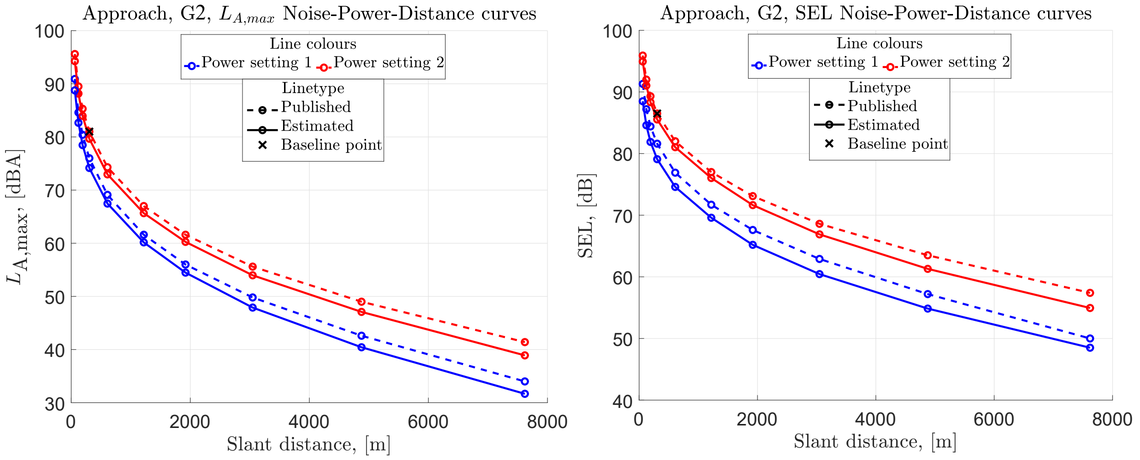


Figure 32: Concept G2 approach $L_{A,max}$ and SEL NPD curves.

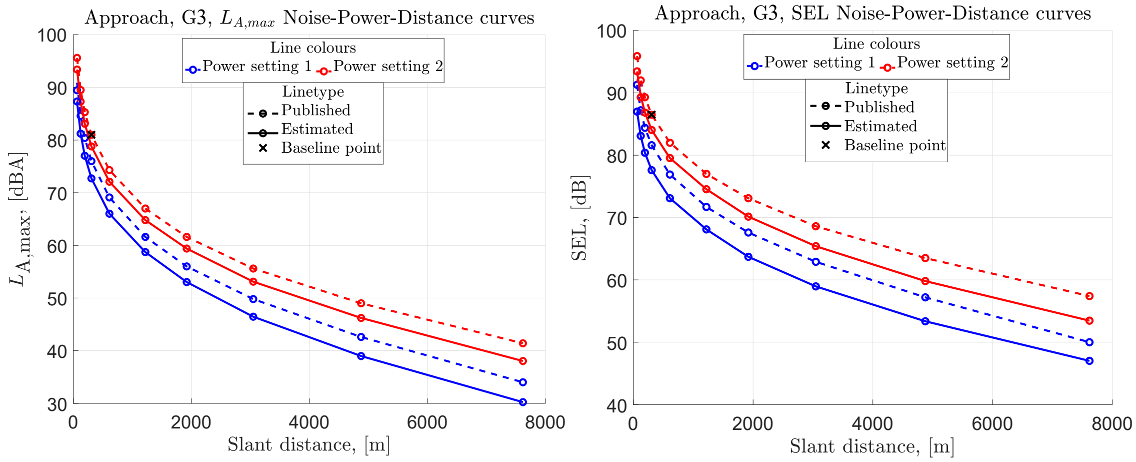


Figure 33: Concept G3 approach $L_{A,max}$ and SEL NPD curves.

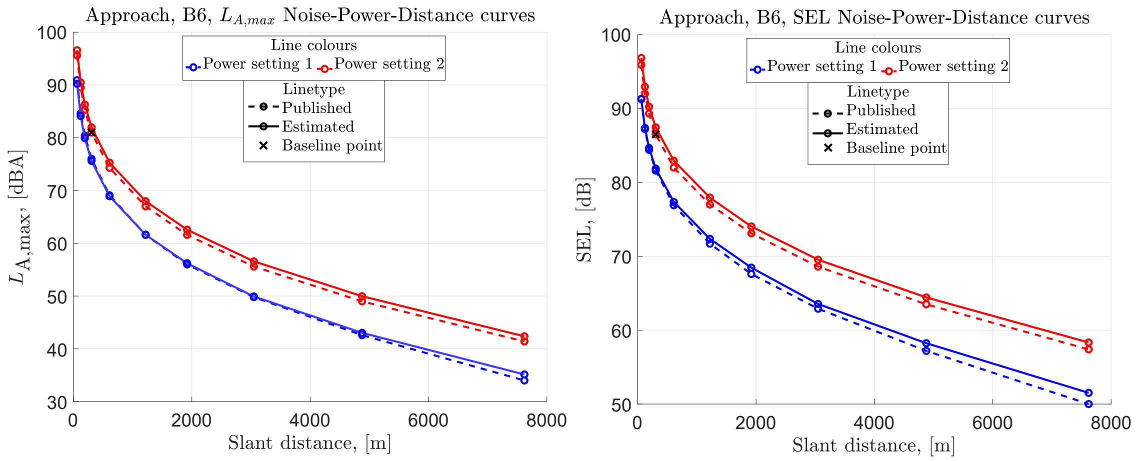


Figure 34: Concept B6 approach $L_{A,max}$ and SEL NPD curves.

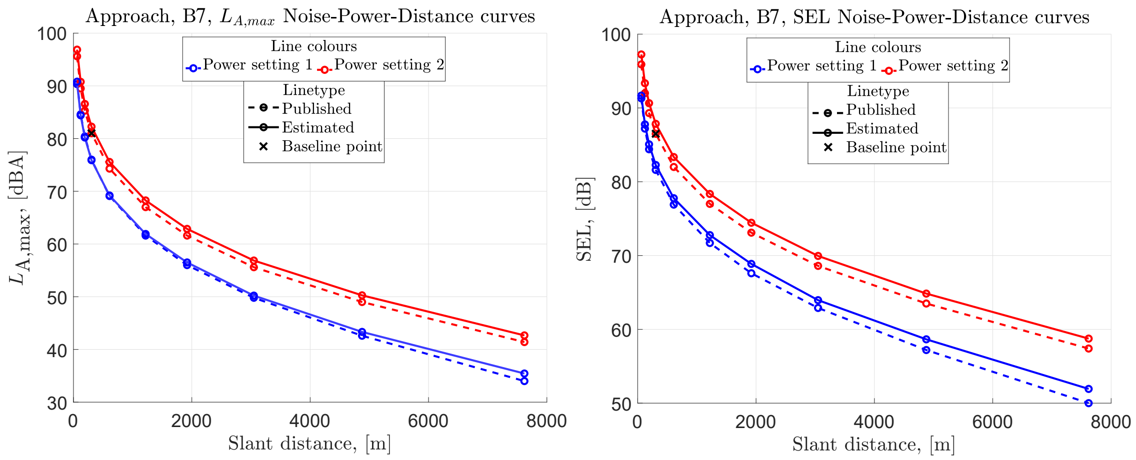


Figure 35: Concept B7 approach $L_{A,max}$ and SEL NPD curves.

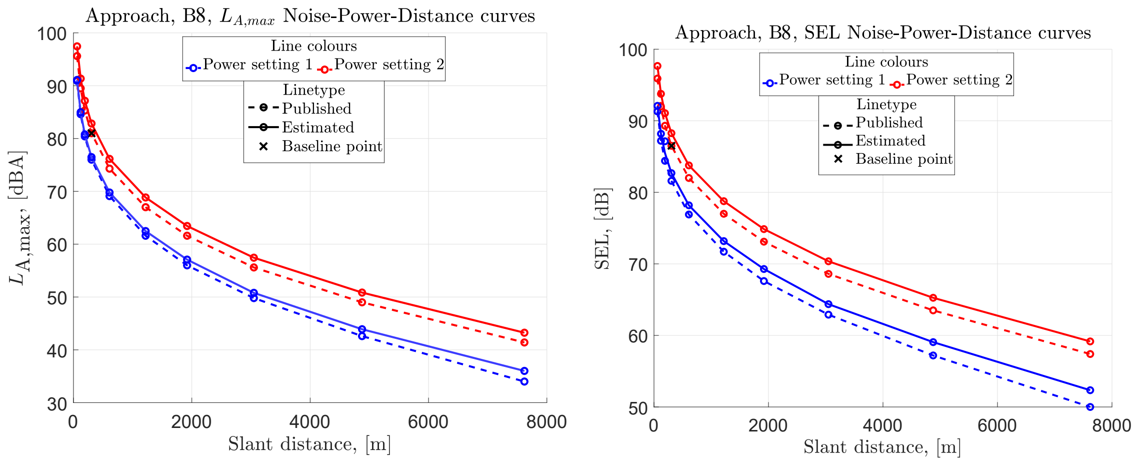


Figure 36: Concept B8 approach $L_{A,max}$ and SEL NPD curves.

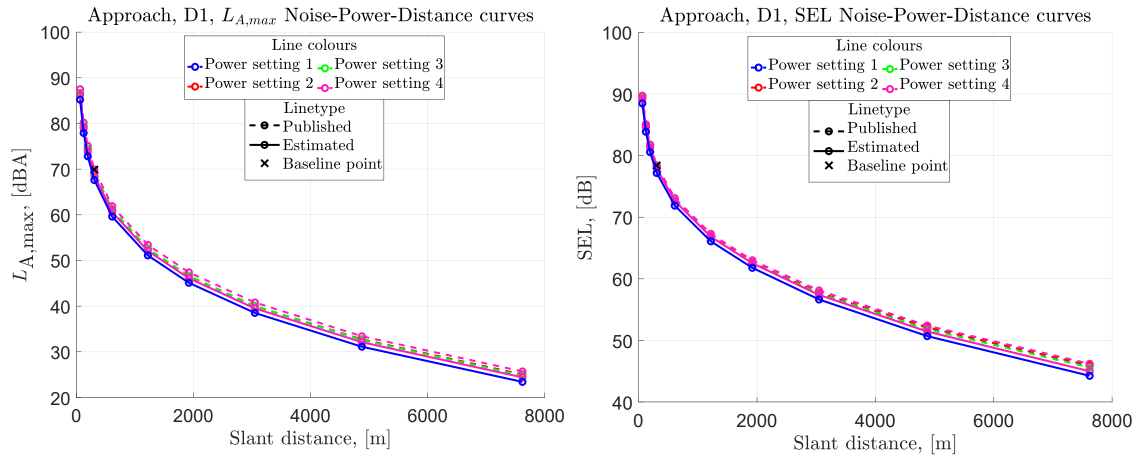


Figure 37: Concept D1 approach $L_{A,max}$ and SEL NPD curves.

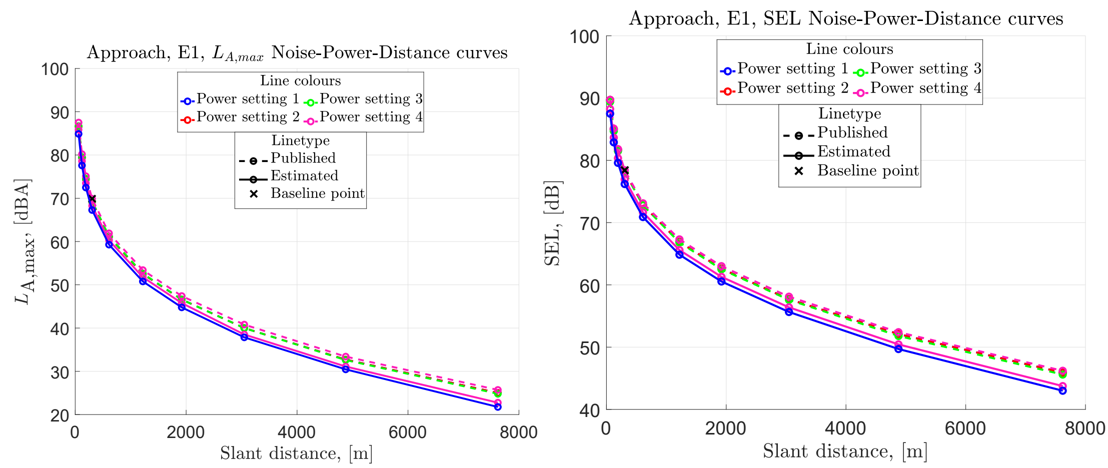
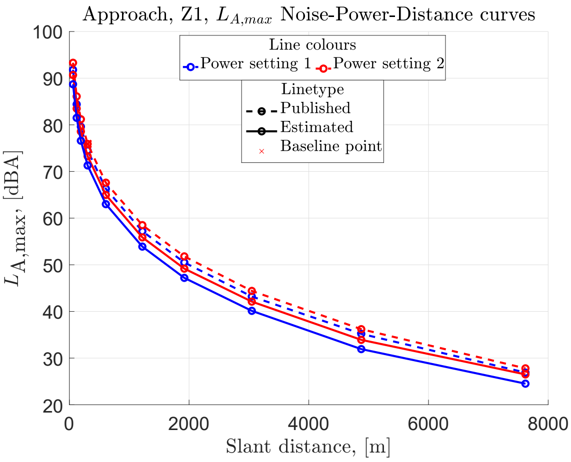


Figure 38: Concept E1 approach $L_{A,max}$ and SEL NPD curves.



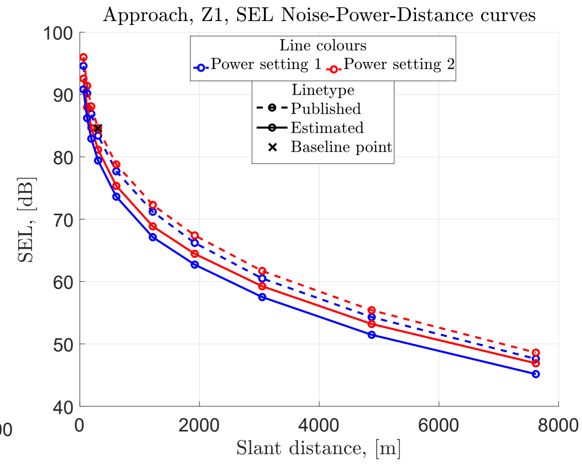


Figure 39: Concept Z1 approach $L_{A,max}$ and SEL NPD curves.

4.2.3 Discussion

<u>Concepts A</u>

Both A concepts are retrofit B-N 2 Islanders

- Instantaneous maximum sound pressure level ($L_{A,max}$) of straight level flyover increases by 1.4dB at all altitudes, relative to baseline.
- Time averaged sound exposure level (SEL) remains relatively unchanged at low altitudes, with a small increase observed at higher altitudes due to increase in levels of the lower frequency harmonics, which are less affected by atmospheric attenuation.
- Noise dominated by propeller discrete tone sources
- Propeller geometry unchanged relative to reference aircraft B-N Islander.
- Operation requires higher loading of blades and increase in power to accommodate slight increase in thrust requirement during take-off.
- The tip Mach number is 0.823, equal to that of reference aircraft. Design could benefit significantly by reduction in tip speed.
- Increase in noise levels observed due to difference in operating setting. Equivalent to higher power setting operation.
- Margin to Chapter 6 reduces, however still within current limits.

<u>Concepts B</u>

Retrofit Twin Otter concepts (CAeS aircraft):

- As with concepts A and C the main sources of sound due to the propulsion system are relatively unchanged with respect to the reference aircraft.

- Operation and geometry of the propeller is identical to the reference Twin Otter, resulting in a noise signature almost identical to it.
- Noise exposure times are also identical to the reference aircraft as the take-off and landing performance of the concept match those of the Twin Otter.
- Design for low noise emission could be achieved through the leverage of the operational characteristics of electric motors, which replace the constant speed operation of the propeller/turboprop configuration.
- High torque electric motors could be coupled with modifications to propeller geometry such as diameter, pitch etc. to gain noise benefits due to reduction in Tip Mach number.

Clean Sheet concepts aircraft based on Twin Otter specifications and performance parameters:

- Concepts B4 and B5 show greatest noise benefits relative to reference aircraft, irrespective of MTOW.
- Reduction of loading of individual propellers due to the increase in propulsors to 4.
- Reduction of rotational speed at take-off and landing conditions. A reduction in Tip Mach number from 0.8472 to 0.8072 has a significant effect, as operation is already in the transonic regime.
- Exposure times of Concept B4 are slightly increased (contributing to approximately +0.36 dB SEL), however are almost negligible relative to the noise benefits due to reduction at the source (of the order of 6 dB SEL).
- Although a great increase in MTOW is observed for both concepts (especially B5) the thrust requirements are identical (ref. CAS/R2646 and CAS/R2647) between the concepts. This results in almost the same noise signature at the certification points for both concepts.

Concept B6 (GKN aircraft)

- The reference aircraft is the DHC-6 Twin Otter, despite the huge difference in MTOW.
- It is important to note that the Twin Otter is certified under Chapter 10 of the ICAO Annex 16, however the all the GKN 19-PAX concepts exceed the MTOW limit and would be certified under Chapter 14. Margins to both Chapter 10 and Chapter 14 are shown for all three concepts.
- The low wing, fuselage mounted design offers noise benefits due to shielding effects caused by the position of the wing and fuselage relative to the fan. In addition, reflection effects are also reduced due to the position of fan being above the wing and fuselage. The high rear horizontal stabiliser causes a reflection in the rear arc, however the small area of the stabiliser and the relatively high polar angle (angle measured from the aircraft flight axis) at which the reflection is present, mean that its effect is negligible relative to the benefits.
- The fan configuration was modelled as propeller with the following modifications:

- The directivity was changed from the dipole like directivity of a typical open propeller, to a directivity pattern similar to that of a turbofan. Two dominant lobes, one in the forward arc and one in the rear arc, represent the emission of the fan source in the forward arc, and the fan and jet commination in the rear respectively.
- The purpose of the specific directivity pattern is to capture the blockage effects due to the duct.
- It is important to note that the only source modelled is the fan rotational self-noise. Effects and sources due to acoustic coupling with the duct, turbulence (including boundary layer) ingestion, stator/strut interaction are not taken into account at this stage. Detailed design of the ducted fan geometry would be required.
- Typically, ducted fan configurations lend themselves to the implementation of acoustic liners for further noise abatement. However again due to lack of knowledge of the dimensions of the ducts, benefits due to liners are not implemented.
- The number of blades and fan geometry was not specified, therefore the parameters of the 19pax high-wing, wing mounted propeller configuration were used. Essentially assuming that the ducted fan has 5 blades.
- Duct characteristics and stator size, number and position were not specified therefore rotor-stator interaction (multiple pure tone noise) noise was not accounted for. Tip relative Mach numbers, however, are significantly reduced compared to those of traditional turbofan engines, therefore blade passing frequency tones and broadband components are likely to dominate the spectra.

Operation of such a fan at the rotational values specified would mean, significantly reduced tip Mach number of approximately 0.45 and therefore per unit thrust, a much-improved design relative to the reference aircraft.

Concept B7 (GKN aircraft)

- The reference aircraft is again the DHC-6 Twin Otter, despite the huge difference in MTOW.
- The same ‘‘issue’’ arises with the certification of the concept.
- The only differentiating characteristic of this concept is the position of the fan relative to the wing and the fuselage.
- The fan is modelled in an identical manner to the fuselage mounted low wing.
- Corrections to account for the increased effect of reflections, and reductions in blockage effects have been added.
- Comparing the NPD curves, increases in A-weighted sound levels and SEL are obtained relative to the reference DHC-6. This is primarily due to the almost doubling of MTOW.
- Exposure times are reduced due to increased take-off and landing speeds.
- Overall, from an acoustic/noise point of view, preliminary calculations point to the fuselage mounted fan being the best choice for noise reduction on the ground (in-line with literature).

Concept B8 (GKN aircraft)

- The reference aircraft is again the DHC-6 Twin Otter, despite the huge difference in MTOW.
- The same ‘‘issue’’ arises with the certification of the concept.
- The position of the propeller relative to the wing and the fuselage follows that of the previous concept. All assumption and corrections to account for reflections and blockage effects are identical.
- The tip Mach number = 0.7454 which is reduced relative to the reference aircraft.
- The increase in number of blades to 5 also account for additional noise reduction.
- The design however could benefit from more closely replicating the design choices of the Jetstream 31 (and therefore the CAeS Concepts G1, G2 and G3) or in a slightly more extreme case the set-up of the ATR42. In both cases the combination of a larger diameter and decreased rotational speed are used to meet thrust requirements. In both cases this achieves a reduced Tip Mach number. The number of blades of the concept would not require a change, as any acoustic benefit from increasing the count further would diminish when considering the complexity of hub design at this scale.

Concepts G (CAeS)

- Calculations for Concepts G1, G2 and G3 were made based on the DHC-6 Twin Otter as reference aircraft. This is due to a lack of noise data publicly available for the Jetstream 31. Both the Jetstream 31 and the Twin Otter are certified for noise under Chapter 10 of the ICAO Annex 16, in the category ‘‘PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8,618 kg’’.
- As with A and B concepts, propeller geometry and operation is unchanged relative to the design reference aircraft (Jetstream 31), however relative to the Twin Otter, design and operation vary.
- The change in noise emission of the Concepts relative to the Twin Otter can be attributed to: the difference in MTOW and therefore thrust requirement per engine. This is the main factor differentiating the noise levels of the Concepts between themselves.
- The design and operation of the propeller is significantly better in the case of the Jetstream 31 and therefore the concepts, relative to those of the Twin Otter, in terms of noise emissions. This can be trivially verified by the significant difference in certification values of the Jetstream 31 and the Twin Otter (77.1 dBA and 85.6 dBA).

- First the propeller Tip Mach number at take-off is approximately 0.66 relative to 0.8472 of the Twin Otter. The almost 25% reduction in rotational speed of the propeller contributes to a reduction in instantaneous SPL in the order of 5-7dB.
- Additional reductions are observed due to the additional blade of the Concept propeller bringing the total number of blade per propeller to 4.

- The increase in number of blades counter balances the reduction in reduction in rotational speed, to slightly increase the BPF (blade passing frequency). This has an effect of increasing the frequency of all subsequent harmonics, therefore maintaining (or even improving) atmospheric attenuation.
- The increased performance capabilities of the Concepts contributes to additional reductions due to reduced noise exposure times.

Concept D1 (GKN Aerospace)

- The reference aircraft was chosen as the ATR42-600. In terms of Noise-Power-Distance curves the ATR42 is indistinguishable from the ATR72 in the ANP noise database. This means that an appropriate reduced power setting must be used as the reference point for the calculations.
- The concept would be certified under Chapter 14 of the ICAO Annex 16.
- All modelling assumptions are identical to those of the GKN 19-PAX low wing, fuselage mounted fan concept.
- Overall, the concept leverages the position of the fan, and its preferential directivity to reduce maximum SPL and SEL noise levels relative to the ATR42-600.

Concept E (Rolls-Royce plc)

Concept E1

- Noise change relative to reference aircraft is predominantly caused by changes in MTOW
- Lower thrust requirements intrinsically reduce loading components of propeller harmonic noise (both lift and drag).
- Operation and design of turboprop blades was assumed identical to reference aircraft. Thickness noise and propeller tip Mach number effects are therefore the same as the reference aircraft.
- Benefits to propeller noise may be achieved by altering the propeller geometry and operational RPM, to take advantage of the lower disk loading.

Concept E2

The distributed nature of the propulsion system could be leveraged to benefit noise performance in a number of ways. An increase in flow area and subsequent reduction in pressure ratio of the individual propulsors would be beneficial as would a careful consideration of blade number. Reduction in the pressure ratio could also allow for a reduction in tip speed for a given propeller diameter. Preliminary analysis indicates that (without considering technological improvements) there is potential to achieve a cumulative margin of up to 16dB relative to Chapter 14. However, there is the risk of new noise sources arising from the positioning of the wing mounted fuel tanks.

Concept Z1 (Rolls-Royce plc)

- Limited data on propulsion system design and operating characteristics available.
- Reference aircraft chosen for calculations is the A320neo, a significantly larger single aisle aircraft (MTOW = 79 t compared to 48.2 of the concept).
- No NPD data is available for A220-100, therefore the NPDs for the A320neo are used and an appropriate power setting chosen as the baseline point.
- At this stage, the LH2 turbofan is assumed to match the performance of the CFM LEAP-1A or the P&W PW1100G. This assumption may not hold true, as design for hydrogen combustion may result in variations of parameters.
- The dominant noise source used to model the LH2 turbofan engine are the fan and jet. Noting that hydrogen combustion may introduce additional source from the core. This may be investigated in future project.
- The directivity of aircraft is chosen to be similar to that of a conventional modern HBPR turbofan engine.
- The take-off maximum SPL's of the concept A220 fall between the lowest and second lowest power setting of the larger A320neo.
- Approach maximum levels are reduced by approximately 3 dBA relative to the A320, while SEL levels are reduced by an average of approximately 2.5 dB over all slant distances.

4.3 CERTIFIACTION LEVELS AND MARGINS

This section outlines the procedure of determining the certification levels from the previously derived NPD curves for each of the concepts.

<u>Lateral:</u>

- Noise at the lateral certification point is defined by two main parameters:
    - The aircraft is in full take-off power
    - A lateral directivity correction to the noise must be applied as the certification point is located on the side-line relative to the flight path.
- The lateral correction is applied using an empirical calculation. The noise model is used to calculate a full-power flyover for the reference aircraft. This level is then subtracted from the lateral certification level of the reference aircraft to give the change in noise level due to the lateral location of the CP. This delta is then added to the full power calculation of the concept aircraft, to give an estimation of the lateral certification point. As the design advances, details about the geometry and operation can provide useful information and further define the lateral directivity of aircraft. This lateral directivity may be used to estimate the lateral certification point.

Approach:

- Limited data is available for all concept for the approach operation.
- As MLW thrust requirements and high-lift devices have not been provided, it was decided to estimate the approach NPDs using % of maximum take-off thrust used by the reference aircraft.
- For each concept, two NPD curves were estimated. The curves represent the maximum and minimum power setting (given in % of max take-off thrust)
- Although these values may not be the realistic operational values of thrust, this method allows for direct comparison to the reference aircraft, while also providing a possible range within which the aircraft might be expected to lie.
- Assuming identical % of max take-off thrust assumes the concepts have the same landing performance (lift and drag characteristics etc.) as the reference aircraft. This might be the case for retro-fit design, whilst clean sheet designs might look to improve on the reference design.
- Where given, landing airspeeds have been taken into account.
- Approach certification levels are typical the highest relative to flyover and lateral levels due to small distance between the aircraft and certification point location.

Table 6: Power setting range assumptions for the approach operation, and NPD calculation.

	Islander	Twin Otter	ATR42-600	ATR72-600	A2202-100
Min (%)	26.6	30	16.7	16.7	12
Max (%)	58.2	100	30	30	26

Flyover (Take-off with cutback):

- The flyover certification point is also a complex point to estimate. This is due to engine cutback taking place, as well as a change in the flight climb profile. The location, and time at which cutback occurs may significantly change the levels at the flyover certification point.
- In addition to the complexity of timing and flightpath geometry, the aircraft power setting is reduced. This would require additional thrust and operational parameters in order to calculate a cut-back power NPD.
- For this reason, an empirical method of estimating the flyover certification point is used. The difference between the reference aircraft lateral and flyover certification points is used a correction factor. Using the estimated lateral certification levels for the concepts and adding this correction factor, the flyover level for the concepts are estimated.
- This approach is taken in the estimation of the flyover certification points for the larger Chapter 14 certified aircraft.

<u>Concept Certification Levels relative to reference aircraft and limits:</u>

Figure 40: Change in flyover certification level relative to the reference B-N Islander aircraft for concepts A1 and A2. Margins to the Annex 16 Chapter 6 are also indicated. to Figure 44: Summary of certification deltas and margins for all concepts whose calculations are based on the DHC-6 Twin-Otter. indicate the $\Delta dB(A)$ at the flyover certification point for the small regional concepts relative to the reference aircraft and to the equivalent limit. Figure Figure 45: Diagram indicating the certification levels of concepts B6, B7, B8, D1, E1 and Z1 and their respective reference aircraft. The solid lines indicate the limits set by Annex 16 Chapter 14 for the approach, lateral and flyover certification points. shows the EPNL levels of the larger regional concept relative to Chapter 14 limits for the three certification points.

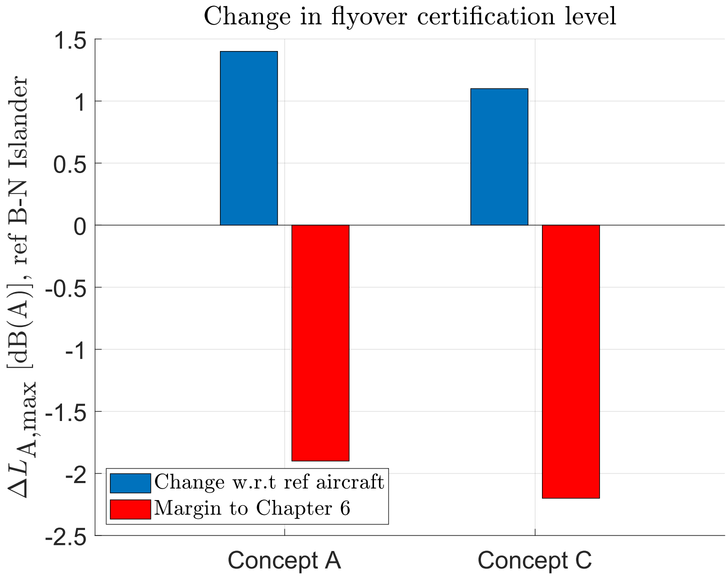


Figure 40: Change in flyover certification level relative to the reference B-N Islander aircraft for concepts A1 and A2. Margins to the Annex 16 Chapter 6 are also indicated.

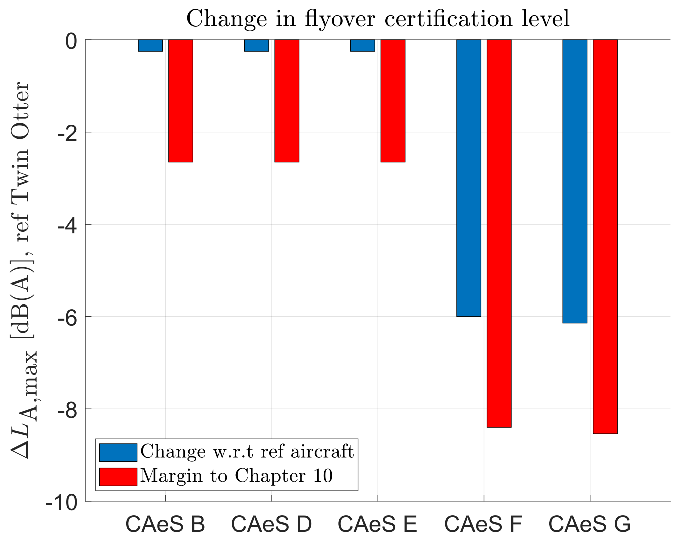


Figure 41: Change in flyover certification level relative to the reference DHC-6 Twin Otter aircraft for concepts B1, B2, B3, B4 and B5. Margins to the Annex 16 Chapter 10 are also indicated.

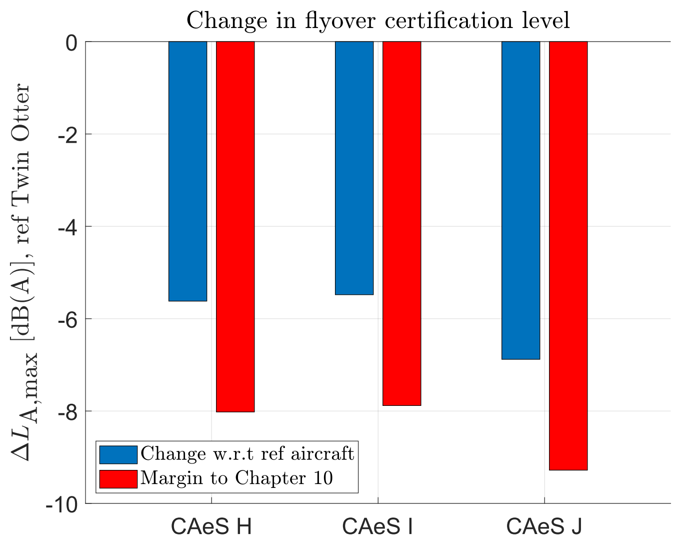


Figure 42 Change in flyover certification level relative to the reference Jetstream 31 aircraft for concepts G1, G2 and G3. Margins to the Annex 16 Chapter 10 are also indicated.

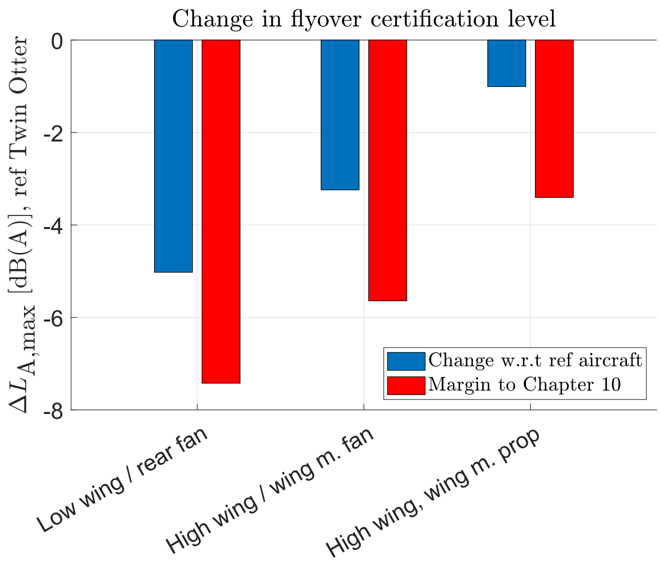


Figure 43: Change in flyover certification level relative to the reference DHC-6 Twin Otter aircraft for concepts B6, B7 and B8. Margins to the Annex 16 Chapter 10 are also indicated.

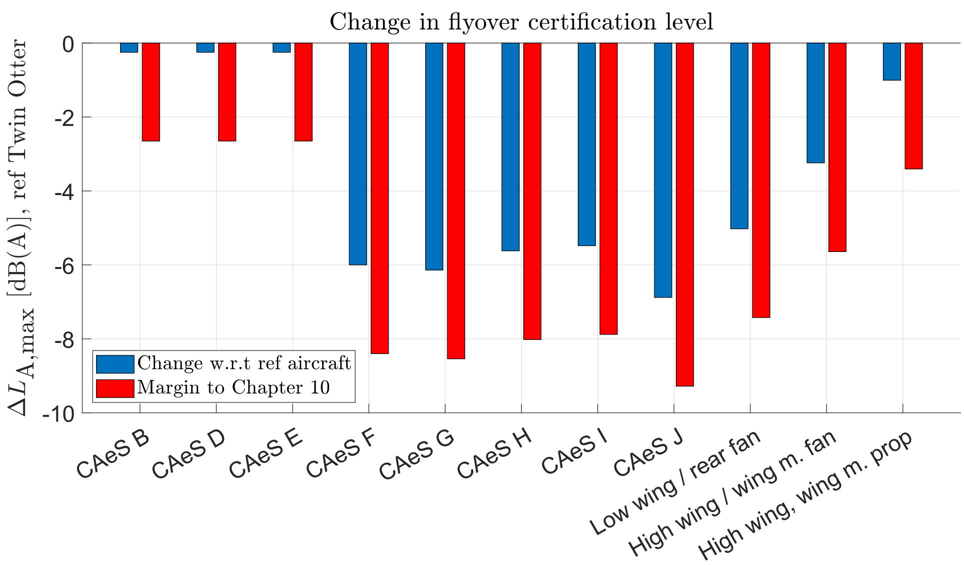


Figure 44: Summary of certification deltas and margins for all concepts whose calculations are based on the DHC-6 Twin-Otter.

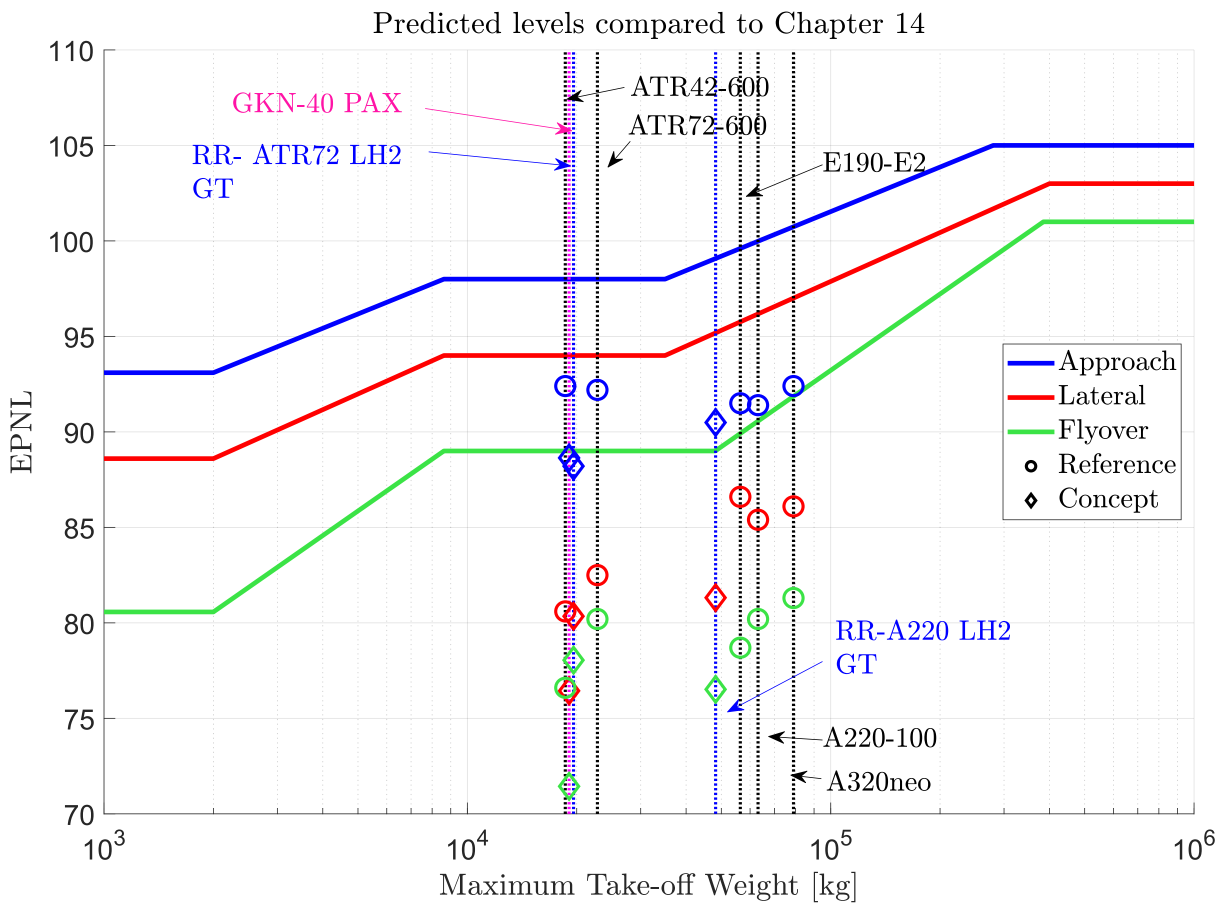


Figure 45: Diagram indicating the certification levels of concepts B6, B7, B8, D1, E1 and Z1 and their respective reference aircraft. The solid lines indicate the limits set by Annex 16 Chapter 14 for the approach, lateral and flyover certification points. For reference the Embraer E190-E2 and the A220-100 noise certification levels are also shown.

5 CASE STUDIES (SCENARIOS)

The development of project NAPKIN led to the definition of four (4) scenarios (use cases) to be defined. The specification of the timeline associated with each scenario is subject to i. the TRL level of the implemented technologies as a part of the part of the design, manufacturing and certification process of the various concept aircraft; ii. the design and certification process itself for each of the concepts; iii. the current aviation market and the trends that determine fleet re-composition, typical aircraft lifespan and break even/profit periods; iv. finally, the ultimate goal of achieving zero emission aviation. The four use cases define expected entry into service for the different types of aircraft as well as viable operation routes.

From a noise perspective, it is of interest to understand the impact of the concepts surrounding airports. The differentiating factors between the scenarios in terms of noise are therefore two: i. the type of aircraft operating, and its acoustic performance relative to the baseline/replacement aircraft, ii. the impact of the concepts on airport cumulative noise levels and the area of the noise exposure contours generated by fleet operation.

The assessment, therefore, has been performed in two ways, initially for each use case, the representative aircraft is compared on a 1-1 basis to the current generation baseline aircraft. The metric of choice is the single event SEL footprint. Noise exposure footprints are generated for one departure and one approach operation. Two levels are chosen for each case. Simple linear flight tracks are used with the approach operation initiating in the negative x-axis and touch-down occurring at the origin, whilst the start-of-roll for the departure operation also occurs at the origin and extends into the positive x-axis. For each concept, the STANDARD ANP departure and approach vertical profiles of their baseline aircraft have been used, with corrections to the initial climb angle according to the specification from the manufacturers. Example STANDARD flight profiles for the A220-100 and the B-N 2 Islander may be seen in Figures Figure 46: Vertical flight profile for the A220-100 for departure (left) and approach (right). Start of roll for take-off and end of roll in landing is located at the [0 , 0] position. and Figure 47: Vertical flight profile for the B-N 2 Islander for departure (left) and approach (right). Start of roll for take-off and end of roll in landing is located at the [0 , 0] position.

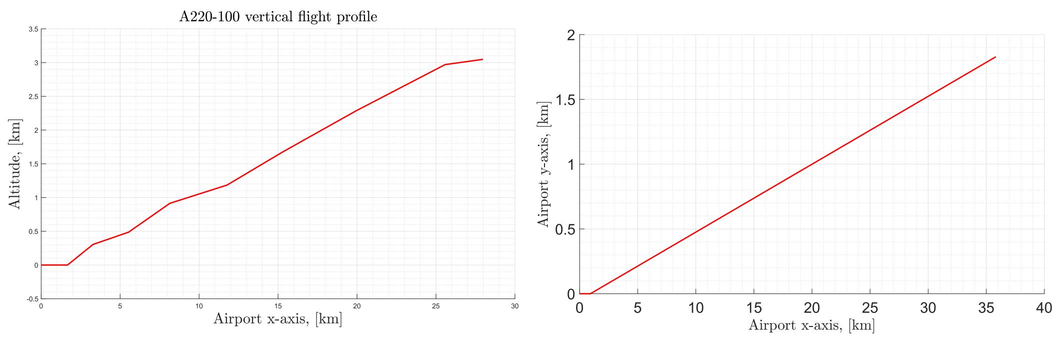


Figure 46: Vertical flight profile for the A220-100 for departure (left) and approach (right). Start of roll for take-off and end of roll in landing is located at the [0 , 0] position.

In addition to the 1-1 comparisons, two studies have been devised to quantify the effect of reduced PAX number and reduced range capability of the concepts. Finally, the noise impact of the concepts in a fully operational airport scenario is presented in Section 6.

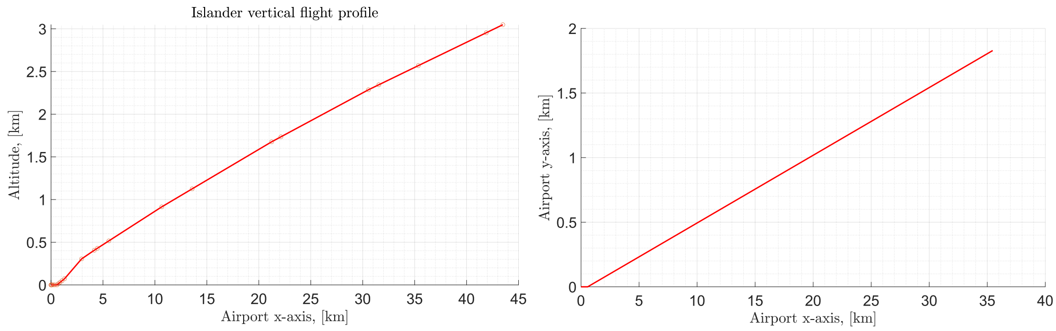


Figure 47: Vertical flight profile for the B-N 2 Islander for departure (left) and approach (right). Start of roll for take-off and end of roll in landing is located at the [0 , 0] position.

5.1 SINGLE EVENT FOOTPRINTS

Single event footprints allow for a one-to-one comparison of the baseline aircraft and concept on a community noise exposure basis. As explained, the footprints have been generated for one approach and one departure operation. Each Figure from Figure 48: SEL noise footprint comparison for one approach and one departure operation of the baseline B-N Islander and Concept A1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE. to Figure 52: SEL noise footprint comparison for one approach and one departure operation of the baseline A220-100 and Concept Z1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE. shows three contours: a baseline calculation for the reference aircraft using the FAA's AEDT (Aviation Environmental Design Tool) software, a calculation for the reference aircraft using RANE (Rapid Aviation Noise Evaluator) the UoS ISVR in-house airport noise model and finally a calculation for the concept using RANE.

Discrepancies in modelling methodology between RANE and AEDT result in expected variation in the contours predictions, primarily due to the finite nature of the aircraft flight trajectory. AEDT assumes that the aircraft trajectory ends abruptly at some specific altitude. This has no effect when looking at high noise levels and metrics that are averaged over a large period of time. However, in the case of the SEL metric and low dB levels (e.g. <60 dB SEL) this has the effect of limiting the calculation of the contour to the contribution of the flight trajectory that has been modelled, giving the contour a semi-circular like closing shape rather than the expected ellipsoidal shape. RANE's assumption of infinite length segments allows for the last segment of the modelled trajectory to be extended to infinity, therefore providing the correct closure to the contour. An example of such an effect may be seen in Figure 48: SEL noise footprint comparison for one approach and one departure operation of the baseline B-N Islander and Concept A1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE. where between $x = 40$ km and $x = 60$ km there is a large discrepancy in the shape and area of the two contours. In the case of RANE this effect has been depicted in two different way: as in Figure 48 the whole contour is depicted, as it is not significantly different to the AEDT prediction, and as is Figure 49: SEL noise footprint comparison for one approach and one departure operation of the baseline DHC-6 Twin Otter and Concept B1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE. where the rest of the contour is not depicted and has been cut to match the length of the AEDT contour to allow for comparison.

5.1.1 Use Case 1

For use case 1, the representative route is Inverness to the Highlands operated by 9 and 19 PAX aircraft. The hydrogen concepts chosen to perform the routes are A1 and B1, a retrofit B-N 2 Islander and a retrofit DHC-6 Twin Otter respectively. Figures Figure 48: SEL noise footprint comparison for one approach and one departure operation of the baseline B-N Islander and Concept A1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE. and Figure 49: SEL noise footprint comparison for one approach and one departure operation of the baseline DHC-6 Twin Otter and Concept B1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE. show the 60 dB and 70 dB SEL contours for each of the aircraft.

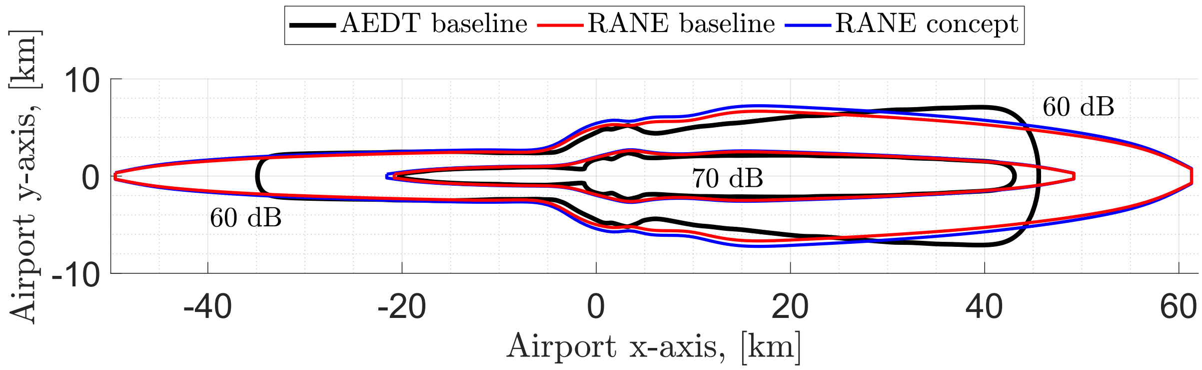


Figure 48: SEL noise footprint comparison for one approach and one departure operation of the baseline B-N Islander and Concept A1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE.

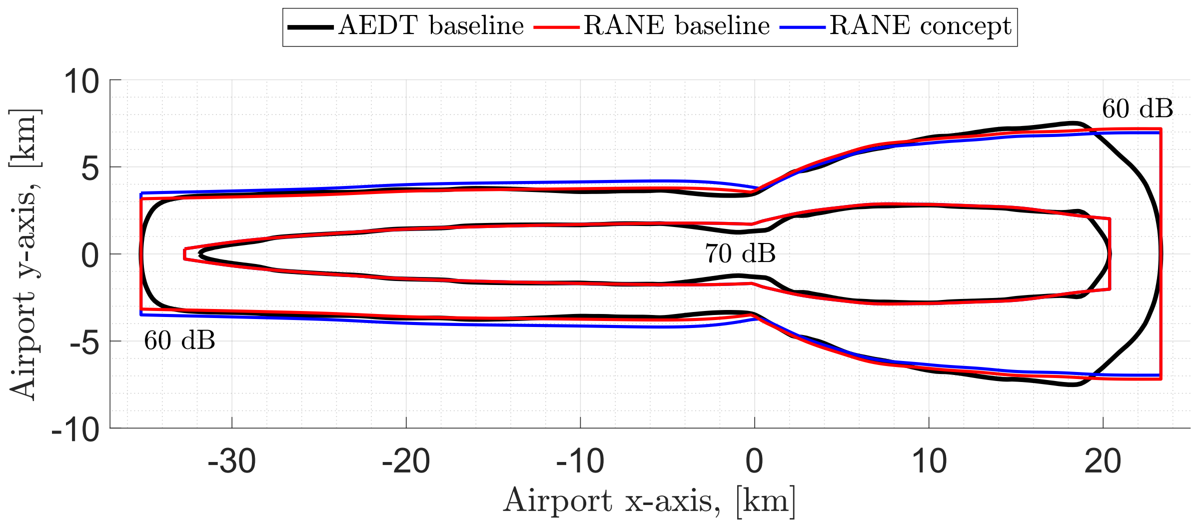


Figure 49: SEL noise footprint comparison for one approach and one departure operation of the baseline DHC-6 Twin Otter and Concept B1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE.

5.1.2 Use Case 2

For use case 2, the representative route is London City Airport to Jersey, operated by 40 PAX regional aircraft. The hydrogen concept chosen to perform the route is D1, the clean sheet design featuring a high-wing and wing mounted ducted fans. Figure 50: SEL noise footprint comparison for one approach and one departure operation of the baseline ATR42-600 and Concept D1 (GKN Aerospace). Calculations for baseline aircraft performed with AEDT and RANE. shows the 55 dB and 70 dB SEL contours for each of the aircraft.

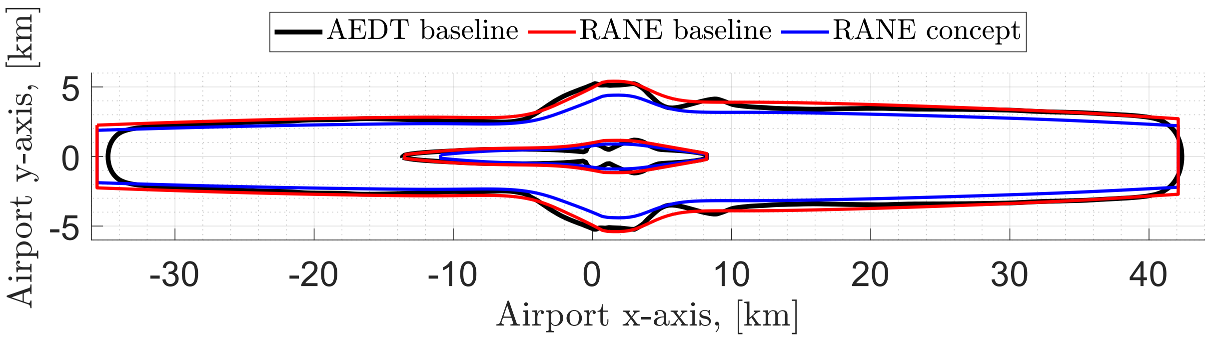


Figure 50: SEL noise footprint comparison for one approach and one departure operation of the baseline ATR42-600 and Concept D1 (GKN Aerospace). Calculations for baseline aircraft performed with AEDT and RANE.

5.1.3 Use Case 3

For use case 3, the representative route is London City Airport to Dundee, operated by 48 PAX regional aircraft. The hydrogen concept chosen to perform the route is E1, a design based on the airframe of the ATR72-600. Figure 51: SEL noise footprint comparison for one approach and one departure operation of the baseline ATR72-600 and Concept E1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE. shows the 55 dB and 75 dB SEL contours for each of the aircraft.

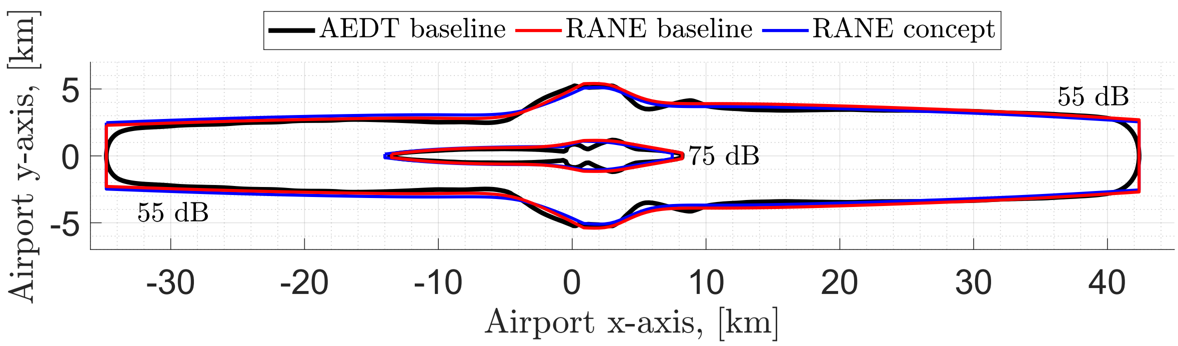


Figure 51: SEL noise footprint comparison for one approach and one departure operation of the baseline ATR72-600 and Concept E1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE.

5.1.4 Use Case 4

For use case 4, the representative route is London City Airport to Edinburgh, a high traffic route, operated by 90 PAX regional jet aircraft. The hydrogen concept chosen to perform the route is Z1, a design based on the airframe of the Airbus A220-100. Figure 52: SEL noise footprint comparison for one approach and one departure operation of the baseline A220-100 and Concept Z1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE. shows the 55 dB and 75 dB SEL contours for each of the aircraft.

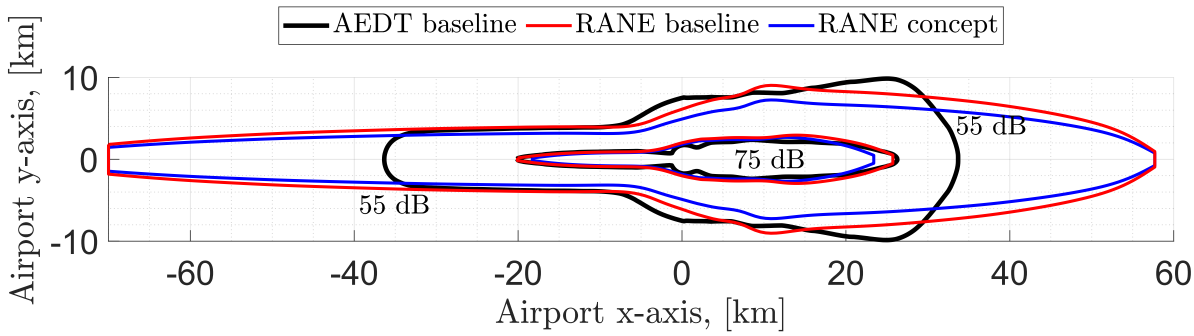


Figure 52: SEL noise footprint comparison for one approach and one departure operation of the baseline A220-100 and Concept Z1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE.

5.2 EFFECT OF NO. OF PASSENGERS

To study the effect of the concepts having reduced passenger capability relative to the baseline aircraft, noise impact was assessed on the basis of the two aircraft carrying a fixed number of passengers. The fixed number of passengers was on data of Q4 2019 at London City airport and varied between aircraft class and therefore between the use cases. The PAX/day numbers are rounded approximations to an "average day" during Q4 2019. The metric used is $L_{eq,T}$ normalised however to a period $T = 1s$, recovering the SEL metric. This can be adjusted to all other cumulative exposure metrics based on SEL. The comparison is between the concept take-off and approach noise exposure performance and that of the baseline aircraft, in the terms of the fleet of aircraft required to carry the specified number of passengers. Table 7: Number of operations required for baseline and concept aircraft to carry constant number of passengers for each use case. gives a summary of the number of operations per use case, between the baseline aircraft and concept. For use case 1, the two numbers indicate the number of operations of a B-N 2 Islander (and concept) and the DHC-6 Twin Otter (and concept) – e.g., 6/14 represents 6 operations of the baseline Islander and 14 of the baseline Twin Otter, and 8/23 represents 8 operations of Concept A1 and 23 of Concept B1.

Table 7: Number of operations required for baseline and concept aircraft to carry constant number of passengers for each use case.

	Use Case 1	Use Case 2	Use Case 3	Use Case 4

Aircraft	Baseline	Concept	Baseline	Concept	Baseline	Concept	Baseline	Concept
Departure	6/14	8/23	32	38	21	32	63	84
Approach	6/13	7/23	31	37	21	31	62	83

5.2.1 Use Case 1

For Use Case 1 predictions are made for both scenarios, the equivalent of an aircraft replacing the B-N 2 Islander and an aircraft replacing the DHC-6 Twin Otter. For Concept A1 total number of passengers for departures and approach are kept constant at 100 PAX / day, while for the larger Concept B1 total PAX for departures and approach are kept constant at 500 PAX / day. The resulting contours are seen in Figures Figure 53: SEL noise contour comparison for constant number of PAX of the baseline B-N 2 Islander and Concept A1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE. and Figure 54: SEL noise contour comparison for constant number of PAX of the baseline DHC-6 Twin Otter and Concept B1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE.

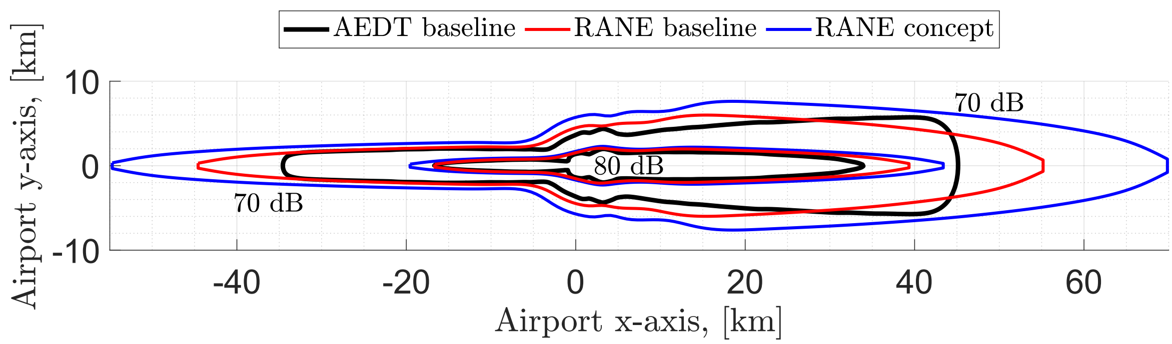


Figure 53: SEL noise contour comparison for constant number of PAX of the baseline B-N 2 Islander and Concept A1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE.

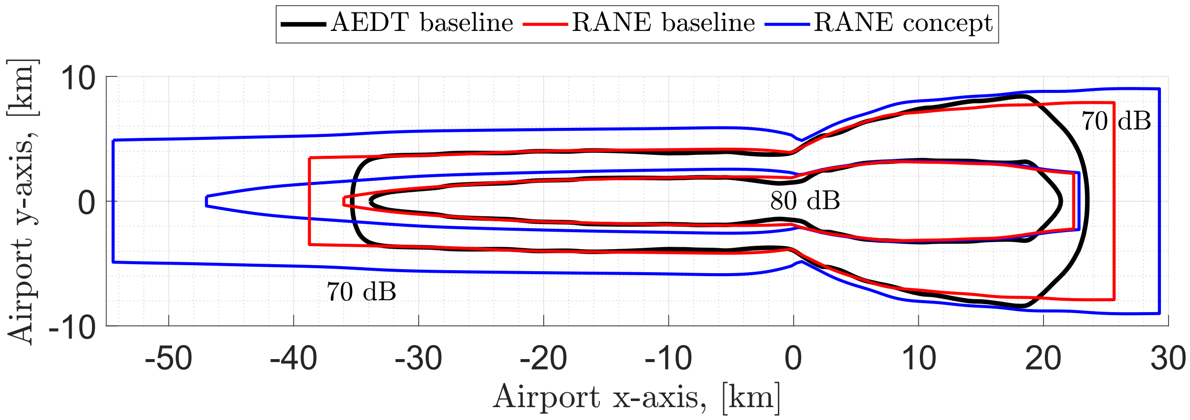


Figure 54: SEL noise contour comparison for constant number of PAX of the baseline DHC-6 Twin Otter and Concept B1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE.

5.2.2 Use Case 2

For Use Case 2 Concept D1 total PAX for departures and approach are kept constant at 3,000 PAX / day. The resulting number of operations are seen in Table 7: Number of operations required for baseline and concept aircraft to carry constant number of passengers for each use case. while the SEL contours in Figure 55: SEL noise contour comparison for constant number of PAX of the baseline ATR42-600 and Concept D1 (GKN Aerospace). Calculations for baseline aircraft performed with AEDT and RANE..

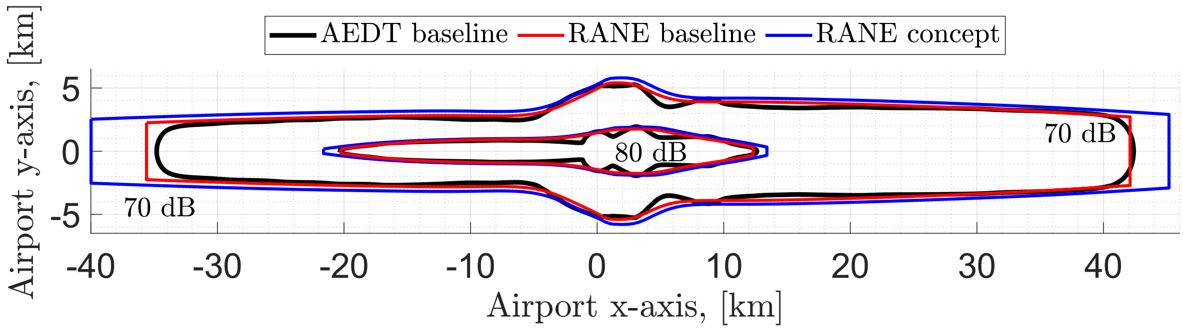


Figure 55: SEL noise contour comparison for constant number of PAX of the baseline ATR42-600 and Concept D1 (GKN Aerospace). Calculations for baseline aircraft performed with AEDT and RANE.

5.2.3 Use Case 3

For Use Case 2 the total PAX for departures and approach are kept constant at 3,000 PAX / day. The resulting number of operations are seen in Table 7: Number of operations required for baseline and concept aircraft to carry constant number of passengers for each use case. while the SEL contours in

Figure 56: SEL noise contour comparison for constant number of PAX of the baseline ATR72-600 and Concept E1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE.

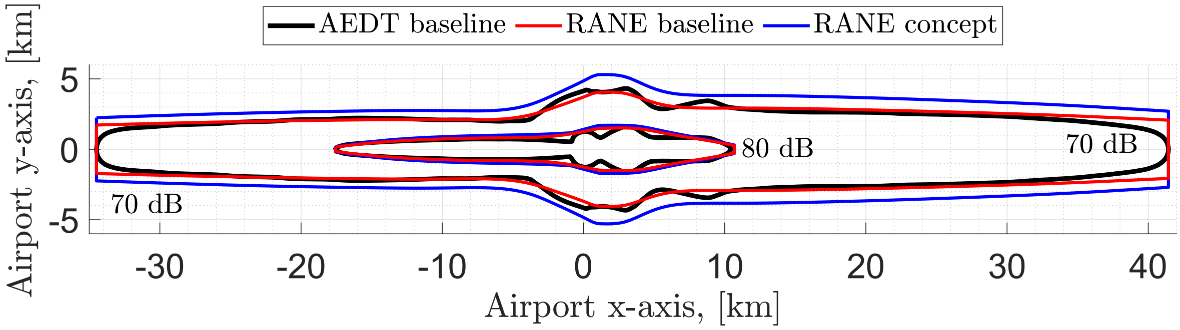


Figure 56: SEL noise contour comparison for constant number of PAX of the baseline ATR72-600 and Concept E1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE.

5.2.4 Use Case 4

For Use Case 2 the total PAX for departures and approach are kept constant at 15,000 PAX / day. The resulting number of operations are seen in Table 7: Number of operations required for baseline and concept aircraft to carry constant number of passengers for each use case. while the SEL contours in Figure 57: SEL noise contour comparison for constant number of PAX of the baseline A220-100 and Concept Z1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE.

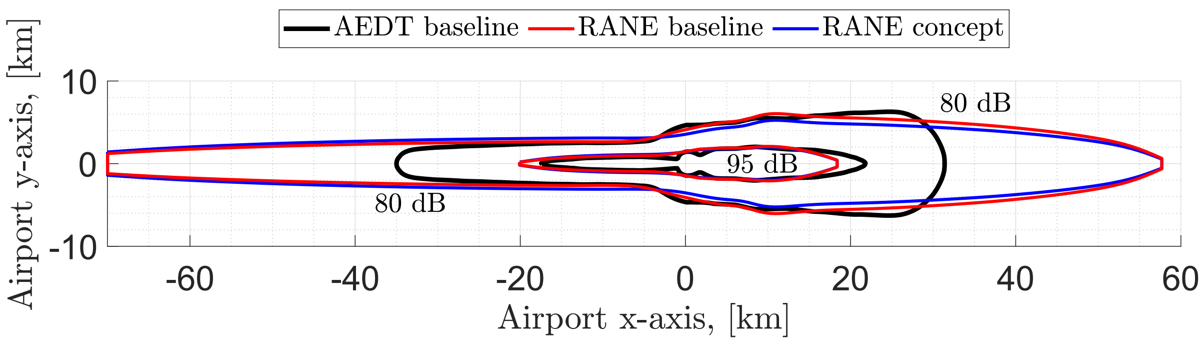


Figure 57: SEL noise contour comparison for constant number of PAX of the baseline A220-100 and Concept Z1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE.

5.3 EFFECT OF CONCEPT RANGE

To study the effect of Concepts A1, B1 and Z1 having reduced range relative the baseline aircraft, the concept take-off and approach noise exposure performance was compared to that to the baseline carrying reduced amount to fuel to match the concept range capabilities. This means that the baseline aircraft is operating at a weight bellow MTOW and therefore reduced power/thrust setting.

Figure 58: Use Case 1, SEL noise contour comparison for concept mission range of the baseline B-N 2 Islander and Concept A1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE.Figure 59: Use Case 1, SEL noise contour comparison for concept mission range of the baseline DHC-6 Twin Otter and Concept B1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE.

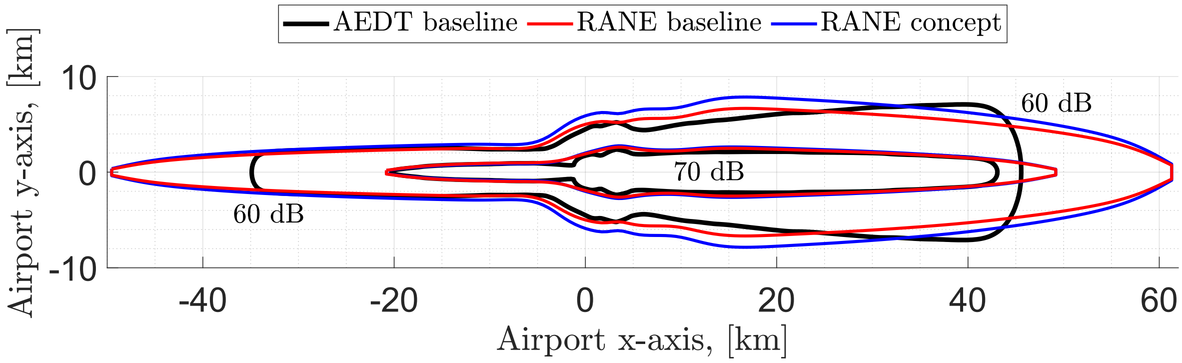


Figure 58: Use Case 1, SEL noise contour comparison for concept mission range of the baseline B-N 2 Islander and Concept A1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE.

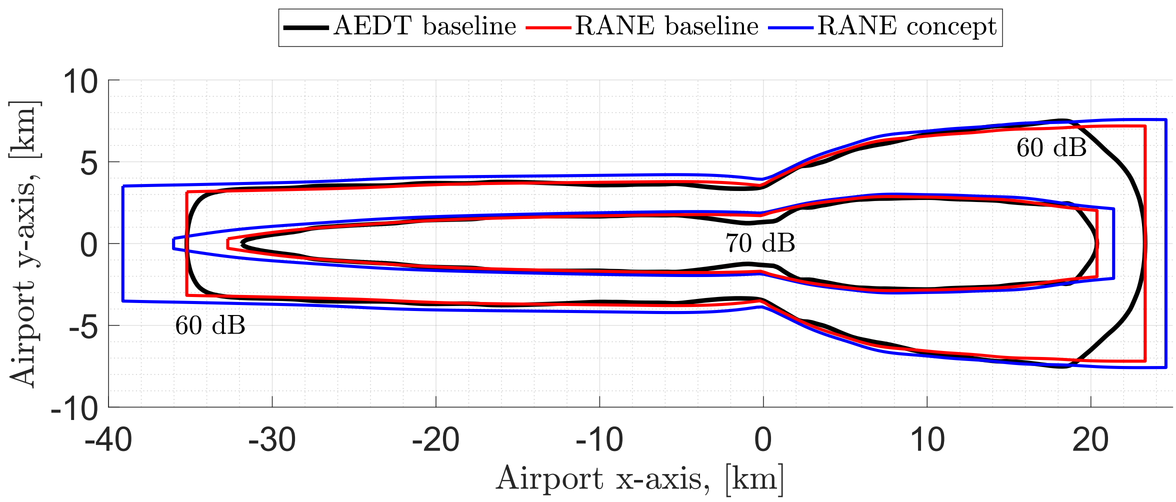


Figure 59: Use Case 1, SEL noise contour comparison for concept mission range of the baseline DHC-6 Twin Otter and Concept B1 (CAeS). Calculations for baseline aircraft performed with AEDT and RANE.

Figure 60: Use Case 4, SEL noise contour comparison for concept mission range of the baseline A220-100 and Concept Z1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE. shows the effect of reduced baseline aircraft MTOW for Use Case 4, the A220-100 and Concept Z1. The contour is generated for a fleet scenario where the number of operations for both baseline aircraft and concept are set to 50 for approach and 50 for departure. The 80 dB and 95 dB cumulative SEL levels are shown.

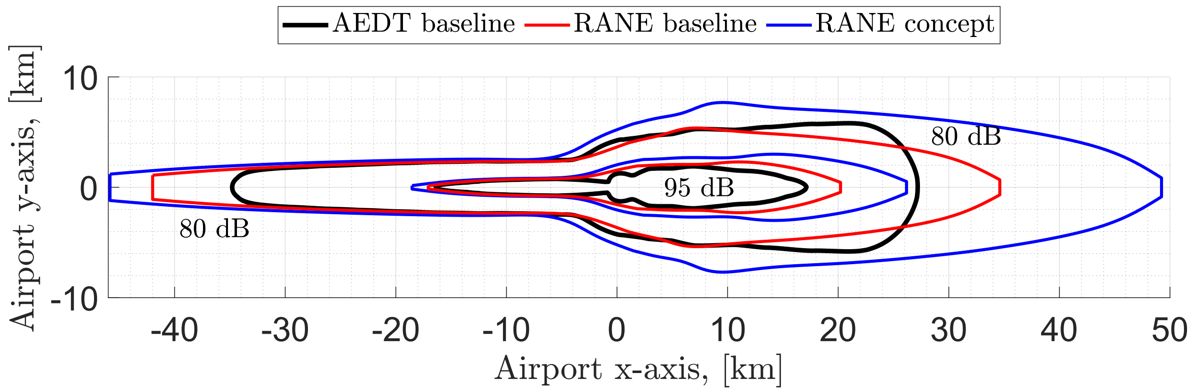


Figure 60: Use Case 4, SEL noise contour comparison for concept mission range of the baseline A220-100 and Concept Z1 (Rolls-Royce plc). Calculations for baseline aircraft performed with AEDT and RANE.

6 AIRPORT STUDY

To demonstrate the effect on noise impact of introducing NAPKIN concept aircraft into a realistic airport scenario, a comprehensive case study is designed around London City Airport (LCY), also a member of the NAPKIN consortium.

6.1 AIRPORT (LCY)

London City Airport is a regional airport that operates out of east London. It has a single 1,508 m runway that operates in the westerly and easterly directions under runways 09 and 27. Its distinct characteristic, with significant importance to noise, is that only multi-engine aircraft with special certification able to fly a 5.5°approach are allowed to operate in and out of it.

Due to the size and layout of the airport, significant complexity arises for taxing procedures during peak times. An average of 38 flights per hour operate in the constricted window between 6:30 and 22:30 Monday to Friday, 06:30 to 13:00 on Saturdays and 12:30 to 22:30 on Sundays. These restrictions are a result of noise abatement procedures aiming to reduce the impact on the surrounding community.

6.2 FLEET

6.2.1 Current Fleet

The aircraft operating at LCY are mid-range airliners or business jets. All aircraft require aircraft and crew specific certification in order to operate the steep descent flight path at approach. The largest aircraft allowed to operate at LCY is the Airbus A318 with an MTOW of 68t. A sample fleet may be seen in Table 8: Sample aircraft fleet composition at LCY airport. Data from Q4 of 2019 and the whole of 2021 .

Table 8: Sample aircraft fleet composition at LCY airport. Data from Q4 of 2019 and the whole of 2021 .

Aircraft Name			
Airbus A220	Cessna Citation Bravo	Embraer Legacy 500	Bombardier Global Express
Airbus A318	Cessna Citation V	Embraer Phenom 300	Gulfstream G650
ATR-42	Cessna Citation Excel	Dassault Falcon 2000	Hawker 800
ATR-72	Cessna Citation Sovereign	Fokker 50	Dornier 328 Jet
Beechcraft Super King Air	Cessna Citation Latitude	Dassault Falcon 900	Learjet 45
BAe-146-100	Bombardier Challenger 350	Dassault Falcon 50	Piaggio P180 Avanti
BAe-146-200	Bombardier Challenger 600	Dassault Falcon 7X	Piper PA31

Bombardier CS-100	Dash 8 Q400	Dassault Falcon 8X	Pilatus PC24
Cessna Citation CJ2	Embraer 135	Gulfstream G280	Avro RJ-85
Cessna Citation CJ3	Embraer 170	Gulfstream GVII-G500	Saab 2000
Cessna Citation CJ4	Embraer 190	Gulfstream GVII-G600	
Cessna Citation Mustang	Embraer E190-E2	Bombardier Global 5000	
Cessna CitationJet	Embraer Legacy 450	Bombardier Global 7000	

6.2.2 Concept Fleet

As the operations at LCY mainly comprise of large regional aircraft, the concept fleet introduced are expected to also be of similar classification. In particular, three aircraft concepts are considered as part of the concept fleet, those are Concepts D1, E1 and Z1. Table 9 summarises the concept aircraft and the chosen aircraft that they will be replacing in the fleet. An important assumption at this point is the 1-1 substitution of concept aircraft to current generation aircraft. This is done on an aircraft basis, rather than a passenger basis. This has an effect on the estimation of aircraft movements when the concept aircraft PAX capabilities does not match that of the current gen aircraft. This is the case with Concepts D1 and E1. However, in the case of Concept Z1 and the E190 the passenger capabilities match at 90 and 96 PAX respectively.

Table 9

Concept Name	Description	Replacing Aircraft
Concept D1	Large regional	ATR-72-600 & DHC-8 Q400
Concept E1	Large regional	ATR-72-600 & DHC-8 Q400
Concept Z1	Small single aisle narrowbody	Embraer E190

6.3 OPERATIONS

6.3.1 Past / Current

In order to model the operations of the selected fleet, 2019 was chosen as the baseline. Specifically, Q4, as it is the last quarter of 'normal' operation, before the effects of the COVID-19 pandemic took effect. For demonstration purposes, Table 10: Number of Aircraft Movements by Aircraft Type: Q4-2019, Q1-2021 and Q2-2021 and Table 11: Number of Aircraft Movements by Aircraft Type: Q3-2021 and Q4-2021 show the number of operations per type of aircraft operating during Q4 2019 and the whole of 2021 (divided into quarters). As of Q4 of 2021 operations at LCY are at approximately 36% of what they were two years prior in 2019.

Table 10: Number of Aircraft Movements by Aircraft Type: Q4-2019, Q1-2021 and Q2-2021

		Q4 - 2019				Q1 - 2021				Q2 - 2021			
Aircraft Name	AC Type	Oct	Nov	Dec	**Total**	Jan	Feb	Mar	**Total**	Apr	May	Jun	**Total**
Airbus A220	A221									0	14	6	**20**
Airbus A318	A318	52	39	23	**114**								
ATR-42	AT42									10	66	98	**174**
ATR-72	AT72	98	89	82	**269**								
Beechcraft Super King Air	B350												
BAe-146-100	B461	2	1	0	**3**								
BAe-146-200	B462	2	4	0	**6**					0	2	0	**2**
Bombardier CS-100	BCS1	236	226	232	**694**								
Cessna Citation CJ2	C25A	21	13	14	**48**	0	0	4	**4**	0	2	8	**10**
Cessna Citation CJ3	C25B	9	0	4	**13**								
Cessna Citation CJ4	C25C	4	0	0	**4**	2	0	2	**4**	0	0	4	**4**
Cessna Citation Mustang	C510	38	23	24	**85**	2	3	9	**14**	8	7	8	**23**
Cessna CitationJet	C525												
Cessna Citation Bravo	C550	4	3	0	**7**								
Cessna Citation V	C560	5	0	0	**5**								
Cessna Citation Excel	C56X	113	42	41	**196**	0	2	15	**17**	23	10	14	**47**
Cessna Citation Sovereign	C680	21	6	15	**42**					0	10	8	**18**
Cessna Citation Latitude	C68A	66	55	59	**180**	2	0	4	**6**	17	10	10	**37**
Bombardier Challenger 350	CL30	0	2	0	**2**	0	2	0	**2**	0	6	2	**8**
Bombardier Challenger 600	CL60	4	2	2	**8**								
Dash 8 Q400	DH8D	1098	882	623	**2603**	38	16	18	**72**	38	36	26	**100**
Embraer 135	E135	12	4	4	**20**								
Embraer 170	E170	786	752	661	**2199**	7	0	0	**7**				
Embraer 190	E190	4240	3777	3622	**11639**	165	95	118	**378**	251	336	531	**1118**
Embraer E190-E2	E290												
Embraer Legacy 450	E545	0	0	2	**2**								
Embraer Legacy 500	E550												
Embraer Phenom 300	E55P	35	32	22	**89**	10	2	12	**24**	10	25	22	**57**
Dassault Falcon 2000	F2TH	26	15	18	**59**	0	0	3	**3**	4	6	10	**20**
Fokker 50	F50	146	130	125	**401**								
Dassault Falcon 900	F900	6	8	4	**18**	0	0	2	**2**				
Dassault Falcon 50	FA50	3	2	2	**7**								
Dassault Falcon 7X	FA7X	25	46	30	**101**					2	0	2	**4**
Dassault Falcon 8X	FA8X	7	14	10	**31**								
Gulfstream G280	G280	2	2	0	**4**								
Gulfstream GVII-G500	GA5C												
Gulfstream GVII-G600	GA6C												
Bombardier Global 5000	GL5T	4	2	0	**6**								
Bombardier Global 7000	GL7T												
Bombardier Global Express	GLEX	21	8	4	**33**	0	1	3	**4**	3	3	2	**8**
Gulfstream G650	GLF6												
Hawker 800	H25B	7	2	2	**11**								
Dornier 328 Jet	J328	98	92	70	**260**								
Learjet 45	LJ45	2	1	0	**3**								
Piaggio P180 Avanti	P180	0	4	4	**8**	2	0	2	**4**				
Piper PA31	PA31	2	0	0	**2**								
Pilatus PC24	PC24	1	0	2	**3**	0	0	2	**2**	6	2	0	**8**
Avro RJ-85	RJ85	322	300	300	**922**								
Saab 2000	SB20	162	144	140	**446**								
Total		**7,680**	**6,722**	**6,141**	**20,543**	**228**	**121**	**194**	**543**	**372**	**535**	**751**	**1,658**

Table 11: Number of Aircraft Movements by Aircraft Type: Q3-2021 and Q4-2021

		Q3 - 2021				Q4 - 2021			
Aircraft Name	AC Type	Jul	Aug	Sept	**Total**	Oct	Nov	Dec	**Total**
Airbus A220	A221					0	34	58	**92**
Airbus A318	A318								
ATR-42	AT42	92	96	94	**282**	88	90	72	**250**
ATR-72	AT72								
Beechcraft Super King Air	B350	0	0	2	**2**				
BAe-146-100	B461	2	0	0	**2**	0	0	2	**2**
BAe-146-200	B462	0	0	2	**2**				
Bombardier CS-100	BCS1								
Cessna Citation CJ2	C25A	8	0	12	**20**	18	12	16	**46**
Cessna Citation CJ3	C25B	4	2	8	**14**	0	2	4	**6**
Cessna Citation CJ4	C25C	0	2	0	**2**	0	0	4	**4**
Cessna Citation Mustang	C510	8	19	29	**56**	28	19	15	**62**
Cessna CitationJet	C525	0	0	2	**2**				
Cessna Citation Bravo	C550								
Cessna Citation V	C560					0	2	0	**2**
Cessna Citation Excel	C56X	22	18	50	**90**	60	47	15	**122**
Cessna Citation Sovereign	C680	4	10	16	**30**	20	4	18	**42**
Cessna Citation Latitude	C68A	16	17	44	**77**	63	46	18	**127**
Bombardier Challenger 350	CL30	4	2	10	**16**	23	23	14	**60**
Bombardier Challenger 600	CL60	0	0	2	**2**	2	0	0	**2**
Dash 8 Q400	DH8D	30	36	64	**130**	106	148	140	**394**
Embraer 135	E135	2	0	0	**2**	4	4	0	**8**
Embraer 170	E170								
Embraer 190	E190	860	1,191	1,715	**3,766**	2,065	2,095	1,628	**5,788**
Embraer E190-E2	E290	0	0	52	**52**	96	84	60	**240**
Embraer Legacy 450	E545					0	0	2	**2**
Embraer Legacy 500	E550	8	4	4	**16**	24	8	0	**32**
Embraer Phenom 300	E55P	10	12	30	**52**	28	10	14	**52**
Dassault Falcon 2000	F2TH	8	16	4	**28**	6	21	7	**34**
Fokker 50	F50								
Dassault Falcon 900	F900	0	0	2	**2**	0	6	0	**6**
Dassault Falcon 50	FA50					2	0	0	**2**
Dassault Falcon 7X	FA7X	4	2	4	**10**	6	8	4	**18**
Dassault Falcon 8X	FA8X	2	4	10	**16**	20	28	4	**52**
Gulfstream G280	G280					2	0	0	**2**
Gulfstream GVII-G500	GA5C					0	4	0	**4**
Gulfstream GVII-G600	GA6C					0	2	0	**2**
Bombardier Global 5000	GL5T	0	2	0	**2**	8	2	0	**10**
Bombardier Global 7000	GL7T	0	2	0	**2**				
Bombardier Global Express	GLEX	2	2	10	**14**	7	9	0	**16**
Gulfstream G650	GLF6					2	0	0	**2**
Hawker 800	H25B								
Dornier 328 Jet	J328								
Learjet 45	LJ45								
Piaggio P180 Avanti	P180	0	2	4	**6**	6	10	2	**18**
Piper PA31	PA31								
Pilatus PC24	PC24	2	0	8	**10**	6	6	6	**18**
Avro RJ-85	RJ85	0	0	2	**2**	5	2	2	**9**
Saab 2000	SB20								
Total		**1,088**	**1,439**	**2,180**	**4,707**	**2,695**	**2,726**	**2,105**	**7,526**

6.3.2 Forecast

Forecast data for 2022 (summary of which are presented in TablesTable 12: Predicted number of total airline operations in 2022 at LCY from 8th of February onwards. and Table 13: LCY 2022 Operation: final summary corrected for actual operations up to 8th of February 2022.) was used to validate the operation assumptions and generate an aircraft loading factor (% occupied seats per flight) forecast model through simple extrapolation technique.

Table 12: Predicted number of total airline operations in 2022 at LCY from 8th of February onwards.

Airline	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Grand Total
AZ			146	156	144	156	52	156	156	966
BA	1076	2228	2670	3067	3004	3034	3153	3038	2988	24258
EZ			2					86	94	182
KL	114	218	340	388	400	276	290	364	364	2754
LG	110	273	287	301	296	280	278	290	292	2407
LH	36	100	128	168	158	178	150	180	178	1276
LM	54	90	80	182	182	188	188	182	186	1332
LO	34	54	50	54	52	52	54	52	52	454
LX	108	180	276	294	288	230	246	286	284	2192
Grand Total	**1532**	**3143**	**3979**	**4610**	**4524**	**4394**	**4411**	**4634**	**4594**	**35821**

Table 13: LCY 2022 Operation: final summary corrected for actual operations up to 8th of February 2022.

Final Summary with Actuals upto 8th Feb												
Airline	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Total**	**Source**
AZ	0	0	0	146	156	144	156	52	156	156	966	*ACL*
BA	866	1,454	2,228	2,670	3,067	3,004	3,034	3,153	3,038	2,988	25,502	*Airline*
KL	154	154	218	340	388	400	276	290	364	364	2,948	*Airline*
LG	68	134	273	287	301	296	280	278	290	292	2,499	*Airline*
LH	24	58	100	128	168	158	178	150	180	178	1,322	*Airline*
LM	74	74	90	80	182	182	188	188	182	186	1,426	*ACL*
LO	52	48	54	50	54	52	52	54	52	52	520	*Airline*
LX	128	136	180	276	294	288	230	246	286	284	2,348	*Airline*
EZ	0	0	0	2	0	0	0	0	86	94	182	*ACL*
Total	**1,366**	**2,058**	**3,143**	**3,979**	**4,610**	**4,524**	**4,394**	**4,411**	**4,634**	**4,594**	**37,713**	

6.3.3 Flight tracks and profiles

Typical fleet operation on an airport level consists of a complex system of flight trajectories that depend on the performance of the individual aircraft, operating constraints at the airport as well as weather conditions. In order for RANE to be applied to the LCY case, an 'acoustically equivalent' flight trajectory is calculated using the operations per aircraft type aircraft NPD data, as well as LCY flight track data and the STANDARD vertical flight profiles (for approach and decent) defined by the ANP database. Note also that the approach profiles were manually modified to comply with the 5.5° approach slope mandated at LCY.

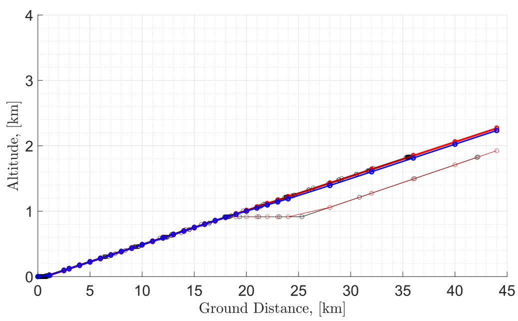
Each individual aircraft flight trajectory is discretised according to flight performance discretisation defined by the STANDARD ANP profiles. Assuming a number of aircraft $a = 1, \dots, A$, flying along a given segment n with a different inclination angle γ_{na}, an "equivalent" inclination angle γ_n (common for the whole aircraft fleet) for such segment n can be obtained as follows (28):

$$\gamma_n = \sum_{a=1}^{A} \gamma_{na} W_{na}$$

with,

$$W_{na} = \frac{\sum_{m=1}^{M} 10^{(L_{am}(P_n, d_i)/10)}}{\sum_{a=1}^{A} \sum_{m=1}^{M} 10^{(L_{am}(P_n, d_i)/10)}}$$

Where A is the total number of aircraft, M is the total number of operations per aircraft type, W is a weighting factor to be applied to each segment inclination angle (also to the angle of rotation in the airport plane for track averaging). $L_{am}(P_n, d_i)$ is the sound level of aircraft a and movement m during the segment of interest, while at power setting P_n and slant distance d_i. The results of the averaging procedure may be seen in Figure 61: Fleet departure (right) and arrival (left) vertical profiles along with calculated average profile (blue). and Figure 62: London City Airport runway 09 and 27 approach and departure flight tracks (left, middle). Calculated average flight track for the runways (right)..



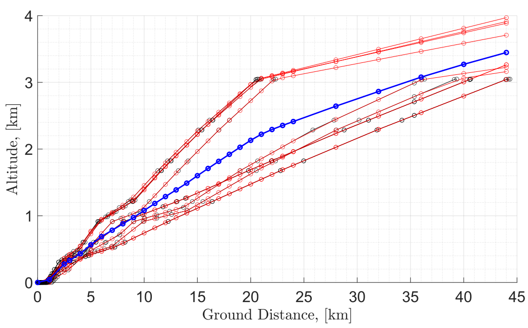


Figure 61: Fleet departure (right) and arrival (left) vertical profiles along with calculated average profile (blue).

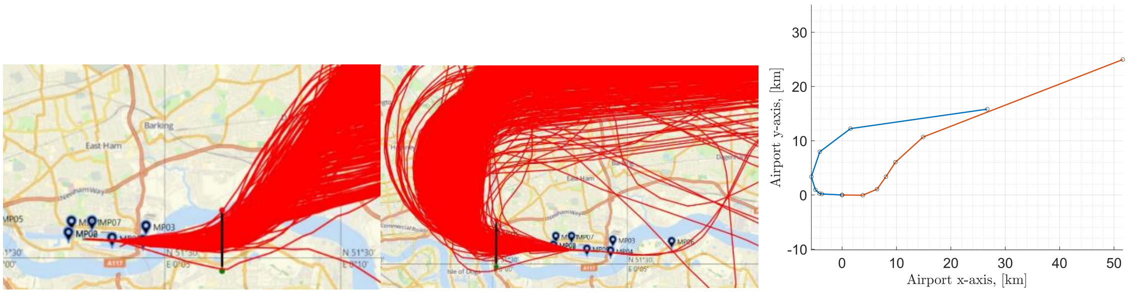


Figure 62: London City Airport runway 09 and 27 approach and departure flight tracks (left, middle). Calculated average flight track for the runways (right).

6.4 MARKET GROWTH AND CONCEPT INTRODUCTION/PENETRATION RATES

To be able to facilitate airport contour predictions for the impact of hydrogen aircraft concepts, it is crucial to understand fleet composition and operations at the points in time that are of interest, i.e. year 2035 and 2040.

EUROCONTROL published its updated growth forecast up to 2027 taking into account air traffic trends, economic growth and the impact of COVID-19 (29). A summary of the flight forecast rates for Europe may be seen in Table 14: EUROCONTROL and NAPKIN annual growth rates forecast. AAGR 2020-2027 vs. baseline 2019.. Based on the EUROCONTROL rates, the NAPKIN consortium adjusted the forecast, being more conservative in the assumptions of market recovery, the results are also presented in Table 14: EUROCONTROL and NAPKIN annual growth rates forecast. AAGR 2020-2027 vs. baseline 2019. These figures were then extrapolated to 2050 providing the movements required for the LCY case study in years 2035 and 2040. The NAPKIN base scenario was chosen for the generation of the LCY noise contours.

Table 14: EUROCONTROL and NAPKIN annual growth rates forecast. AAGR 2020-2027 vs. baseline 2019.

Annual Growth	Low	Base	High
EUROCONTROL	-0.1%	0.7%	1.9%
NAPKIN	-0.4%	0.4%	1.8%

In addition to the overall growth model, assumptions regarding concept introduction rates and fleet replacement were made []. For the noise contour modelling presented herein, the middle base scenarios were chosen, the percentages of hydrogen aircraft relative to the whole UK market being shown in Table 15: Estimated share of hydrogen aircraft (% UK market penetration).

Table 15: Estimated share of hydrogen aircraft (% UK market penetration)

UK market penetration	2035	2040
Large regional	1%	3%
Narrowbody	1%	5%

6.5 Results

Before making predictions for the years 2035 and 2040, RANE was used to reproduce the LCY airport noise contours published in the Annual Performance Report Annex 1. The baseline contours used were the Summer 2019 Average Mode $L_{eq,16h}$. The result of the RANE prediction may be seen compared to the actual contours in Figure 63: Baseline calculation of the $L_{eq,16\,h}$ for 2019 using RANE. Results are compared to the published contours for LCY in 2019. The error in the high noise levels is minimal but increases as the distance to the runway increases. Flight track dispersion has minimal effect on the noise contour, meaning the averaging technique of the flight trajectory is an effective mean for simplifying the calculation.

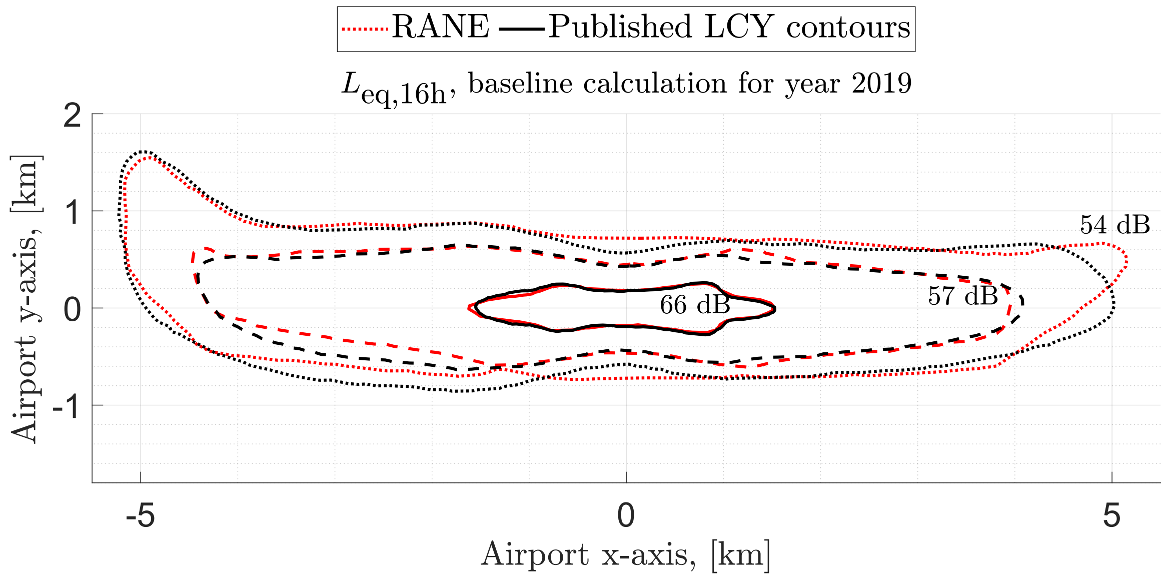


Figure 63: Baseline calculation of the $L_{eq,16\,h}$ for 2019 using RANE. Results are compared to the published contours for LCY in 2019 (30)

It is important to note that both runways 09 and 27 are used for approach and departure operations, rendering the y-axis of the airport frame a symmetry axis. In addition, the contribution to the total cumulative contour, of the approach segments is minimal, meaning that take-off operations dominate, giving the final shape and size of the contours.

6.5.1.1 2035

In order to assess the impact of introducing the concept aircraft to the fleet, the predictions for 2035 and 2035 have been performed twice: once for a baseline scenario, where no concepts are introduced but the overall traffic growth still takes place, and once for the scenario where hydrogen concepts have been introduced. The presented contours are based on the requirements of appraisal module 5: "Noise" (31) and comprise the 54 dB, 57 dB and 66 dB $L_{eq,16h}$. Specifically, the 57 dB and 66 dB $L_{eq,16h}$ contours are chosen as they represent the first tier works eligibility boundary and second tier works eligibility boundary[1] respectively, for the case of the City Airport Development

[1] Boundaries indicated by the mentioned contours are eligible to different tiers of the sound insulation schemes of residential building under CADP 1.

Programme (CADP), while the 54 dB $L_{eq,16h}$ is predicted for information purposes as it is of interest to LCY and third parties as a result of the CADP 1 planning enquiry (32).

Figure 64: $L_{eq,16\ h}$ contour calculation for 2035. Results are compared to the published contours for LCY in 2019 and a baseline calculation for year 2035 assuming no hydrogen aircraft introduction. Line types indicate different contour levels. shows the predicted contours for the year 2035. As expected, the 2035 baseline contours (green) extend beyond the those of 2019, influenced by the fleet growth of 0.4 % AAGR. When the concepts are introduced, a small increase in the area of the contours is observed. This increase is of the order of 0.5 km^2 for the 54 dB $L_{eq,16h}$ and 0.2 km^2 for the 66 dB $L_{eq,16h}$ relative to the baseline 2035 case. This primarily due to the operations of the large regional concepts being almost double those of the current generation aircraft, without gaining a significant advantage on the aircraft source level.

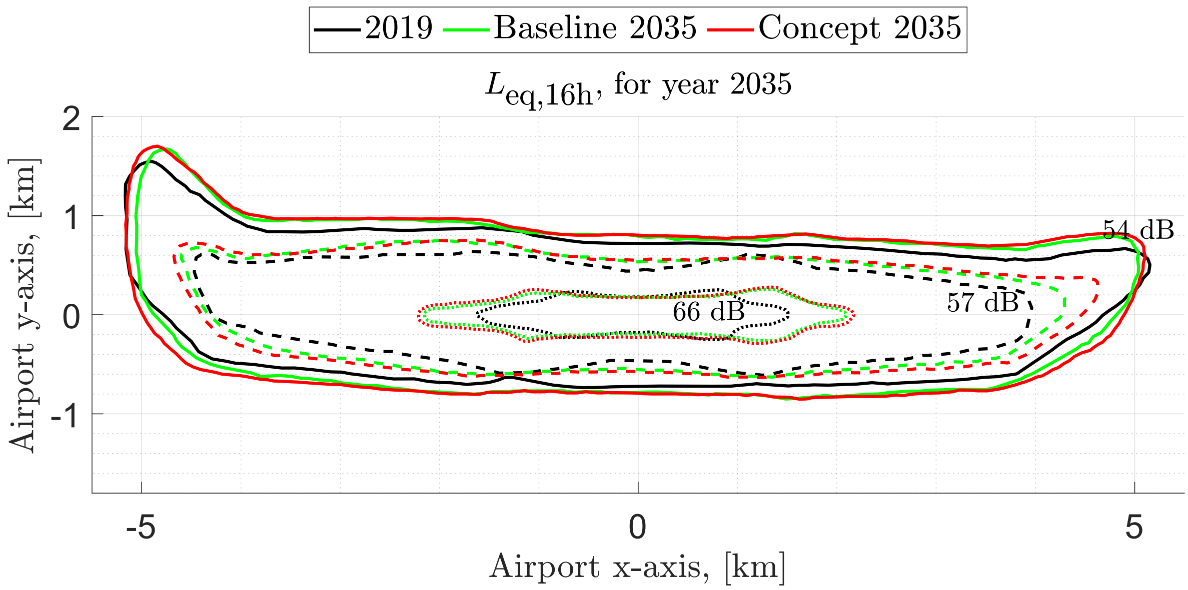


Figure 64: $L_{eq,16\ h}$ contour calculation for 2035. Results are compared to the published contours for LCY in 2019 and a baseline calculation for year 2035 assuming no hydrogen aircraft introduction. Line types indicate different contour levels.

6.5.1.2 2040

In 2040 the concept penetration rates become substantial, meaning that Concept Z1 (single aisle narrowbody) is represented by 1,115 movements over a three-month (quarter) period, whereas the Embraer 190 by 11,542 which is below the 2019 baseline movements. Additionally, ATR72-600 movements have been completely phased out with the Dash 8 representing the current generation large regional aircraft with 2,455 movements, whilst Concepts D1 and E1 combine for 670 operations.

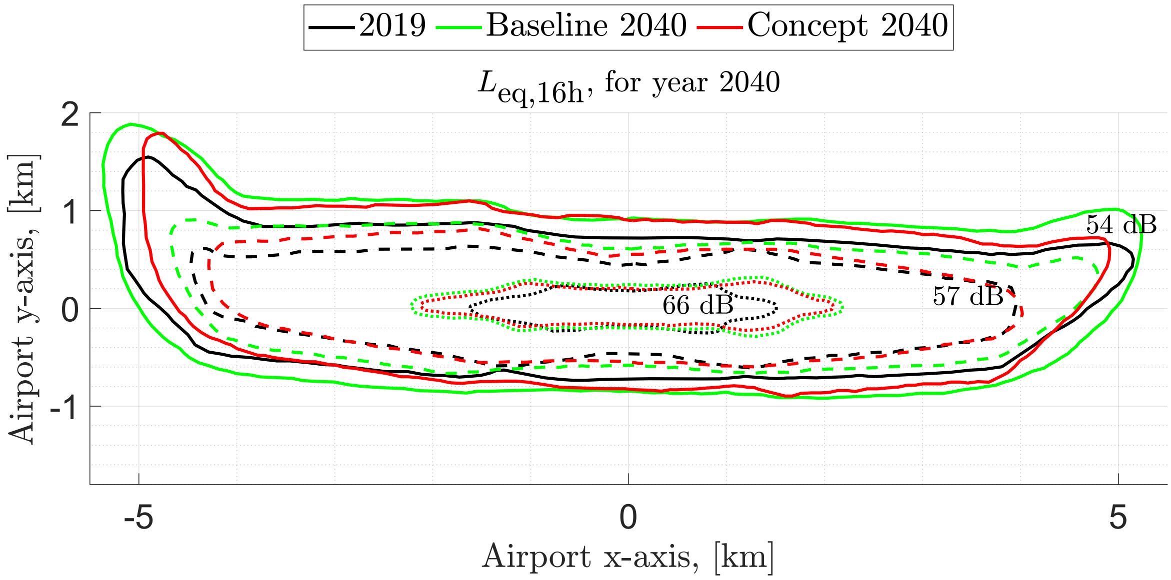


Figure 65: $L_{eq,16\ h}$ contour calculation for 2040. Results are compared to the published contours for LCY in 2019 and a baseline calculation for year 2040 assuming no hydrogen aircraft introduction. Line types indicate different contour levels.

The effect is visible in Figure 65: $L_{eq,16\ h}$ contour calculation for 2040. Results are compared to the published contours for LCY in 2019 and a baseline calculation for year 2040 assuming no hydrogen aircraft introduction. Line types indicate different contour levels., where the introduction of the concepts, that are quieter at take-off, means that the contour areas are reduced relative to a continuous growth scenario with current generation aircraft. The significant difference between the predicted certification levels (resulting from the NPDs) for Concept Z1 and those of the Embraer E190 mean that noise reduction at source dominates the fleet effects, as increases in movements due to difference in PAX capabilities are minimal (Concept Z1 90 PAX whereas E190 100 PAX single class, or 96 PAX dual class).

6.5.1.3 Summary

Figures Figure 66: Comparison between the 66 dB $L_{eq,16\ h}$ contour area for 2019, 2035 and 2040, with and without concept introduction., Figure 67: Comparison between the 57 dB $L_{eq,16\ h}$ contour area for 2019, 2035 and 2040, with and without concept introduction. and Figure 68: Comparison between the 54 dB $L_{eq,16\ h}$ contour area for 2019, 2035 and 2040, with and without concept introduction. summarise the previous contour results in the form of contour area comparison. The blue bars capture the traffic increase from 2019 all the way to 2040, whilst the red bar show the effect of the concepts on the fleet noise impact.

An interesting observation occurs at the comparison of the contour area between 2035 and 2040 when the concepts have been introduced. In 2035, the introduction of the concepts leads to a slight increase in noise exposure area relative to the no-concept baseline scenario. Counterintuitively, in 2040, the larger uptake of the hydrogen concepts has led the overall sound exposure area around the airport to drop relatively to a no concept scenario.

The apparent incongruity between 2035 and 2040 can be explained by the load factor (% of occupied seats) of the operating aircraft, as well as the assumptions around aircraft replacement in this case study. Concepts are introduced to the fleet, on a % of total UK movements basis, whereas the total movements of aircraft are dictated by the total number of passengers.

Example – Assuming a total number of 1,000 passengers to be flown per day. This corresponds to 10 operation of a 100-PAX conventional aircraft. Assuming a 10% penetration rate of an 80-PAX concept aircraft, this corresponds to 1 movement, leading to 20 passengers requiring an additional concept movement to fulfil the total PAX/per requirement. This leads to a situation where 1 movement was replaced by 2 with a gross load factor significantly below 100%.

In a scenario where a 40% penetration rate of a 80-PAX concept aircraft is assumed, this corresponds to 4 movements, leaving 80 passengers without a flight. One more movement is required to carry these passengers. The load factor is 100%. The noise exposure due to the one extra movement required does not outweigh the benefit of replacing 4 conventional aircraft with the quieter hydrogen concepts.

It is a balance between the number operation of required concept operations and the noise benefit each individual aircraft has relative to the replacement aircraft. Eventually the benefit of replacing the older generation noisier aircraft outweighs the additional noise exposure due to additional movements required.

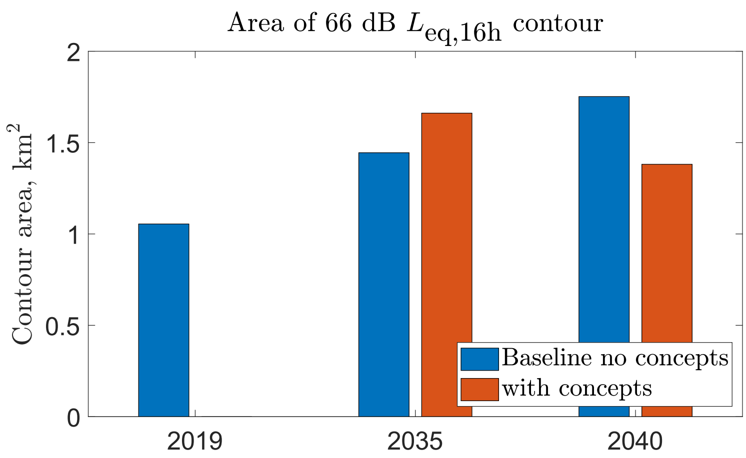


Figure 66: Comparison between the 66 dB $L_{eq,16\ h}$ contour area for 2019, 2035 and 2040, with and without concept introduction.

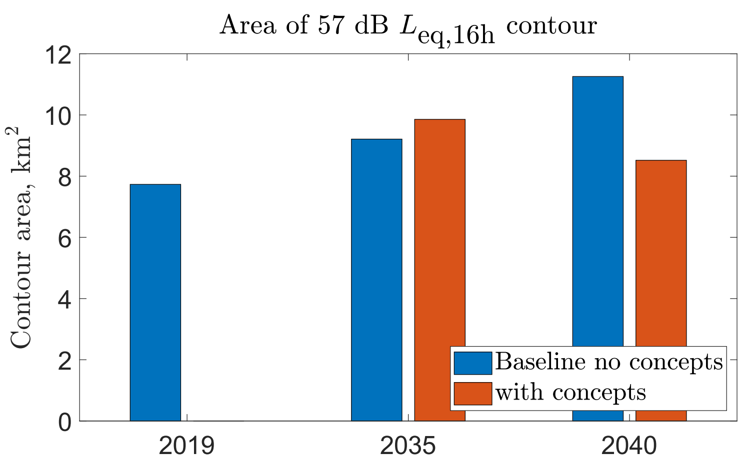


Figure 67: Comparison between the 57 dB $L_{eq,16\ h}$ contour area for 2019, 2035 and 2040, with and without concept introduction.

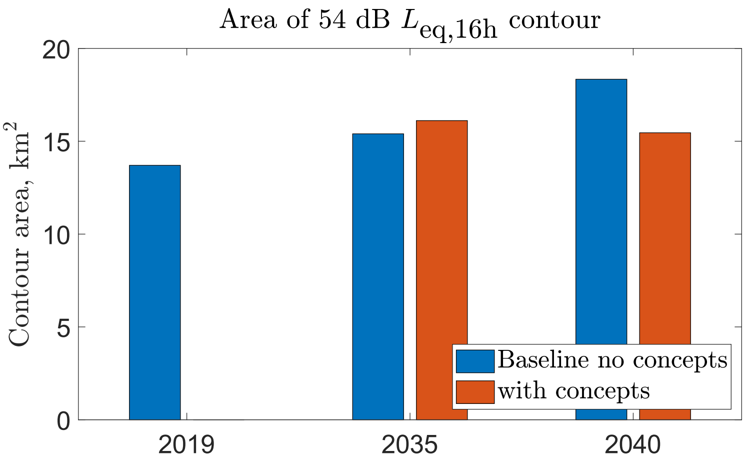


Figure 68: Comparison between the 54 dB $L_{eq,16\ h}$ contour area for 2019, 2035 and 2040, with and without concept introduction.

7 UK-WIDE AVIATION NOISE

Using the same methodology as the Sustainable Aviation Noise Roadmap (34), and given the penetration rate of zero carbon aircraft assumed in the NAPKIN studies there is no significant change in overall UK aviation noise beyond that which would be expected were improved conventional kerosene aircraft used as replacement for older aircraft types being taken out of service and the same growth in passenger numbers assumed. (The calculated difference being less than 1% which is much less than the margin of error in such calculations.) Such a result is not unsurprising given that, looked at on a national basis, aviation noise is dominated by larger aircraft than those studied within NAPKIN.

NAPKIN concept aircraft tend to have lower PAX and range capacity than their corresponding baseline cases and when normalised for this (essentially a change in TO Mass) an increase in noise is observed. Such an affect will be minimal for individual aircraft operations, and hence for low use small airports. It will also be unnoticeable at very large airports such as Heathrow where the operation of larger aircraft than those studied in NAPKIN will dominate the community noise metrics. However, as the London City study shows, it will manifest at certain airports where the use of aircraft of the size of the NAPKIN concept aircraft is prevalent.

8 ZERO EMISSION AICRAFT NOISE IMPACT

The impact of the NAPKIN concept fleet will have on noise emissions is best assessed through the method described by the ICAO Balanced Approach to Aircraft Noise Management (34). Reduction of the noise at the source involves the design and introduction of quitter aircraft relative to current generation aircraft. This involves aircraft manufacturers including noise specific input into the design process. The next three points on the balanced approach involves the operation of the aircraft in the vicinity of airports while attempting to optimise for minimal noise exposure on the ground. The main stakeholders responsible for aircraft operations are airports and airlines along organisations and authorities such as the CAA and EASA who set and oversee the regulations regarding these operations. Finally, and maybe the most important is the impact on the community itself. Community response to aircraft noise is the key reason of the development of the balanced approach as it impedes the operation and development of airport and the aviation sector in general.

8.1 MANUFACTURERS / AIRCRAFT

The impact of the NAPKIN (and novel zero-emission hydrogen aircraft in general) on an aircraft and manufacturer level in terms of noise can be summarised in the following points:

- Retrofit designs suffer from penalties due to reduction in PAX, Range in addition to any excess increase in MTOW.
- Retrofit concepts “suffer” from design and operational characteristics of their baseline aircraft. This limits the possibilities for noise mitigation, which in most cases will lead to the concepts holding on to current technology and operation standards that are not in line with future noise goals trends.
- Clean sheet hydrogen concepts allow opportunity for noise abatement technology to be implemented from the conceptual design stages all the way through to detailed design in an optimised way.
- Individual aircraft penalties introduced due to reduction in PAX, Range etc.
- Potential novel noise sources. Research is required to identify these potential sources and understand the underlaying mechanisms in order to avoid or minimise their contribution to the noise profile of aircraft in departing or approach configurations.

Following are some key design elements that have either been leveraged by the NAPKIN concepts to reduce noise or could provide additional noise abatement benefits if considered in the design process:

- Aircraft Noise is due to Aerodynamic interactions - Reducing flow Mach numbers reduces noise.
- Reduce maximum take-off weight and landing weight to reduce thrust required.
- Reduced fan pressure ratio fan (leading to higher fan diameter), reduced fan speed, reduced turbomachinery flow Mach numbers and exhaust velocities.
- Increase height above the ground – Steeper take-off and landing (trade with take-off / landing weight)
- Aircraft configuration and engine mounting arranged to maximise noise shielding to ground and minimise noise reflection of airframe surfaces. (tail mounted engines good, blended wing body with engine mounted above very good)

- Short landing gear – important noise source on landing. (Large diameter engines under wing may limit this)
- Landing gear fairings – may case trade off due to increase in weight of the landing gear assembly
- Maximise acoustic liner treatment in nacelle and increase nacelle length to duct width ratio.
- Optimised number of turbomachinery blades and vanes to avoid high noise interactions.
- Minimise flow distortion into engine during take-off and landing flight envelope. (Tail mounted engines good).

8.2 AIPORTS / AIRLINES

From a manufacturer perspective the NAPKIN aircraft concepts were designed to match or better the performance of the reference aircraft, while operating within the current regulations of UK airspace. This would allow the seamless introduction of the concepts to the market in the present day, but not necessarily at the EIS dates proposed by NAPKIN.

Airports and airlines are currently working with the CAA to design and modernise UK airspace. This involves following best practice for all aspects of aircraft operation, including operation for low noise. In 2018 the UK Government set up the Independent Commission on Civil Aviation Noise (ICCAN) for the specific purpose of, within the context of airspace change, providing the best practice on the best noise management techniques and accessibility of noise information. However, as of September 2021, most ICCAN functions have been transferred to the CAA with the intention of implementing findings in the airspace modernisation strategy. As operation for low noise is inevitably part of future airspace its is important the future concepts, including NAPKIN, follow the best practice operation for noise in design and mission considerations. Examples of such operational constraints are:

- Speed at approach, it is important for noise exposure considerations as well as for aircraft landing rate per runway (ATC, air traffic control point of view.
- Aircraft concepts ready for Performance based navigation (PBN) systems.
- Curved approach to avoid noise sensitive areas. Approach flight track dispersion becomes possible.
- Automated thrust control for departure operations.

Adherence to low noise operations is equally as important as generating policies and regulations regarding them. Radar and satellite systems in place to provide feedback to airports and airlines on the actual operational characteristics of their fleet relative to the desired ones. Platforms such as ANOMS (Airport Noise Monitoring Systems) and ELVIRA (safety and environmental management tool). Breaches of operating rules and restrictions would result in fines, as for example operators that breach night restrictions or exceed the aircraft noise thresholds.

8.2.1 Low noise operation

In many cases, low noise operation changes the perception of noise and annoyance, just because of the positive attitude of the environment (community) to the implementation of noise reduction/control techniques. Although in terms of dB(A) or EPNdB level, only marginal improvement is gained perceived annoyance drops significantly (36).

London Heathrow airport proves this its implementation of scheduled on and off periods for runways. The community provides positive response although the yearly averaged noise level is not affected.

Additional noise abatement operational procedures can be categorized in the following groups, noting the existence of trade-offs between in the implementation of multiple such procedures.

1. Noise abatement flight procedures,
    a. such as Continuous Descent Arrival (CDA)
    b. Noise Abatement Departure Procedures (NADP)
    c. Modified approach angles, staggered, or displaced landing thresholds
    d. Low power/low drag approach profiles
    e. Minimum use of reverse thrust after landing
2. Spatial management
    a. Noise preferred arrival and departure routes
    b. Flight track dispersion or concentration
    c. Noise preferred runways
3. Temporal management
    a. Vary ground tracks by time of day
4. Ground management
    a. Hush houses and engine run up management (location/aircraft orientation, time of day, maximum thrust level)
    b. APU management
    c. Taxi and queue management
    d. Towing and Taxi power control (Taxi with less than all engines operating)
    e. Single engine taxi
5. Aircraft-ATC technology
    a. Automated trust reduction for NADP 1
    b. Trajectory base operation (TBO)

8.2.2 Quota Count (QC) system

As expected, all NAPKIN concepts fall within the “exempt” category of the Quota Count (QC) system (35) implemented at London Heathrow, Gatwick and Stansted, as the significantly larger Airbus A320neo only just falls into the QC/0.125, after an amendment to the original eight bands with the additional QC/0.125. The exempt category of aircraft is currently not restricted in any way, either by number of movements or other noise quota limits, therefore effectively the NAPKIN fleet could operate without restrictions in the night quota period.

This however highlights a possible limit to the QC system, as currently the majority of exempt aircraft are also regional turboprops and business jets. As with the introduction of new quieter jet aircraft, such as versions of the Airbus A320neo, novel hydrogen concepts (such as the ones presented within NAPKIN, but also larger narrowbody and midsized aircraft proposed by projects such as FlyZero) with ambitious noise limits goals, will come into service that are quieter than the current QC/0.125 standard and will therefore be exempt from both the movement and the quota limits under the current restrictions. This would promote the production and purchasing of quieter aircraft.

8.3 COMMUNITY

The impact of the NAPKIN concept fleet on the communities surrounding airports will be minimal until the percent of hydrogen movements relative to the total number of UK movements is in the order of approximately 8% (as assumed in the 2040 LCY airport case study).

The results vary between differently sized airports. Small airports, such as Inverness and other Highlands and Islands airports could see an increase in the number of operations in the order of 50% to 100%, just due to the reduced size of the aircraft passenger capacity (based on Concept A1 and B1 data). This, as shown in Section 5.2, to an equivalent increase in acoustic energy due to noise, correlating to increase in exposed area on the ground. In SEL terms, this almost doubling of noise, due to operation number alone would correspond to a +3 dB increase in noise levels, neglecting the impact of noise source differences. In paper this looks bad, however, the absolute number of operations at such airport is low relative to the likes of larger airport of Heathrow and Gatwick, meaning that when look at a metric such as $L_{eq,16h}$ of the period of 16 hours for example, the corresponding increase in of 3 dB would still result great margins relative to limits of cumulative exposure (usually set with large airports in mind).

For medium sized airports, the impact on community follows the conclusions of the LCY airport case study. The NAPKIN fleet (especially the larger >40 PAX concepts) constitute the exact size/classification of regional aircraft that are currently dominantly active at LCY and similarly sized airports. Therefore, benefits to noise exposure area and shape due to the introduction of NAPKIN aircraft will be visible once the fleet composition is made up of approximately 8 % (in terms of UK movements) of hydrogen aircraft, as in the 2040 example of Section 6. This size of airport will be impacted the most by the introduction of regional zero-emission aircraft.

For large airports, the noise impact on the community is unsurprisingly negligible. Regional aircraft movements at this size of airport are orders magnitude less than those of large narrowbody, single and twin aisle aircraft, as well as larger quad engine aircraft.

Finally, the effect of population growth was not studied in this report. It is important that the growth of population and increase in air traffic demand will increase the number of people exposed to noise, and therefore noise impact, regardless of the improvements (or non) of aircraft noise at the source. The following statement summarises this point:

“The effect of population growth is significant and would result in a 19% increase in assessed population from 2013 to 2050 for the 54 dB LAeq,16h metric if the noise impacted area were to remain constant over this period.” (33)

8.4 FUTURE NOISE GOALS / LIMITS

Overall, the performance of the NAPKIN aircraft relative to the expected noise reduction goals set by the ICAO (see Table 16: Noise Goals Expressed as EPNdB below Chapter 14 levels. ICAO Environmental Report 2019) is in line with what is expected of the next generation of regional aircraft.

Table 16: Noise Goals Expressed as EPNdB below Chapter 14 levels. ICAO Environmental Report 2019 (39)

EIS Date	Business Jet	Regional Jet	Single Aisle	Twin Aisle
2027	10.0	14.5	15.5	19.5
2037	15.0	17.0	24.0	26.5

Tables Table 17: Predicted noise margins expressed as cumulative EPNdB below reference aircraft noise levels for project NAPKIN concepts. and Table 18: Predicted noise margins expressed as cumulative EPNdB below Chapter 14 levels for project NAPKIN concepts summarise the cumulative certification levels relative to the reference aircraft and Chapter 14. These margins however, as a result of the three-point certification procedure, are based on single event operation and classification using the absolute value of MTOW of the aircraft. This disregards the effect of reduced passenger capacity and range capability of some of the concepts. The notion of applying a correction factor (noise penalty, $\Delta\ EPNLdB$) to account for these reductions, before calculation of the applicable limits for these aircraft is something to be considered. Another approach to classifying and generating the limits for noise certification levels of future aircraft would be the use of payload (kg/tonnes) or payload fraction. This could help identify the efficiency of an aircraft of a specific MTOW at carrying useful payload and reward or penalise said aircraft appropriately. This discussion forms part of the future work required on noise impact of novel hydrogen aircraft.

Table 17: Predicted noise margins expressed as cumulative EPNdB below reference aircraft noise levels for project NAPKIN concepts.

EIS Date	Medium Regional	Medium Regional	Medium Regional	Single Aisle
	Concept D1	Concept E1	Concept E2	Concept Z1
2035	13.2	8.3	16[2]	11.4

Table 18: Predicted noise margins expressed as cumulative EPNdB below Chapter 14 levels for project NAPKIN concepts

EIS Date	Medium Regional	Medium Regional	Medium Regional	Single Aisle
	Concept D1	Concept E1	Concept E2	Concept Z1
2035	44.5	34.4	42.1	34.9

[2] Based on empirical evidence and previous work on regional DEP architectures. Actual predictions are part of future work recommendations.

9 CONCLUSION

Aircraft Noise

Historically technology improvements have had the effect of lowering the noise emission of individual aircraft. Broadly this trend is continued with hydrogen fuelled aircraft when judged against their corresponding kerosene fuelled baseline, but with less (or no) improvement in approach noise compared to take-off noise.

Limitations of the NAPKIN noise study mean that there is an element of risk in this conclusion in so far as additional sources of noise introduced by the fuel change have been underestimated (or not included at all). For example, direct hydrogen combustion noise is assumed comparable to that of kerosene combustors and any additional noise due to fuel cell cooling systems has been disregarded. To offset this, however, there are opportunities for noise mitigation that have not been considered, such as advanced liners.

To maximise the potential for decreased noise R&D programmes addressing both risk and opportunities will be required. There is also the opportunity to decrease noise via changed operational procedures such as increased approach angle.

Airport Noise

Whilst individual aircraft noise may decrease, airport noise is also dependent on the number of operations which, given aviation growth, tends to act to increase noise. How the introduction of hydrogen aircraft affects airport noise depends broadly on the size of the airport and the fleet composition.

For small airports (in the sense of a small number of small aircraft movements) there is little change in noise. Equally, for large airports such as Heathrow, the size of aircraft considered in NAPKIN have such a small contribution to the overall airport noise that, again, little or no difference in noise is discernible.

Between these two extremes it has been found that for medium airports the introduction of hydrogen aircraft may act to decrease or increase noise. This is because the (generally) lower PAX capacity of hydrogen aircraft may entail an increased number of operations to maintain overall passenger numbers (although this depends on assumed load factors).

Other Points to Note

Hydrogen aircraft concepts often involve propeller or ducted fans as propulsers and it should be noted that these aircraft have a more tonal noise signature than turbofan powered aircraft. Thus there is likely to be a change in the overall nature of noise heard around airports and the impact of this may not be correctly captured by current metrics.

While the broad outlook for noise from hydrogen powered aircraft is optimistic, it needs to be recognised that these aircraft will still produce a level of noise sufficient to impact a sizeable number of people. It is therefore important that those likely to be affected are informed as to realistic noise expectations.

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