

High-Level Airport Assessment of Noise and Carbon Emissions Trade-off for Novel Aircraft - A Holistic Approach to Decision Making

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As aviation demand grows, controlling carbon emissions is crucial for meeting 2050 net-zero targets. Complaints relating to airport noise have increased over recent years despite individual aircraft noise levels decreasing. Current aircraft designs face competing requirements to reduce fuel-burn or noise. To date, no existing high-level tools exist that determine the trade-offs between these two aircraft emissions at an individual aircraft or airport fleet level. This paper extends Powell's (2003) methodology, scaling the procedure for individual aircraft operations to enable a fleet-level assessment and allowing the impact of novel aircraft to be determined. The results of linear regression analysis were reproduced in AEDT (where Powell used INM) and included additional aircraft, such as business jets and propeller planes, to improve the accuracy for smaller, regional airports. A case study has been run for a UK airport with assumed noise levels of future aircraft based on Sustainable Aviation guidance, to demonstrate the change in noise and CO₂ levels when introducing novel aircraft to the fleet. This has shown that the noise contour area increases when introducing novel hydrogen and electric aircraft compared to future low-noise technology designs with conventional propulsion mechanisms. The CO₂ emissions were shown to decrease substantially when introducing novel hydrogen and electric aircraft, but increase for future low-noise technology designs with conventional propulsion mechanisms. This highlights the trade-offs between noise and CO₂ and indicates that careful consideration must be given to future aircraft designs and fleet mixes if both emissions are to be reduced simultaneously.

I. Nomenclature

A	Noise contour area, km ²
c	CO ₂ emission index, kg/kg fuel (3.15 for typical aviation fuel)
C	Constant for sound propagation (20 dB for spherical sound propagation)
e	Number of operational engines
EPNL	Effective perceived noise level, dB
$\dot{f}$	Fuel flow rate, kg/s
F_{oo}	Maximum sea level thrust, kN
L	Noise level, dB
N	Number of LTO movements
s	Constant relating to the slope derived from least-squares linear regression
SEL	Sound exposure level, dB

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t	Time, s
x	Distance from aircraft brake release point along the runway centreline, m
y	Perpendicular distance from runway centreline, m

Subscripts

$\square_T$	Takeoff noise certification point
$\square_S$	Sideline noise certification point
$\square_A$	Approach noise certification point
$\square_i$	Individual flight mode i.e. taxi-out, climb, approach

II. Introduction

With the demand for aviation increasing, there is a growing urgency to control the carbon emissions from the industry if the net-zero carbon targets are to be met by 2050. Aviation currently contributes between 2.0 - 2.5% to the global annual carbon emissions [1] and is projected to increase its share if there are no radical changes, as other industries decarbonise faster. ICAO has forecast an annual average increase in demand for revenue passenger kilometres (RPKs) of 3.6% between 2018 and 2050, even after accounting for the effect of the COVID-19 pandemic [2]. The international aviation sector has adopted its own targets to strive to comply with the 2015 Paris Agreement [3], aiming for net-zero carbon emissions by 2050 [4, 5]. Individual countries have set even more ambitious targets such as the UK's Jet Zero strategy which aims for net-zero emissions from domestic aviation by 2040 [6].

In addition to ambitious net-zero targets, noise is an increasing concern at both airport and aircraft level. Noise regulations for aircraft certification are becoming more stringent. ICAO defines maximum noise limits at three measurement points with cumulative limits also applying. Aircraft recently entering into service are 5-15 dB below current cumulative limits [7], meaning future aircraft must be designed well below future limits to stay competitive. Noise regulations influence aircraft design, however current designs are reaching the point where beneficial noise changes negatively impact fuel-burn, suggesting that future aircraft will have competing requirements to reduce either fuel-burn or noise. Technology projections show that future aircraft will have reduced carbon and noise emissions compared to today's aircraft, but radical design changes will be required to meet the carbon and noise targets individually. Figure 1 shows predicted improvements in fuel consumption and noise reductions for novel aircraft configurations compared to NASA N+3 fuel-burn and noise emission goals [8]. It is clear that no design achieved both target levels simultaneously, indicating a trade-off between prioritising low-carbon emissions or low-noise emissions. For example, contra-rotating open-rotors alone are predicted to reduce fuel-burn by 36% (compared to a 1998 contemporary counterpart) [9] but increase cumulative noise levels by 14-22 dB compared to their contemporary counterpart [10] due to removal of the nacelle.

Regarding airports, noise management is key for community engagement. Even though aircraft are becoming quieter, the population around airports have been reporting increased annoyance [11]. The UK House of Lords Science and Technology Committee recently found noise to be the most significant environmental factor affecting community health after air quality [12]. The CAA has linked high noise levels to cardiovascular diseases, cognitive impairment, sleep disturbance and annoyance [13]. Consequently, noise in the vicinity of airports is heavily scrutinised. Airports have limited control of noise emissions through operational restrictions, operational procedures, aircraft technology and land management [14]. Therefore changes in aircraft source levels could significantly affect an airport's operations.

If achieving the ambitious carbon and noise targets individually is already challenging, achieving both of them in parallel requires careful consideration and a clear appreciation of the inter-dependencies between these key drivers [15]. However, not much attention has been given to this subject and most executive decisions to date have been driven by carbon outcomes (e.g. choice of future fleet mix by airlines).

The novelty of this study is a combined analysis of noise and carbon emissions to drive decision-making, including scenarios for future aircraft fleets. Existing modelling tools can predict carbon and noise emissions separately. This is the case with the FAA's AEDT [16] or NASA'S ANOPP2 [17], which require detailed flight performance data available only from field measurements or proprietary inputs. This information is not available for future aircraft designs, limiting these tools to existing aircraft. Recently, methods have been developed to predict noise from novel aircraft and airport operations without requiring detailed inputs, such as MONTANA [18] and RANE [19]. However, no existing tools efficiently predict both carbon and noise and determine the trade-offs for novel aircraft and future airport operations. This paper develops a method to assess the cumulative impact of noise and carbon emissions from current and novel aircraft at an airport fleet level.

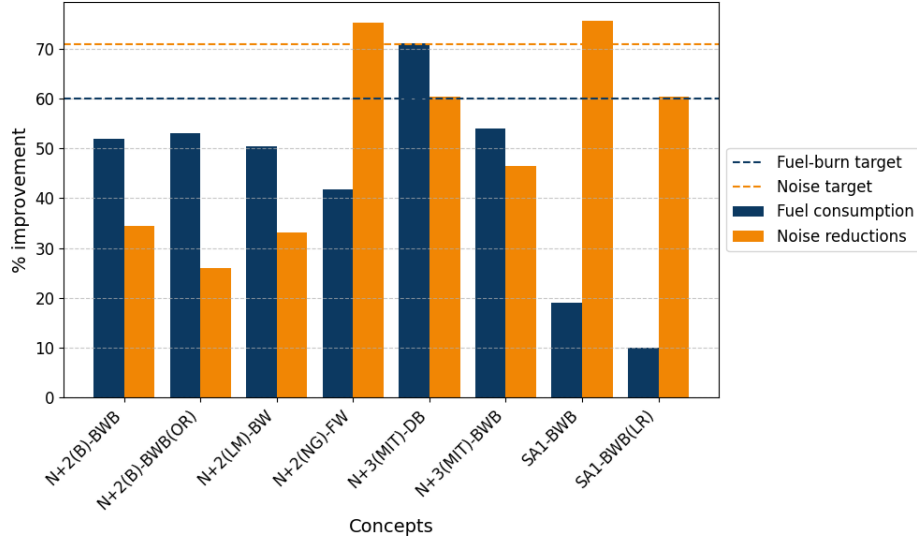


Fig. 1 Noise and carbon performance for novel aircraft designs against the NASA N+3 goals*. Adapted from [8].

III. Methodology

A. Noise

The methodology employed for the noise assessment in this paper is an extension of that presented by Powell [20], who developed an analytical expression between the measured noise level at the three certification points and the noise contour area for individual aircraft operations. The three certification points are defined as:

- Takeoff (T): 6.5km (x_T) from the brake release position along the runway centreline,
- Sideline (S): 450m (y_S) parallel to the runway centreline, at the distance of maximum noise during takeoff,
- Approach (A): 2km (x_A) before the touchdown position along the runway centreline.

The method assumes a generalized elliptical noise contour shape that is symmetrical about the runway axis with fixed noise level, L , along the circumference. Assuming constant power, acoustic output, ascent/descent angle of the aircraft operation and spherical spreading of sound, the method finds the maximum distances (x , y) to the contour level of interest by relating them to the noise levels measured at the certification points (L_T , L_S and L_A). The area of the final contour, A , is taken to be proportional to the product of these distances and is shown in Equation 1.

$$A \propto (x_T \cdot y_S) \left\{ \frac{10^{(L_T+L_S)/C}}{10^{2L/C}} \right\} \quad (1)$$

Figure 2, taken from [20], demonstrates the geometric relationships for a generalized departure operation. The full derivation of the method is provided in [20].

Powell [20] then developed an equation to determine the change in noise contour area (ΔA) based on a change in source noise levels (ΔL) for a single aircraft operation. This is shown in Equation 2

$$\Delta A = A \left(1 - 10^{s\Delta L} \right) \quad (2)$$

where s is the relationship determined through regression analysis between the certification noise level and noise contour area when modelling using higher fidelity modelling tools such as AEDT.

For this work, 47 aircraft were chosen, covering a range of aircraft sizes and propulsion mechanisms that are typically used across major airports. 37 of these matched those chosen by Powell [20] with the additional 10 aircraft

*Noise performance is relative to Chapter 4 ICAO limits and carbon performance is relative to their 2014 contemporary counterparts. Concept aircraft codes relate to the following aircraft: NASA ERA N+2 Boeing blended-wing body (BWB) with geared turbofans, NASA ERA N+2 Boeing BWB with open rotors, NASA ERA N+2 Lockheed Martin box-wing with geared turbofans, NASA ERA N+2 Northrop Grumman flying wing with embedded turbofans, NASA ERA N+3 MIT double-bubble with integrated turbofans, NASA ERA N+3 MIT BWB with embedded, distributed propulsion, NASA N+3 Silent Aircraft Initiative noise-optimised BWB with embedded turbofans, NASA N+3 Silent Aircraft Initiative noise-optimised BWB with conventional turbofans.

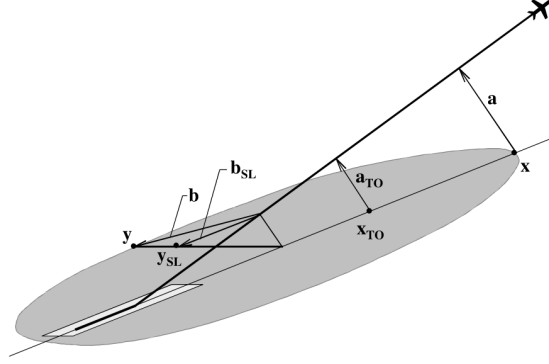


Fig. 2 Generalized departure noise contour with geometric relationships. Taken from [20], where TO stands for takeoff (T) and SL for sideline (S)

corresponding with those typically used at smaller airports, consisting mostly of business jets, regional jets and propeller aircraft. Only aircraft that achieve the ICAO Chapter 3 and/or Chapter 4 noise limits were chosen as they represent the aircraft in use today. A full list of the aircraft used is presented in Appendix I.

A single departure operation of each aircraft was run in the FAA's AEDT software to predict the noise contour area and the noise level at each certification point. Least-squares linear regression analysis was run for each combination of the following inputs, resulting in a total of 90 combinations.

Certification point	Certification noise level	Noise contour metric	Noise contour level
T	Measured	EPNL	85dB
S	AEDT predicted EPNL	SEL	90dB
T+S	AEDT predicted SEL		95dB
			100dB

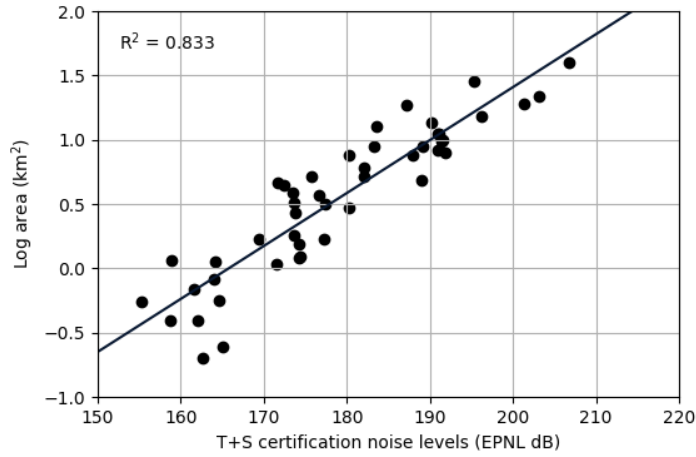
Table 1 Parameters used for least-squares linear regression analysis

Examples of the relationships for the 90 dB SEL noise contour are shown in Figure 3 along with their variance, which present values between 0.83 - 0.88. Relationships for the combinations of other noise levels and noise metrics presented variances that ranged from 0.75 - 0.98, with the T+S certification noise levels showing higher correlations than other noise measurement positions, and the EPNL noise contour area showing greater correlation than the SEL contour area. Since this method is intended for high-level analysis and feasibility assessments of future scenarios — including applications to novel aircraft types with inherent uncertainties in their design and noise performance — the variances found in this work are generally considered acceptable within the airport industry.

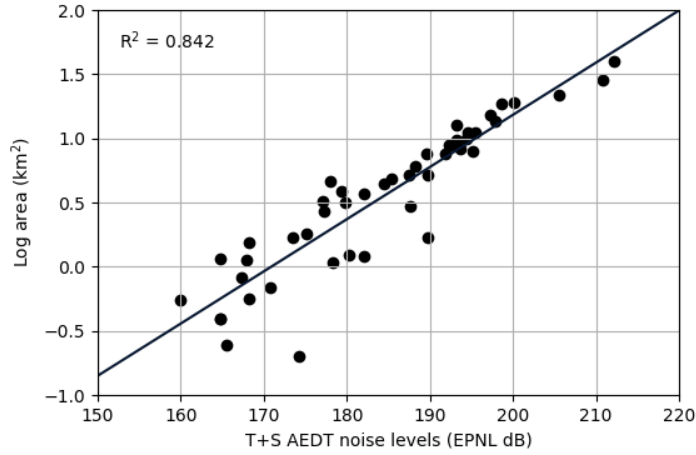
The formula developed by Powell [20] applied to one single aircraft operation. As the aim of this work is to undertake a fleet-level assessment, the equations shown above were applied to a full airport fleet by logarithmically summing the contributions from each aircraft movement at the certification points using the equation below:

$$L_{\text{total}} = 10 \cdot \log_{10} \left(\sum_{i=1}^n N_i \cdot 10^{\frac{L_i}{10}} \right) \quad (3)$$

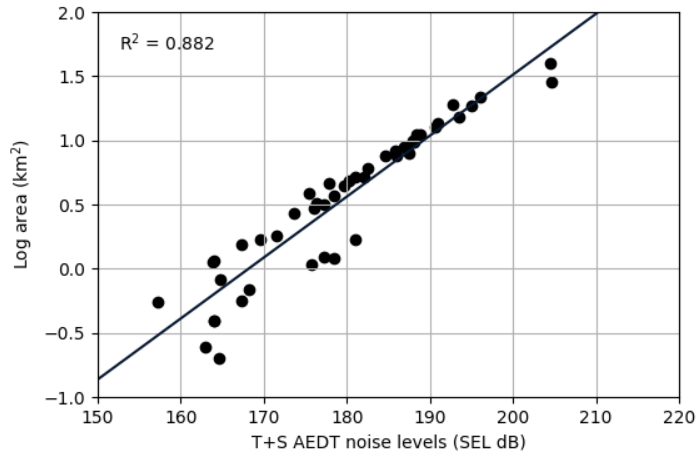
where L_{total} is the total noise level, n is the number of different aircraft types and N_i is the number of operations for each aircraft type.



(a) Measured EPNL noise levels at certification points



(b) Predicted EPNL noise levels at certification points



(c) Predicted SEL noise levels at certification points

Fig. 3 Relationship between the 90 dB SEL noise contour area and the sum of noise levels at the takeoff (T) and sideline (S) certification points. For each relationship, the variance is shown (the square of the correlation coefficient, R)

B. Carbon

The methodology employed to calculate the carbon emissions in this paper is based on the standard method used in industry, introduced in EEA Report 06/2023 [21] and described in Part B: 1.A.3.a Aviation 2023 of the report. Engine fuel burn and emissions data are sourced from the ICAO Aircraft Engine Emissions Databank [22] and the FOI Turboprop Emissions Database (Swedish Defence Research Agency) [23].

The majority of an aircraft's fuel — typically between 75% and 95% [24] — is consumed during the cruise, climb, and descent (CCD) phases of flight, rather than during the landing and take-off (LTO) cycle. This fuel consumption is highly dependent on the route of each aircraft. There is significant variation in route distances between airports, which can change over time as airports update their destination offerings in response to passenger demand.

The LTO cycle is defined by ICAO as the aircraft operations up to 3000ft above ground level [25]. It consists of four engine operation modes which are outlined in Table 2. The LTO cycle consumes more fuel per unit distance than the CCD phase [21] due to the higher thrust levels required during take-off. It is a well-defined standardized profile used for engine certification, which removes the dependence on aircraft destination and therefore allows for direct comparisons between various engine types across a fleet of different aircraft. For these reasons, this work has only considered the CO₂ emissions generated as part of the LTO cycle.

Operating mode	Thrust setting	Time in operating mode (s)
Take-off	100% F_{oo}	42
Climb-out	85% F_{oo}	132
Approach and landing	30% F_{oo}	240
Taxi-in / taxi-out	7% F_{oo}	1140 / 420

Table 2 Different operating modes in the LTO cycle, their engine thrust setting as a percentage of maximum sea level thrust (F_{oo}) and the ICAO default time spent in each mode [25]

The amount of CO₂ produced in the LTO cycle for each aircraft type was determined using Equation 4:

$$CO_2 = N \cdot \left(\sum_i \dot{f}_i t_i e_i \right) \cdot c \quad (4)$$

where i is each mode of the LTO cycle (Table 2), N is the number of LTO movements for the particular aircraft type, $\dot{f}_i$ is the fuel flow rate in each mode (kg/s), t_i is the time spent in mode (s), e_i is the number of engines used in each mode per aircraft, and c is the CO₂ emission index (i.e. the amount of CO₂ emitted per kilogram of fuel burnt, kg/kg fuel). Aviation fuel (kerosene) typically has a value of $c = 3.15$ [26].

The fuel flow rate for each aircraft type during each operating mode was taken from the ICAO emissions database and the FOI emissions databank mentioned above. ICAO also provides the historical annual average time spent in each operating mode for various European airports, as well as ICAO default times.

The total CO₂ produced for the airport as a whole was then determined by evaluating Equation 4 for each aircraft type and summing the results for the entire fleet mix.

IV. Test Case

The work presented in this paper has been conducted using data for a specific UK airport. The total number of commercial aircraft movements across a 92-day summer period in the baseline year of 2023 was found and decomposed into aircraft types. Forecast number of movements and fleet composition were provided by the airport up to 2037. To simplify the model, the forecast fleet composition was analysed to determine the most common aircraft that contributed to >85% of the flights. Ten aircraft were selected and the total number of movements was scaled up to represent all of the flights, substituting less common aircraft for proxy models. All of the final aircraft selected were included in the linear regression analysis carried out above. Figure 4 shows the forecast operations used in this work.

This work has assumed that there are no changes to the operational profile of the aircraft and the flight profiles are all based on those used for noise certification measurements.

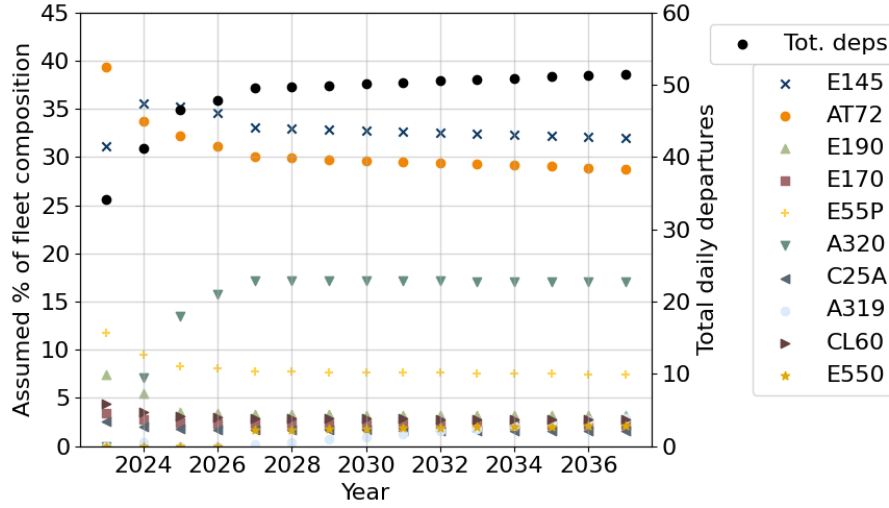


Fig. 4 Forecast operations between 2023-2037 for a UK airport

V. Preliminary Results and Discussion

A. Verification Against AEDT Noise Modelling

The operational forecasts between 2023 - 2037 were modelled in AEDT based on the average daily number of departures, to validate the high-level fleet analysis presented in this paper. The extended Powell method was run using the same assumptions. To determine the best relationship, s , to use in Equation 2, all 90 calculated values were used in combination with the change in noise levels based on those calculated through Equation 3 for certification noise levels determined through measurements (EPNL), AEDT predictions of EPNL or AEDT predictions of SEL, resulting in a total of 270 combinations tested.

As the extended Powell method calculates the area proportional to the noise levels, it cannot accurately determine the absolute noise contour area. Therefore to compare the two methods, the percentage increase in noise contour area was determined for each forecast year compared to the baseline year of 2023. The combination that provided the most similar results to the AEDT model across all forecast years, noise metrics and contour levels was produced using the measured EPNL noise levels at certification points as input to Equation 2 with the linear regression slope from the relationship between measured EPNL noise levels at T+S against the SEL predicted noise contour area (shown in Figure 3a). Figure 5 shows the difference in the percentage increase in each of the predicted noise contour areas between the extended Powell method and AEDT predictions.

It is clear that the 90 dB contour for both SEL and EPNL metrics provide the most similar outcome to the AEDT modelling, with an absolute difference of $<3\%$ across all forecast years. The method over predicts the increase in noise contour area for quieter noise contours and under predicts the increase for louder noise contours. These findings can be explained through the assumptions of the model - mainly that the thrust and atmospheric attenuation are assumed to remain constant along the flight path as per the level experienced at the certification points. The thrust at the take-off certification point (and therefore assumed throughout the model) will be similar to the cut-back thrust, whilst in reality the thrust would be higher closer to the runway, as the aircraft takes off, and lower further away. Similarly the acoustic losses due to atmospheric attenuation assumed throughout the model will be based on the distance between the aircraft and the ground at the certification points. The assumed losses will therefore be larger than reality for louder noise contours (i.e. closer to the runway) and smaller than reality for quieter noise contours (i.e. further from the runway). These findings agree with those found in Powell [20] for single aircraft movements.

A noise level of particular interest to UK airports is the 51dB $L_{Aeq,16hour}$ contour (defined as the A-weighted equivalent continuous sound level over the 16-hour period between 07:00-23:00), as the UK Government have defined this as the level above which adverse health and quality of life impacts can be detected at a community level (referred to as the Lowest Observed Adverse Effect Level, or LOAEL) [27]. This translates to an SEL of 99dB(A) for which the errors that arise from this methodology are higher than those observed at lower noise thresholds. Whilst the results

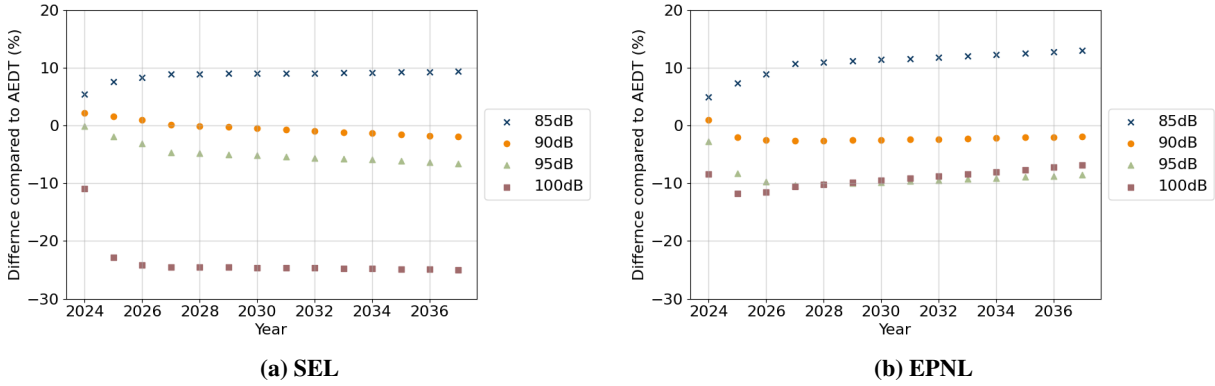


Fig. 5 Error of Powell method compared to AEDT for prediction of the increase in noise contour areas

should be interpreted with caution, they remain valuable for industry applications at this stage, particularly in the absence of more accurate or practical alternatives. Furthermore, as this method is proposed for future scenarios, the magnitude of these errors should be considered in the context of the broader uncertainties inherent in other key modelling assumptions.

B. Noise Results

To demonstrate the intended use of this method, the case study for the same UK airport was extended to include new aircraft. These have been defined as Generation 1 and Generation 2 aircraft, in addition to the Generation 0 aircraft that were used in the validation exercise. The definitions of each generation are based on Sustainable Aviation's definition [28] and broadly correspond to current, imminent and future aircraft. Assumptions for the noise levels for G1 and G2 aircraft have been based on Sustainable Aviation guidance. These did not differentiate between multiple aircraft models, instead having one representative aircraft for each class: regional turboprops, regional turbofans and small single-aisle aircraft. Therefore the ten aircraft modelled previously (shown in Figure 4) were further simplified down to these three categories.

Three scenarios were modelled using the airport's forecast movements between 2023-2037. These are shown in Figure 6 and consist of:

- Scenario 1: Current fleet mix (G0) – Current aircraft technology levels remain without improvements in noise or carbon. Used for the validation exercise and acts as a benchmark to allow comparison to AEDT;
- Scenario 2: Introducing next-generation conventional aircraft (G1, G2) – Aircraft assumed to retain conventional design and propulsion mechanisms, experiencing noise and carbon reductions through advances in traditional noise mitigation options;
- Scenario 3: Introducing novel next-generation aircraft (G2) - G1 aircraft assumed to retain conventional design and propulsion mechanisms. G2 aircraft assumed to include novel designs and the introduction of hydrogen and electric powered aircraft.

It should be noted that the assumptions regarding entry-into-service dates for G1 and G2 aircraft and their modelled up-take rates are purely fictional at this stage for the purposes of demonstrating the capability of this method. Each aircraft class has been assumed to upgrade to G1 and G2 aircraft at the same rate. Further work will include developing realistic assumptions for these key parameters.

The predicted change in noise contour area compared to a 2023 baseline year was determined for the scenarios described above and the results are presented in Figure 7.

It can be seen from Figure 7 that the noise contour area for Scenario 1 is predicted to increase until 2037, with the rate of increase generally proportional to the rate of increase in number of daily movements shown in Figure 4. As the aircraft technology levels do not change in this scenario, this result is as expected. Scenario 2 shows a gradual decrease in noise contour area, with the rate of decrease initially increasing from 2028 onwards as the new G1 and G2 aircraft make up the majority of the fleet. The predicted noise contour area falls below the 2023 baseline area by 2030, however the rate of decrease in the noise contour area then slows down from 2032 onwards, when G2 aircraft make up the majority of the fleet. Scenario 3 shows a similar trend until 2032 albeit with a less pronounced decrease in noise contour area. In 2032 the predicted noise contour area reaches the same as in the baseline year, however it then starts to

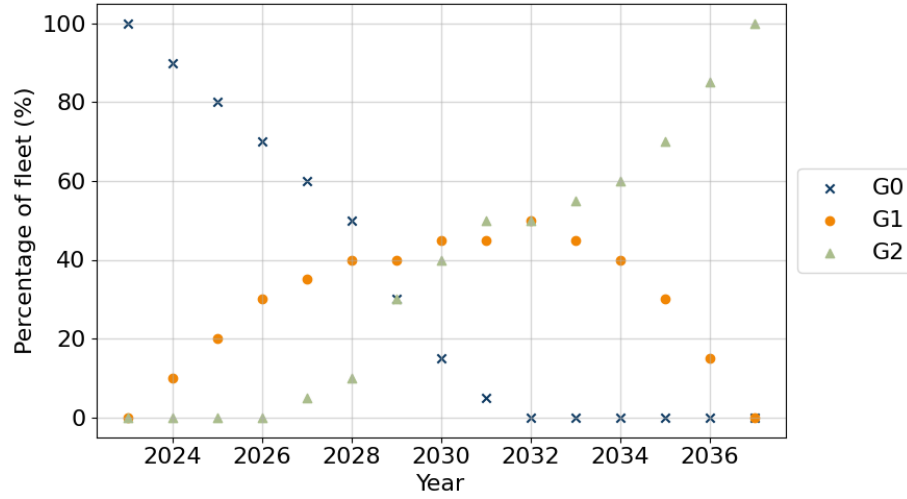


Fig. 6 Modelled uptake rates of next generation (G) aircraft

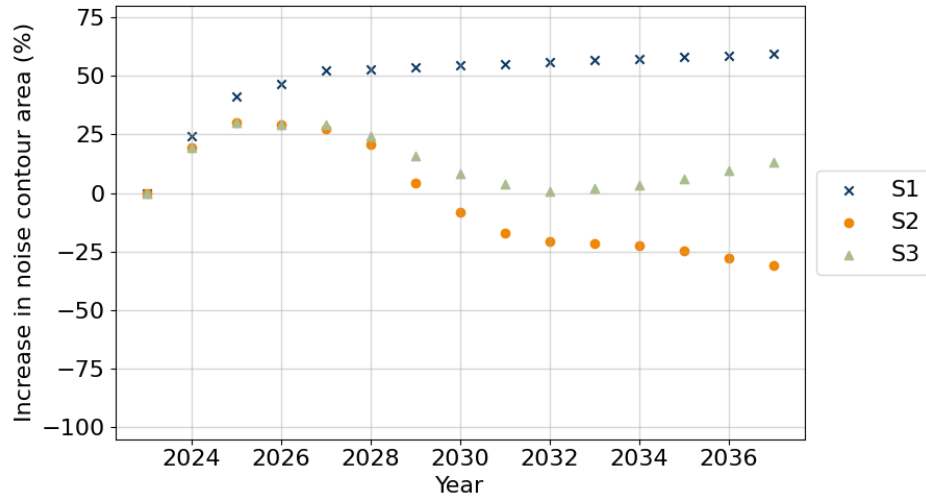


Fig. 7 Percentage increase in predicted noise contour area compared to 2023 baseline year for three scenarios (S)

increase again due to G2 aircraft making up the majority of the fleet.

The G2 aircraft are assumed to be powered by non-hydrocarbon fuels such as electric batteries and hydrogen fuel cells, which can significantly increase the aircraft's overall weight. The added mass leads to higher thrust requirements during take-off, which elevates the engine power settings and therefore the noise output. As a result, despite the cleaner energy sources, these aircraft are shown to produce greater noise contour areas during departure operations compared to conventional aircraft.

It should be noted that the method employed in this work assumes a single, fixed flight trajectory for all operations. As such, it does not account for potential variations in operational flight profiles that may be enabled by non-hydrocarbon aircraft technologies. In addition, although out of the scope of this paper, it is important to consider that unlike conventional aircraft - which gradually lose weight as fuel is burned throughout the flight - aircraft powered by batteries or fuel cells maintain a nearly constant weight, as they do not shed mass during operation. This results in a higher overall

aircraft weight throughout the entire flight envelope for these new aircraft, which can affect aerodynamic efficiency and noise generation during later flight phases.

C. Carbon Results

The carbon assessment was carried out for the same case study of the UK airport detailed in Section IV and uses the same assumptions described in V.B regarding the categorisation and uptake rates of next generation aircraft (G1 and G2 aircraft). The fuel burn rates (and therefore CO₂ emissions) for engines associated with these aircraft were determined as follows:

- G0 aircraft: as these aircraft are already in service and certification information is available, the ICAO and FOI published fuel burn rates were chosen for the three proxy aircraft that represent the full fleet mix.
- G1 aircraft: the noise levels used for these aircraft in the previous section (that were determined based on Sustainable Aviation guidance) were compared to the EASA noise certification database to find the aircraft/engine combination with the most similar certification noise levels. These broadly corresponded with aircraft that have recently entered into service e.g. the Airbus NEOs, which matches the definition of G1 aircraft and therefore the closest matching aircraft were chosen and published fuel burn rates were found.
- G2 conventional aircraft: as these aircraft do not exist yet, there is no available certification data for them. Therefore, a linear improvement in fuel burn rates was assumed across successive aircraft generations, with the G2 conventional fuel burn rates being extrapolated from those of G0 and G1 aircraft types. This assumption has been based on research from the International Council on Clean Transportation [29] and EASA [7].
- G2 hydrogen and electric aircraft: this assessment is only looking at in-flight CO₂ emissions during the LTO cycle. For fully electric and hydrogen aircraft (both liquid hydrogen and hydrogen fuel cell), there are zero in-flight CO₂ emissions. It is noted that the life-cycle CO₂ emissions of future hydrogen and electric aircraft can differ from conventional aircraft depending on how the electricity and hydrogen are produced as well as the manufacturing processes for the batteries and fuel cells. However this assessment is only looking at in-flight emissions and therefore any alterations in life-cycle CO₂ emissions do not factor into this assessment.

The percentage change in LTO CO₂ emissions compared to a 2023 baseline year was determined for the same three scenarios analysed in the noise assessment and is shown in Figure 8.

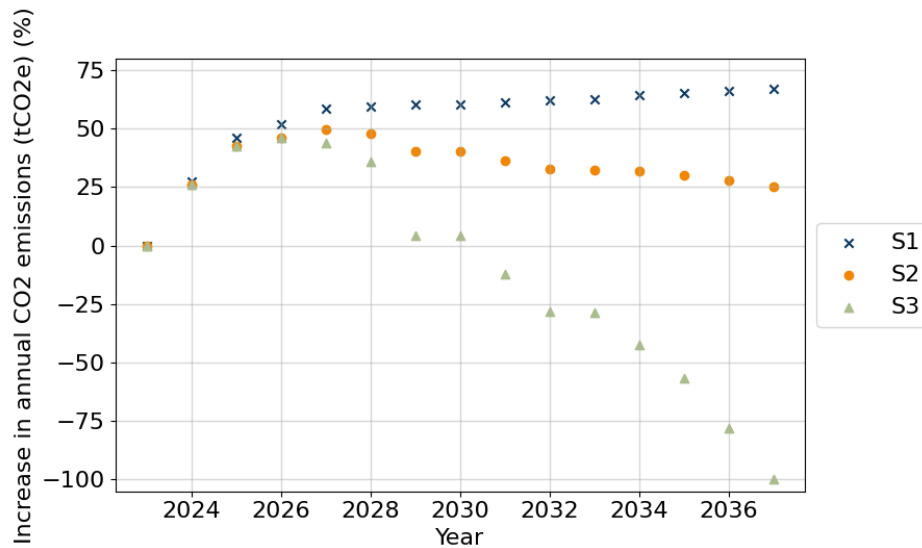


Fig. 8 Modelled uptake rates of next generation (G) aircraft

It can be seen from Figure 8 that the CO₂ emissions for Scenario 1 are predicted to increase until 2037, with the rate of increase being proportional to the rate of increase in number of daily movements shown in Figure 4, similarly to the noise results. This result is expected as the aircraft technology levels do not change. Scenario 2 shows an overall increase of 25% in annual CO₂ emissions, though the emissions peak in 2027 and then reduce despite an increase in number of movements. This coincides with the majority of the fleet becoming G1 and G2 aircraft with improved fuel

burn performances. Scenario 3 shows a dramatic decrease in CO₂ emissions from 2028 onwards as the G2 aircraft start to dominate the fleet, and eventually the emissions reach a 100% reduction as expected due to the hydrogen and electric aircraft having zero in-flight CO₂ emissions.

D. Noise and Carbon Trade-Offs

Comparing Figures 7 and 8, we can see that Scenario 1 provides a similar result, with both noise and carbon emissions increasing proportionally to the number of movements. Scenario 2 shows an overall reduction in noise contour area of 31% whilst there is an overall increase in CO₂ emissions of 25%. Finally Scenario 3 shows the opposite trend, with an overall increase in noise contour area of 13% but an overall reduction in CO₂ emissions of 100%, completely removing the in-flight CO₂ emissions.

This case study demonstrates that there is an inherent trade-off between the noise and carbon emissions of future aircraft, as none of the scenarios tested for this particular airport show a reduction in both noise and carbon emissions compared to the baseline year.

VI. Conclusions and Future Work

It is clear from literature and industry that there is a real need to have a quantitative understanding of the trade-offs and interdependencies between noise and CO₂ emissions for future aircraft and currently this is not available. Having this understanding would enable real-world impacts such as optimizing the sustainable strategies for individual airports and airline operators, facilitating the decision-making process to reach net zero by 2050 and identifying investment requirements in new technologies, fuels or required mitigation strategies.

To date this work has extended a methodology introduced by Powell (2003) to carry out a high-level prediction of the change in noise contour area based on the changes in noise level of individual aircraft, the number of operations and the fleet composition of an airport. The method shows <3% difference to predictions from AEDT for the 90dB noise contour. This paper has shown, using assumptions of future aircraft noise levels based on Sustainable Aviation guidance, that the noise level of the studied airport will increase when introducing novel hydrogen and electric aircraft compared to using conventional propulsion and fuel mechanisms.

To compliment this, a similar assessment has been undertaken to determine the CO₂ emissions based on the same assumptions in order to obtain a holistic view of the impact that future aircraft might have at a fleet level. When retaining conventional aircraft design and propulsion mechanisms for future aircraft, we see a decrease in noise levels compared to the baseline year but an increase in CO₂ emissions. In contrast, when introducing novel hydrogen and electric aircraft, we see a large decrease in CO₂ emissions compared to the baseline year but an increase in noise levels. This has shown that there is an inherent trade-off between the noise and CO₂ emissions at an aircraft fleet level.

Future work will focus on improving the fidelity of the noise level predictions of novel aircraft, the noise contour area predictions and the CO₂ models.

Appendices

Part I

Aircraft Selection

AEDT ID	Manufacturer	Model	Engine model	Stage	AEDT TOW, 1000kg	Takeoff	Sideline	Approach
717200	Boeing	B-717-200	BR700-715C1-30 (MP)	3	54.88	82.2	91.5	92.1
737300	Boeing	B-737-300	CFM56-3-B1	3	63	87.5	89.9	100.1
737800	Boeing	B-737-800	CFM56-7b27/2b1 DAC	3	78.15	85.9	94.3	96.8
747400	Boeing	B-747-400	PW4056	4	382.38	101.6	99.7	104.7
757300	Boeing	B-757-200	PW 2037	3	100.7	88.4	94.8	97.7
767300	Boeing	B-767-300	PW 4060	3	166.79	93.2	97	100.2
767400	Boeing	B-767-400	CF6-80C2B8F	3	191.61	91.2	96.8	98.7
777200	Boeing	B-777-200	GE90-76B	3	242.67	88.8	93.2	97.8
777300	Boeing	B-777-300	RR TRENT 892	3	288.53	94.2	96.9	100.4
727EM2	Boeing	B727-200 (FED EX; STC SA5839NM)	JT8D-15 w/Burbank inlet + fan CSD	3	85.73	97.7	97.6	98.6
737N17	Boeing	B-737-200 ADV (NORDAM; STC ST00131SE)	JT8D-17/-17A w/LGW Hushkit	3	47.63	89.7	97.5	96
74720B	Boeing	B-747-200	JT9D-7Q	3	351.53	103.2	103.5	106.6
747SP	Boeing	B-747-SP	JT9D-7A	3	283.5	102	101.1	102.9
757PW	Boeing	B-757-200	RB211-535E4-B	3	94.8	86.2	94	95
757RR	Boeing	B-757-300	RB211-535E4-B	3	122.2	81.3	94.4	95.4
A300	Airbus	A300B4-203	CF6-50-C2	3	161.92	94	96.9	102.4
A30062	Airbus	A300B4-622R	PW-4158	3	170.51	93.1	97.9	101.9
A310	Airbus	A310-304	CF6-80C2A2	3	150	92.9	96.1	98.8
A319	Airbus	A319-111	2x SNECMA, CFM56-5B5/3	4	68	83.5	90.8	93.2
A319	Airbus	A319-131	V2522-A5	4	64	85.3	91.4	94.5
A320	Airbus	A320-214	2x SNECMA, CFM56-5B4/3	4	73.5	83.7	93.6	95.5
A320	Airbus	A320-211	CFM56-5A1	4	73.48	87.8	94.3	96.4
A330	Airbus	A330-301	CF6-80E1A2	4	211.83	94.2	97.2	98.7
A340	Airbus	A340-212	CFM56-5C3	3	256.96	96.1	95.4	97.2
AT72	Aerospatiale	ATR 72-212 A	1 x PRATT & WHITNEY CANADA PW127F (HAMILTON SUNDSTRAND 568F-1) 1 x PRATT & WHITNEY CANADA PW127M (HAMILTON SUNDSTRAND 568F-1)	4	22.8	80.2	82.5	92.2
BAE146	BAE Systems	146-200A	ALF502R-5	3	41.28	85.2	87.3	95.8
C25A	Cessna	CESSNA 525A / CitationJet CJ2	2 x WILLIAMS INTERNATIONAL FJ44-3A-24	4	5.67	75.5	86.1	89.7
CL60	Bombardier	Bombardier Challenger 650	2xGE CF34-3B	3	21.863	79	85.6	91.3
CL600	Bombardier	CL-600	ALF-502L/L-2/L-2C	3	16.33	84.7	89.5	91.6
CNA55B	Cessna	550 Citation Bravo	PW530A	4	6.71	73.7	85.2	91.2
CNA750	Cessna	750 Citation X	AE3007C	3	16.19	72.3	83	90.2
E145	Embraer	EMB-145EP	2 x ALLISON AE 3007/A1/1	4	20.99	80.1	85	92.6
E170	Embraer	Embraer 170-200STD	CF34-8E5	3	35.998	80.8	90.7	95.2
E190	Embraer	ERJ 190-100 SR	2 x GENERAL ELECTRIC CO CF34-10E5A1 G07	3	45.99	81.4	93	91.8
E550	Embraer	Embraer EMB-550 Legacy 500	2 x Honeywell HTF7500E turbofan (Honeywell AS-907-3-1E)	4	19.44	75.1	86.9	90.3
E55P	Embraer	Embraer 505 Phenom 300	Pratt & Whitney Canada PW535E	4	8.15	69.9	88.8	88.9
EMB14L	Embraer	EMB-145LR	AE3007A1/1	4	22	79.4	84.6	92.5
F10065	Fokker	F100	TAY MK650-15	3	43.55	81.8	91.7	93
GIV	Gulfstream	G-IV	TAY 611-8	3	28.76	76.8	87.3	91
GV	Gulfstream	G-V	BR700-710A1-10	3	34.89	80.3	89.1	90.8
IA1125	Israel Aircraft	1125 Astra	TFE731-3A-200G	3	10.66	84.1	89.7	89.8
LI0115	Learjet	35A/36A	TFE731-2-2B	3	8.3	98.4	97.8	91.4
LEAR35	Lockheed	L-1011-500	RB211-524B	3	213.19	83.9	87.8	101.5
MD11GE	McDonnell Douglas	MD-11	CF6-80C2D1F	3	263.08	92.8	96.3	103.6
MD11PW	McDonnell Douglas	MD-11	PW4460	3	263.08	95.8	96.1	104.4
MD81	McDonnell Douglas	MD-80	JT8D-209	3	62.14	88.9	94.7	92.8
MD9028	McDonnell Douglas	MD-90-30	V2528-D5	3	70.76	82.6	91	91.9

Table 3 Overview of the aircraft used for this work.

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