The benefits of validating your aircraft noise model

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Summary

This paper explores the potential implications of adopting the default aircraft noise database presented in Appendix I of Commission Directive (EU) 2015/996 and as featured in most commercial aircraft noise modelling packages including the Federal Aviation Administration's (FAA) Aviation Environmental Design Tool (AEDT). The authors demonstrate the implications of this database in the context of the Quality Framework defined by the Directive and with respect to the latest guidance on aircraft noise modelling through the UK's Airspace Change Process, as set out by the UK Civil Aviation Authority (CAA). The paper highlights approaches adopted by the Authors that seek to validate the aircraft procedures adopted in noise modelling against actual radar data, along with adjustments to Noise-Power-Distance (NPD) information. The paper presents comparisons of validated data against the default values and highlights the potential implications with regards to Directive 2015/996.

1. Introduction

The incorporation of ECAC Doc. 29 3rd Edition [1] within Directive 2015/996 [2] is achieved by describing the process for noise contour generation as per the ECAC document within Section 2.7 of the Directive, along with supporting information which is provided within a set of Appendices. Appendix I describes a database for aircraft sources which includes:

- Aerodynamic coefficients
- Aircraft general information
- Default approach procedure steps
- Default departure procedure steps
- Default fixed point profiles
- Default aircraft weights
- Jet engine coefficients
- Propeller engine coefficients; and
- Noise-Power-Distance (NPD) data

In addition to the above, Appendix I includes information on spectral classes, general aviation types and helicopters.

The contents of Appendix I are fundamental components to the computation of aircraft noise contours and associated noise exposure information under the ECAC document. The data contained within Appendix I is industry recognized aircraft noise performance data, obtained from manufacturers and the noise certification process. This data is readily available within commercial computation aircraft noise modelling software packages including the Federal Aviation Administration's (FAA) Aviation Environmental Design Tool (AEDT).

As part of the noise calculation process described by the ECAC document, flight path geometries are combined within arrival or departure profile information to describe the altitude, speed and the amount of noise generated by an aircraft. This is mainly governed by the arrival and departure procedure profiles themselves which outline a number of 'steps' that describe how an aircraft will reach a certain altitude.

In the case of arrival profiles, these combine information such as engine, flap and gear deployment settings, approach speeds and decent angles. For departures, the procedure profiles describe aircraft departure power settings, flap settings, climb rates and step completion altitudes.

Directive 2015/996 recognizes that the contents of Appendix I should be viewed as input data to the methodologies. The Directive however recognizes that:

"In cases where input data provided in Appendix F to Appendix I are not applicable or cause deviations from the true value that do not meet the conditions presented under 2.1.2 and 2.6.2, other values can be used, provided that the values used and the methodology used to derive them are sufficiently documented, including demonstrating their suitability. This information shall be made publicly available."

This statement relates to the Directive's Quality Framework where the accuracy of input values affecting the emission level of a source, including its position should be determined with an accuracy corresponding to an uncertainty of at least +-2 dB, and that the use of default values, such as those described within Appendix I, should in general not be relied upon but can be accepted. An example provided is the use of modelled routes instead of radar derived flight paths, if the collection of real data is associated with disproportionately high costs.

1.1. Wider UK Considerations

The accuracy of a noise model and its representation of local impacts is key concern of communities and for decision-makers.

In the UK, with the emergence of web-based tools such as WebTrak and FlightRadar24, aircraft performance information such as flight paths, speeds and altitudes are much more readily available. This has given local stakeholders the ability to challenge any noise modelling. This has placed further emphasis on ensuring that noise models are developed and best represent local and airport specific circumstances.

The UK Civil Aviation Authority (CAA) has published advice to noise modelers within its guidance as part of the Airspace Change Process (ACP) [3]. This guidance includes the use of AEDT for noise modelling and makes reference to the default aircraft noise datasets held within AEDT as reproduced in Appendix I of the Directive. The guidance state that "The default settings for the model may not be appropriate under particular circumstances and therefore use of those default settings may generate inaccurate results". The CAA guidance goes on to describe a range of techniques and references for improving the accuracy of the noise contours such as the dispersion of aircraft and how this is considered in the modelling of tracks. In relation to default departure profiles, the guidance states that:

"For nearly all aircraft types, the AEDT default departure profile uses maximum thrust generating the maximum climb rate. Use of maximum thrust on take-off is not a typical mode of operation for most civil jet aircraft. Engine maintenance considerations dictate a lower thrust setting on take-off than that typically assumed by AEDT. Thus the default profile can alter the modelled distribution of noise exposure on the ground compared to normal operation – i.e. in some locations it may overestimate noise exposure, while underestimating in other locations."

1.2. Moving Away from Default Values

The framework described by Directive 2015/996 means that any deviation from the default input data presented in Appendix I is acceptable providing that a methodology is sufficiently documented to demonstrate how a shift away from the default was justified. It also requires that the methodology is publicly available.

It is important to note that Directive 2015/996 does not describe any methodologies for these purposes. Indeed the guidance provided in Volume 3 of the ECAC document does not provide a specific process for how and what information should be documented for these purposes.

1.3. Background

This paper has been prepared during work which has been undertaken on behalf of Heathrow which has sought to identify how their in-house noise tools could potentially be made more representative of airport operations. These tools are based on AEDT and fully integrate radar data that allow actual track data to be used as the basis of the noise modelling, allowing investigation along with the testing of 'what-if' scenarios. These tools however rely upon default aircraft noise databases. The authors have therefore explored methodologies and processes for validating these models and improving Heathrow's tools in a transparent manner. This paper utilizes some of this work.

2. Interpreting Radar datasets to determining aircraft performance

Most major airports operate noise and track keeping (NTK) systems which provide information on both the horizonal and vertical position of aircraft by route, along with their type and speed. This information can be used to help identify trends in aircraft performance during arrivals and departures.

With use of Heathrow's ANOMS system and corresponding dataset, the authors developed bespoke analysis which processed this data into a format consistent with the data and descriptions required within a standard aircraft procedure profile as held within AEDT and as reported in Appendix I.

Figures 1, 2 and 3 present interpreted radar data for Boeing 747-400 movements on Heathrow's 09R DET route. These figures sequentially present aircraft performance with respect to altitude and speed, and time. When processing arrivals data, the illustrations can also highlight decent angles.

This information forms the basis of the preparation of procedure profiles. Using this data, the ECAC method enables flight profiles to be calculated resulting in the altitude, speed and angle of the aircraft along a ground track expressed in distance to or from the runway, as articulated in Figure 2.

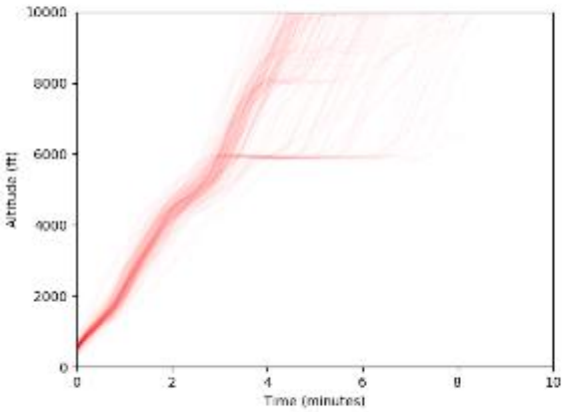

Figure 1. Aircraft altitude against time

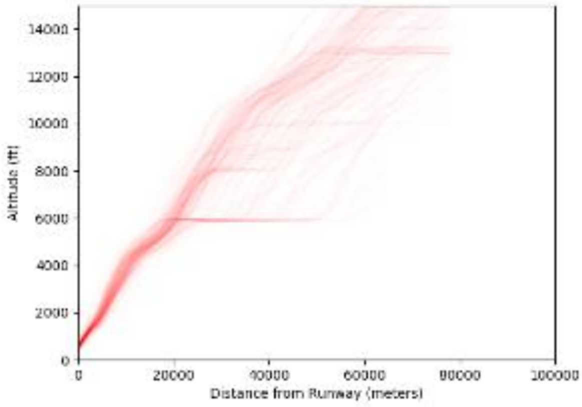

Figure 2. Aircraft altitude against track distance

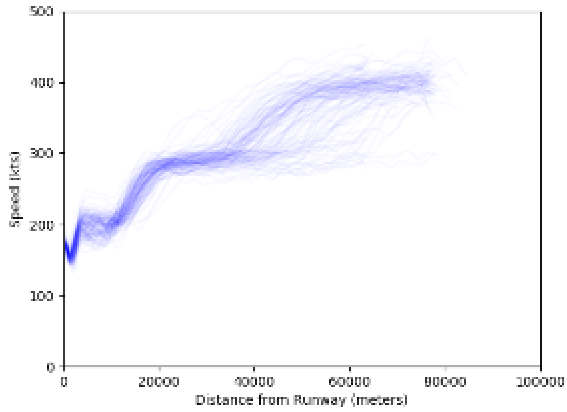

Figure 3. Aircraft speed against track distance

In undertaking this analysis, an outline process was developed and followed as shown in Figure 4. This process enables data relating to a certain route, aircraft and operation to be grouped. In the case of departures, the authors ensured that the concept of stage lengths were maintained so that take-off weight assumptions remain a variable. On this basis, departure analysis was broken down by stage length.

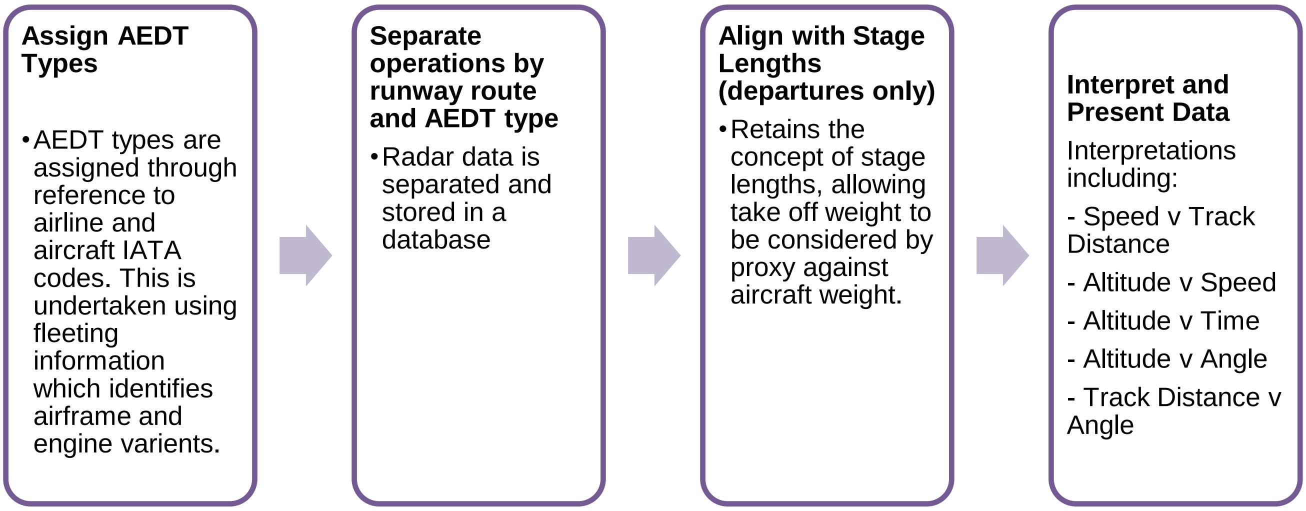

Figure 4. Process steps for describing aircraft performance

3. Developing Procedure Profiles using Radar Information

The development of procedure profiles using interpretted radar data was built around the requirements of the procedure profiles within AEDT, and as outlined in Appendix I. This relies on specifying a number of 'procedural steps' which enable the construction of flight profiles within the ECAC method.

Figure 5 illustrates how the data can be aligned to identify discrete steps, as highlighted by the dashed lines. The example provided in Figure 5 is for the Boeing 747-400 as presented in Figures 1 – 3 above. In this example, the profile in development is one which represents the aircraft being instructed to climb continusouly.

As shown by Figure 5, judgements are required with respect to determining at what point a new step is required. This is determined through a cross reference of the altitude and speed information as this can be used to highlight whether aircraft are climbing, leveling, accelating or a combination of these factors, which are all allowable combinations within the scope of the method.

The development of radar-derived profiles is time consuming as human judgement is a necessity. As part of this work, the authors have investigated options for developing parameters which may help automate. To assist the development, statistical parameters relating to the aircraft performance were reported such as average speeds and altitudes along with statistical variance and standard deviations around the average. These statistics were found to be helpful in determining transitions between profiles steps.

4. Comparison of Radar-Derived Profile Against Default

Using AEDT's detailed grid fucntion, the authors developed a prcoess for extracting, and comparing input prodceudres against the interpreted flight profiles within AEDT, and the original radar analysis. This process was developed as it became clear that the development of the procedure did not mean that the resultant flight profile, mainly for departures, would correspond to the radar analysis.

3.1. Effect of Rerated Departures

As part of modelling departure procedures from the radar data, it was found that climb rates within the profiles did not fit those observed unless amendments were made to modeled departure thrust settings. In most cases, in order to ensure a best fit without changing profiles parameters such as speeds and altitude attainments, departure thrust was set typically to around 80% of maximum take-off thrust. This finding aligned with technical information provided by the airlines and supported statements made within UK CAA guidance.

Figure 6 presents an example for the Boeing 747-400 where changing the departure thrust to a user-defined value less than the default assumption of maximum take-off thrust resulted in a much better

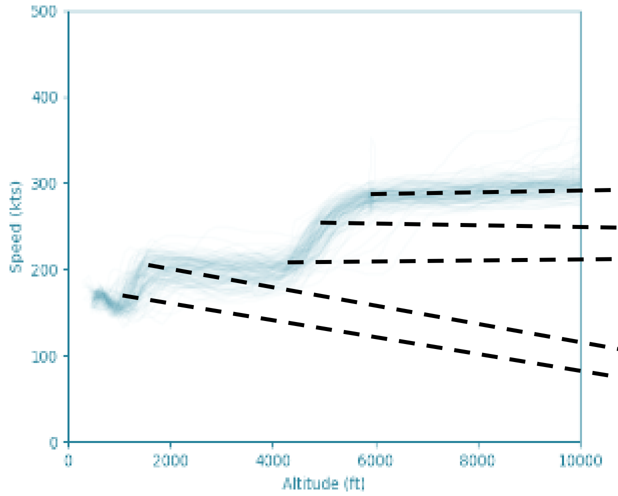

Figure 5. Example identifying procedure steps

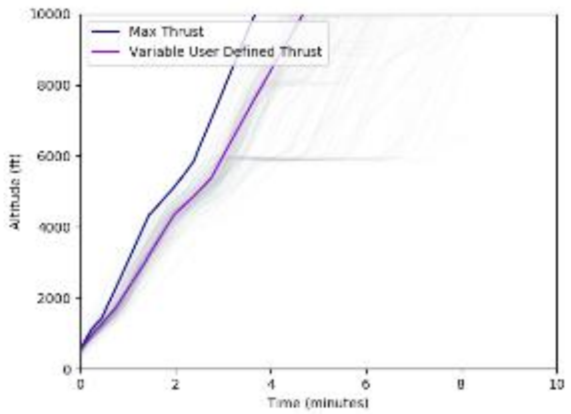

Figure 6. Effect of thrust on flight profiles

correlation of the resultant flight profile. In most instances de-rated departure thrust settings were necessary with the exception of any aircraft appraching their maximum take-off weights. This underlined the decision by the authors to retain the logic of maintaining the concept of stage lengths.

Other parameters such as flap settings were also found to affect the flight profile. The authors therefore researched and incorperated rules regarding flap use based on the flap schedule speeds reported for each aircraft type.

3.2. Graphical Comparison of Default and Radar-Derived Flight Profiles

Figure 7 presents a graphical comparison of the flight profiles developed using default procedures against the radar-derived profiles. A comparison of aircraft speed is also presented.

Figure 7 shows that the difference between altitude for the various profiles can be as much as 1,000ft under 4,000ft and within 10km of the start of roll point. The figure shows that in the example, the radar data shows some operations that level off at 6,000ft which is not accommodated within the default profiles but could be included as a further customization of the radar-derived procedure.

The speeds shown in Figure 7 highlight a broad difference between the various flight profiles in the range 1,000ft to 5,000ft. As part of other work being undertaken by the authors the sensitivity of the SEL metric to modelled aircraft speed was found to relatively high.

Figure 7 demonstrate that the procedure profile developed from the radar data overlays on the radar data demonstrating that the noise model is in principle based on actual operations data.

5. Adjusting Noise-Power-Distance Datasets

Developing procedure profiles that reflect recorded aircraft activity is one step in developing a robust and defensible noise model. However, this does not necessarily mean that noise levels from these procedures reflect what is measured on the ground.

Heathrow holds data for a significnat number of noise monitoring terminals. Using this data, the authors have reviewed measured and modelled data to identify whether adjustments to the underlying default NPD data is required in order to improve the accuracy of the nosie model. This process has relied upon the modelling comparison of actual flight

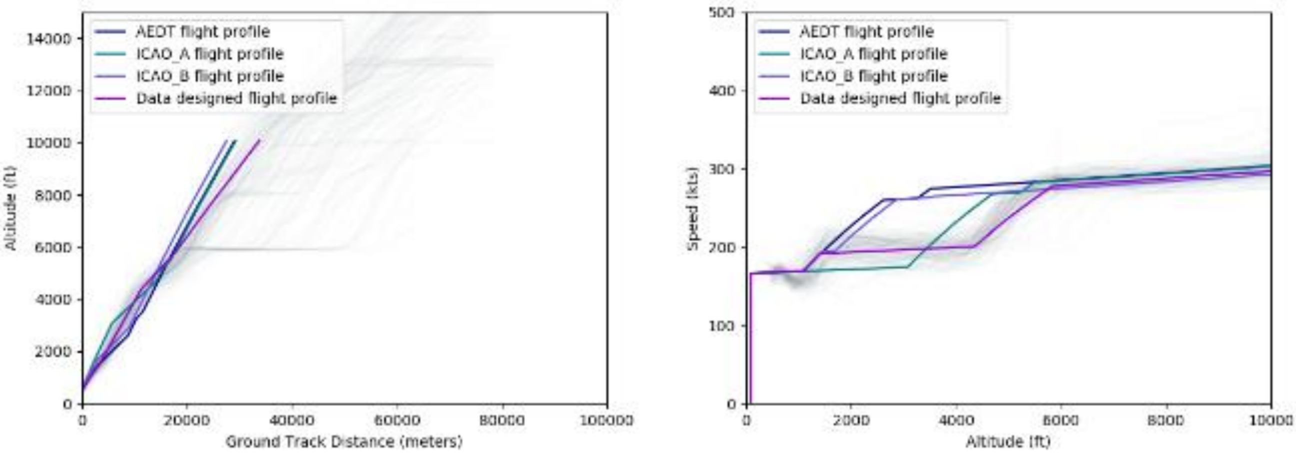

Figure 7. Example profiles for the 747400 stage 5 departure on 09R showing the profiles from the data in grey, the AEDT flight profile in navy and the profile designed from data in purple. The data designed profile has a much better fit

tracks and the corresponding noise level at relevent noise monitoring terminals (NMTs). This has yielded a comparison between the actual measured level and the modelled level from the corresponding aircraft track. The following process has been developed and adopted by the authors to allow for this comparison, as shown in Figure 8.

The process relies upon the use of AEDT's detailed grid outputs as these allow not just the modelled level at each noise monitoring terminal (NMT) but the interpreted thrust, altitude, elevation angles and speeds related to each modelled aircraft event. With the exception of thrust data and elevation angle, this information can be cross-referenced to the radar data.

The absense of recorded thrust data is a limitation and this cannot be overcome without access to the flight data recorder (FDR) information for each operation. However as outlined in Section 3.1 above, thrust can be reasonably estimated ~~assumed~~ based on the climb rates determined by the model and ensuring adherance to the average flight profile. On this basis it is considered that the thrusts adopted within the model where a procedure profile has been verified are informed estimates and the identification of that thrust value can be used to assist in any modficiations to the NPD curves.

The process yields a comparision between measured and modelled aircraft events of the same aircraft type and operation. The use of actual flight tracks within this process has the advantage of accounting for dispersion i.e. the fact that not all aircraft will directly overfly the NMTs.

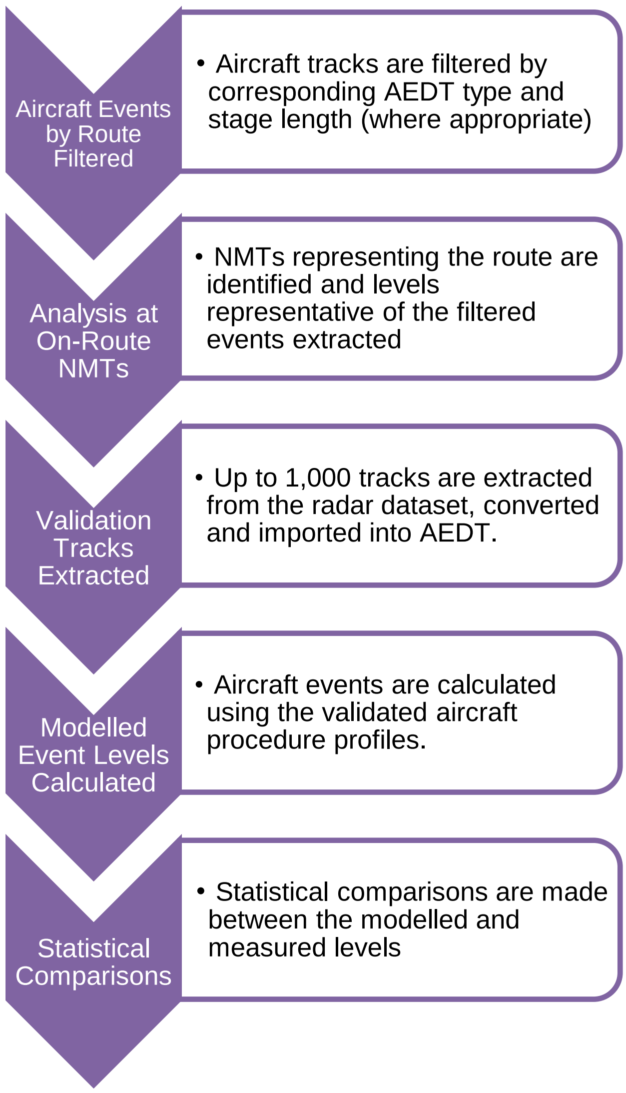

Figure 8. Staged process for obtaining noise event comparisons

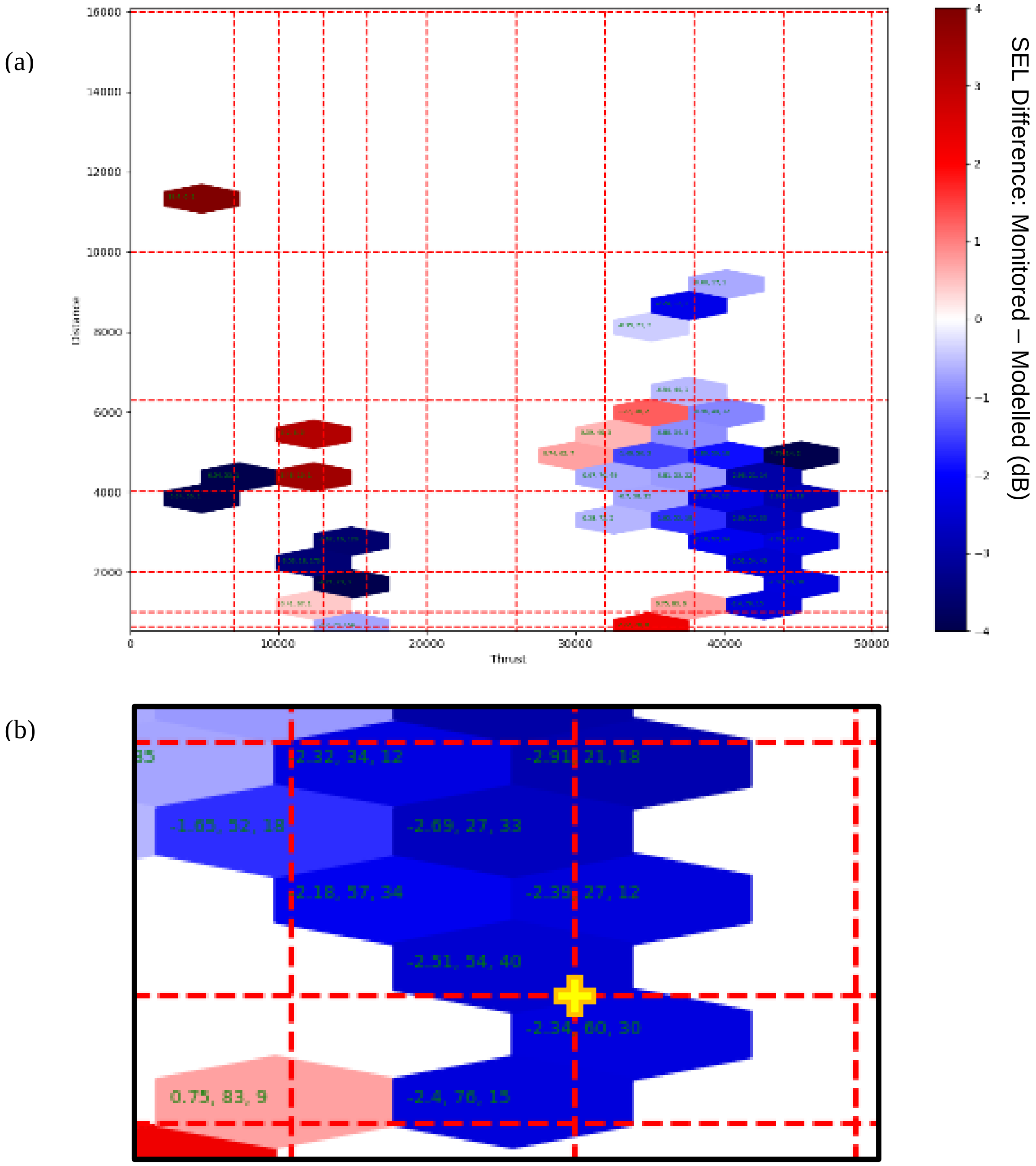

Figure 9 (a) Hexagon bin plot for the 747400 aircraft using the data designed profile and the original NPD curves. (b) Zoomed in section around the point (44000,2000).

The statistical comparisons for each NMT allow differences between measured and modelled values to be revealed with respect to altitude and thrust, the two key factors in the NPD data. To articualte these differences, the authors developed a matrix which presents comparisons against these factors as shown in Figure 9.

The matrix provides the basis for reducing the net average difference between the measured and modelled values by identifying average differences which can be used as a basis for adjusting the NPD data. This has been achieved by taking the average differences by thrust and distance between aircraft and monitor, as represented within the matrix by a hexagon and applying these back to the NPD data.

In the example shown in Figure 9 (a) the distances are defined at 200, 400, 630, 1000, 2000, 4000, 6300, 10000, 16000, 25000 ft and thrusts are defined at 7000, 10000, 13000, 16000, 20000,

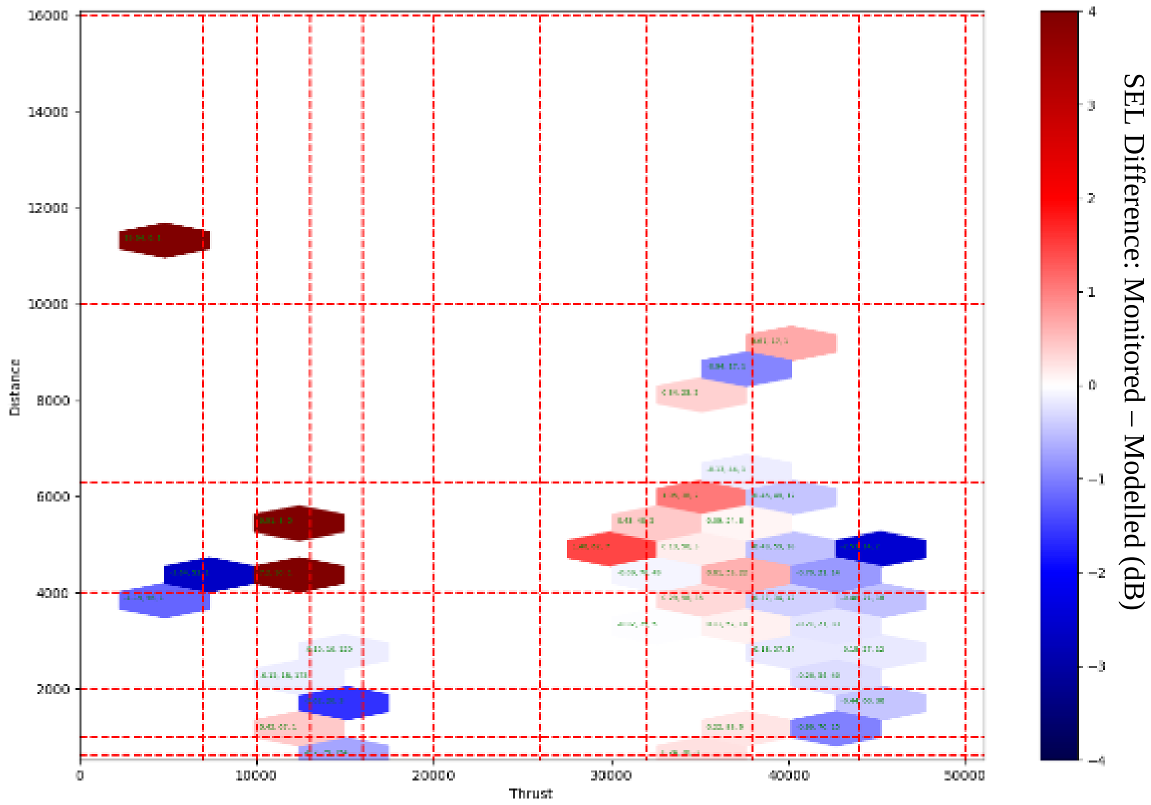

Figure 10 Hexagon bin plot for the 747400 aircraft using the data designed profile and the validated NPD curves. The differences in this plot are much smaller than those observed in Figure 9 (a).

26000, 32000, 38000, 44000, 50000 pounds, as indicated by the red lines. Note that only the distances for which events exist are shown.

The hexagons around the highlighted point in Figure 9 (b) all have differences of around -2.5 dB, hence at this point the differences can be reduced by subtracting 2.5 dB from the NPD curve. Similar adjustments are made for all other points on the plot, ensuring that the NPD curves for different thrusts and distances do not cross – i.e. a lower thrust does not produce a higher SEL than a higher thrust, or a shorter distance does not produce a lower SEL than a longer distance. This, along with situations where negative and positive cells lie adjacent to each other, means that in some cases the desired changes cannot always be applied and differences must remain large.

It is stressed that through this method, it is only possible to validate the parts of the NPD curves for which data allows. Distances are mostly restricted to less than 6300 ft due to the locations of the NMTs and the SEL which would be recorded at larger distances. Any adjustments which are made are extrapolated to be applied to the parts of the NPD curves for which data is not available to ensure that calculations produce logical and contiguous results.

When adjusting the NPD curves, priority was given to aircraft at elevation angles greater than 45°. In situations where alterations would improve the fit for some operations and deteriorate the fit for other operations, the operations with the largest angle were given priority i.e. where aircraft may be considered to be an overflight.

The updated NPD curves were input into AEDT for the same aircraft, flight profiles and tracks as initially used and the modelling is re-run to test the effect of the changes.

Figure 10 presents the matrix once the NPD adjustments have been made for the aircraft, this is the validated NPD curve version of Figure 9.

When comparing Figure 10 with Figure 9, this shows the improvement made to the average differences between the measured and modelled values. Differences are close to zero for most hexagons which contain more than one event and have an angle of over 45 degrees. There are some hexagons where the differences are still large, these are for events at very small angles or where there is only one event and so alteration of the NPD curve could not be undertaken reliably.

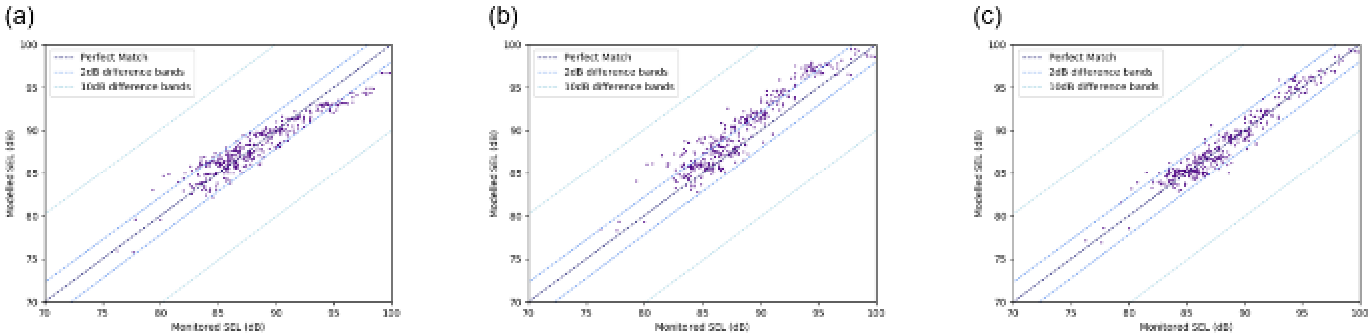

Figure 11 Comparison of measured and modelled levels for three modelled cases (a) default values (b) validated procedure and default NPD data (c) validated procedure and NPD data

3.3. Comparison of Validated and Default Event Levels

Figure 11 presents a comparison of default, procedure validated, and procedure and NPD validated modelled and measured comparisons. The example provided is for a Boeing 747-400.

Figure 11(a) shows that the use of default values leads to underprediction at noise event levels above 90 dB SEL. When validating the procedure and whilst using the default NPD data, Figure 11(b) shows that this leads to an over-prediction in event levels, i.e. 2 dB and above, for event levels above 85 dB SEL. Once the NPD data has been validated and applied to the valided procedure, Figure 11(c) shows that the majority of the modelled and measured values are within 2 dB of the measured SELs over the range 75 to 100 dB SEL.

Statistical analysis of the three modelled procedures and NPD data as presented in Table 1 shows that the mean difference between the measued and modelled SEL values can be reduced to nearly zero and that the statistical variation between the measured and modelled values are reduced to within 2 dB.

In this example, the statistics demonstrate that by simply amending the procedure does not guarentee that modelled event levels will be more accurate. This has not been the case for all aircraft validated by the authors.

Figure 12 presents a comparison of an SEL footprint for the Boeing 747-400 produced using three cases outlined in Figure 11(a) to (c). This shows that the impact of validating the model of the event is to enlongate and narrow the SEL footprint. Figure 13 which presents a noise diference map, shows that close into the airport, i.e. within the 95 dB SEL contour, the noise levels are higher from the validated procedure and NPD model than when using defaults.

Figure 13 highlights that beyond the 80 dB and the 75 dB SEL contours that the validated prodecued and NPD model result in levels around 3 dB higher than for the default model.

In the region of 80 to 95 dB SEL, Figure 13 shows differences generally within 2 dB, reflecting the statistical changes shown in Table 1.

Whilst this event analysis is not the same as a full noise exposure model, the differences presented in

Table 1. Statistical analysis and comparison of default and validated Boeing 747-400 event models

Aircraft	*Procedure Profile*	*NPD Curve*	*Mean Difference (dB)*	*RMS difference (dB)*	*St. Dev (dB)*
747400	Default	Default	-2.5	3.3	2.2
747400	Radar Derived	Default	-2.5	3.4	2.3
747400	Radar Derived	Modified	-0.1	1.7	1.7

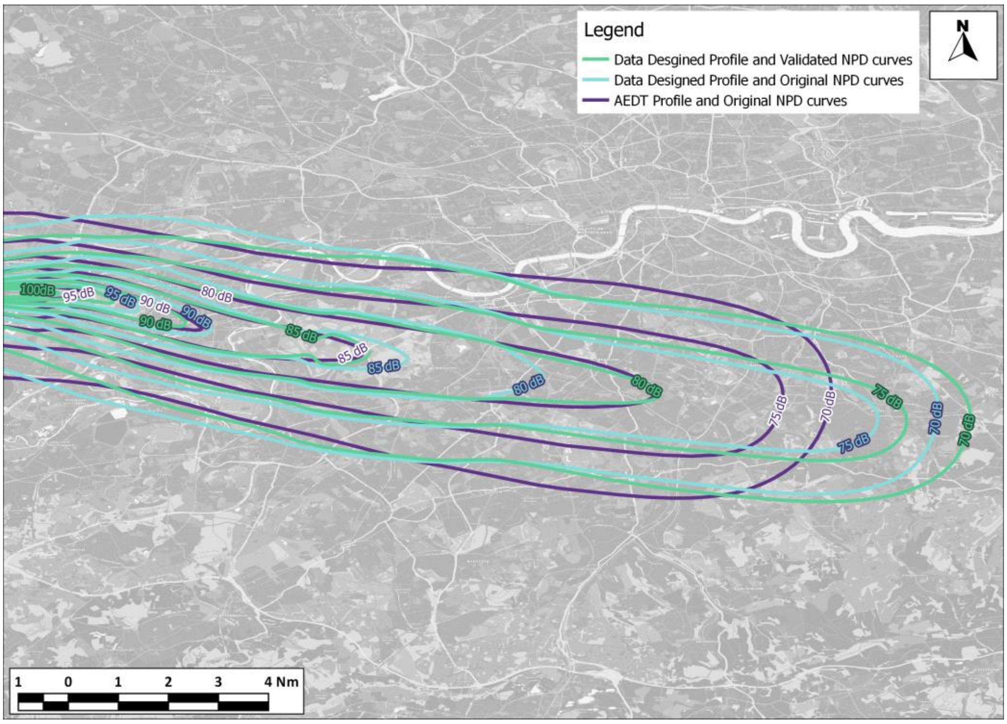

Figure 12 Noise contours for the 747400 stage 5 departure on the 09R DET route for a single flight. Contours are shown for the three scenarios which have been used in the examples above. All three scenarios use the same track, but the flight profile and NPD curve are altered as described in the figure legend.

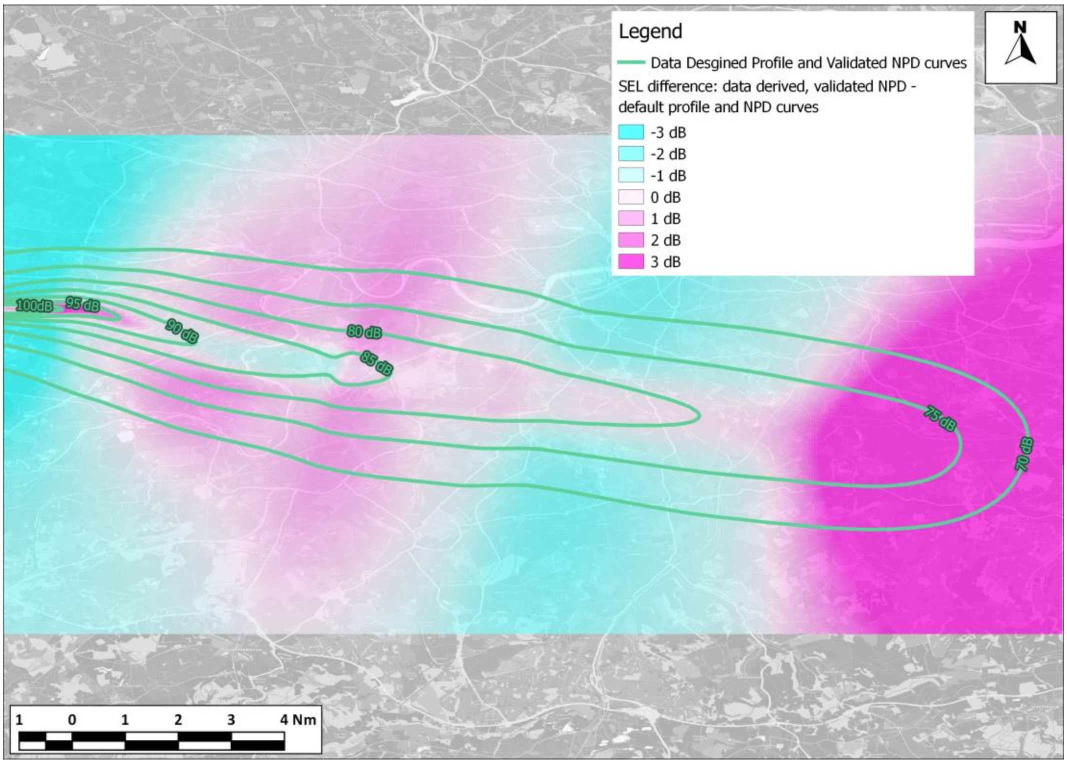

Figure 13 Differences between the modelled SEL using the ICAO_A stage 5 departure with the original NPD curves and the modelled SEL using the data designed profile and validated NPD curves. The data derived profile contours are shown on top.

terms of the SEL metric as highlighted in this section will propagate through to an Leq-based metric.

Should the differences presented in this example propagate through to overall noise exposure contours, this could result in a marked change in the level and location of noise exposure contours. This could potentially have knock-on effects in terms of decision-making, particularly where overall effects, namely total annoyance and monetized health are concerned.

6. Conclusions

This paper demonstrates the potential implications of relying upon default aircraft noise datasets as set out in Directive 2015/996. The authors show that when such data is reviewed, modified and verified against real-world data, this can have potentially significant effect upon the noise model outputs, and has the potential to change results beyond the ± 2 dB range described in the Directive's Quality Framework. In the example presented, the authors show that simply amending procedure data may not actually make the noise model more accurate but does allow the operations to be more representative.

The work highlights a potential difficulty in demonstrating that a noise model which relies on default values falls within the ± 2 dB range described in the Directive's Quality Framework and highlights a potential need for more work to be undertaken that relates to good practice in relation to aircraft noise model validation.

The work undertaken by the authors points to two key benefits for validating an airport noise model in this way and moving away from default datasets.

(1) Key stakeholders such as the community can draw more confidence that the noise model is representative of the aircraft operations and noise they experience. This is particularly true in an age where more people can obtain access to airport noise and track keeping information;

(2) Validation of operating procedures provides a baseline upon which other procedures can be tested. This feeds directly into exploring whether alternative or new procedures, including those designed for noise abatement, can result in improvements. If the noise model does not reflect current activities, it cannot be relied on to represent or make decisions with respect to proposed changes. This has potentially serious implications when reviewing noise abatement in the context of restrictions through the implementation of EU Regulation 598 [4].

Acknowledgement

The authors would like to thank Heathrow Airport for the use of their data in the preparation of this paper.

References

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[2] Commission Directive (EU) 2015/996 of 19 May 2015 establishing common noise assessment methods according to Directive 2002/49/EC of the European Parlaiment and the Council

[3] UK Civil Aviation Authority, CAP1616a Airspace Design: Environmental requirements technical annex, December 2017

[4] Regulation (EU) No 598/2014 of the European Parliament and of the Council of 16 April 2014 on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at Union airports within a Balanced Approach and repealing Directive 2002/30/ECP.