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Uncertainty in Aircraft Noise Modelling

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ABSTRACT

Nowadays highly sophisticated computer models are commonly used to assess the impact of aircraft and helicopter movements around airports [1, 8]. The computer model provides a cost effective method of assessing noise impacts around airports across large areas and also provides results in a format easily understood by the general public and specialists in the industry. It is therefore important to maintain the confidence of the people using the modelling results.

This paper presents the results of a study into the effect of uncertainty in various input variables on the accuracy of the calculated noise levels in aircraft noise modelling. Based on the results of the study, practical guidance on the effect of variations in the accuracy of input datasets used in aircraft noise modelling is provided.

This paper investigated the decibel error due to uncertainty in

- Aircraft flight track;
- Aircraft flight height; and
- Ground terrain profile.

The study has shown that considerable decibel errors can occur due to various assumptions made in the calculation. The stage length is an important parameter and an incorrect assumption could lead to a high uncertainty in noise modelling results. Terrain height and modulation have a small influence on the calculated noise levels. Employing dispersion in the modelling will widen but shorten the noise contours calculated. The effect is more pronounced at the lower noise levels. There are small differences in the calculated noise levels with increases in the number of sub-tracks from 2 up to 8 using the default percentage movement distribution provided by the software.

1. INTRODUCTION

Nowadays highly sophisticated computer models are commonly used to assess the impact of aircraft and helicopter movements around airports [1, 8]. The computer model provides a cost effective method of assessing noise impacts around airports across large areas and also provides results (noise contours) in a format easily understood by the general public and specialists in the industry. In order to maintain our confidence in the modelling results, it is important to be aware of the accuracy issues inherent in noise modelling and address them accordingly [2]. As precise as the computer models can be, the accuracy of the results is dependent on the inaccuracies implicit in the model as well as those caused by erroneous or

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imprecise input data entered into them [3, 4, 5, 7, 8, 9, 10, 11, 12, 13]. Among the potential sources of error in the modelling are; errors in calculation methodologies, error in computer implementations of methodologies, errors in input data, errors introduced in process data for noise modelling, errors introduced in the software calculation of noise levels result of efficiency techniques [4, 5]. This study will be focused on the effect of uncertainty in the input data on the modelling result. Uncertainty in the input data may be amplified in the output results, to a greater or lesser extent and in some cases offering unreliable predictions.

This paper presents the results of a study into the effect of uncertainty in various input variables on the accuracy of the calculated noise levels in aircraft noise modelling. The study aims to extend understanding in this area through a systematic investigation of the various input variables and to provide practical guidance on the effect of variations in the accuracy of input datasets used in aircraft noise modelling.

The study is similar to the Restrick [9] and Flindell and Humpheson [10] work which involved examining the uncertainty in aircraft noise modelling. In [9], the effect of errors in the inputs to each of the equations used in the US Federal aviation Authority's Integrated Noise Model (INM) was assessed using the linear small approximation theory. The study has made assumptions that the equations are linear and the errors in the input variables are small. A number of examples covering a range of aircraft types over various flight conditions were considered. The study concluded that the most influential variables are found to be aircraft weight, local pressure and a number of aircraft flap and engine coefficients.

In the Findley and Humpheson work [10], the effects on the results of making alternative input assumptions in an INM model about aircraft flight track dispersion, height profiles and aircraft operating conditions were investigated. A generic airport model with straight in and out approach and departure tracks was assumed in the study. The study concluded that flight track dispersion marginally decreases sound levels on the extended runway centreline and marginally increases sound levels off to either side of the runway. The study also found that changing the aircraft departing weight can have 4 to 8 dB difference in noise levels in particular for heavy and noisy aircrafts e.g. 747-400. This is because the departing weight affects both the sound power level at source and the rate of climb.

2. METHODOLOGY

A model-based approach similar to those used in the study by Shilton, Leeuwen and Nota [12] was employed to assess the accuracy impact of various input variables using a set of test scenarios.

A baseline model and a series of meta-models were constructed in order to quantify the decibel errors due to variation in:

- Aircraft flight track – flight dispersion;
- Aircraft flight height – flight load; and
- Topography – effect of variation of ground terrain profile.

The study was carried out using a common commercial aircraft noise modelling software package – US Federal Aviation Authority's Integrated Noise Model (INM) version 7.0a. A notional airport was modelled with a runway length of approximately 3 kilometres in an east west direction. Three westerly departure routes were modelled; one on a straight departure, one turning north and one turning south. A westerly arrival route was also modelled. Figure 1 presents the setup of the model. For simplicity and independency of time and number of aircraft, noise levels in terms of sound exposure level (SEL) were calculated. The model was run with a grid spacing of approximately 200 metres over the study area.

The baseline model was defined in order to quantify the potential errors due to the various input variables. The baseline model consisted of flying a single Boeing 747-400 aircraft on each of the three departure routes and one arrival route. The aircraft was assumed to be at maximum takeoff weight and minimum landing weight. Dispersion around each flight route was simulated by introducing 2 sub-tracks, one to each side of the route centre line and by spreading the noise source across those routes in the ratio of 68% on the centre and 16% on each of the dispersion routes (this is a default setting in INM which is widely used). A flat ground terrain was considered.

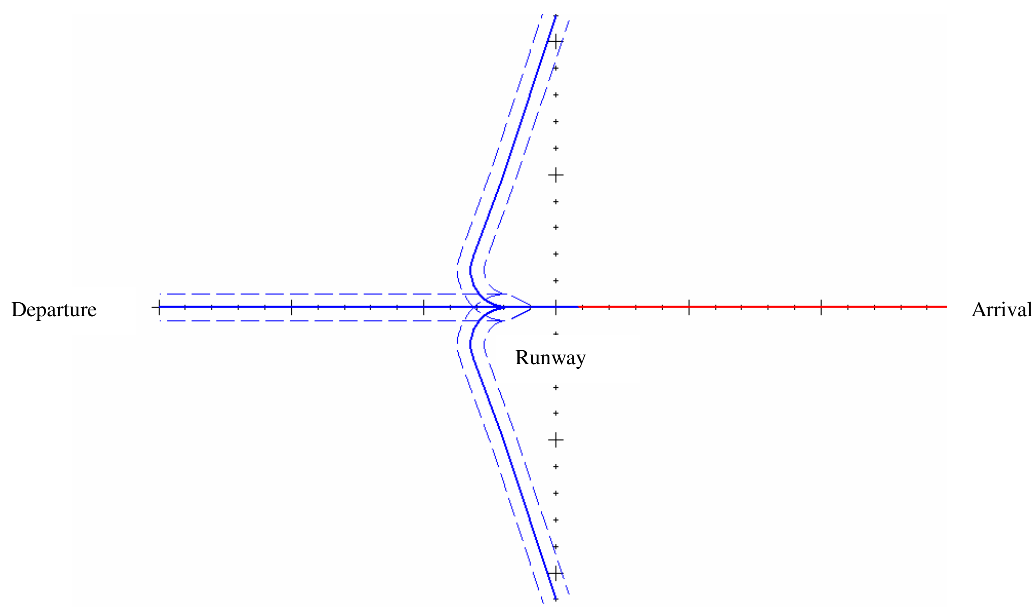

Figure 1: Model setup.

The noise model calculation runs produced a series of grid point result datasets which were then analysed statistically to provide information such as mean, range, maximum, minimum and 95% confidence interval due to uncertainty in the input. The result datasets were filtered to form the ‘acoustically relevant’ footprint, i.e. where the SEL noise levels are more than 70 dB(A) for all the scenarios considered. This filtering process ensured that the results of the statistical analysis were not contaminated by the potentially large number of grid points for which the noise levels are significantly below the 70dB(A).

Noise level difference maps were also calculated to illustrate the geographical location of errors and inaccuracies.

2. TOPOGRAPHY

In this part of the study, the effects of topography on the accuracy of the calculated noise levels were investigated. Meta-models with various terrain profiles as shown in Figures 2 and 3 were constructed. In Figure 2, all the terrains have the same peak height of 14 metres relative to the runway but with graduated differences in the peak to peak separation. The effect of gradually increasing the peak height was also assessed - see Figure 3, which shows the various peak heights considered from 6 metres to 22 metres in 4 metres steps. A buffer zone of flat ground of approximately 18 x 4.5 kilometres was assumed around the runway which is centred in the terrain plot. The study only considered geometrical corrections for source-receiver distances and elevation angles. Effects such as lateral attenuation from uneven ground surfaces and noise screening due to topographical features were not taken into consideration.

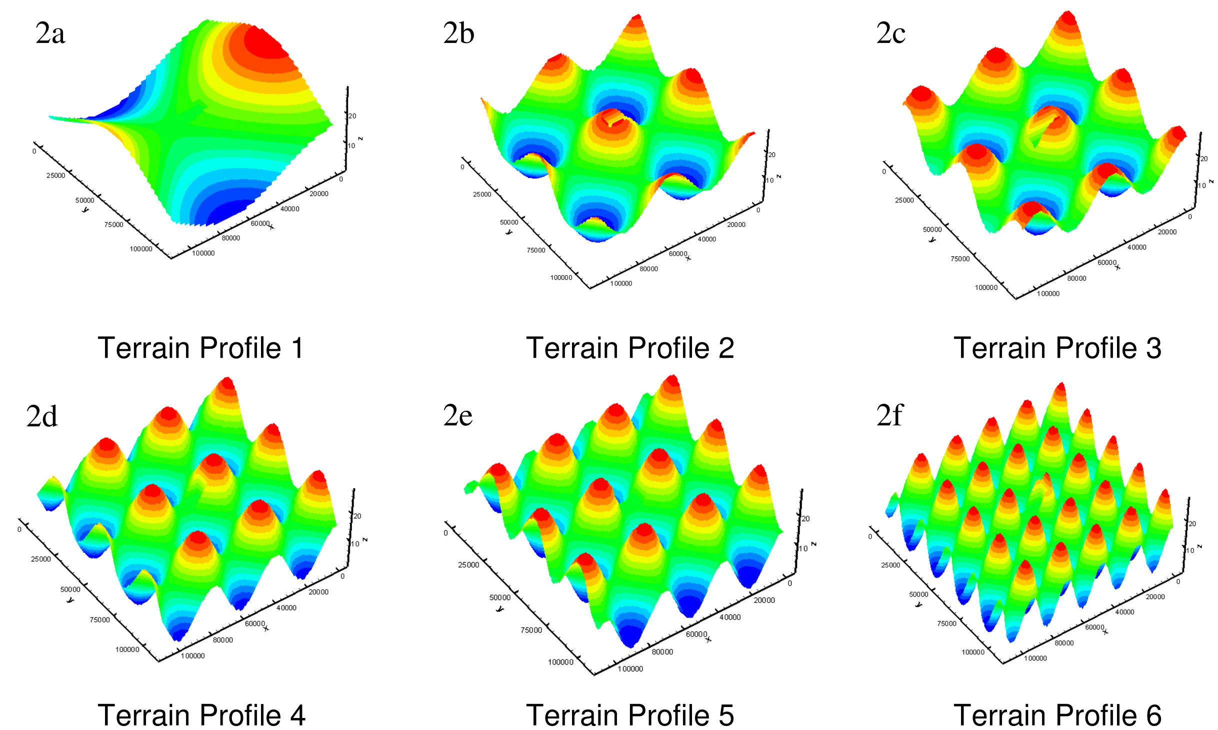

Figure 2: Terrain profiles.

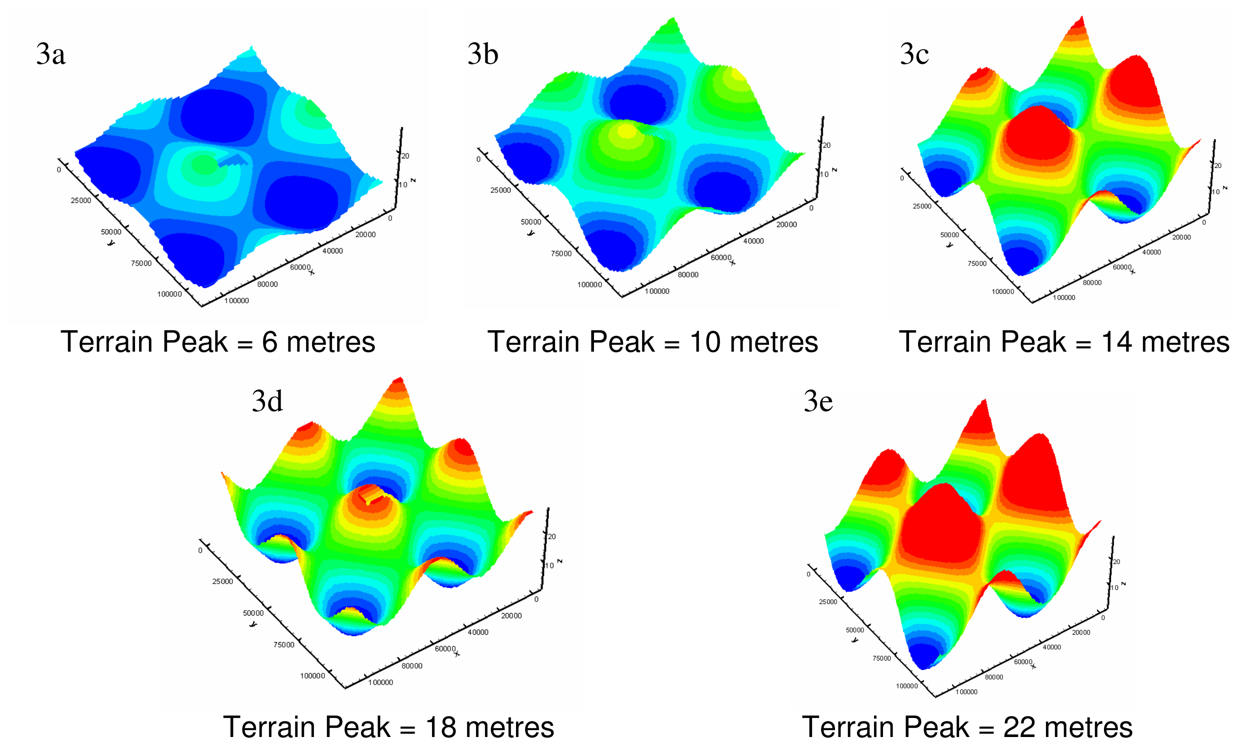

Figure 3: Topography with varying peak heights.

3. FLIGHT HEIGHT

Aircraft generally take off in a straight line from the runway to a safe height before reducing the engine power setting and/or turning onto a different heading. The rate of climb and the resulting height profile of an aircraft is related to its overall weight. Heavy aircrafts generally have higher sound power which may have a direct effect on sound level on the ground because of the decreased rate of climb during take-off.

The uncertainty associated with flight height profiles during take-off was investigated. In INM, the effect of flight height is considered by the stage length number. The stage length number is defined based on the distance to destination. This means that the longer the trip, the heavier the average takeoff weight due to increased fuel requirement hence reduced climb rate. The study quantifies the decibel errors due to the various stage length defined in the software using a Boeing 747-400 by gradually decreasing the aircraft stage length from 9 to 1 where 9 being the heaviest setting available within the software.

4. FLIGHT TRACK

This part of the study quantified the decibel error due to various track dispersion configurations. The spread of the sub-tracks, the number of sub-tracks and the distribution of the noise source amongst these sub-tracks as shown in Figure 4 were investigated and Table 1 details the default percentages that INM assigns to the sub-tracks. The centre track is assigned as sub-track identifier of “0”.

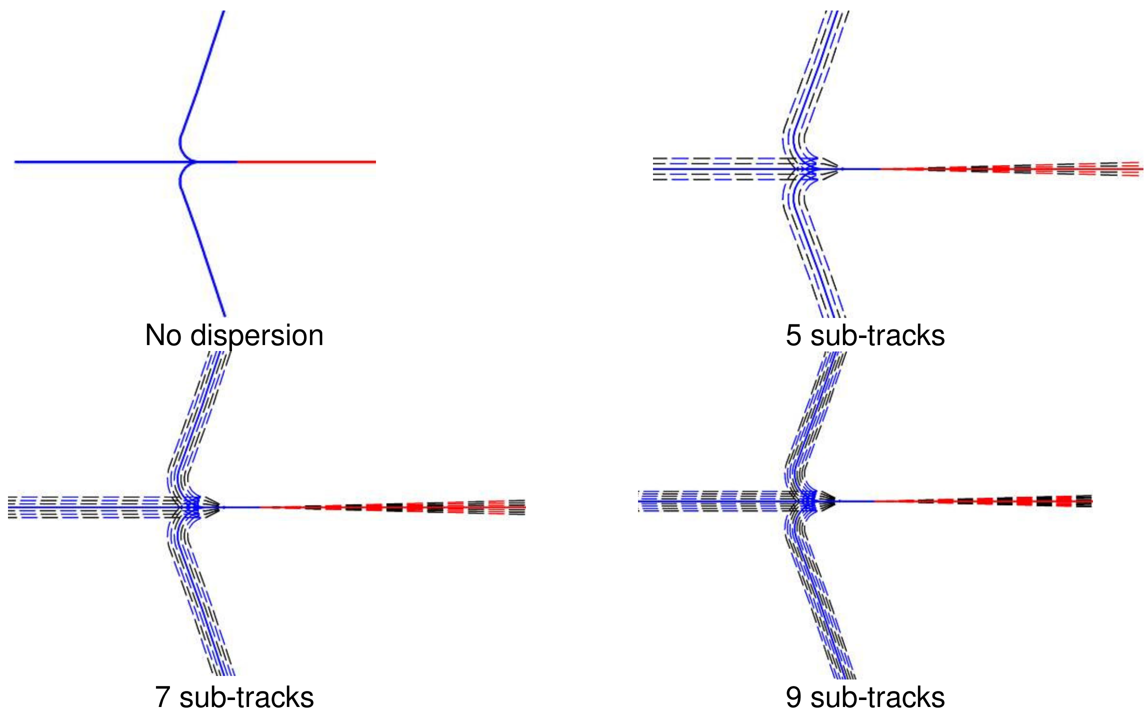

Figure 4: Dispersion with varying sub-tracks.

Table 1: Default percentages that INM assigns to the sub-tracks.

Number of tracks	Sub-track identifier	Percent on sub-track
1	0	100%
3	0 1 & 2	68.26% 15.87%
5	0 1 & 2 3 & 4	38.6% 24.4% 6.3%

7	0 1 & 2 3 & 4 5 & 6	28.2% 22.2% 10.6% 3.1%
9	0 1 & 2 3 & 4 5 & 6 7 & 8	22.2% 19.1% 12.1% 5.7% 2.0%

5. RESULTS

Topography

Figure 5 presents the difference maps for each meta-model with varying ground topography when compared to the baseline model which has flat ground. In Figure 6, difference maps showing the effect of increasing the terrain height compared to flat ground are presented. Tables 2 and 3 present the statistical analysis results of the noise level differences between the various meta-models compared to the baseline model.

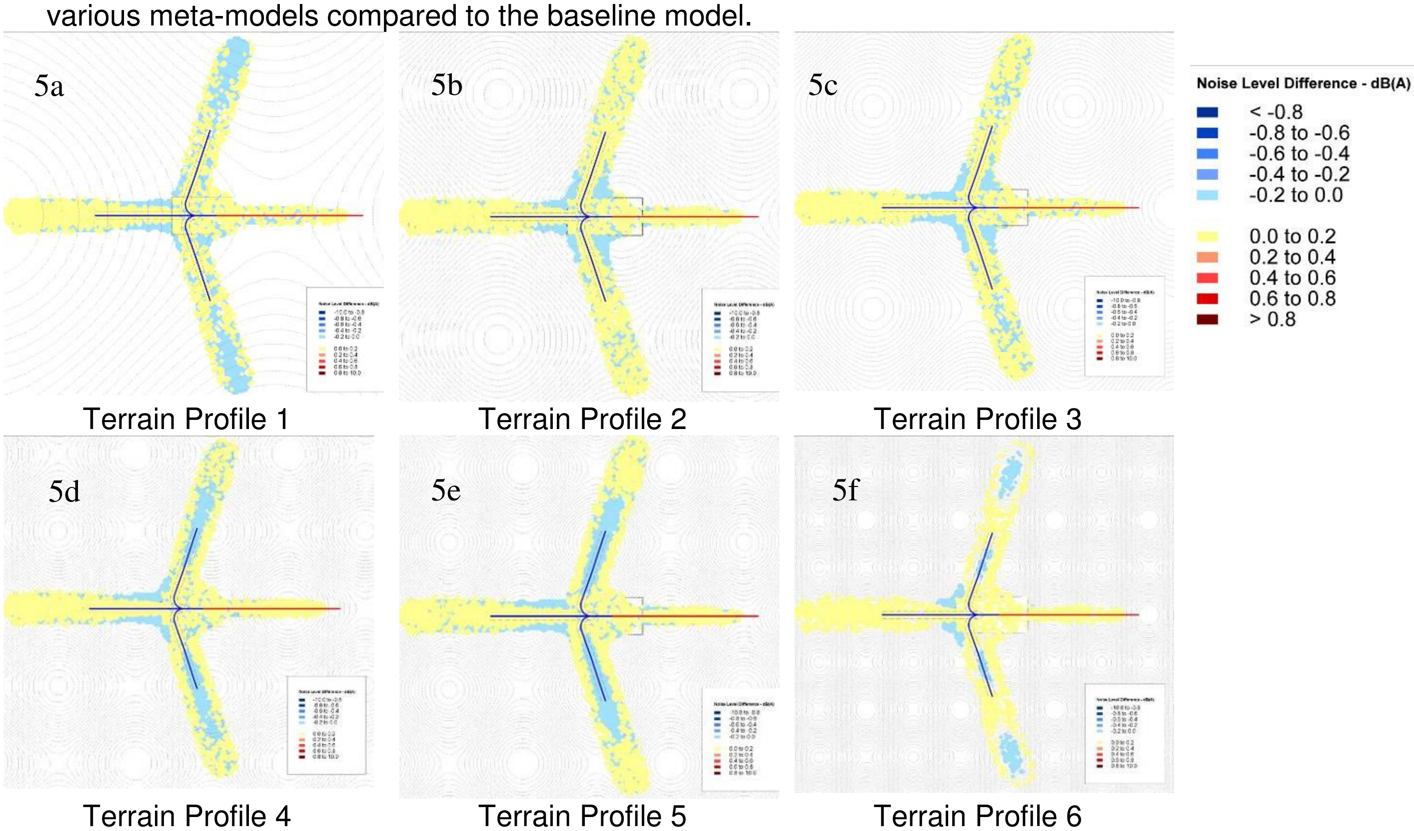

Figure 5: Noise level difference maps of meta-models with varying topography compared to the baseline model which has a flat ground.

Table 2: Statistical analysis results of noise level differences due to varying topography.

	Terrain Profile 1	Terrain Profile 2	Terrain Profile 3	Terrain Profile 4	Terrain Profile 5	Terrain Profile 6
Mean	0.02	0.02	0.02	0.02	0.02	0.02
Min	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
Max	0.10	0.20	0.20	0.20	0.20	0.20
Range	0.20	0.30	0.30	0.30	0.30	0.30
95CI	0.16	0.18	0.18	0.19	0.19	0.17

The results presented in Figure 5 and Table 2 show that there is little difference in calculated noise levels due to the variation in the ground topography. The difference maps presented in Figure 5 show that maximum noise level differences of 0.3 dB are observed in areas of varying elevations relative to the runway. The mean noise level differences due to variation in topography when compared to flat ground is less than 0.1 dB with a 95% confidence interval of less than 0.2 dB. The difference in noise levels is more pronounced for noise due to take-off than arrival.

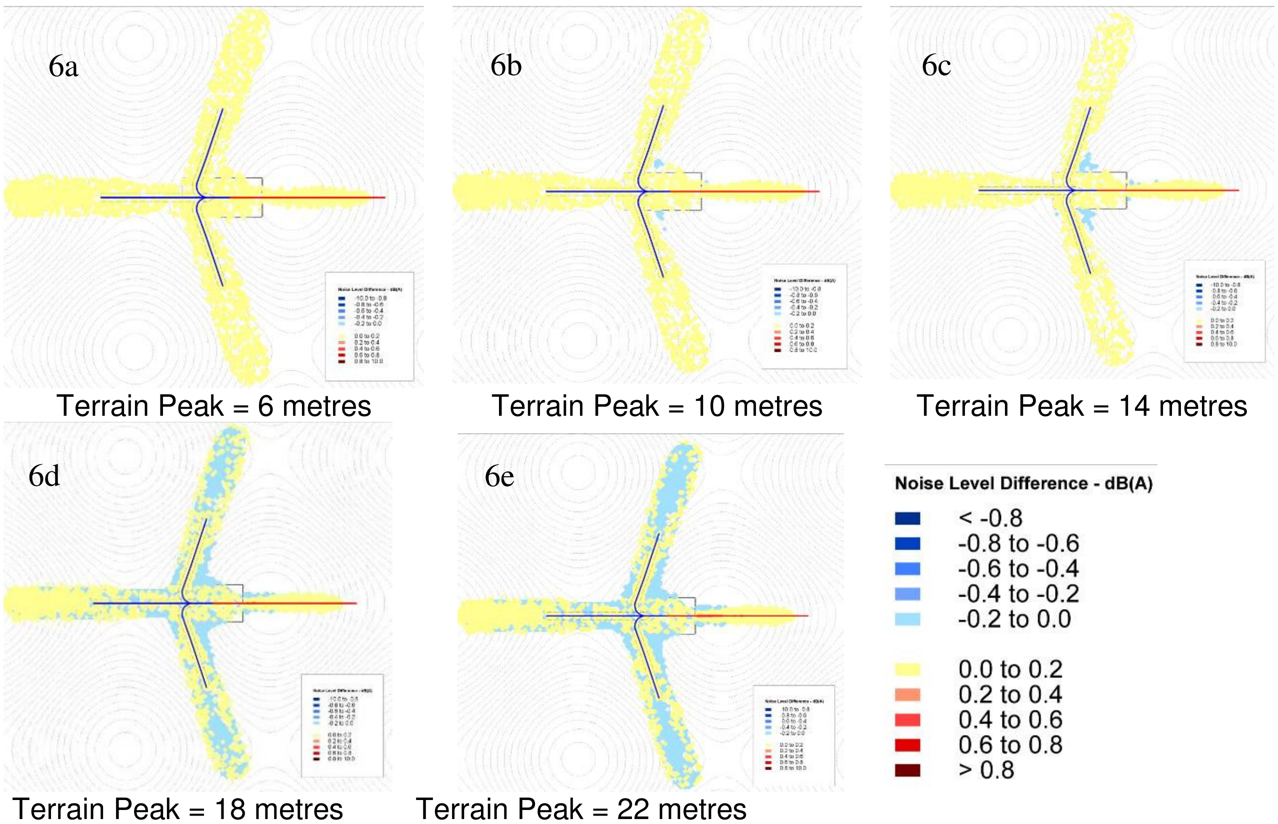

Figure 6: Noise level difference maps of meta-models with increasing terrain height.

Table 3: Statistical analysis results of noise level differences due to varying terrain height.

	Peak height 6m	Peak height 10m	Peak height 14m	Peak height 18m	Peak height 22m
Mean	0.02	0.02	0.02	0.02	0.02
Min	0.00	-0.10	-0.10	-0.10	-0.10
Max	0.10	0.20	0.20	0.30	0.30
Range	0.10	0.30	0.30	0.40	0.40
95CI	0.16	0.16	0.17	0.17	0.18

The results presented in Figure 6 and Table 3 show that there is little difference in calculated noise levels due to the variation in the ground height from 6 metres to 22 metres when compared to the baseline case of 14 metres. The difference maps show maximum noise level differences of 0.4 dB in areas of varying elevations relative to the runway. The difference in noise level is more pronounced for noise due to take-off than arrival. The statistical analysis shows mean noise level differences of less than 0.1 dB with a 95% confidence interval of less than 0.2 dB.

Aircraft Flight Height

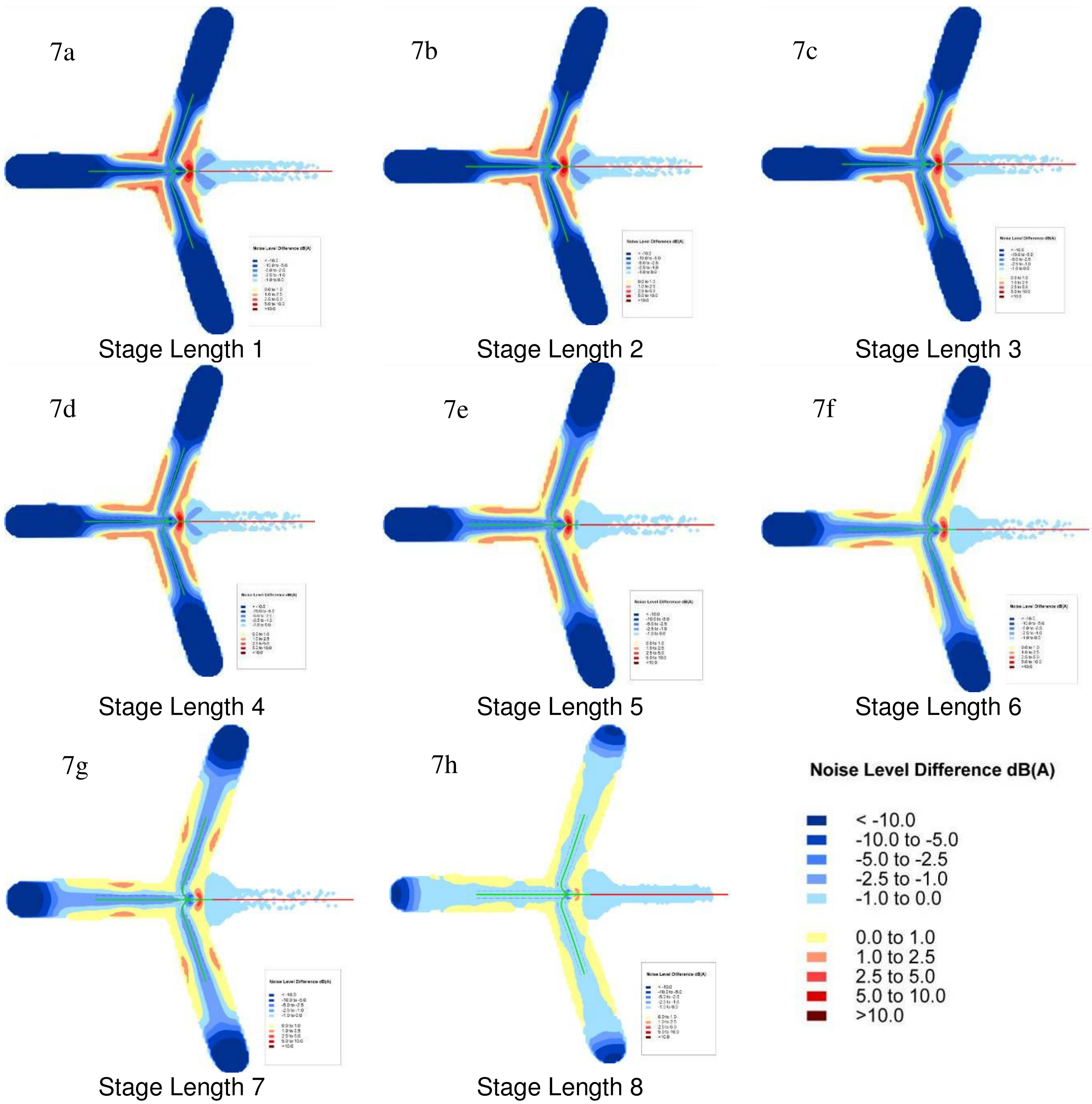

Figure 7: Noise level difference maps of meta-models with different flight height profiles.

Table 4: Statistical analysis results of noise level differences due to varying flight height (stage length).

	Stage Length 1	Stage Length 2	Stage Length 3	Stage Length 4	Stage Length 5	Stage Length 6	Stage Length 7	Stage Length 8
Mean	-12.99	-12.37	-11.62	-10.10	-8.16	-5.94	-3.24	-0.92
Min	-36.70	-36.30	-35.90	-34.70	-33.00	-29.70	-23.40	-12.20
Max	9.50	9.80	9.60	9.50	8.60	7.20	5.50	2.70
Range	46.20	46.10	45.50	44.20	41.60	36.90	28.90	14.90
95CI	50.21	49.54	48.62	46.25	42.15	35.45	24.39	9.04

Figure 7 presents difference maps for each scenario when compared to the baseline scenario, which was set at stage length 9 for departures. Table 4 presents the statistical analysis of the noise level differences between the different scenarios when compared to the baseline scenario. The general result is that a substantial difference is observed in altering the stage length, with a mean difference of 13 dB between stage length 9 to 1. It can be clearly seen that as the stage length reduces, the difference map highlights a significant reduction in noise level further out along each departure track. However, there is an additional phenomenon occurring close to the runway, where the noise at the edges of each footprint increases with decreasing stage length. It is considered that such an effect may be the product of the reduced take-off weight of the aircraft. The lighter load enables the aircraft to climb at a slightly steeper angle, and therefore engine noise is directed slightly more towards the ground. This is observed as a 9 dB increase in some areas from stage length 9 to stage length 1-4. At stage length 8 there is a negligible effect and it is likely that a selection of either stage length 8 or 9 would yield insignificantly different results. The stage length is nevertheless a very important parameter and an incorrect assumption could lead to a high error in noise modelling results.

Aircraft Flight Track Dispersion

The results and difference maps presented in Figure 8 and Table 5 are comparisons of scenarios with different flight track configurations compared to the baseline scenario which includes 2 sub-tracks. On inspection of the difference map with no dispersion, there is a definite effect. Close to the runway, there is a reduction in noise on either side of the centre track of up to 7 dB, and an increase of up to 2 dB very close to the centre track. As an aircraft continues to depart, it is noted that this effect is less marked, and the blocks of increased noise far away from the runway show that the dispersion of the noise about sub-tracks leads to a shorter departure contour. Of particular interest is the limited effect of increasing the number of sub-tracks from 2 up to 8 – a mean difference of less than 0.1 dB has been observed except near the runway. It can be concluded from this that, although it is possible to select many sub-tracks, using the default percentage distribution which is based on normal distribution provided by the software only has a very small effect on the results.

Table 5: Statistical analysis results of noise level differences due to varying flight track dispersion.

	No Dispersion	4 sub-tracks	6 sub-tracks	8 sub-tracks
Mean	-0.25	-0.05	-0.08	-0.09
Min	-7.30	-2.00	-3.00	-3.40
Max	1.60	3.30	3.00	2.90
Range	8.90	5.30	6.00	6.30
95CI	2.53	0.79	1.02	1.13

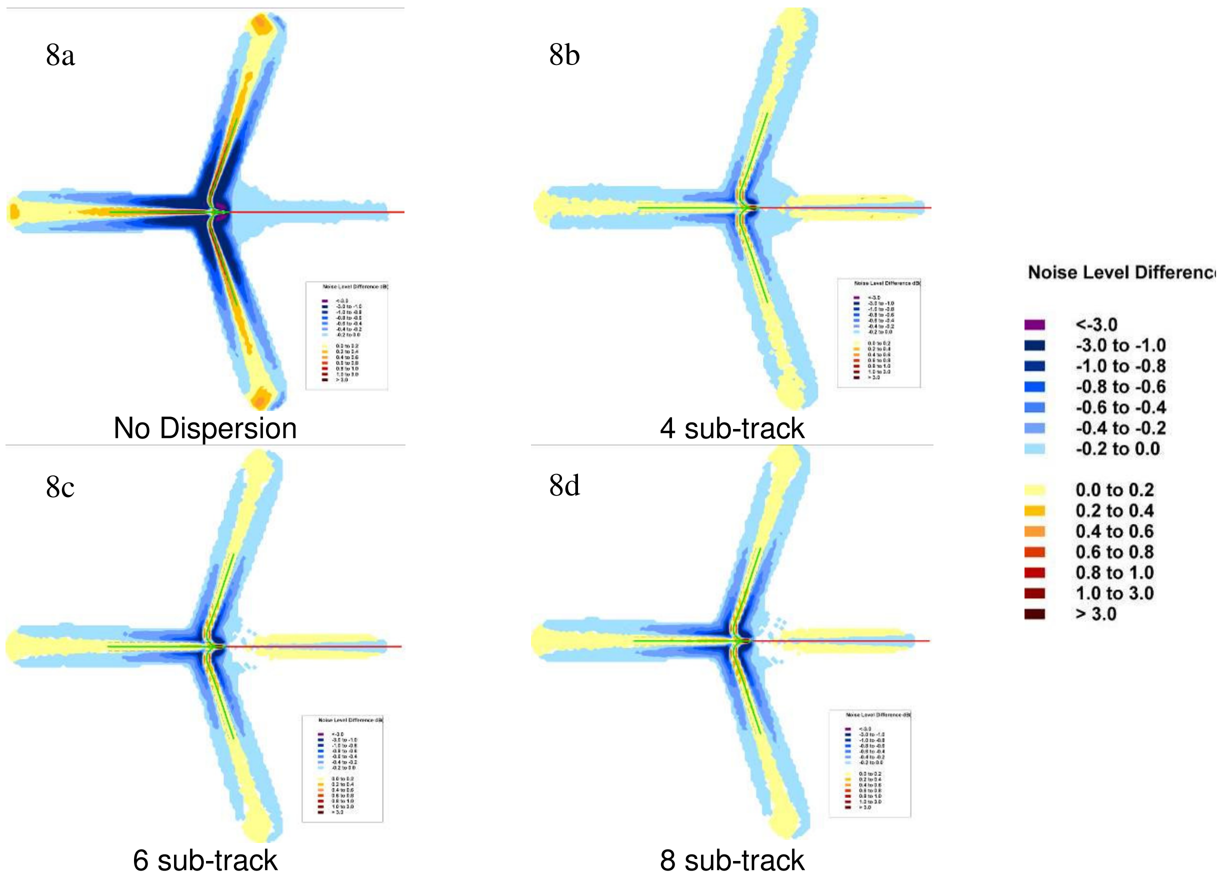

Figure 8: Noise level difference maps of meta-models with different track dispersion configurations.

6. DISCUSSION

Terrain height and modulation have been found to have little influence on the calculated noise levels. The difference in the calculated noise levels when compared to flat ground is less than 0.5 dB. It can be concluded from the results of this part of the study that the air noise contours are not sensitive to the ground topography. This finding is consistent with the results of a research study on aircraft noise mapping at Heathrow Airport conducted on behalf of Defra [11].

The investigation of variations in stage length has shown that significant impacts can result due to uncertainty in the flight stage length which is consistent with the finding of Restrick [9] and Flinder and Humpheson [10]. It is general practice to assume that the longer the trip, the heavier the average take-off weight due to increased fuel requirements. However, some short-haul flights could carry a full load of passengers and ferry with extra fuel. In these cases, setting the stage length based on flight distance will under predict the noise impacts. It is therefore important in the modelling that the aircraft take-off weight is obtained or estimated as accurately as possible.

Employing dispersion in the modelling will widen but shorten the noise contours calculated as shown in Figure 9. The effect is more pronounced at the lower noise levels especially at the end of the contour loop at the centre of the flight track. This finding implies that new aircraft navigation systems such as the P-RNAV system can result in better control of noise impacts on the ground as there will be less flight dispersion and noise impact will be localised beneath the nominated flight tracks.

In the study, the default distribution of source power based on the number of sub-tracks around the flight track in the software has been assumed. However in reality, the spread of flights might not approximate a normal distribution in which the study has shown might have a significant impact on the calculated air noise contours i.e. widening of the contour areas. This finding is consistent with the finding of Flindell and Humpheson [10].

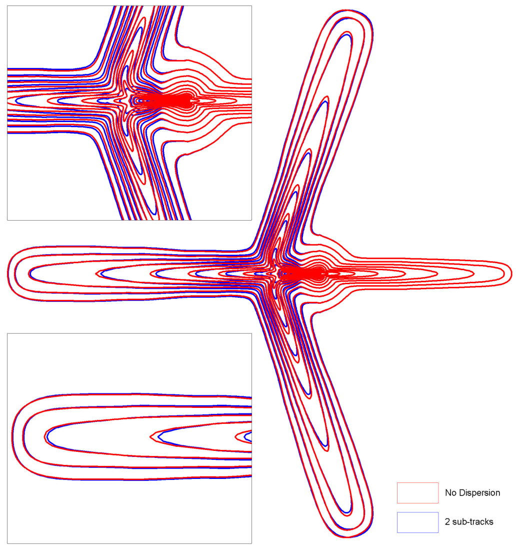

Figure 9: Noise contour comparison with and without dispersion.

7. CONCLUSION

A study has been carried out to quantify the uncertainty in model outputs resulting from the variations in model inputs for aircraft noise modelling. A model-based approach, through the construction of a series of meta-models, has been used to quantify the potential decibel errors due to uncertainty in the aircraft flight track dispersion, aircraft flight height and topography. The impacts of varying accuracy of various input variables have been assessed by comparing the results of the meta-models with a baseline model result.

The results of the study have shown that considerable decibel errors can occur due to various assumptions made in the calculation. The stage length is an important parameter and an incorrect assumption could lead to a high uncertainty in noise modelling results. Terrain height and modulation have only a small influence on the calculated noise levels. Employing dispersion in the modelling will widen but shorten the noise contours calculated. The effect is more pronounced at the lower noise levels. There are small differences in the calculated noise levels with increases in the number of sub-tracks from 3 up to 9 using the default percentage of distribution provided by the software.

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REFERENCES

1. P. Bouter, F. D. van der Ploeg, Aircraft noise management in The Netherlands vs. limited prediction capabilities of causal aircraft noise calculation models, *The 2001 International Congress and Exhibition on Noise Control Engineering, The Hague, The Netherlands, August 27th-30th 2001.*

2. P. Hepworth, Accuracy implications of computerized noise predictions for environmental noise mapping, *Inter-Noise 2006 Honolulu, Hawaii USA, 3-6th December 2006*.

3. P Hepworth, J Trow and V Hii, Reference settings in noise mapping software – a comparison of the speed of calculation for different software, *Proceedings of EuroNoise 2006, Tampere, Finland (2006).*

4. P Hepworth, J Trow and V Hii, User controlled settings in noise mapping software – the effects on calculation speed and accuracy, *Proceedings of EuroNoise 2006, Tampere, Finland (2006).*

5. Simon Shilton and Hardy Stapelfeldt, Noise Mapping with GIS – Managing uncertainty helps promote quality, *Proceedings of 13th International Congress on Sound and Vibration, Vienna, (2006).*

6. European Commission Working Group on the Assessment of Exposure to Noise "Good practice guide for strategic noise mapping and the production of associated data on noise exposure (2003).

7. G. Thomann, Uncertainties of Measured and Calculated Aircraft Noise and Consequences in Relation to Noise Limits, *Acoustics 08 Paris*

8. Hisashi Yoshioka, Evaluation and prediction of airport noise in Japan, *J. Acoustic Society of Japan* (E) 21, 6 (2000)

9. Error Sensitivity Analysis of the Integrated Noise Model, EUROCONTROL Experimental Central, EEC/ENV/2002/006 – Year 2002.

10. Flindell, I.H and Humpheson, D, Aircraft Sound Level Modelling Assumptions, *Proceedings of the Institute of Acoustics 2006.*

11. A research study on aircraft noise mapping at Heathrow Airport conducted on behalf of Defra. ERCD Report 0306, 2004 – CAA.

12. S Shilton, H. van Leeuwen and R. Nota, Error Propagation Analysis of XPS 31-133 and CRTN to Help develop A Noise Mapping Data Standard, *Ince Symposium on Uncertainties in Noise, Le Mans, June 2005.*