AIRCRAFT SOUND LEVEL MODELLING ASSUMPTIONS

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1 INTRODUCTION

This paper reports an investigation of the effects of making alternative input assumptions in an INM model about aircraft flight track dispersion, height profiles, and aircraft operating conditions in terms of the resulting differences in calculated sound levels on the ground. Providing that aircraft sound level contours are produced by a method which is fully compliant with the recommendations set out in ECAC Document 29 [1], and which are in turn based on the procedures outlined in the Society of Automotive Engineer's specifications SAE-AIR-1751 [2] and SAE-AIR-1845 [3], then by definition the results will also meet the requirements imposed under the 2002 European Directive on the Assessment and Management of Environmental Noise (EC, 2002) [4]. The calculation procedures adopted within the US Federal Aviation Authority's Integrated Noise Model (INM) are widely accepted as being fully compliant with EC Requirements and as such, the results of any calculations carried out by using the INM are often assumed to be equally compliant. However, as with any calculation model, the accuracy of the results depends not only on the calculation methods used but also on the input data used to inform the model.

Aircraft flight track and height data can be obtained from the air traffic control radar systems at most large airports, but the data is usually restricted and is not usually in any format which can be directly incorporated into INM or any other aircraft sound level calculation model. Aircraft operating condition data is not generally available except by interrogating the aircraft flight data recorder after landing and this is not a preferred option. Aircraft operating conditions can be inferred from flight track and height profile data but not to the same degree of precision as from direct measurement. Even if the precise flight track, height profile and aircraft operating conditions for every single flight over a long term LAeq contour averaging period could be determined by some technical means, it would not generally be feasible to model every single one of these flights separately.

To avoid these difficulties, it has become standard practice to adopt a limited number of standardised flight track, height profile and aircraft operating conditions assumptions which are generally considered as being representative of average or typical operating conditions. Variability to either side of the standardised flight track, above and below the standardised height profile, and above and below the standardised engine power setting and other operating conditions assumptions can be dealt with by modelling additional flight track, height profile and operating conditions assumptions and making further assumptions about the relative proportions of the overall traffic following each track/profile/operating condition combination. All calculations carried out for this paper used a simplified 'generic' airport model with straight in and out approach and departure tracks to avoid any further complications arising from the additional problem of modelling aircraft sound level characteristics during turns which cannot be dealt with on a generic basis as the precise effects would be specific to actual airports considered separately.

The work reported in this paper was carried out to illustrate the range of uncertainties associated with the aircraft sound level modelling component of the recent Attitudes to Noise from Aviation Sources in England (ANASE) study carried out for the Department of Transport (MVA Consultancy, publication expected late 2006).

2 AIRCRAFT SOUND LEVEL MODELLING UNCERTAINTIES

The INM and other aircraft sound level models calculate a range of sound level metrics at specific points or across an entire grid of point locations distributed across the area surrounding the airport runways. Aircraft sound level iso-contours are then interpolated from the grid point locations data.

The computation process requires knowledge of:

- the aircraft's position in 3 dimensions (i.e. flight track and height profile);
- the aircraft's speed along the defined flight track; and
- thrust or power setting of the aircraft's engines.

The software calculates the slant distances from each flight track and height profile to each point location on the ground and then determines the SEL for each assumed flyover event at each point location on the ground by using pre-defined Noise Power Distance (NPD) curves. In INM, the equivalent LAmax sound levels for each flyover event are calculated from the SELs using the formula *LAmax=SEL-7.19.log(D/1000)*, where *D* is the slant distance to the aircraft. Cumulative metrics such as the various forms of long term average A-weighted sound levels (LAeq, LDN, Lden, etc) are then calculated by summing and averaging SELs, or can be calculated separately outside of the INM software using standard spreadsheets.

Theoretical analysis reveals that the relative importance of the different potential sources of uncertainty is likely to vary depending on the situation being modelled. The first major source of uncertainty is the aircraft position relative to each point location on the ground. For arrivals, the range of variation to either side of or above and below the standard 3 degree glide slope is usually negligible close to the airport, although the range of variation increases at greater distances and there may be some uncertainty about the precise points at which arrivals join the glide slope. There may be considerable uncertainty associated with actual flight tracks and height profiles during the earlier part of the descent before aircraft actually join the glide slope, because while the general approach routes are usually very clearly defined, there is often considerable flexibility allowed to air traffic controllers to sequence different aircraft onto the final approach. For example 'tromboning' is a common method of providing additional flexibility whereby arrivals may be directed away from the airport for a short period while waiting their turn to be slotted into a continuous arrivals sequence. Air traffic controllers normally require arrivals to maintain a particular speed during the approach and this can also effect aircraft operating conditions.

Uncertainties associated with departures arise from a number of different causes. All departures are required to climb away from the runway in a straight line to a 'safe' height before reducing the engine power setting and/or turning onto a different heading. The optimum engine take-off power setting depends on the overall aircraft weight including passengers, cargo, and fuel, and this affects the rate of climb and the resulting height profile. The maximum take-off power settings are not used except for the heaviest aircraft weights because this saves on fuel and reduces wear on the engines. Using the maximum take-off power setting available increases the sound power generated at source but may have an opposite effect on sound level on the ground because of the increased rate of climb. The initial climb is carried out at a relatively low airspeed requiring the use of wing flaps and other low speed high lift devices to achieve sufficient lift. As soon as the aircraft reaches the defined 'safe' height (note that this can vary between different airports and for different aircraft types), the rate of climb must be reduced to allow more of the available thrust to be used to increase the aircraft speed to a point where the low speed high lift devices can be withdrawn. The aircraft then continues to both climb and accelerate to cruising speed and altitude at a lower power setting, thereby saving fuel burn and engine wear and tear. Because the use of engine cut-back during the climb has become a standard procedure, the engines are designed such that they are only expected to operate at maximum power settings without overheating for a few minutes at a time, and this achieves further savings in engine weight and component costs. The point on the ground above which the 'safe' height is achieved varies for different aircraft types and weights and this in turn can have a considerable effect on the actual flight track achieved when aircraft are required to turn onto a different heading after the initial climb.

For the ANASE study, it was necessary to construct detailed sound level models for all of the busiest civil (ie non-military) airports in England. Historic radar height and track data was available for some but not all of these airports, but none of this data was in a format which could be inserted directly into an INM model. Most airports have standard arrivals and departures routes defined for air traffic control purposes and while these can be downloaded from the UK Aeronautical Information Package (UK AIP - see www.ais.org.uk), they only show the defined route centrelines and not the extent to which actual flights deviate to either side (and above and below). However, this is often the only information about historic flight tracks and height profiles which is publicly available. Where radar height and track data is available, this can then be used to show dispersion to either side or above and below the nominal tracks as shown in the UK AIP, but where radar height and track data is not available, flight track dispersion can only be assumed.

There is usually no information available about actual aircraft operating conditions, other than standard operating procedures which may or may not apply at specific airports and this part of the modelling has therefore to be based almost entirely on standard assumptions. On the other hand, because the actual operating conditions are constrained by safety, efficiency, and capacity requirements, variation in sound levels on the ground due to differences in aircraft operating conditions is likely to be less than variation due to flight tracks and height profiles, particularly at greater distances from the airport where the sound levels are lower.

For the ANASE study, the detailed sound level models were constructed using only a limited number of generically representative aircraft types at each airport. This simplification was adopted for three main reasons. First, the modelling had to be completed within a relatively short time scale in order to support the quasi-random survey sample selection process which had been agreed with the study steering group. Full modelling of every single aircraft type and engine fit variant at each of 20 separate airports could not have been completed within the available time scale. Secondly, the ANASE questionnaire included a large Stated Preference component which requires respondents to choose between a number of alternative hypothetical scenarios. Pilot studies had shown that most respondents could not discriminate between more than around three or four generic aircraft types at most, and it became clear that the sound level model did not need to discriminate between all possible aircraft type and engine fit combinations. Thirdly, the actual aircraft type and engine fit combinations adopted as generic representative types for the modelling were selected as providing the closest match in terms of sound level characteristics to the average sound level characteristics for each group of aircraft type and engine fit combinations defined as within each generic type category at each airport, taking into account the actual numbers of each aircraft type and engine fit combination at each airport separately. This means that considered overall, the output cumulative sound level metrics calculated using this approach would be likely to be very similar to what would have been calculated if every single aircraft type and engine fit combination at each airport had been modelled separately. The main separate event indicator used in the subsequent data analysis, LAmax, would of course represent the average LAmax for the noisiest generic aircraft type category rather than the noisiest example of aircraft type and engine fit combination within that category, but this was not considered to be a problem for the adopted approach. It should also be noted that the standardised NPD curves for each aircraft type and engine fit combination provided within the INM are necessarily based on limited measurements and cannot therefore represent all possible circumstances under which those aircraft types may be flown. In practice, there is often considerable variation in actual sound level levels above and below the long term average sound level levels arising simply from random variations in operating conditions and acoustical propagation.

2.1 Track Dispersion

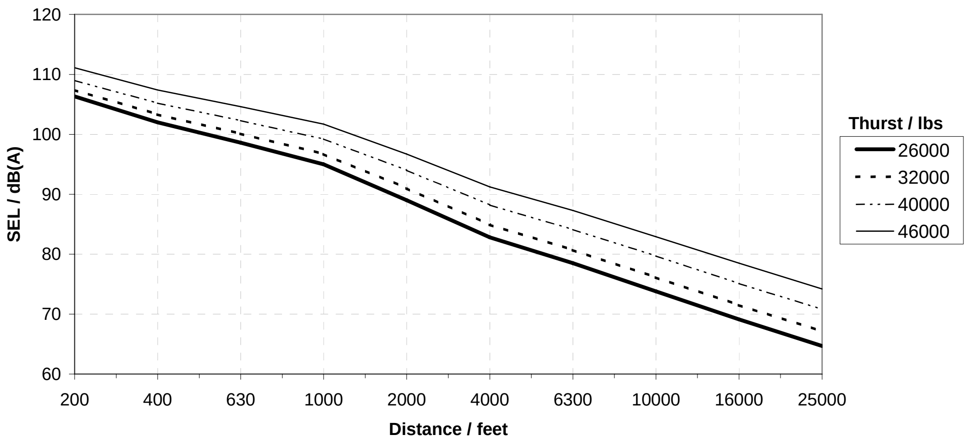
During approach, the least variation in ground track occurs during the final stages when arrivals must be precisely aligned to the extended runway centreline. The largest variation in ground track occurs before the aircraft has lined up on the extended runway centreline and after the engine cut-back during departures where there can be considerable variation in ground track during turns. Many airports publish swathe maps showing the expected maximum extent of flight tracks to either side of the published routes although these do not always co-incide with what actually happens as shown on radar tracks. Since flight track dispersion tends to increase at increasing height and distance away from the airport where sound level levels are lower than closer in, the effects on sound levels may not be as significant as they would be if significant dispersion occurred closer in.

2.2 Height Profile

Figure 1 (taken directly from the INM model) shows a 5 to 10 dB range in calculated SEL at different distances for a range of engine power settings used during standardised B747-400 (fitted with PW4056 engines) departures. It should be noted that variation of the kind shown in figure 1 arises both from the differences in sound power level radiated at source and the differences in rate of climb above the ground associated with differences in engine power setting, which are to some extent confounded within the INM model. In figure 1, the highest power setting shown gives the highest sound level levels at any distance but this only applies where the higher power is used to compensate for higher take-off weight. If the take-off weight was the same, the higher power setting would give a higher rate of climb leading to reduced sound levels on the ground at the bigger distances. The standard departure procedures included within INM can be modified by the user if required, but this is not recommended unless the modifications can be fully justified by specific information for that aircraft type as it is typically operated at that airport.

Within INM, the simplest method of dealing with the above complexities is by selecting the most appropriate 'stage length' for each modelled operation. Stage length refers to the distance flown which is often less than the maximum capabilities of the aircraft type and engine fit combination in question. The shorter stage lengths require less fuel and all other things being equal would therefore require a lower take-off weight with consequent reductions in sound level on the ground. In practice, aircraft flying shorter stage lengths could still be loaded up to similar overall weights and this might not be properly reflected by calculated sound levels. The worst case assumption is to assume the maximum stage length for all flights even though this will lead to some over-prediction of sound levels on the ground for the less heavily loaded aircraft.

Figure 1 : NPD Curve for B747-400 PW4056 Engine (Departure)



3 METHOD

A simplified generic airport model was set up to investigate the different effects of flight track dispersion and height profile and operating conditions combined (stage length) on two representative aircraft type and engine fit combinations as follows;

B747-400 with PW 4056 engines
A321-232 with IAE V2530-A5 engines

The generic model was set up with a single runway with straight in and out approach and departure routes with sound level calculation points distributed on a 1 km grid to either side of the extended runway centreline (over a 65 km by 20 km total area). The model was set up to calculate LAeq,16hr for an arbitrary number of 60 B747-400s and 240 A321-232s during the 16 hour period.

A number of scenarios were then tested and compared to the base case as shown in the following table. These scenarios included dispersion on departure, increased weight on arrivals, different stage length profiles based on the INM standard procedural profiles and increased weight on departure using an INM stage length 1 profile.

Label	Descriptor
Dispersion - INM STD1	Comparison with and without departure dispersion using Stage 1 profile – short stage length (+ve - base case louder than with dispersion)
Dispersion - INM STD2	Comparison with and without departure dispersion using Stage 2 profile – medium stage length (+ve - base case louder than with dispersion)
Dispersion - INM STD7	Comparison with and without departure dispersion using Stage 7 profile – long stage length (+ve - base case louder than with dispersion)
INM STD2 – STD1	Comparison of a Stage 2 profile with a Stage 1 profile (+ve – Stage 2 louder than Stage 1)
INM STD7 – STD1	Comparison of a Stage 7 profile with a Stage 1 profile (+ve – Stage 7 louder than Stage 1)
Dispersion INM STD2 – STD1	Comparison (including departure dispersion) of a Stage 2 profile with a Stage 1 profile (+ve – Stage 2 louder than Stage 1)
Dispersion INM STD4 – STD1	Comparison (including departure dispersion) of a Stage 4 profile with a Stage 1 profile (+ve – Stage 4 louder than Stage 1)

A comparison of the sound levels at all grid points was undertaken, and 7 of the 1386 calculation points were identified as illustrating the key points arising from the analysis, as follows; for approach 6 km from runway threshold at 2 km sideline, and for departures at 6 km, 10 km and 14 km from start of roll both directly underneath the extended runway centreline and at 2 km off to one side.

Figure 2 : 6km before runway threshold and 2km from runway centreline

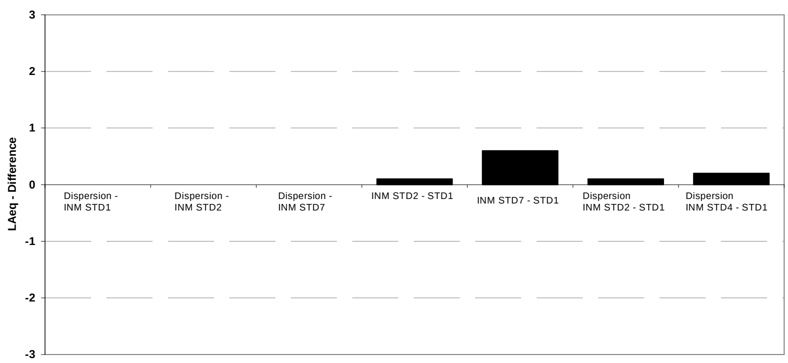


Figure 3 : 6km after start of roll and on runway centreline

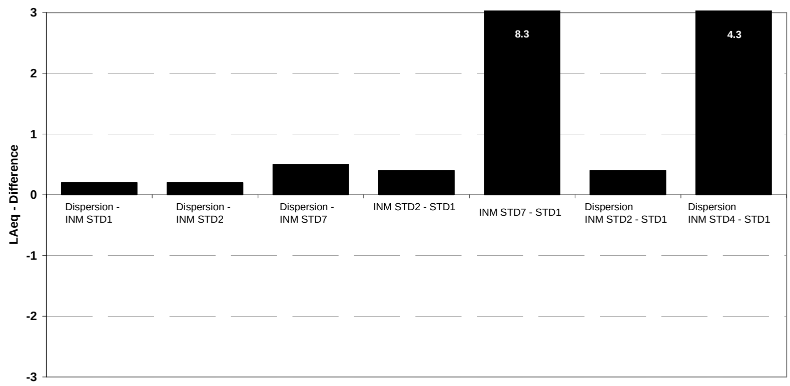


Figure 4 : 6km after start of roll and 2km from runway centreline

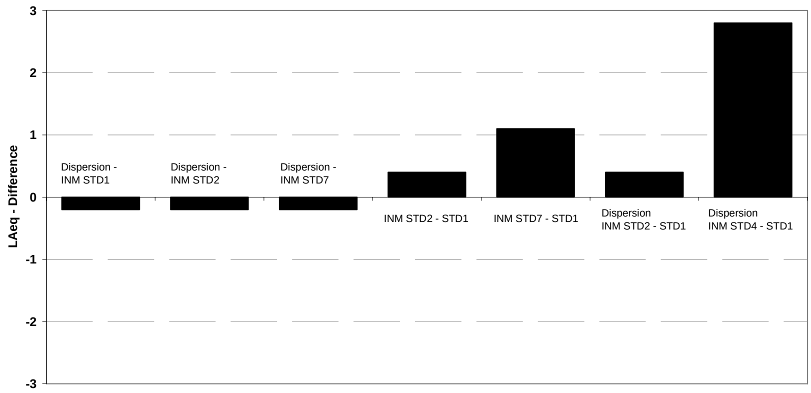


Figure 5 : 10km after start of roll and on runway centreline

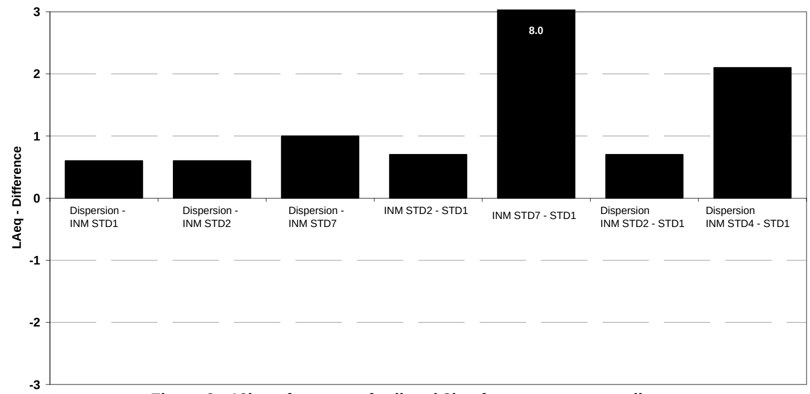


Figure 6 : 10km after start of roll and 2km from runway centreline

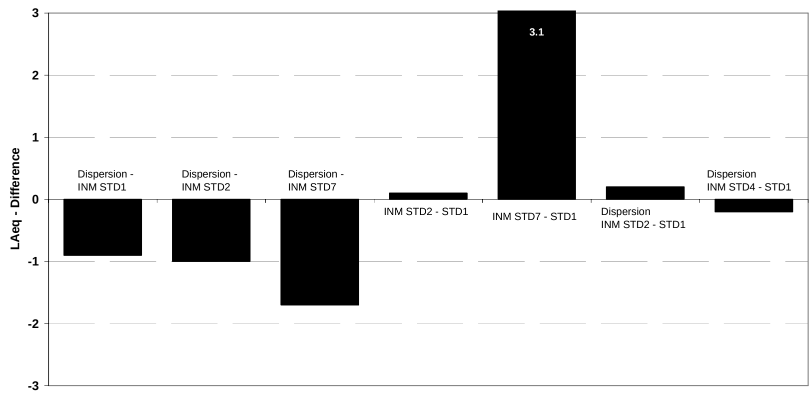


Figure 7 : 14km after start of roll and on runway centreline

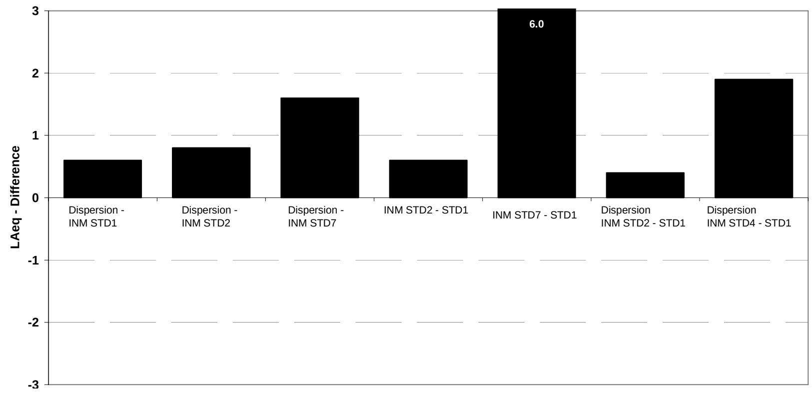
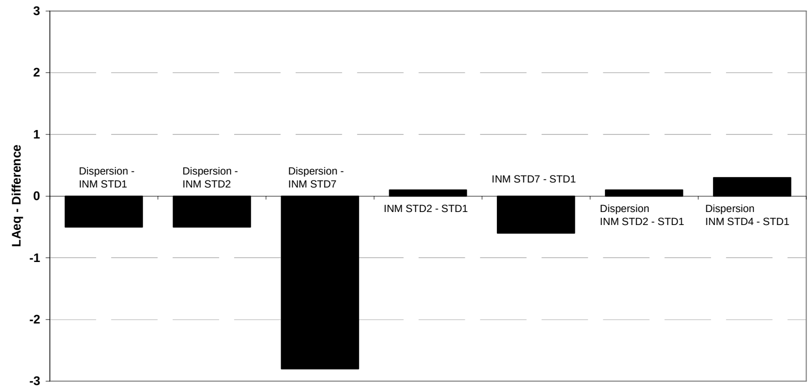


Figure 8 : 14km after start of roll and 2km from runway centreline



4 FINDINGS

4.1 Aircraft Weight on Approach

Figure 2 shows marginally higher sound levels for heavier aircraft on approach, although the maximum difference in LAeq,16hr is only 0.6 dB at 6km from landing threshold at 2 km off to one side. This small difference is negligible for most practical purposes, and provides a strong indication that changing the aircraft landing weight in INM makes no significant difference to the modelled outputs.

4.2 Dispersion

Figures 3, 5 and 7, for calculation points 6 km, 10 km and 14 km from start of roll on the extended runway centreline, show marginally lower sound levels with modelled dispersion. This is because with dispersion there are fewer flyovers directly overhead. With dispersion, for the shortest stage length, LAeq,16hr is reduced by 0.2 dB at 6 km and by 0.6 dB at 14 km. For the longest stage length, LAeq,16hr is reduced by 0.5 dB to 1.6 dB at the same distances.

Figures 4, 6 and 8, for calculation points 6 km, 10 km and 14 km from start of roll at 2 km off to the side of the extended runway centreline, show marginally higher sound levels with modelled dispersion. This is because with dispersion there are more flyovers off to either side. With dispersion, for the shortest stage length, LAeq,16hr is increased by 0.2 dB at 6 km, increased by 0.9 dB at 10 km and reduced by 0.5 dB at 14 km. For the longest stage length the increases in LAeq,16hr are bigger.

4.3 Stage Length

Figures 3, 5 and 7, for calculation points 6 km, 10 km and 14 km from start of roll on the extended runway centreline show that stage length assumptions can have a more significant impact on sound level than dispersion. For an aircraft with a marginally greater take-off weight (4% heavier) than the base case (INM STD2- STD1), the effect of increased take-off weight is marginal (ie less than 0.7dB) irrespective of distance from the runway. For an aircraft at maximum take-off weight (48% heavier than the base case - INM STD7 – STD1), the generic model shows sound level differences of 6.0 to 8.3 dB due to the higher engine power setting and lower rate of climb.

Figures 4, 6 and 8, which are respectively 2 km off the centreline at distances of 6 km, 10 km and 14 km from start of roll, show that at calculation points off to one side, the stage length assumption has a much bigger effect than the dispersion assumption.

For aircraft with marginally greater take-off weight than the base case, LAeq,16hr is greater close to the runway (0.4 dB) than further away (0.1 dB). For an aircraft at maximum authorised take-off weight, LAeq,16hr differences of 1.1 dB at 6 km, 3.1 dB at 10 km reducing to –0.6 dB at 14 km (base case louder than stage length ‘7’). This is again principally due to the aircraft’s performance characteristics at 14 km from start of roll.

5 SUMMARY

For a generic model with flight tracks in line with the extended runway centreline, flight track dispersion marginally decreases sound levels on the extended runway centreline and marginally increases sound levels off to either side. The overall effects are mostly quite small, with a maximum difference of 2.9 dB.

For the same generic model, changing the stage length assumption on departure can have a much bigger effect, typically around 4 dB but possibly as much as 8 dB for the most extreme aircraft weight assumptions. This is because the stage length assumption affects both the assumed sound power level at source and the assumed height profile as the aircraft climbs away from the runway.

The combined effects of alternative dispersion and stage length assumptions are not necessarily additive because of the interaction between height profile and relative slant distance to calculation points off to either side of the extended runway centreline.

6 REFERENCES

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