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PRACTICALITIES OF APPLYING Leq AS AN AIRPORT NOISE INDEX

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1. INTRODUCTION

For more than twenty five years, the official unit of aircraft noise exposure in the UK has been the Noise and Number Index (NNI). During that time the CAA's Directorate of Operational Research and Analysis (DORA) has maintained a computer model which generates contours of aircraft noise exposure from input information describing flight routeings and the aircraft traffic upon them. This has been used for many purposes including the preparation of evidence for most major airport public inquiries.

While Inspectors and Government Ministers have, on the whole, accepted NNI as a well-based planning tool, it has been the subject of numerous criticisms from inquiry participants [1]. In the light a major study published in 1984 [2] the Government now considers that Leq may be a more appropriate measure of aircraft noise.

While the Department of Transport (DTp) has been engaged in consultations on the question of switching from NNI to Leq for aircraft noise exposure rating purposes, on its behalf the CAA has been examining the practicalities of such a change including the development of a computer model to calculate Leq contours.

2. THE NNI MODEL

The Noise and Number Index is usually defined as

$$NNI = L + 15 \log_{10} N - 80 \quad \ldots (1)$$

where N is the number of events exceeding 80 PNdB between 0700 and 1900 hrs local time on an average summer day and L is the (log) average maximum perceived noise level of these N events. Since the input data are measured in dB(A) and converted to PNdB by the ICAO recommended approximation PNL = L_A + 13, (1) may be written:-

$$NNI = L_{Amax} + 15 \log_{10} N - 67 \quad \ldots (2)$$

* This paper describes the views of the authors. It should not be construed as reflecting official CAA or DTp policy.

where L_{Amax} is the log average of the N values of L_{Amax}. It is calculated by summing contributions from all relevant aircraft traffic on nearby flight paths.

The maximum noise level generated by an aircraft at any point is assumed to be determined by its minimum slant distance. L_{Amax} is computed using the approximation that it falls by 8dB per doubling of distance (dd) from a Reference Noise Level (RNL) defined 152m from the aircraft. For this attenuation the aircraft must be more than 15° above the horizon; at smaller angles the attenuation rat increases progressively to 10dB/dd as the elevation falls to zero.

This range of attenuation rates is central to the NNI concept. It was based on data available when the model was first developed and has been kept unchanged. The 8dB figure is firmly linked to the RNLs which are derived by applying that attenuation rate to measurements made at various distances. Since 'spherical spreading' accounts for 6dB/dd, these rules attribute 2dB/dd each to atmospheric and ground absorption. This is an approximation to what is really a very complex process but it has generally been considered adequate for quantifying relative noise impact.

A major use of the NNI model is in the preparation of annual noise contours for the London Airports. A foundation of the official NNI methodology, which distinguishes it from other procedures, is that such computations are based on actual measurements: the model has a firm empirical base. Each summer, hundreds of noise levels and, in alternate years, flight tracks are recorded near the airports and added to the CAA's data bank. As necessary, average flight profiles and RNLs are adjusted so as to reflect gradual improvements in aircraft performance, noise emissions and air traffic control practice.

3. THE Leq MODEL

At the outset, three computer modelling options were considered: (i) develop an entirely new model tailored to specific UK needs, (ii) adopt a 'standardised' procedure [e.g 3-5] or (iii) modify the existing NNI software. Of these, the first was considered too expensive in terms of both time and costs. The second had obvious attractions, especially since the CAA had made substantial contributions to the international procedures. However, such an approach would require comprehensive tabulations of aircraft noise and performance data (including standardised aircraft flight profiles and noise-distance curves for different engine power settings) which could not be obtained from NNI-type field measurements (they would have to be acquired from the aircraft and engine manufacturers). Although such a change was not ruled out for the longer term, it was considered too radical a departure from past UK practice which would take too long to introduce and substantiate. It was expected that the DTp would wish to publish NNI contours alongside the Leq ones during some overlap period. To ensure comparability, the Leq model should ideally retain the same basic structure and the same database as the NNI model, at least during its early life. Thus the third option was chosen.

In theory, if no background noise from other sources were present, aircraft noise Leq could be described by the continuous integral

$$\mathrm{Leq} = 10 \log_{10} \left(\int 10^{L(t)/10}\, dt/T \right) \quad \ldots(3)$$

where L(t) is the instantaneous sound level and T is the total integration time. Since aircraft noise events usually fill a small fraction of the total time period, equation (3) may be written

$$\mathrm{Leq} = SEL + 10 \log_{10} N - \mathrm{constant} \quad \ldots(4)$$

where N is the total number of aircraft noise events, the constant depends upon the measurement period and *SEL* is the log-average sound exposure level of the N events, any one of which is given by

$$\mathrm{SEL} = 10 \log_{10} \left(\int 10^{L(t)/10}\, dt \right) \quad \ldots(5)$$

It should be noted here that (3) and (4) give practically identical results. However the relative magnitudes of *SEL* and $10 \log_{10} N$ in equation (4) may vary markedly with the integration limits used to evaluate (5), which are in turn dictated by the sound level threshold above which the SEL measurement is accumulated. As this is lowered, average *SEL* goes down and N increases - and *vice-versa* - tending to maintain a constant Leq. This fact must be taken into account if *SEL* is required as well as Leq. Of practical significance too is the effect of this threshold on the relationship between L_{Amax} and *SEL*, experimental measurements of which are used to test the computer model.

In the computer model, SEL could be specified directly as a suitable function of minimum slant distance; for air-to-ground propagation from a uniform, straight, flight path a change of 5dB per doubling of slant distance would broadly be consistent with the 8dB/dd figure used for L_{Amax} in the NNI algorithm - and other functions could be tabulated. But because SEL is affected by changes of direction and engine power along the flight path, the result would have to be adjusted when these occur. Also, such SEL functions would effectively introduce variable thresholds or cutoffs - a matter discussed below. These difficulties have been avoided altogether by obtaining SEL by time-integration of L_A at the receiver point. This has been done by retaining the flight path structure of the NNI model, which approximates actual geometries (including the dispersed tracks) by series of straight line segments, and summing the contributions from *all* significant segments of each path to obtain the SEL for each aircraft on that path. A single segment contribution can be shown to be

$$\Delta SEL = SEL_{\infty} + 10 \log F - A_{lat} \qquad \ldots(6)$$

where $$SEL_{\infty} = L_{Amax} + 10 \log (R_{min}/V) + D \ldots(7)$$

Here, SEL_{∞} is the value obtained for a segment of infinite length, F is a 'noise fraction' which accounts for the finite dimensions of the segment (a modified version of the function used in the FAA's Integrated Noise Model [6]), A_{lat} is the excess lateral attenuation at low angles of elevation (see below), R_{min} is the minimum slant distance to the hypothetical infinite segment, V is the aircraft speed and D is an adjustment to account for source directivity.

Although this alternative approach requires rather more computer time, it has the important advantage that the segment SEL contributions are calculated via L_{Amax} values computed from the existing NNI database. The only additional input information required is the speed of the aircraft on each segment.

Further changes from the NNI model include the replacement of the simple ground attenuation function by the SAE 'lateral attenuation' algorithm [7] and the use of SAE recommended improvements to the way in which 'start-of-roll' noise is modelled (behind aircraft at brake-release). These potential improvements to the NNI model had been held back because of the comparability argument already noted; it was logical to defer their introduction to the new Leq model.

4. IMPLEMENTATION OF THE Leq MODEL

DORA's Leq model is now operational following extensive improvements made to achieve economical computer running times and the analysis of numerous test cases. The flight profiles for different aircraft types and the associated reference noise levels are taken from the standard NNI data files; the segment flight speeds have been estimated from analyses of radar-measured flight paths. The SEL algorithms have been 'calibrated' initially by matching the measured and computed relationships between L_{Amax} and *SEL* associated with particular aircraft types, modes of operation and flight paths through adjustment of the directivity terms D.

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A practical requirement is a fixed sound level threshold or *cutoff* below which minor aircraft noise energy contributions can be neglected. Without one, the number of events 'heard' is calculated to be everywhere equal to the number of aircraft movements at the airport. Average *SEL* values, especially lower ones, are also sensitive to this choice; so too is the subsequent computation time. It has been noted that the question does not really affect the accuracy of the Leq output; higher *SELs* are compensated by lower numbers and vice-versa. But the *measured* relationship between L_{Amax} and *SEL*, used to verify the computer model, involves averages of measured noise level samples. The selection of these samples is influenced by local background noise and the omission of lower values inevitably distorts the distribution of levels at any measurement site. This matter will require close attention in the design and planning of future measurement excercises.

By definition, the peak noise levels averaged in the NNI formula exclude values below 67dB(A). One of the most common criticisms of NNI made by environmental groups is that the 67dB(A) cutoff is too high, resulting in the exclusion of quieter, but still audible aircraft events. This concern has increased as aircraft have tended to become quieter generally. Since reasonably accurate estimation of SEL requires integration over at least the highest 10 dB of the event time-history , *full* retention of the event SELs for the sounds included in NNI requires the Leq cutoff to be below 57dB(A). But this automatically adds sound energy associated from events, not included in NNI, which peak between 57 and 67dB(A). (The time-histories if these events are truncated less than 10dB below their peaks; the corresponding SELs thus underestimate the 'full' values. However, this is quite consistent with the concept of a fixed audibility threshold.) Still lower cutoffs increase N fairly rapidly but the practical aim must be to estimate numbers actually heard as closely as possible. It is expected that for the majority of major airport applications a threshold of 55dB(A) will provide valid estimates of Leq, *SEL* and N. But any threshold can be specified in the Leq model and for special applications, for example in the case of lightly used aerodromes in areas of low background noise, the use of lower values could be considered.

It is recognised that the initial Leq contour calculations will only be supported by introductory validation of the computer model. Experimental data will be required from a rather wider range of locations than has been used for the maintenance of the NNI database and this will necessarily take some time to assemble and analyse. Particular attention is required to the effects of turns and power changes and to the accuracy of the calculations over large distances. A particular question to be addressed in the model's continued development is the validity of the simple NNI-based air-to-ground propagation rules. Standardised procedures for the estimation of atmospheric absorption [8-10] indicate that, while an attenuation rate of 8dB/dd may be a good average figure for aircraft peak levels over distances up to about 1000m (from within which most DORA data has been obtained), the average rate is different at greater distances. Alternative algorithms to take account of this need to be evaluated against new experimental data. Furthermore, the latter will have to take more account of weather variations than has been necessary for the shorter range measurements.

The ANIS research study [2] revealed no 'better' predictor of annoyance than 24-hour Leq. But the adoption of a 24-hour index would be rather a radical change from the present 12-hour one and in any event it would not recognise the somewhat different considerations applying to the evaluation of noise by day and by night. The two DORA studies of the effects of aircraft noise upon sleep [11 & 12] have shown that Leq for the period 2300 - 0700 hrs is a relevant measure of night noise and it is logical to complement this with a 16-hour day value. The great majority of all aircraft movements occur between the hours of 0700 and 2300 and, furthermore, as a predictor of annoyance, Leq(16-hr) is statistically little different from Leq(24-hr). The 8-hour night covers the typical hours of sleep and encompasses that part of the night during which night restrictions on aircraft operations are imposed at the London airports. Contours of Leq(8-hr) are already required for evaluating the effectiveness of these restrictions. With regard to longer term averaging, for the present there appears to be no reason to change the NNI practice of computing noise exposures for the average summer day (taken at present as between mid-June and mid-September) for day or night values.

Ideally the use of Leq as an index of aircraft noise impact should meet four basic requirements:

1) Published daytime contours should be indicative of the same levels of noise impact, ie average annoyance levels, as the long established 35, 45 and 55 NNI contours (irrespective of any intermediate values which could be included).

2) Published contours should have values which are convenient and logical, eg they should be integers at equal intervals which are related to key properties of decibel and/or decimal scales. For example, steps of 3dB or 5dB would meet this requirement.

3) The number and spacing of Leq contours should not differ markedly from customary NNI practice.

4) At the time of change, equivalent Leq and NNI contours should be reasonably matched in shape and size.

It is impossible to meet all these requirements exactly and some compromise of these ideals is unavoidable.

Technical support for the change of index comes from the ANIS study [2]. While Leq (which was determined in that study by measurement rather than computer modelling) was shown to be slightly more highly correlated with public annoyance reactions than NNI, no particular values of Leq separated significantly different reactions, although there was some evidence of a step increase in annoyance at about 57dB(A) Leq(24-hr) (58dB(A) Leq(16-hr)). Regression lines relating measurements of NNI and Leq were presented but these must be considered specific to the conditions in 1982. In any event there is no unique physical relationship between Leq and NNI.

For busier airports, 3dB intervals of Leq are roughly equivalent to 5-unit intervals of NNI. Therefore suitable daytime Leq values covering the range equivalent to 35-55 NNI will probably span the interval from 58 to 70 dB(A) Leq(16-hr) in steps of 3 or 6dB.

5. SUMMARY

1 Although Leq can be applied to any time interval, the 24-hour period can suitably be divided into sixteen-hour day (0700-2300) and eight-hour night (2300-0700) averaging periods. Calculations would relate to the 'average summer day' defined for NNI.

2 The DORA model computes Leq from the existing NNI database. Only the aicraft speed profiles have had to be added. This will help ensure that Leq and NNI contours, expected to be published in parallel during the changeover period, are directly comparable.

3 For various reasons, a threshold or 'cutoff' level is necessary when calculating Leq contours. The DORA model allows any threshold to be specified; a choice must be made which is consistent with the objectives of the specific application.

4 For fast computation, the duration factor inherent in Leq could be accounted for by defining SEL as a convenient function of slant distance and adjusting the result to allow for the effects of turns and power changes. Although computationally more complicated, the preferred approach is that of time integrating L_A. This allows a sound level threshold to be handled in a more rational way and has been readily implemented through an extension of the existing NNI model.

5 A continuing aim will be to achieve the best possible accuracy at reasonable cost. It is clear that the accuracy of the model will continue to improve as better data become available and as experience of noise modelling continues to grow. It is expected that improvements will be made to the model as soon as they have been fully tested.

6. REFERENCES

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