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THE UK AIRCRAFT NOISE INDEX STUDY: 20 YEARS ON

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1 INTRODUCTION

In the early 1980s the UK Department of Transport (now the Department for Transport: DfT is used here to cover all its incarnations) commissioned a study to determine what index should be used to assess aircraft noise disturbance near major airports. This Aircraft Noise Index Study – ANIS – was completed in 1984 and published shortly afterwards (Brooker et al – 'ANIS Report' [1]). This study included extensive social surveys and noise measurements around these airports, plus detailed statistical analyses. The main result of the study was that Leq (A-weighted) would be an appropriate index. Following publication of the ANIS Report, consultation, and some further work [2], the decision to use the 16-hour Leq for the UK aircraft noise index was announced in September 1990. The standard calculation method is described in Ollerhead et al [3].

This paper reviews the methodology of the ANIS work and the subsequent criticisms of ANIS and Leq, with the hindsight of 20 years. Obviously, with such a large subject, it is only possible to give a flavour of the material, so reference should be made to the source documents regarding detailed questions. Unless otherwise noted, references are to data in the ANIS Report.

2 BEFORE ANIS

The growth of aviation in the 1950s and 60s, led to increased disturbance of people near airports, particularly for Heathrow. Jet traffic, at first in the mid-1950s with the Comet, and then in the 1960s with a variety of types, produced considerable increases in the noise environment.

The 'Problem of Noise' was investigated by the Government's Wilson Committee, which reported in 1963 [4]. It covered all kinds of noise but made some very specific recommendations about a suitable index to measure the disturbance caused by exposure the aircraft using an airport. 'Disturbance' and 'annoyance' were loosely used as synonyms: they did not include sleep disturbance (or difficulty getting to sleep) or possible long-term medical or psychiatric effects. The convention has developed that a phrase such 'noise exposure' is generally used to describe the noise 'climate' around an airport rather than the noise levels etc produced by a single aircraft. [This convention is not always appreciated, which has therefore led to difficulties in explaining the results of work such as ANIS to general audiences.]

The Wilson' Committee's aircraft noise studies – social surveys and noise measurements – led it to the conclusion that a good noise index would be of the form (the Noise and Number Index – NNI):

$$NNI = L + 15 \times \log N - 80$$

Here L is the logarithmic (base 10) average [again a source of confusion with general audiences] of the noise events 'heard' and N is the number of such events. 'Heard' was taken to be ≥ 80 PNdB during the average summer day (0700 to 1900 local time, peak three summer months). The use of PNdB was actually not much more than an attempt to link in to aircraft certification. The work to support the development of NNI in 1963 actually used an early version of dBA. In practical

assessments, L was measured in dBA and increased by 13 (or more complex variants dependent on the ICAO guidance about conversion factors). NNI contours were produced for Heathrow, and subsequently other airports, until Leq replaced NNI. Such contours were used in planning inquiries and departmental guidance about building development. 35 NNI was taken as Low annoyance and 55 NNI High annoyance. The relationship of annoyance and disturbance was recognised to be a complex issue.

By about 1980, the DfT had become concerned that the NNI was 'out-of-line' with aircraft noise 'nuisance' indices used in other countries, which tended to be based on Leq. It commissioned the studies that led up to ANIS. CAA used expert contractors, in particular John Ollerhead of Loughborough University and Chris Rice of Southampton University, to help in the design of a study that would assist the DfT in creating a better – methodologically and statistically sound – aircraft noise index. Ollerhead also carried out for DfT a number of small-scale studies to investigate various aspects of aircraft noise exposure and disturbance. Thus started ANIS.

3 PROBLEMS AND DESIGN SOLUTIONS

To understand the nature of the problem, it is necessary to go back to basics – to at least to a 'Holy Grail' version of it. Figure 1 shows this ideal: there is something called the Dose and something called the Response, and the relationship between them is a monotonic sigmoid curve. The Response is something like the expression of annoyance and the Dose is some physically measurable combination of noise parameters. There is some value of the Dose that is the 'Onset' of rapidly increasing Response. Policy makers would value knowing if there were some Dose below which people 'are not annoyed', and hence do not need to be accounted for in decision-making. For NNI, the Onset was often taken to be 35 NNI, although the Wilson report did not equate Low annoyance with such an Onset – but some press notices and policy statements tended to give this impression.

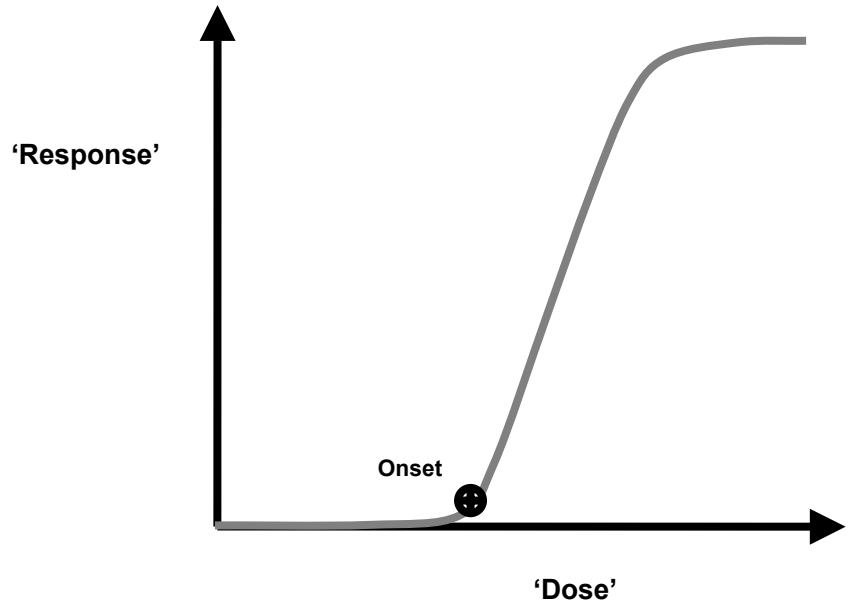

Figure 1. Ideal dose-response relationship

Response and Dose are very different things:

> Dose: combination of objective physical, measurable parameters about aircraft noise at a particular location
>
> Response: measure – or combination of measures – of people's feelings about aircraft noise for someone in that location.

The ANIS aim was to find something that measures Response accurately, and then to find a Dose that best matches this. So why is this so difficult? There are several reasons.

The most important reason is the huge variability in people's feelings about the same exposure to aircraft noise. Consider one of the response scales used, ANAS, when people are asked how much aircraft noise bothers or annoys them:

> Very much?
>
> Moderately?
>
> A little?
>
> Not at all?

ANAS is the prime example of a simple annoyance-based scale. Note that it has no middle ranking choice – so the interviewee is not able to take the 'easy way out' by choosing an 'average' figure. When this question is asked in small geographical communities near an airport, ie with about the same noise exposure, there is considerable variation. People's responses to the same noise exposure vary widely, probably traceable back to inherent psychological differences. Even at one of the noisiest ANIS sites near Heathrow, Feltham site A, (from Table C2) 52% were 'very much annoyed', but 48% rated annoyance as less than that, and 2% said they were 'not at all annoyed'. Much further down the noise exposure spectrum, at Willesden, 11% were 'very much annoyed' and 42% were 'not at all annoyed'. This wide range of people's responses implies that any statement about Response has either to be about some kind of 'average person' or about the proportion of people getting the same noise exposure who are (say) 'very much annoyed'. Both approaches were used in ANIS.

This wide variation in individual responses produces both statistical (examined later) and 'public relations' problems. The latter problem is that it is sometimes very difficult for residents who are themselves 'very much annoyed' to accept that their feelings are not universally shared in their local community. This leads to distrust of honestly collected and analysed data.

The second important problem is that of determining what is the 'right' scale of annoyance or disturbance – the Response variable. Social scientists have devoted considerable effort to finding out what might be 'good' scales (but there is no 'recipe book'). Two questions quickly arise. Is annoyance meaningful in itself or does it have to be characterised by reference to (eg) activities being disturbed? To what extent is a possible scale cardinal in nature (ie corresponding to the properties of integers, rather than just being 'ordinal' – ranking responses), and hence capable of being manipulated by all the rules of arithmetic?

Another type of scale used focused on 'acceptability'. The argument was that people might have different and subtle views about annoyance but would be more able to provide a clear 'yes or no' answer. So, they were asked

> All things considered, do you personally think the amount of aircraft noise here is acceptable or unacceptable?

More complex scales based on the interference with someone's activities were used to construct 'Guttman annoyance scales' (GAS – the ANIS report provides references to the literature). For example, interviewees would be asked if aircraft noise interfered with their relaxation, made them

shut windows, interfered with listening to radio, TV or 'Hi-fi'; and if so how annoyed they were. By analysing the responses to such questions and ranking their 'intensity', a GAS was constructed, with individuals scoring for zero (no annoyance) to 6 (highest annoyance). [NB: aircraft noise annoyance/exposure is measured in the summer, when people tend to have their windows open and spend leisure time outside, ie more activities can be 'interfered with' and hence result in annoyance.]

One of the hopes was that the GAS would be a cardinal scale, in which score of 3 would be one unit more than a score of 2, itself an identical unit of annoyance greater than a score of 1; and that a score of 4 would be 'equal' to two scores of 2. How one would prove this to a sceptical statistician, let alone a member of the public, was never resolved. GAS was therefore seen as a rather complex scoring mechanism shrouded in some mystery. ANAS was sometimes used as a cardinal scale, eg with Very much/Moderately/A little/Not at all being taken to have values of 3, 2, 1, 0; but this 'interval' property could not be proved (eg what would be wrong with values of 9, 4, 1, 0?).

The key statistical design problem to be solved was that of correlated noise parameters. For example, one of the objectives was to find out if NNI or Leq was a better match to disturbance. NNI has an explicit weighting of 15 in its log N, whereas Leq has implicitly a weighting of 10 (doubling the traffic, all other things being equal, adds 3 dBA). Statistical techniques – multiple regression analysis would be the one most commonly used – lose their effectiveness if the independent variables are correlated. The L and log N (or N) values for a particular survey respondent generally tend to be positively correlated, ie people tend to get high L and high N together or low L and low N together. This led to the idea of choosing a set of survey sites for which L and N were de-correlated, ie the team looked hard for high L/low N and low L/high N locations. The former included areas close in to runways at moderately busy airports, while latter were found near Heathrow but away from the main routes. These locations often occur in comparatively small pockets, so the decision was made to carry the ANIS work at 'common noise areas', each having a small range of L and N variation. There were eventually 26 of these areas, with typically 80 people being interviewed at each of them.

4 MAIN RESULTS OF ANIS

The ANIS Report is more than 200 pages long. Hindsight has changed ideas about its most important results.

Statistical analyses demonstrated that it actually did not matter very much which scale was taken as the response: the correlations between people's response on the scales were very high. For example, the Spearman ranked correlation between the percentage 'Very much annoyed' and the percentage rating aircraft noise unacceptable was 0.92 (Table 8.1). Given the complexity of GAS and the concerns about results derived by assuming cardinal scales, these percentage scales are probably as good as anything else – and the general public should have little difficulty with them.

A key conclusion with hindsight (para 9.3) was that there was no hard statistical evidence for an 'N' variation in disturbance, as compared with the log N of NNI and Leq. This was over a very wide range of N – more than a factor of 5 (TableC2). This was not a new result, but the de-correlating design of ANIS meant that a high degree of statistical confidence could be attached. If there is any variation with N, then it has a much smaller coefficient than the log N term over a very wide range of L and N values.

With the de-correlating design, it was possible to demonstrate with statistical confidence at >5% level that Leq fitted the data better than NNI. Leq includes all aircraft noise events, so the 'number' issues raised by a noise cut-off (compare NNI's 80 PNDB) were largely removed. The correlation of disturbance scales and Leq for the areas was typically 0.9. There was some evidence of an Onset value just above 55 Leq for some scales, but it was not a particularly strong effect.

There was no indication of statistically significant differences in response characteristics between respondents at the five airports. However, one demographic variable that did show a large effect was the proportion of people who worked at or who had business with the airport, eg in some areas this effect produced a 25% lowering in the percentage saying that aircraft noise was 'not acceptable'

5 TERMINAL 5 INQUIRY

The Public Inquiry into a new Terminal 5 took place between 1995 and 1999, at an estimated cost of £80m. It was the longest Public Inquiry in UK history. Roy Vandermeer QC, who headed the Inquiry, gave his report to the DfT in March 1999. In 2001, the Secretary of State for Transport gave the go-ahead for a fifth terminal at Heathrow.

Increased passenger numbers at Heathrow translated into increased aircraft noise, so this topic, amongst other 'externalities', was a major topic at the Inquiry. Much of the debate was in fact about night movements and sleep disturbance, but the results of ANIS and the use of Leq occupied many days of evidence and pages of transcripts. The Inspector's Conclusions on aircraft noise disturbance covered paras 21.2.29 to 21.3.54 in his Report. He generally accepted that Leq was a worthwhile index to use in the Inquiry decision-making, but had several criticisms.

One of his concerns was that the Leq in use covered a 16-hour period rather that the whole 24 hours. Four hours of 'evening' had been added to the NNI period. The ANIS report had actually recommended the use of a 24 hour index, but the DfT had rejected this, on the grounds that disturbance at night, mainly through sleep interference, is a separate issue (but why could there not have been extra night-time metrics/constraints?).

The Inspector was critical of the emphasis being put on 57 Leq in official contours. DfT press material had been somewhat over-enthusiastic, and gave the impression that 57 Leq represented a rapid increase in disturbance – a 'concrete Onset'. ANIS had indicated rather a weaker effect. 57 Leq can be no more than a conventional – 'consistent' – starting point for contours.

Many of the environmental groups (covering a wide variety of organisations) expressed their doubts about Leq (para refs are to the Inspector's Report):

> *21.3.33 The greatest single criticism of the LAeq approach was that it failed to give adequate weight to the number of aircraft movements…The issue is whether that [logarithmic] influence is sufficient to reflect the experience of those affected.*
>
> *21.3.34 In fact, many of those appearing at the inquiry told me that the noise climate had deteriorated and that this was largely due to the increase in the number of movements. They were unconvinced by claims based on LAeq 16hour that the noise climate had improved. A substantial number genuinely find the existing noise levels distressing and unacceptable. Since there is no dispute that individual aircraft have become quieter in that period (by a factor of 3.3 according to BAA) I am satisfied that their perceptions must be based on the substantial increase in the number of movements. I also conclude that this is not truly reflected in the LAeq 16hour index.*

Thus, the Inspector was uncomfortable with the logarithmic variation in Leq. However, the Inspector's phrase 'must be based' does not obviously pass the kinds of test that should be applied to evidence. People in environmental groups could be expected to be very suspicious of any possible future increases in the noise level and/or the number of aircraft. They might well feel that any admission by them of any past improvement in the noise climate (through reduced airframe/engine noise) would be a sign of weakness. If one does not like aircraft noise and distrusts airport operators, then one would not want to expose any 'chink in the armour'.

The Inspector did note some caveats [HACAN = Heathrow Association for the Control of Aircraft Noise]:

> *21.3.34 …While I recognise that the sample of people canvassed by HACAN might not be representative…*

But the problem is that environmental groups' criticisms are not representative. Individuals join such groups because they find aircraft noise highly annoying or unacceptable – but a significant proportion of people at almost all levels of Leq will be in this category, not necessarily because there has been any deterioration in the noise climate. For example, Figure 2 illustrates the typical variation of 'Aircraft noise unacceptable' with Leq. The percentage increases from around 15% at 57 Leq to around 75% at 69 Leq, roughly in a straight line.

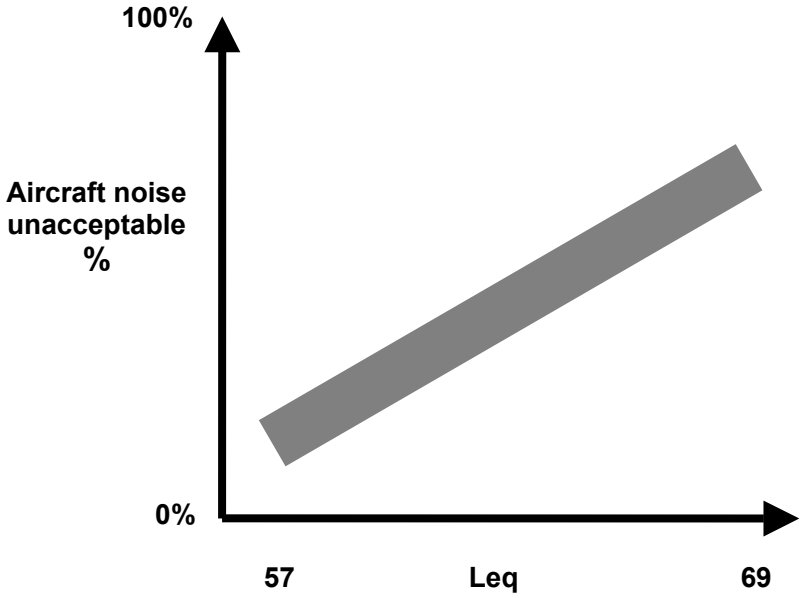

Figure 2. Percentage of survey respondents saying that levels of aircraft noise are unacceptable (rough trend approximation to Figure 9.10, ANIS Report)

These numbers are used in Table 1 for some recent Heathrow contours [5].

Leq Band dBA	Population in band – 000s	% unacceptable	Number rating unacceptable 000s
>72	1.4	90	1.3
69-72	4.7	75	3.5
66-69	14.6	60	8.8
63-66	36.2	45	16.3
60-63	54.2	30	16.3
57-60	132.3	15	19.8
		Total	66.0

Table 1. Illustrative comparison of populations in Leq bands for Heathrow and rating unacceptable percentage (Standard contours for 2001 – very few Concorde flights)

Table 1 takes the proportion rating unacceptable – at the lower end of each Leq band – and multiples it by the population in the band. This produces an ANIS-based estimate of the population within each band who rate aircraft noise unacceptable. The numbers increase for lower Leq values – because the larger contour area more than matches the smaller proportion of people deeming the aircraft noise unacceptable. This explains inter alia why airports receive quite high numbers of complaints from people living in areas of comparatively low noise exposure. [Moreover, the 57 Leq contour should only be used for comparisons when it is calculated accurately and cautiously on a standardised basis [6].]

The point is that ANIS dealt with representative samples of people, and therefore provided a good picture of the variation with Leq, both in terms of the typical person and the variation in response for people receiving the same noise exposure.

Moreover, the Inspector did not recognise the relevance of research done in other countries. Disturbance caused by aircraft noise is not special to these islands. There have been dozens of good quality aircraft (and other transport modes) noise disturbance studies carried out. Recent relevant work includes Miedema et al [7] and Fidell [8], each of which gives a wide range of further references. The central message is that Leq-derived indices fit people's responses well: there are no compelling examples of 'N' variation in responses.

The Inspector was concerned about

> *21.3.35 …people's perceptions of noise may well have changed in the 18 years since the ANIS report was produced. The Department recognised that it was very difficult to establish the true underlying relationship between the noise of individual events and their number and accepted that it would have been useful if further social surveys had been carried out. I strongly endorse this view. If parties are to have confidence on the indices used to measure the noise climate they need to be founded on a sound basis of up-to-date research. Unfortunately the Department's own evidence suggests that this does not apply to the use of LAeq, in spite of their argument that research had guided the choice of noise indices since 1967.*

On *'research'*, the comment can again be made that this seems a rather 'insular British' view.

The kind of model that the inspector would want to test might have the form:

$$\text{Annoyance} = K \times P(t) \{ \text{Leq} + Q(t) \times N \}$$

N would be the number of aircraft heard above some appropriate threshold (presumably markedly less than 80 PNDB). P and Q are unknown functions of time t, where t extends over several years. K is a normalising constant. A simple hypothesis of a logarithmic N dependence would equate to $Q(t) \approx 0$ – reasonable if international research has merit. A hypothesis that annoyance characteristics change over time would be that $P(t) \neq 1$ – which is possible, given that people's habits, behaviour, and attitudes to environmental issues can develop over time (so 57 Leq would not correspond to, eg, the same proportion of people 'very much annoyed'). This would need substantial research commanding the widest possible confidence, with objectives such as: survey sufficient people to provide the same degree of accuracy about community annoyance as in ANIS; or, survey at least as many people – and as thoroughly – as in previous major UK studies. The DfT has not chosen to carry out further statistically decisive studies of this kind.

6 FURTHER ENVIRONMENTAL GROUP CRITICISMS

The Terminal 5 Inquiry was not the end of environmental group concerns about Leq. Much of the criticism comes from groups focusing on Heathrow. These have been exacerbated by the suggestions for further development there, made in the recent White Paper on Air Transport [9], in the context of Figure 3.

13.1.3 Moreover, if my view that Terminal 4 is necessary in the national interest is accepted by the Secretaries of State, I am strongly of the opinion that all possible steps should be taken to satisfy those living around Heathrow that this is the last major expansion at the airport

98 I agree with BAA that the evidence placed before me demonstrates that a third main runway at Heathrow would have such severe and widespread impacts on the environment as to be totally unacceptable.

Figure 3. From Inspectors' Reports on Terminal 4 Inquiry, 1979, and Terminal 5, 1997

The problems at other UK airports are significant and important to those affected, but they are not in any way of comparable magnitude to those at Heathrow.

HACAN and other environmental groups produce many documents criticising airports policy and operations. One of the themes appears to be to 'detach' Leq from its roots in measured disturbance of communities exposed to aircraft noise. HACAN ClearSkies [10] is a recent document on Leq, which provides some examples of current arguments about Leq.

The Fact	The disturbance ratings of communities exposed to aircraft noise correlated very highly with Leq.
The ANIS Expert Witness	Leq indicates average, long-term noise impact: it does not provide answers to all possible questions.
The Inspector	The expert witness for the Department did not attempt to hide the deficiencies of LAeq measures…The evidence confirms the Department's view that the contours are not faultless…
The Environmental Group	An admittance by the Government that the way it currently assesses aircraft noise is faulty.

Table 2. How the message changes about Leq

One of problems with such documents is what might kindly be called 'semantic shift'. Table 2 is an example: the words are slightly simplified (but not distorted) quotes. Thus, what starts as scientific statements, intended to indicate statistical precision, is 'spun' into a spurious admission of failed research.

The major fallacy in the HACAN ClearSkies arguments is that they ignore that Leq was derived through ANIS from the disturbance ratings of people and communities exposed to aircraft noise. Leq is a physical measure but it was chosen specifically because it matches the annoyance responses of people.

Table 3 responds to some of the points made in the HACAN ClearSkies Press Release.

HACAN ClearSkies text	Response
[DfT] Gives undue weight to the noise of each aircraft passing overhead and not enough weight to the number of planes.	Not so, the weighting is what matches people's annoyance responses best.
[DfT] Refuses to measure low-frequency noise - the rumble and roar of an aircraft…[dBC] should be used to allow low-frequency noise to be captured.	A-weighted dB was used because dBA correlates well with certification units PNDB and EPNDB, which are specifically chosen to match people's perception of individual noise events. The measured high correlation was between disturbance and Leq dBA. [dBC may be preferable in evaluating sounds whose low-frequency components are responsible for secondary effects such as the shaking of a building, window rattle, and perceptible vibrations.]
[Leq] Doesn't reflect the real level of noise people experience when a plane passes overhead. This is because the Department includes the quiet times of the day, and the quiet days of the year, when averaging out the noise.	Leq values are calculated for an average summer day, rather than for those days in which the airport operational mode produces the highest noise for the location in question – the 'worst mode'. If worst mode were to be used, then someone receiving worst mode for 75% of the time would be equated with someone else receiving the same Leq value for 25% of the time. In ANIS, three-month average mode Leq correlated highly with people's annoyance.
At Sydney Airport…maps are produced showing the density of air traffic, and also maps giving information such as the number of noise events above 70dBA on an average day…	The number of such noise events does not correlate as well with community disturbance as Leq, so the data would paint a misleading picture.

Table 3. Responses to key points made in HACAN ClearSkies Press Release

7 WEIGHTINGS: LEQ VERSUS Lden

Lden is the day/evening/night noise index. If L_{day}, $L_{evening}$, L_{night} are the Leq values for those periods, covering 12, 4 and 8 hours respectively, then Lden is the (logarithmic) average of L_{day}, $L_{evening}$ + 5, L_{night} + 10. So it is the ordinary Leq except that flights in the evening have 5 dBA added to their energy value and those at night have 10 dBA added. A variant DNL has no weighting applied to the evening and a 9 (*sic)* hour night-time period. Lden has been put forward as the European Union common indicator [11, 12].

Statistical evidence from ANIS yielded no support for the inclusion of a night weighting in a noise exposure index, and indicated that an appropriate evening weighting would be less than 3dB. The experimental and statistical justification for these 'precise' weightings in the acoustics research literature is weak. The origins for them are discussed in section 2.5.1 of Critchley and Ollerhead [2], referring back to Ollerhead [13]. The weightings first started to appear – as hypothesized values? – in USA literature in the 1960s and '70s, but they were not supported by statistically significant quantitative evidence.

Fields [14] found considerable variations in the estimates of evening and night-time weightings from a detailed re-analysis using multiple regressions of previous studies. Fields explains that these estimates of the weightings from multiple regressions are unreliable because the day, evening and night noise environments are highly inter-correlated (so the clever de-correlation of ANIS cannot be extended – hence 24 hour Leq and Lden would match the ANIS annoyance data about as well). There was certainly a high correlation between day and evening exposures in the ANIS areas, but a marked change in the diurnal pattern would be an additional reason for properly designed follow-up to ANIS. In recent work, Miedema et al [7] found evidence to support a 10 dBA night-time weighting, but no strong evidence for an evening penalty (which remains an unverified hypothesis). However, when they reanalysed the ANIS data, their techniques 'weakly' support such a weighting. Remember that UK noise policy treats night disturbance, mainly through sleep interference, as distinct from annoyance.

8 FINAL COMMENT

The DfT civil servants gave every indication that they wanted ANIS to be objective and unbiased. The Report was ready in December 1984, but publication was delayed until the next month – because the DfT did not want to be accused of 'burying it' at Christmas-time.

A version of this paper is to be published in Acoustics Bulletin.

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