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THE MODELLING OF SOURCE SPECIFIC AND TOTAL NOISE ANNOYANCE USING SOURCE SPECIFIC NOISE MEASUREMENTS.

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1. INTRODUCTION

The influence of background noise on aircraft noise annoyance is a long-standing issue that has not been resolved in previous laboratory and field studies. The general feeling in scientific circles is that whilst the effects are felt to be second order to those of level and number, they nevertheless still need to be quantified.

This paper presents the results of a small scale study designed to provide some initial field evidence on the magnitude of the background noise effect. In addition the data collected allow the relationship between total noise annoyance and source specific noise levels to be evaluated.

2. DESIGN OF THE STUDY

The study was carried out as an extension to the 1982 CAA Aircraft Noise Index Study (ANIS) and used a subset of the study areas already chosen for the ANIS study. The areas were delineated by the restriction that any respondent within an area must experience an aircraft noise level within a maximum of 3 or 4 dB of that measured at the single aircraft noise monitoring site for the area. Within each area two zones were chosen such that background noise level within each zone was as homogeneous as possible and that the difference between the background noise levels for each zone was a minimum of 15 dB(A), with the low background level being of the order of 50 dB(A). The noise measurement used was the 12 hour L_{Aeq} (0700-1900 BST). As comparisons between zones within areas were of direct interest target sample sizes for the social survey were made equal for all zones (circa. 40 based upon the available resources). With an expected response rate of 75%, a maximum sampling fraction of 1/3 and one respondent per household, each zone needed to contain at least 160 households. The design details are given in Table 1.

3. DATA RECORDED

3.1 *Aircraft noise exposures* were recorded as the average and worst mode NNI and L_{Aeq} values over the twelve hour period 0600-1800 GMT. The data are displayed in Table 3. The characteristics of the areas may be summarised as: *Chiswick* situated on the eastern side of the airport, north of the line of the runways. Noise exposure solely from westerly landings. Usually no direct overflights. Difference between worst and average mode noise exposures about 3 dB; *Stanwell and Horley* no direct overflights but start of roll noise, and noise from aircraft turning after take off. Little difference between worst and average mode noise exposure; *Harlesden and Feltham* direct overflying by easterly departures. Some westerly turning (Harlesden) and approach noise (Feltham). Difference between worst and average noise exposure (6dB), largest in the study.

3.2 *Background noise*; all noise other than aircraft, with traffic noise predominant. Average background L_{Aeq} varied between 49 and 55 dB(A) in the low, and 64 and 69 dB(A) in the high zones. Within areas the separation between zones varied between 13 and 18 dB(A) (Table 3). Within zones the standard deviations (over individual respondents) of the estimated background noise level was of the order of 2 dB(A) except at Chiswick.

Background and aircraft L_{Aeq} values were combined to produce total L_{Aeq} values and Signal (Aircraft) to Noise (Background) measures for each zone (Table 3). The difference in total noise levels between zones decreases with increasing aircraft noise level from > 10 dB(A) at Chiswick and Stanwell to < 5 dB(A) at Horley and Feltham.

3.3 *The questionnaire* asked the noise annoyance questions in Table 2. The response rates, sample sizes and the means and standard deviations of these noise annoyance responses are given in Table 3.

4. RESULTS

4.1 *Differences between zones within areas.* Aircraft noise annoyance at Harlesden (for all 3 measures) is significantly greater in the low zone than in the high zone. At Horley and Chiswick the differences are in the same direction as at Harlesden, but the observed values range from about 1.5 to 0.5 times their standard errors. At Stanwell and Feltham the differences are much smaller than at Horley and Chiswick, and in all but one case, negative. None of the differences at Horley, Chiswick, Stanwell and Feltham is significantly different from zero at the 5% level.

Between zone within area differences are likely to be free of other effects which may be confounded with the effect of background noise levels on response to aircraft noise. An exhaustive investigation of the social, demographic and other characteristics has not shown differences between zones, which might have an increasing or decreasing effect on annoyance responses. Harlesden was the only area in which significantly greater aircraft noise annoyance was found in the low zone. A factor which could explain this is the larger differential between the high and low zones, occasioned by slightly higher than average background noise levels in the high zone. The low response rate (45%) in the high zone may have introduced a bias in the measured reactions.

4.2 *Modelling the Aircraft Noise Annoyance Relationships.* Table 3 demonstrates the dangers of pooling the information from the five areas to estimate noise-annoyance relationships. For example, if average mode NNI is used to explain aircraft annoyance then whilst higher NNI values are generally associated with greater aircraft noise annoyance, this increased annoyance may equally well be attributed to other characteristics which vary in a similar way between the areas e.g. average mode less worst mode NNI, proportion of residents in social classes I and II. Despite these caveats some possible model forms are described and estimated.

4.2.1 *A suggested behavioural model.* Reactions to aircraft noise may only differ in the presence of high and low background noise if the level of aircraft noise were high enough to dominate the low but not so high as to dominate the high background noise environment. If aircraft noise were very high, then it would dominate both the low and the high background noise environments and no difference in the reaction to aircraft noise would be expected. Similarly, if the aircraft noise were very low then it would be an insignificant feature of both the low and high background environments and no difference in the reaction to aircraft noise would be expected. A possible functional form is displayed in Figure 1. Although many features of aircraft noise could influence the effect of background noise, previous studies have shown that the number of events above a given threshold and the peak noise level of the events are important correlates of the level of annoyance.

Figure 2 shows curves which locate equal doses of aircraft noise (NNI = 33, 35, 40 and 42 respectively). The levels of background noise in the low zones range from 49 to 54 L_{Aeq} and in the high zones from 64 to 69 L_{Aeq}. Thus the levels of aircraft noise that might be expected to dominate the low background noise environment but not the high background noise environment range from 33 to 35 NNI up to 40 to 42 NNI, say. Figure 2 indicates the position of the five study areas with respect to the band within which a background noise effect might be expected, and suggests that the expected rank order of differences between reactions to aircraft noise in the low and high background noise zones would be those shown in Table 4, which also displays the rank orders based upon the observed differences shown in Table 3.

The proposed model seems plausible. The limited number of areas in the current study does not allow it to be investigated further. The consistent ranking of Stanwell, which has a large number and small noise level (Table 1) suggests that level and number may not be the appropriate way of expressing dominance. Rice and Izumi (1984) present laboratory data which support this model.

4.2.2 *Regression Models of Aircraft Noise Annoyance*. The three aircraft noise annoyance measures have intercorrelations of the order of 0.8 and the two aircraft noise measures have an intercorrelation of 0.98. The correlations between NNI and the annoyance measures are 0.51 (4 pt. scale), 0.45 (7 pt. scale) and 0.51 (Guttman Scale) and the corresponding L_{Aeq} correlations are 0.48, 0.42 and 0.48. The conclusion is that alternative models with the three annoyance variables are unlikely to be very different either in functional form or interpretation. To aid comparison with previous work the models with the Guttman Annoyance Scale (GAS) score as the dependent variable and independent variables aircraft NNI and traffic L_{Aeq} are presented. Figure 3 displays the GAS scores for the ten zones together with their standard errors. An analysis of variance shows that the linear component of the variation with NNI is more important than the non-linear component in both high and low backgrounds. The significant non-linear effect in the high zones is attributable almost entirely to the response in the high zone at Harlesden. Previous studies using a larger range of NNI values have postulated a sigmoid-type relationship in which response is constant below and above specified NNI levels, but increases linearly between these values. The range of NNI values used in this study are from the straight line segment of such sigmoid curves. This, and the previous caveats concerning the low response rate in the high zone at Harlesden, suggest that the non-linear features observed are merely sampling or non-sampling error and that a linear relationship is the appropriate one.

4.2.3 *Linear Regression Models for GAS Scores*. The regression of the Guttman Annoyance Scale Scores on average mode NNI, a dummy for background noise level and an interaction term, (with standard errors of coefficients in brackets) is:

$$GAS = -4.655 + \underset{(0.023)}{0.181}\ NNI - \underset{(1.228)}{0.772}\ \frac{\text{Background}}{\text{Noise Dummy}} + \underset{(0.032)}{0.002}\ NNI \times \frac{\text{Background}}{\text{Noise Dummy}}$$

The separate models for high and low background noise zones are:

(low) $GAS = -5.427 + 0.183\ NNI$; (high) $GAS = -4.655 + 0.181\ NNI$

The slopes are equal within sampling error. The parallel regression lines fitted to the high and low zones are:

(low) $GAS = -5.065 + 0.191\ NNI$; (high) $GAS = -5.051 + 0.191\ NNI$

The intercepts are not significantly different at the 5% level. The common regression equation fitted to both zones is:

$$GAS = -5.046 + \underset{(0.016)}{0.191}\ NNI$$

This model explains 26% of the variation in the GAS Scores. Figure 4 displays the fitted line together with its 95% confidence band. The fitted equation from previous studies is also plotted. This lies outside the confidence band indicating a noise-annoyance relationship which is significantly steeper (at the 5% level) than that in previous studies. This may be the result of a real change in community response or, at least in part, an artefact of the current study design which used areas tightly clustered around aircraft noise measurement sites with the result that measurement error in the NNI values was posssibly smaller than previously.

4.3 *Linear Regression Models of Total Noise Annoyance using NNI and Background Noise level as independent variables*

Figure 5 displays the aircraft, traffic and total noise annoyance (4 point) scale score regressions. Background noise levels average about 52 L_{Aeq} in low zones and 67 L_{Aeq} in high zones. In the low background noise zones as soon as aircraft NNI exceeds about 33-34 (equivalent to an aircraft L_{Aeq} of approximately 55-56), then on average the expressed aircraft annoyance exceeds the expressed total annoyance which in turn exceeds the expressed traffic annoyance.

Aircraft annoyance increases more than twice as rapidly as total noise annoyance with increasing NNI, whereas traffic noise annoyance is independent of NNI. In the high background noise zones the pattern is the same, except that it begins when aircraft noise exceeds 40 NNI, equivalent to approximately 62 L_{Aeq}.

The Total NAS regressions fit the data much less satisfactorily (less than 10% of the total variation explained) than the source specific annoyance scale score regressions. Two possible explanations are (i) that the total noise annoyance question is invalid i.e. either its wording or its context in the questionnaire mean that the responses do not in fact reflect total noise annoyance or (ii) total noise annoyance is strongly influenced by other features of the environment which have not been measured. Since the total noise energy in the environment is almost solely that from the aircraft and background sources, the first of these hypotheses seems the more plausible. This is further supported by the fact that in this study total annoyance responses were solicited at ANIS Question 7, before any detailed mention had been made of noise at all. It is not unreasonable to suppose therefore that 'round here' was taken to refer to the respondent's immediate environment and that the total annoyance judgement related to this background (mainly traffic) noise, and excluded aircraft which were considered as being 'up or over there'.

5. CONCLUSIONS

Influence of background noise levels. There is no strong evidence to suggest that background noise plays a significant role in the annoyance responses to aircraft noise for *all levels* of aircraft noise. In Chiswick, Stanwell and Feltham no significant differences were noted between aircraft noise annoyance responses in the low and high zones. At Horley there was the suggestion of an effect, whereas at Harlesden, aircraft noise was significantly more annoying in the low zone than in the high. Three possibilities have been explored: (i) that Harlesden has particular socio-economic characteristics which explain the different response to aircraft noise. This is not supported. (ii) that the lower response rate in the high zone at Harlesden means that part of the explanation for the differences observed may be non-response bias. (iii) that a new behavioural model of the response to aircraft noise is appropriate. This model is consistent with the differences observed but without more extensive data it is not possible to argue that it offers a definitive explanation of them.

Modelling Total Annoyance. In future it is proposed that at the end of the questionnaire a supplementary question based on the 4 point 'very much', 'moderately', 'a little' and 'not at all' annoyed scale be included as follows:

> During this interview you have been asked about your annoyance reactions to many kinds of noise including aircraft and traffic. Just to be sure I have your reactions correct could you please finally tell me how bothered or annoyed you are by
>
> (a) aircraft noise
> (b) traffic noise or (b) noise other than aircraft noise
> (c) the total noise

A similar question has been used successfully in laboratory studies of combined impulse and traffic noise (Rice, 1984) and combined aircraft and traffic noise (Rice and Izumi, 1984) and shows that subjects can integrate the separate aircraft and traffic responses into a subjectively summed total response which can then be modelled.

6. REFERENCES

1. DORA 1981. Communication 7907: The Noise and Number Index.
2. C.G. RICE 1984. Proc. of 4th Int. Cong. Noise as Public Health Hazard 2, 1073-84. CEC Joint research on annoyance due to impulse noise: laboratory studies.
3. C.G. RICE, K. IZUMI 1984. Session C Paper. IOA Spring Conference. Annoyance due to combinations of Noises.

7. ACKNOWLEDGEMENT

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Table 1: Details of Target Design for Study.

Area	Area Number	Nominal Aircraft Noise Level (PNdB)	Nominal Number of Aircraft per 24 hours	Nominal NNI Level	Target Low Background Noise Level L_{Aeq}, 24h (Target sample size)	Target High Background Noise Level L_{Aeq}, 24h (Target sample Size)
Harlesden	2	95	31.6	37.5	52 (40)	67 (40)
Chiswick	8	83	56.2	29.3	52 (40)	67 (40)
Feltham	9	101	100.0	51.0	52 (40)	67 (40
Stanwell	16	83	177.8	36.8	52 (40)	67 (40)
Horley	23	89	277.0	42.0	52 (30)	67 (50)

Table 2: Noise Annoyance Questions in Questionnaire.

7. Taking all things into account, how much would you say the noise round here bothers or annoys you? SHOW CARD: Very much, Moderately, A little, Not at all.

11A. (Aircraft) Please look at this scale and tell me how much the noise of aircraft here bothers or annoys you. SHOW CARD: Very much, Moderately, A little, Not at all.

11A. (Traffic) Repeat of above aircraft question for traffic.

17. Guttman Item questions as in previous aircraft noise studies (see DORA (1981))

Do the aircraft ever ....?

When they ...., how annoyed does this make you feel?

23. Just to be sure I have it all straight, how do you feel overall about the amount of noise here from aircraft?

Please give how you feel a score out of seven.

SHOW CARD: 1 2 3 4 5 6 7
Definitely satisfactory ... Definitely NOT satisfactory

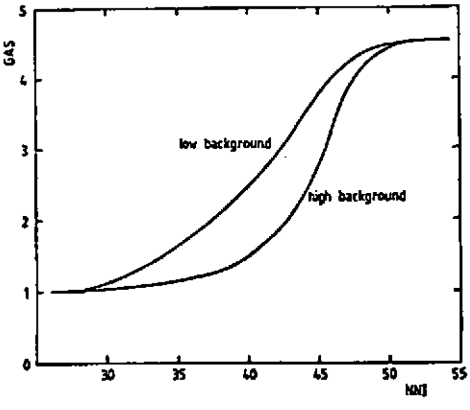

Figure 1: Possible Form of a Model.

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Table 3: Mean values of Noise Exposures and Subjective Reactions by zone. Estimated range of aircraft peak levels (L) is shown. Standard Errors of Annoyance Measures and Standard Deviations of Background and Total Noise Exposures are given in brackets.

AREA	CHISWICK		STANWELL		HARLESDEN		HORLEY		FELTHAM	
ZONE	Low	High	Low	High	Low	High	Low	High	Low	High
Aircraft Noise										
NNI (average)	32.6	32.6	32.7	32.7	37.8	37.8	42.3	42.3	44.7	44.7
NNI (worst)	37.3	37.3	33.5	33.5	45.6	45.6	42.2	42.2	52.8	52.8
L_{Aeq} (average)	54.9	54.9	57.4	57.4	60.9	60.9	64.6	64.6	66.4	66.4
L_{Aeq} (worst)	56.1	56.1	57.9	57.9	66.5	66.5	65.2	65.2	72.0	72.0
Range	(3)		(4)		(2)		(3)		(5)	
Aircraft Annoyance										
4 pt. scale	1.09	0.93	0.88	0.86	1.33	0.67	1.62	1.34	2.38	2.31
(0 to 3)	(0.13)	(0.13)	(0.12)	(0.13)	(0.17)	(0.13)	(0.13)	(0.18)	(0.11)	(0.12)
7 pt. scale	1.97	1.88	1.06	1.51	2.41	1.15	2.84	2.48	3.69	4.00
(0 to 6)	(0.30)	(0.24)	(0.18)	(0.22)	(0.28)	(0.22)	(0.26)	(0.32)	(0.25)	(0.23)
Guttman	1.54	1.75	1.00	1.26	2.03	1.00	2.89	2.59	3.90	3.90
(0 to 6)	(0.27)	(0.23)	(0.22)	(0.24)	(0.27)	(0.22)	(0.24)	(0.38)	(0.19)	(0.20)
Background Noise										
L_{Aeq}	54.6	67.4	52.5	67.7	50.9	69.3	49.1	64.4	52.0	67.2
	(1.7)	(8.0)	(1.6)	(2.0)	(0.7)	(0.8)	(2.7)	(1.9)	(2.6)	(3.0)
Traffic Annoyance										
4 pt. scale	0.71	1.62	0.66	1.34	0.64	1.48	0.43	1.07	0.74	1.57
(0 to 3)	(0.18)	(0.18)	(0.12)	(0.15)	(0.15)	(0.22)	(0.09)	(0.19)	(0.14)	(0.15)
Total Noise										
L_{Aeq}	57.8	68.0	58.7	68.2	61.3	69.9	64.7	67.6	66.6	70.0
	(0.7)	(7.3)	(0.5)	(1.8)	(0.1)	(0.7)	(0.1)	(0.8)	(0.1)	(1.4)
*Signal to Noise	0.3	-12.5	4.9	-10.3	10.0	- 8.4	15.4	0.2	14.4	- 0.8
	(1.7)	(8.0)	(1.6)	(2.0)	(0.7)	(0.8)	(2.7)	(1.9)	(2.6)	(3.0)
Total Annoyance										
4 pt. scale	1.00	1.27	0.78	1.33	1.18	1.22	1.31	1.38	1.69	1.90
(0 to 3)	(0.16)	(0.18)	(0.10)	(0.14)	(0.18)	(0.19)	(0.13)	(0.19)	(0.13)	(0.13)
Response Rate (%)	50	80	83	78	65	45	73	81	65	78
Base	35	40	50	47	40	27	61	29	40	48

*Aircraft L_{Aeq} less Background L_{Aeq} (both measured over the NNI period)

Table 4: Differences in Aircraft Annoyance between High and Low Background Noise Zones.

	Rank order of differences			
Area	Predicted from Behavioural Model	Observed 4 pt. Scale	Observed 7 pt. Scale	Observed Guttman Score
Harlesden	1	1	1	1
Horley	2	2	2	2
Stanwell	3	5	5	5
Chiswick	4	3	3	4
Feltham	5	4	4	3

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Figure 2:

Observed Aircraft Noise Environments of areas plotted in Peak noise Level (L) and number of Events (above 80 PNdB cut-off) (N) space.

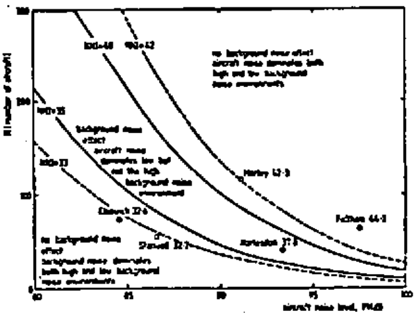


Figure 3: Mean GAS scores and ± 2 standard errors of the mean band for each zone.

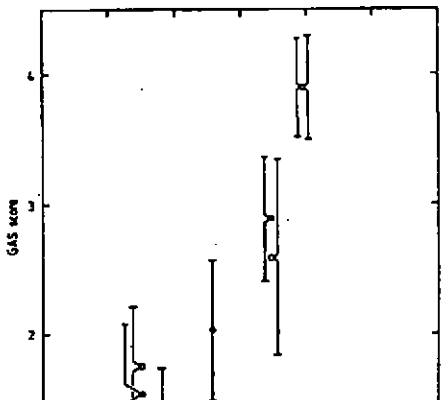
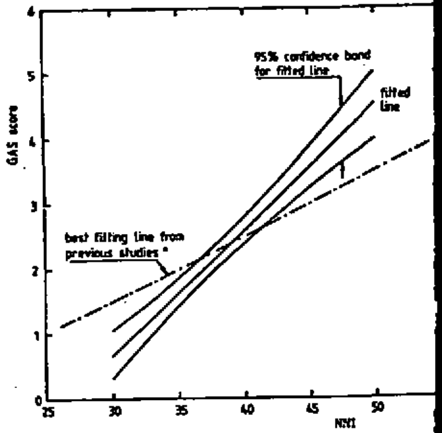


Figure 4: Best fitting linear regression model for GAS score



* DORA 7907 figures 6 and 7

Figure 5: Regression of Aircraft, Total and Traffic 4 point Annoyance Scale Scores on NNI and Background level