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EQUIVALENT VALUES OF TRAFFIC, AIRCRAFT AND INDUSTRIAL NOISE.(U)
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EQUIVALENT VALUES OF TRAFFIC, AIRCRAFT AND INDUSTRIAL NOISE

by B F Berry

Approved on behalf of Director, NPL by
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NATIONAL PHYSICAL LABORATORY

Teddington, England

(6) Equivalent values of traffic, aircraft and industrial noise.

by (9) Acoustics rept.,

(10) B. F. Berry

Summary

L sub 1Ø

Equivalent values of traffic, aircraft and industrial noise, as rated by the separate indices L_{10} (18 hour), Noise and Number Index (NNI), and Corrected Noise Level (CNL) respectively, are derived by a translation method which uses L_{eq} and L_{NP} as intermediate measures. L sub eq and L sub NP

L sub 1Ø

The value of NNI numerically equivalent to a particular value of L_{10} as derived by the L_{eq} translation differs by approximately 10 units from that derived by the L_{NP} translation. The origins of this numerical difference are outlined and the implications discussed.

L sub eq

L sub NP

Evidence is presented which suggests that L_{NP} is the more appropriate measure to use in equating levels of separate indices in terms of acceptability.

L sub 1Ø

The result of the translation from L_{10} to NNI using L_{NP} confirms the implied equivalence between the traffic and aircraft noise criteria recommended in the Department of the Environment Circular 10/73, 'Planning and Noise', within the tolerance imposed by the limitations of the respective descriptors.

(A)

CONTENTS

1. INTRODUCTION

The three major sources of noise, and annoyance, in residential communities - traffic, aircraft and industrial premises - are currently assessed in the United Kingdom for environmental planning purposes by three separate noise indices, L_{10} (18-hour), daytime Noise and Number Index NNI, and Corrected Noise Level CNL, respectively.

There is currently much debate about whether the coexistence of these and other rating methods represents a satisfactory situation and as Schultz (1972) concludes, "For each particular task one must, like a skilled woodworker, select a tool that is neither more nor less complex than is needed for the job", or whether a unified noise index and a unified system of assessment applicable to all sources is required.

The importance of this question is illustrated by the recognition, on the part of the Acoustical Society of America, at a recent Conference on Acoustics and Societal problems (Johnson and Stuart, 1973) of the need to "develop, in conjunction with other related societies, a uniform set of definitions, measurement techniques and evaluation procedures used to assess man's acoustic environment, particularly with regard to community noise and its sources, such as motor vehicles, aircraft and industrial and construction equipment".

The Research Sub-Committee of the Noise Advisory Council is also studying the question of noise units and the necessary careful consideration will of course take time. Meanwhile we must make the best use of the separate indices to tackle today's problems.

One difficulty which arises in the present situation is that of comparison of numerical values on the separate rating scales and of translation between them. Research is in progress in the United States (Copley, 1973) but efforts have already been made in this direction by Robinson (1972) in which traffic noise at $L_{10} = 70$ dB(A) was compared with industrial noise. The results of this exercise were used by the Department of the Environment in the preparation of a Circular to Local Authorities in England and Wales laying down principles and specific criteria for guidance in planning decisions (Department of the Environment, 1973). Guidance is also given in the Circular on aircraft noise, this being based upon a policy evolved by planning authorities whose areas are affected by Gatwick airport.

In this report we extend the scope of the earlier work of Robinson in two directions, firstly to include aircraft noise in the numerical translation and so test the validity of the recommendations in the Circular and secondly to consider the effects of reducing the traffic noise limit from $L_{10} = 70$ dB(A) to $L_{10} = 65$ dB(A).

2. DERIVATION OF EQUIVALENT VALUES

2.1 Outline of approach

An estimate is made of the form of the distribution of noise levels in the traffic noise condition. From this, translation values of L_{eq} and L_{NP} corresponding to a given value of L_{10} are estimated. The levels of industrial noise, and aircraft noise, as rated by CNL and NNI respectively required to produce these translation values of L_{eq} or L_{NP} are then determined. This initial derivation of translation values is the key element in the exercise whether we are equating traffic noise to industrial, aircraft or any other noise. This is therefore a good opportunity to reassess the earlier derivation before going on to look at the effect of reducing L_{10} to 65 dB(A).

2.2 Traffic noise conditions

To recapitulate on the approach used, the results of two noise surveys (Delany et al, 1971; Noise Abatement Group, 1971) were examined and a sample of results taken from each in which L_{10} lay in the range 65-75 dB(A). For these samples the mean and dispersion of the value of $(L_{10} - L_{90})$ were calculated. The results of this calculation for the combined sample were then inserted in equations relating L_{NP} and L_{eq} to $(L_{10} - L_{90})$ for the case of a Gaussian distribution of noise levels. In this way $(L_{NP} - L_{10})$ and $(L_{eq} - L_{10})$ were estimated. This estimate was then compared with that obtained from the Noise Abatement Group (Medford) data in which L_{NP} and L_{eq} had been calculated directly from the noise level distributions. From the two estimates an overall estimate of L_{NP} and L_{eq} for the condition $L_{10} = 70$ dB(A) was obtained.

Retracing these steps it was noticed that of the 51 examples from the data of Delany et al in which L_{10} lay in the range 65 to 75 dB(A) many were not independent in that they resulted from common time samples recorded at different microphone heights or positions. The data were reassessed and 22 independent samples found in the same range. For these the mean value of $(L_{10} - L_{90})$ was 9.4 with standard deviation 1.9.

To deal with the lower value of L_{10}, i.e. 65 dB(A), a sample of 27 was taken for which L_{10} lay in the range 60 to 70 dB(A). For these the mean value of $(L_{10} - L_{90})$ was 7.9 with standard deviation 2.4.

A slight change of approach is also indicated by re-examination of the Medford data. Of the 46 examples with $65 \leq L_{10} \leq 75$ dB(A) in the earlier exercise 8 refer to measurements during the night-time period (00.01 to 06.00 hours) in 24-hour surveys at two sites near the Interstate 93 highway. Although the number of such examples is small the effect on the estimate of $(L_{10} - L_{90})$ is great since the night-time values of this can be as much as 8 dB more than those found in daytime at the same site, a deviation as big as the quantity itself. Also since the translation refers to the 18-hour value of L_{10}, i.e. 06.00 to 24.00 hours, it would appear to be more correct to exclude night samples.

Of the other sites from which sample measurements were taken one was in a predominantly industrial area and the L_{10} levels were dominated by individual events such as stationary trucks idling and rail-freight cars being switched on nearby tracks. Another was in a residential area where the L_{10} levels would not have exceeded 60 dB(A) but for the influence of children playing in the street nearby.

Although it is true that conditions such as those above are more realistic of urban areas, in establishing the nature of conditions due to traffic noise some degree of "editing" is required, albeit post-hoc.

A new selection of Medford results was therefore made. This included those obtained in the period 06.00 to 24.00 at the two 24-hour survey sites close to the Interstate 93 highway and a sample from the 44 locations at which measurements were taken during the morning rush-hour and midday periods on weekdays. This latter sampling was again done on the basis of proximity to the major highway.

This selection produced 32 examples with $65 \leqslant L_{10} \leqslant 75$ dB(A). For these the mean value of $(L_{10} - L_{90})$ is 8.3 with standard deviation 3.6. Also there are 51 samples with $60 \leqslant L_{10} \leqslant 70$ dB(A) for which the mean value of $(L_{10} - L_{90})$ is 7.8 with standard deviation 2.5.

Combining the results from the two surveys within each range of L_{10} values we obtain the following:-

$65 \leqslant L_{10} \leqslant 75$ dB(A): $L_{10} - L_{90}$, mean = 8.8, S.D. = 3.0

$60 \leqslant L_{10} \leqslant 70$ dB(A): $L_{10} - L_{90}$, mean = 7.8, S.D. = 2.5

Now using the combined distribution of $(L_{10} - L_{90})$ values within each range and the equations:-

$$L_{eq} - L_{10} = -\tfrac{1}{2}(L_{10} - L_{90}) + (L_{10} - L_{90})^2/57$$

$$L_{NP} - L_{10} = \tfrac{1}{2}(L_{10} - L_{90}) + (L_{10} - L_{90})^2/57$$

we obtain the following results:

	$65 \leqslant L_{10} \leqslant 75$ dB(A)	$60 \leqslant L_{10} \leqslant 70$ dB(A)
$L_{eq} - L_{10}$	Mean = -2.9, S.D. = 4.4	Mean = -2.7 S.D. = 4.4
$L_{NP} - L_{10}$	Mean = 5.9, S.D. = 2.7	Mean = 5.1 S.D. = 2.1

Looking next at the values of L_{NP} and L_{eq} calculated directly from the noise level distributions in the Medford survey we obtain:

	$65 \leqslant L_{10} \leqslant 75$ dB(A)	$60 \leqslant L_{10} \leqslant 70$ dB(A)
$L_{eq} - L_{10}$	Mean = -2.7, S.D. = 1.4	Mean = -2.6 S.D. = 1.4
$L_{NP} - L_{10}$	Mean = 6.1, S.D. = 3.8	Mean = 6.1 S.D. = 3.9

Comparing this result with that in the earlier work we see that the agreement between the empirical and semi-theoretical results is even closer but in this case the semi-theoretical result shows greater dispersion than the empirical for L_{eq} but the opposite is true for L_{NP}.

Comparing the actual values obtained for $(L_{eq} - L_{10})$ and $(L_{NP} - L_{10})$ with those in the earlier work we find, as expected, little change in $(L_{eq} - L_{10})$ and a small decrease in $(L_{NP} - L_{10})$.

Taking again an intermediate position between the empirical and semi-theoretical results above the following values are taken for present purposes as equivalent to the traffic noise conditions:

L_{10} = 70 dB(A)		L_{10} = 65 dB(A)	
L_{NP} = 76.0	± 6.0	L_{NP} = 70.5	± 6.0
L_{eq} = 67	± 6.0	L_{eq} = 62	± 6.0

The tolerances are ± 2 standard deviations

One aspect of this result which at first may seem surprising is that with a difference, between the two traffic noise conditions, of 5.5 dB in L_{NP}, and a tolerance of ± 6.0 in each translation there may exist cases where L_{NP} is greater when L_{10} = 65 dB(A) than it is when L_{10} = 70 dB(A).

Another way of showing that this is possible is to take the equations derived by Delany (1972) for predicting L_{10}, L_{50} and L_{90} at a given distance from a road carrying freely flowing traffic. Using these equations and those in the same report for predicting variation of noise level with distance we see that a condition L_{10} = 70 dB(A) occurs at a distance of 52 metres from a road carrying 2000 vehicles per hour where the mean speed is 80 km/h and the percentage of heavy vehicles is 20. The predicted values of L_{50} and L_{90} are 65.6 and 60.3 respectively. Using the equation:-

$$L_{NP} = L_{50} + (L_{10} - L_{90}) + (L_{10} - L_{90})/57$$

a value of $L_{NP} = 76.9$ is obtained. If the flow rate now drops to 550 vehicles per hour with all other parameters constant then the following levels are predicted at the same point:

$$L_{10} = 65.0 \qquad L_{50} = 57.1 \qquad L_{90} = 48.3$$

The large increase in $(L_{10} - L_{90})$, i.e. 9.7 to 16.7, compensates for the reduction in L_{50} and L_{NP} increases to 78.7.

The important question is, does annoyance follow the 5 dB reduction in L_{10} or the 2 dB increase in L_{NP}? Discussion of this critical point will be deferred until later.

2.3 Industrial noise conditions

In the earlier exercise general formulae for L_{eq} and L_{NP} in terms of the noise levels L_1 and L_2 and the percentage on-time p_2, as defined in British Standard 4142, were derived i.e.

$$L_{eq} = L_1 + 10 \log \left[p_2 \, 10^{(L_2-L_1)/10} + 100 - p_2 \right] - 20$$

$$L_{NP} = L_{eq} + 0.0256 \, (L_2 - L_1) \sqrt{p_2 \, (100-p_2)}$$

Then using the translation values of L_{eq} and L_{NP}, the values of L_1 and L_2 corresponding to various combinations of $(L_2 - L_1)$ and p_2 were calculated from the equations and tabulated. Corrections for intermittency dependent upon the assumed values of p_2 and of t, the on-duration, were then applied and the resulting values of Corrected Noise Level tabulated. The mean and standard deviation of the ensemble of CNL values resulting from the L_{eq} and L_{NP} translations were then determined.

Using the revised translation values of L_{NP} and L_{eq} for the condition $L_{10} = 70$ dB(A) and the new values for $L_{10} = 65$ dB(A) this process has been repeated.

Thus beginning with the A-weighted values $L_{10} = 70$, $L_{NP} = 76$, $L_{eq} = 67$ Table 1 shows values of L_1 and L_2 for the various combinations of p_2 and $(L_2 - L_1)$ on the L_{eq}-basis and Table 2 the same data on the L_{NP}-basis. Blanks appear in Table 2 where L_1 falls below the assumed ambient level L_0 of 50 dB(A) and the corresponding values in Table 1 are bracketed and eliminated. Tables 3 and 4 show the values of L_2, for each translation, when L_1 falls below 50 dB(A). Application of the intermittency corrections results in the two tables of CNL values, Table 5 for the L_{eq} translation and Table 6 for the L_{NP} translation. Summarising the results of each translation:

$$L_{10} = 70 \begin{cases} L_{eq}\text{-basis:} & \text{CNL,} \quad \text{mean} = 70.1 \quad \text{S.D.} = 3.1 \\ L_{NP}\text{-basis:} & \text{CNL,} \quad \text{mean} = 69.1 \quad \text{S.D.} = 6.5 \end{cases}$$

Tables 7 to 12 show the results of the same process for $L_{10} = 65$, $L_{NP} = 70.5$, $L_{eq} = 62$. For this condition the results may be summarised by:

$$L_{10} = 65 \begin{cases} L_{eq}\text{-basis:} & \text{CNL,} \quad \text{mean} = 65.0, \quad \text{S.D.} = 3.1 \\ L_{NP}\text{-basis:} & \text{CNL,} \quad \text{mean} = 65.0, \quad \text{S.D.} = 5.1 \end{cases}$$

The aircraft noise condition will now be considered before bringing all results together for the complete translation.

2.4 Aircraft noise conditions

The daytime Noise and Number Index for aircraft noise combines the number of aircraft heard in the period 06.00 to 18.00 hours with the logarithmic average of their individual peak perceived noise levels L_{imax} (PNdB) in the formula:

$$NNI = 10 \log_{10} \left[\frac{1}{N} \sum_{i=1}^{N} 10^{L_{imax}/10} \right] + 15 \log N - 80$$

In order to relate NNI values to values of L_{10} and CNL by means of the translation values of L_{eq} and L_{NP} we need details of:-

1) the time history of the noise level during each aircraft flyover.
2) the distribution of background noise levels during the period.

We then combine the aircraft noise with the background noise, to produce the indices of total noise exposure L_{NP} and L_{eq}, by treating the aircraft noise and the background noise as series of samples of noise level in dB(A). A given flyover might appear at any point in the pattern of background level fluctuations and its impact upon the total noise would depend upon its "relative phase". To allow for all statistically possible cases we must combine each sample of the aircraft noise with each sample of the background noise.

2.4.1 Prediction of aircraft noise time history

The main factors affecting the noise time history are:-

1) noise source characteristics of the aircraft
2) position of the aircraft with respect to the observer during the course of the flyover
3) velocity and acceleration of the aircraft
4) atmospheric conditions

A variety of systems, some very sophisticated, have been developed to incorporate the above and other factors in the prediction of aircraft noise exposure (Spencer and Meyer, 1972; Beland et al, 1972; Dickinson and Cooper, 1971; Serendipity, 1970). For the present purposes and with the limited time available a relatively simple computer model has been used which incorporates the following features.

All aircraft are considered as belonging to one of three classes dependent upon basic noise characteristics and operational performance, following the classification used in the Department of Trade and Industry method for NNI predictions (as described by Lam, 1972):

Medium Jets - 2- and 3-engine aircraft such as the Trident, BAC 1-11, Boeing 727 and DC9.

Large Jets - 4-engine aircraft such as Boeing 707 and 720, DC8 and VC10.

Jumbo Jets - Boeing 747.

Aircraft of the types within these classes predominate in the transport movements at the major British airports (British Airports Authority, 1972).

The directivity of the intrinsic noise source (for all classes) is incorporated by assuming the axially symmetrical radiation pattern shown in Fig. 1. When θ, the angle between the jet axis and the line joining the aircraft to the observer is less than 90 degrees the rear lobe due to primary jet noise is modelled by the function $1 + \sin 2\theta$. This function has some basis in the theory of jet noise (Lighthill, 1952) and the pattern is very similar to those observed for modern turbofan engines (Serendipity, 1970; Environmental Protection Agency, 1971).

In this report only take-off operations have been considered but the results would not be significantly different for landings with the possible exception of an observation point directly under the glide path which however is a more specialised case than we are concerned with here. On take-off each aircraft is assumed to follow the altitude distance profile appropriate to its class, shown in Fig. 2. The upper profile, for medium jets, is derived from current operating practice for the Trident 3 and BAC 1-11 (see Acknowledgement). The other profiles are estimates derived from a study of profiles used in various prediction models.

Computation is simplified if the aircraft are assumed to be at altitudes greater than 900 m (3000 feet) and in the accelerating, steady climb-out segment of the operation following the steep take-off and transition phases. Accordingly an observation point at 24 km (80,000 feet) from start of roll is considered. All aircraft are assumed to be climbing at a rate of 300 m (1000 feet) per minute and to be accelerating at a constant rate of 0.5 $m.sec^{-2}$ (1 knot per second) from an initial speed of 99 m per second (195 knots) at the start of the segment. These are typical values for the aircraft types considered.

In the model each of the three classes of aircraft, following its own particular vertical flight profile, may travel along one of 5 horizontal paths, A - immediately over the observation point, B - passing 1 mile either side of the observation point and C - passing 2 miles either side of the observation point. There are thus nine different noise time histories possible at this point.

A computer program is used to calculate, at 1 second intervals during the climb-out segment, the distance from the observation point to the aircraft and the angle θ. The reference noise level relevant to the particular aircraft class is then corrected for directivity and for distance using the 8 dB(A) per doubling of distance rule. The actual reference levels used and the correction for distance were those used in the DTI procedure for NNI prediction (Lam, 1972 Appendix 1). The program then prints out the noise level at every second during the overflight for a period of 50 seconds before the peak level is reached to 50 seconds afterwards. This sampled noise time history is stored for later use. In this way the nine possible noise time histories were generated.

2.4.2 Background noise

When sampled over a substantial period of time such as the 18 hours considered here, typical residential area background noise approximates to a Gaussian distribution of levels. The noise is therefore fully defined by the median level, L_{50} in dB(A), and the standard deviation of the noise level variations s. In practice it is useful to define the noise climate $(L_{10} - L_{90})$ which corresponds to 2.56 s.

To estimate representative values for L_{50} and $(L_{10} - L_{90})$ we can make reference to several general noise surveys. The results of these as they relate to average suburban residential areas are brought together in Table 13. The range of L_{50} values, 41 to 61 dB(A), is typical of such areas. $(L_{10} - L_{90})$ may vary even more than indicated in this table but a value of 10 dB is typical. Accordingly three background noise conditions are assumed with L_{50} = 40, 50 and 60 dB(A) and in all cases $(L_{10} - L_{90})$ = 10 dB.

A computer program is used to generate the required Gaussian distribution of 64,800 samples of sound level in dB(A). This corresponds to one sample per second for 18 hours. The resultant distribution is in the form of a histogram giving the number of samples in each class of sound level. 1 dB(A) class intervals are used.

2.4.3 Combination of aircraft noise and background noise

The combination of aircraft noise and background noise is achieved by means of a computer program the fine details of which will not be described here. Suffice to say that the program begins by calculating L_{NP} and L_{eq} for the background noise distribution and this information is printed out.

To limit the cases tested to a reasonable number whilst retaining a degree of variability in the aircraft noise conditions, the nine assumed noise-time histories were formed into groups of three and nine such combinations selected. The table below illustrates the selection.

	Medium Jets	Large Jets	Jumbo Jets
Combination 1	Flight path A	Flight path A	Flight path A
" 2	" B	" B	" B
" 3	" C	" C	" C
" 4	" A	" B	" C
" 5	" A	" C	" B
" 6	" B	" A	" C
" 7	" B	" C	" A
" 8	" C	" A	" B
" 9	" C	" B	" A

In all the combinations tested, a constant mix of 70% medium jets, 20% heavy jets and 10% jumbo jets is assumed. This "typical mix" is derived from data in the BAA annual report for 1971/1972, with a small correction for an increase in the proportion of jumbo jets and a corresponding reduction in the proportion of large jets.

The total number of aircraft per day using all flight paths was varied from 10 to 500. In fact the program uses a scaling technique in which the number of noise time histories actually manipulated is always 10 but the noise exposure period is varied. This results in a considerable saving in computing time with no significant loss in accuracy.

The program takes each of the 10 noise time histories in turn and logarithmically adds each sample to each sample of the background noise distribution to produce a continually updated histogram. When all are completed the program fills in the time remaining in the 18 hour period with background noise. The values of L_{NP} and L_{eq} for the final distribution are then calculated and printed out, together with the effective number of aircraft.

For each of the three background noises, the effects of each of the nine combinations of aircraft class and flight path shown above were computed. NNI values for each aircraft noise condition were also calculated. The final result is 27 sets of data relating L_{NP} to NNI and 27 relating L_{eq} to NNI over a range of NNI values. Each of the 54 curves generated by the above data has been plotted and a sample is shown in Fig. 3. This gives, for each of the background noise conditions, the relationship between L_{NP} and NNI for the first aircraft/flight path combination, i.e. all aircraft overhead.

Now using each of the sets of translation values of L_{eq} and L_{NP} derived earlier we can read off from each of the 54 curves the corresponding value of NNI. The results are presented in full in Tables 14 and 15. Taking the mean across the various combinations for each background level the results appear in summary form in the Tables below.

$L_{10} = 70$	$L_{eq} = 67$		$L_{NP} = 76$	
	NNI		NNI	
L_{50}	Mean	S.D.	Mean	S.D.
40	49.9	0.74	34.7	1.97
50	49.8	0.73	38.9	1.13
60	47.9	0.85	40.7	1.02
Overall	49.2	1.22	38.0	2.96

$L_{10} = 65$	$L_{eq} = 62$		$L_{NP} = 70.5$	
	NNI		NNI	
L_{50}	Mean	S.D.	Mean	S.D.
40	42.4	0.63	30.9	1.75
50	41.8	0.61	33.4	1.17
60	-		-	
Overall	42.1	0.68	32.2	1.91

The gaps in Table 14 are due to the fact that in the condition where all aircraft pass along the path furthest from the observation point L_{NP} never attains the translation value. The corresponding values of NNI in the L_{eq} translation are bracketed and omitted from the above summary. The gaps in Table 15 are due to the fact that in the condition $L_{50} = 60$ dB(A), $(L_{10} - L_{90}) = 10$ dB the value of L_{NP} due to the background alone exceeds the translation value. The corresponding terms in Table 14 are omitted from the summary for the sake of an equitable comparison. In fact, in these cases the value of L_{eq} due to the background alone is only 0.25 dB(A) less than the translation value.

2.5 Translations

2.5.1 Traffic and industrial noise

Considering first the traffic noise condition $L_{10} = 70$ dB(A) the results of the translation to CNL via L_{eq} (section 2.3) may be written as follows:

$$L_{10} = 70 \quad : \quad L_{eq} = 67.0 \pm 6.0$$

$$L_{eq} = 67.0 \quad : \quad CNL = 70.1 \pm 6.2$$

whence $$L_{10} = 70 \quad : \quad CNL = 70.1 \pm 8.6$$

Translating via L_{NP} we obtain:

$$L_{10} = 70 \quad : \quad LNP = 76.0 \pm 6.0$$

$$L_{NP} = 76.0 \quad : \quad CNL = 69.1 \pm 13.0$$

whence $$L_{10} = 70 \quad : \quad CNL = 69.1 \pm 14.3$$

The tolerances are $\pm$ 2 standard deviations and the overall tolerance is taken to be the root-sum-square of the two step-wise tolerances.

For the traffic noise condition $L_{10} = 65$ dB(A) the translation via L_{eq} is:

$$L_{10} = 65 \quad : \quad L_{eq} = 62.0 \pm 6.0$$

$$L_{eq} = 62.0 \quad : \quad CNL = 65.0 \pm 6.2$$

whence $$L_{10} = 65 \quad : \quad CNL = 65.0 \pm 8.6$$

Translating via L_{NP} we obtain:

$$L_{10} = 65 \quad : \quad L_{NP} = 70.5 \pm 6.0$$

$$L_{NP} = 70.5 \quad : \quad CNL = 65.0 \pm 10.2$$

whence $$L_{10} = 65 \quad : \quad CNL = 65.0 \pm 11.8$$

The agreement between the results obtained via the L_{eq} and L_{NP} translations is closer in both the above cases than that obtained in the previous report (Robinson, 1972). It is also interesting to note that the difference in the uncertainties is also less and Robinson's suggestion of a deceptively small tolerance in the L_{eq} translation is substantiated.

The results suggest a convenient but wholly fortuitous numerical similitude between the values of L_{10} and CNL. In order to accord with current usage we must apply the correction for the difference in time periods, i.e. the 18 hours for L_{10} and 10 hours for CNL. The CNL equivalent to an 18-hour L_{10} of 70 dB(A) thus becomes approximately 72, and for an L_{10} of 65 the number is 67.

2.5.2 Traffic and aircraft noise

Taking the overall results, averaged over all aircraft/flight path combinations and background noise conditions, the translation to NNI via L_{eq} for the traffic noise condition $L_{10} = 70$ is as follows:

	$L_{10} = 70$	:	$L_{eq} = 67.0 \pm 6.0$
	$L_{eq} = 67.0$	:	$NNI = 49.2 \pm 2.4$
whence	$L_{10} = 70$	:	$NNI = 49.2 \pm 6.5$

Translating via L_{NP} we obtain:

	$L_{10} = 70$	:	$L_{NP} = 76.0 \pm 6.0$
	$L_{NP} = 76.0$	:	$NNI = 38.0 \pm 5.9$
whence	$L_{10} = 70$	:	$NNI = 38.0 \pm 8.4$

For the traffic noise condition $L_{10} = 65$ the translation via L_{eq} is

$L_{10} = 65$	:	$L_{eq} = 62.0 \pm 6.0$
$L_{eq} = 62.0$	:	$NNI = 42.1 \pm 1.4$
$L_{10} = 65$	:	$NNI = 42.1 \pm 6.2$

And for the L_{NP} translation

$$L_{10} = 65 \quad : \quad LNP = 70.5 \pm 6.0$$

$$L_{NP} = 70.5 \quad : \quad NNI = 32.2 \pm 3.8$$

$$L_{10} = 65 \quad : \quad NNI = 32.2 \pm 7.1$$

Clearly the most important observation to be made on this result is that the difference in the NNI values obtained by the L_{eq} and L_{NP} translations is large, averaging 11.2 units when $L_{10} = 70$ and 9.9 units when $L_{10} = 65$. In fact one would only expect similar NNI values if the total noise distribution, aircraft combined with background noise, was similar to that implied by the translation values of L_{eq} and L_{NP}. In the case considered here the background noise is in effect due to traffic noise and its noise-level distribution is similar to that assumed for the traffic noise in the derivation of the translation values of L_{eq} and L_{NP}. As the number of aircraft increases, L_{NP} increases more quickly than L_{eq} and so the difference between them increases. Thus for example, for the condition in which all aircraft pass overhead and $L_{50} = 50$ dB(A) the background noise conditions are $L_{NP} = 61.8$, $L_{eq} = 51.8$. When the number of aircraft is such that NNI = 39.6 L_{NP} has reached the translation value of 76 whilst L_{eq} has only increased to 61. As the number of aircraft increases further until NNI = 49.2 L_{eq} has reached the translation value of 67 whilst L_{NP} is now 89. As this difference in the NNI values is dependent upon the difference between L_{NP} and L_{eq}, i.e. 2.56 s, it is susceptible to background noise level. Thus referring to the summary chart on page 13 for the condition $L_{10} = 70$ dB(A) the difference decreases from 15.2 units to 7.2 units as L_{50} increases from 40 to 60 dB(A).

For the moment, treating the problem as one of numerical equivalence only, it is concluded that the traffic noise condition $L_{10} = 70$ dB(A) is equivalent in terms of L_{eq} to aircraft noise at 49 NNI and in terms of L_{NP} to aircraft noise at 38 NNI. As L_{10} decreases to 65 dB(A) the NNI values decrease to 42 and 32 respectively.

It should be pointed out that, as in the case of the traffic-industrial noise translation, there is a disparity in the time periods used in the indices being compared. Thus the L_{10} value is the 18-hour average (06.00 to

24.00 hours) and the NNI value is that for daytime defined as 06.00 to 18.00 hours (Noise Advisory Council, 1973). The above analyses are valid when a common period, in this case 18 hours, is considered. Thus the results still apply when NNI is reckoned over the shorter, daytime period provided all aircraft movements are confined to that period.

3. DISCUSSION

In this report, as in the earlier one, the comparison of the various noises has been treated as one of the numerical equivalence of values on certain scales. The results of the translations, if they are to be of practical value, have to go further than this and imply equivalence of acceptability. In the earlier work, as in the present comparison of traffic and industrial noise, practically identical results are obtained using either of the two intermediate measures, L_{eq} or L_{NP}. This however turns out to be far from true when the comparison is extended to include aircraft noise and clearly both intermediate measures cannot be right when they lead to a discrepancy as large as 10 or 11 units of NNI.

In deciding which of these measures better reflects the purpose of the comparisons we have therefore to decide which of them is related, or which is the more closely related, to acceptability. The evidence from laboratory experiments (Fuller and Robinson, 1973) with steady and varying noise exposures where conditions could be well controlled was quite clearly in favour of L_{NP} and this would lead us to the conclusion that the equivalent of traffic noise at $L_{10} = 70$ is aircraft noise at some 38 NNI rather than the alternative much higher value.

That this conclusion is realistic can be corroborated by a direct comparison of social survey data from which the levels of different noises which under real-life conditions produce equal annoyance can be estimated. The scope of such a comparison is limited however by the disparate procedures used in the various surveys. The crucial disparity is usually in the subjective scale used to rate annoyance or dissatisfaction which makes the determination of points of equal acceptability difficult. For instance, it is difficult to equate the points on the seven-point dissatisfaction scale of Griffiths and

Langdon (1968) with the points on the derived, Guttman-type scale of annoyance used in the two surveys of aircraft noise at Heathrow (McKennell, 1963; MIL Research, 1971). Even the fact that certain points on this scale can be shown to approximate to categories on the verbal self rating scale, "not at all" to "very much" annoyed, is of little assistance. However there has been one social survey of traffic noise annoyance in Paris (Lamure and Bacelon, 1967), in which the rating scale used was identical, allowing for language translation, to that used at Heathrow. The objective measure of traffic noise used in this survey was L_{50} but since the traffic involved was of high volume and freely flowing, i.e. on urban motorways and ring-roads, we can relate L_{50} to L_{10} using the equation:

$$L_{10} = L_{50} + (L_{10} - L_{90})/2$$

The mean value of $L_{10} - L_{90}$ was estimated earlier as 8.8. Thus the condition $L_{10} = 70$ corresponds to $L_{50} = 65.6$. The results of this traffic noise survey show that at this noise level the total percentage of persons rating themselves "moderately" or "very much" annoyed was 60. For comparison the percentage of persons, around Heathrow, rating themselves similarly annoyed, is shown as a function of NNI in Fig 4, the data points on which derive from both the 1961 and the comparable part of the 1967 surveys. The line has been fitted by linear regression. The NNI value corresponding to 60% "moderately" and "very much" annoyed is 42.

To relate this result to our numerical equivalence we should, of course, narrow the range of assumed conditions to those likely to have applied in the surveys cited Thus, the background level of 40 dB(A) can be left out of the reckoning (see Table 14) and even 50 dB(A) may well underestimate the typical median levels in the neighbourhood of Heathrow. The average result of our translation by L_{NP} at the two upper background levels is 40 NNI and if one considers only the 60 dB(A) background level it is 41 NNI. The concordance between these and the value of 42 derived above is very good, and even allowing for appreciable uncertainties in this use of survey data there is no support for the higher value (49) obtained by using L_{eq} as the intermediate measure.

It remains to consider the recommendations in the Planning and Noise Circular. This document recommends in one place that no new housing development be permitted where traffic noise is such that L_{10} exceeds 70 dB(A) and that if these conditions cannot be avoided sound insulation measures should be taken. In another place it identifies the 40 NNI boundary as that above which it is recommended that no new major residential developments be permitted. If permission is granted then conditions requiring sound insulation measures should be imposed. The implied equivalence of these criteria is believed to have been derived from general considerations independent of any formal numerical translation: the results of the present exercise confirm that this equivalence is realistic.

The various problems involved in determining equivalent values of different noises and in particular the difficulty of comparing dissatisfaction due to traffic noise in Griffiths and Langdon's survey with annoyance due to aircraft noise in the Heathrow surveys highlight the difficulties existing in this area of work. There is an obvious need for careful reanalysis of both noise exposure and annoyance data in existing published surveys and for thoughtful planning of future surveys. In this context the results of the National Environmental Survey carried out by the Department of the Environment and of the second, more extensive noise and social survey of Greater London by the Building Research Establishment, are awaited with interest.

It was pointed out earlier that conditions may arise in which a reduction in L_{10} is accompanied by an increase in L_{NP}, because of the increase in the variability of the noise. In considering whether, in such a situation, annoyance would increase or decrease we must be careful to make a distinction between annoyance due to noise alone and the response to other noxious effects of road traffic such as exhaust fumes and dust. Experiments in this laboratory have shown clearly the increase in noise annoyance due to increased variability in the noise environment (Fuller and Robinson, 1973). However in the real world it may well be that even though a change in traffic characteristics such as reduced flow produces increased noise variability the noise annoyance due to this is masked by the beneficial effects of this reduced flow.

A final comment on the current situation with regard to noise indices is provided by the fact that not only do the three discussed here; L_{10}, NNI and CNL, rate the noise for different time periods, but NNI and CNL use different interpretations of the concept of daytime. A unification of these time periods at least is clearly desirable.

4. CONCLUSIONS

Traffic noise with an 18-hour average L_{10} of 70 dB(A) is equivalent to industrial noise with a daytime (08.00 to 18.00 hours) CNL of 72 and to aircraft noise at 38 NNI. If L_{10} is reduced to 65 dB(A) the corresponding values are a CNL of 67 and 32 NNI. The value 72 for CNL is slightly smaller than that given in an earlier report (74); this change results from re-examination of field data.

These values are derived by a translation method using L_{NP} as the intermediate measure. If L_{eq} is used the numerically equivalent aircraft noise levels increase by some 10 or 11 NNI units. Experimental evidence of the greater relative predictive power of L_{NP} and evidence from a comparison of equivalent levels of annoyance from social surveys of traffic and aircraft noise effects lead to the conclusion that these higher aircraft noise levels do not represent equivalence, in terms of acceptability, with the traffic noise conditions.

The results confirm that the recommendations in the Planning and Noise Circular are compatible as between road traffic and aircraft noise, and the numerical values on the respective scales of measurement quoted in the Circular correspond, as best we can determine, to nearly equal degrees of acceptability.

Detailed reanalysis of unpublished data from previous noise and social surveys might possibly shed light on the problem of equivalent values but it is important that future surveys should be planned to include the possibility of measurement of the complete distribution of noise levels from all sources and the ability to rate the individual annoyance contributions of each of the contributing noise sources as well as the total annoyance.

The techniques used here to predict aircraft noise time histories and to combine aircraft noise with fluctuating background noise to produce indices of total noise exposure are capable of greater sophistication and versatility. An on-line computer system, capable of performing real-time analysis of total noise exposure on actual noises, recordings or simulations is in preparation.

5. ACKNOWLEDGEMENT

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TABLE 1

Values of L_1 and L_2 for $L_{eq} = 67.0$

p_2		$(L_2 - L_1)$				
		5	10	15	20	25
1	L_1	66.9	66.6	65.8	64.0	60.8
	L_2	71.9	76.6	80.8	84.0	85.8
2	L_1	66.8	66.3	64.9	62.3	58.4
	L_2	71.8	76.3	79.9	82.3	83.9
5	L_1	66.6	65.4	62.9	59.2	(54.8)
	L_2	71.6	75.4	77.9	79.2	(79.8)
10	L_1	66.2	64.2	60.9	56.6	(51.9)
	L_2	71.2	74.2	75.9	76.6	(76.9)
20	L_1	65.5	62.5	58.4	(53.8)	-
	L_2	70.5	72.5	73.4	(73.8)	-
50	L_1	64.0	59.6	(54.8)	-	-
	L_2	69.0	69.6	(69.8)	-	-

For $p_2 = 0$, $L_1 = 67.0$ always; for $p_2 = 100$, $L_2 = 67.0$ always

TABLE 2

Values of L_1 and L_2 for $L_{NP} = 76.0$

p_2		$(L_2 - L_1)$				
		5	10	15	20	25
1	L_1	74.6	73.0	70.9	67.8	63.3
	L_2	79.6	83.0	85.9	87.8	88.3
2	L_1	74.0	71.7	68.5	64.0	58.3
	L_2	79.0	81.7	83.5	84.0	83.3
5	L_1	72.8	68.7	62.4	56.9	-
	L_2	77.8	78.7	77.4	76.9	-
10	L_1	71.3	65.5	58.2	50.0	-
	L_2	76.3	75.5	73.2	70.0	-
20	L_1	69.3	61.1	57.8	-	-
	L_2	74.3	71.1	66.8	-	-
50	L_1	66.5	55.6	-	-	-
	L_2	71.5	65.6	-	-	-

For $p_2 = 0$, $L_1 = 76.0$ always; for $p_2 = 100$, $L_2 = 76.0$ always

TABLE 3

Values of L_2 for $L_{eq} = 67.0$ when $L_0 = 50$

P_2	L_2
1	86.9
2	83.9
5	79.9
10	76.9
20	73.9
50	70.0
100	67.0

TABLE 4

Values of L_2 for $L_{NP} = 76.0$ when $L_0 = 50$

P_2	L_2
1	85.3
2	75.1
5	66.2
10	61.7
20	58.8
50	57.0
100	76.0

Table 5

Values of Corrected Noise Level (translation by $L_{eq} = 67.0$)

p_2	$(L_2 - L_1)$	CNL											
1	5	67	67	67	67	67	67						
	10	69	67	67	67	67	67						
	15	73	72	70	69	67	66						
	20	76	75	73	72	71	69						
	25	78	77	75	74	72	71						
2	5	67	67	67	67	67	67	67					
	10	71	70	69	67	66	66	66					
	15	74	73	72	71	69	68	67					
	20	77	67	75	73	72	71	69					
	25	78	77	76	75	73	72	71					
5	5	68	67	67	67	67	67	67	67				
	10	72	71	70	69	68	67	67	66				
	15	75	74	73	72	71	70	69	68				
	20	76	75	74	73	72	71	70	69				
10	5	69	69	68	67	67	66	66	66	66			
	10	72	72	71	70	70	69	68	67	67			
	15	74	73	73	72	71	70	70	69	68			
	20	75	74	73	73	72	71	70	70	69			
20	5	70	69	69	68	68	67	67	66	66	65		
	10	72	71	71	70	70	69	69	68	68	67		
	15	73	72	72	71	71	70	70	69	69	68		
50	5	69	69	68	68	68	68	68	67	67	67	67	
	10	70	69	69	69	69	68	68	68	68	68	67	
	$L_o = 50$												
1		79	78	76	75	73	72						
2		78	77	76	75	73	72	71					
5		77	76	75	74	73	72	71	70				
10		75	74	74	73	72	71	70	69				
20		73	73	72	72	71	71	70	70	69	69		
50		70	70	69	69	69	69	69	68	68	68	68	
100		67	67	67	67	67	67	67	67	67	67	67	67

TABLE 6

Values of Corrected Noise Level (translation by $L_{NP} = 76.0$)

p_2	(L_2-L_1)	CNL											
1	5	75	75	75	75	75	75						
	10	75	74	73	73	73	73						
	15	78	77	75	74	72	71						
	20	80	79	77	76	74	73						
	25	80	79	77	76	75	73						
2	5	74	74	74	74	74	74	74					
	10	76	75	74	72	72	72	72					
	15	78	77	76	74	73	72	71					
	20	78	77	76	75	74	73	71					
	25	78	77	76	74	73	72	70					
5	5	75	74	73	73	73	73	73	73				
	10	76	74	74	73	72	71	70	69				
	15	74	73	72	71	70	69	69	68				
	20	74	73	72	71	70	69	68	67				
10	5	75	75	73	72	72	71	71	71	71			
	10	74	73	72	72	71	70	69	69	68			
	15	71	71	70	69	69	68	67	66	66			
	20	68	68	67	66	65	65	64	63	62			
20	5	74	73	73	72	72	71	71	70	70	69		
	10	70	70	69	69	68	68	67	67	66	66		
	15	66	66	65	65	64	64	63	63	62	62		
50	5	71	71	71	71	70	70	70	70	70	70	69	
	10	66	65	65	65	65	64	64	64	64	64	63	
	$L_o = 50$												
1		77	76	74	73	72	70						
2		69	68	67	66	65	64	62					
5		63	62	61	60	59	58	57	56				
10		60	59	58	58	57	56	56	55	54			
20		58	58	57	57	56	56	55	55	54	54		
50		57	57	56	56	56	56	56	55	55	55	55	
100		76	76	76	76	76	76	76	76	76	76	76	76

TABLE 7

Values of L_1 and L_2 for $L_{eq} = 62.0$

p_2		$(L_2 - L_1)$				
		5	10	15	20	25
1	L_1	61.9	61.6	60.8	59.0	55.8
	L_2	66.9	71.6	75.8	79.0	80.8
2	L_1	61.8	61.3	59.9	57.3	53.4
	L_2	66.8	71.3	74.9	77.3	78.4
5	L_1	61.6	60.4	57.9	54.2	-
	L_2	66.6	70.4	72.9	74.2	-
10	L_1	61.2	59.2	55.9	(51.6)	-
	L_2	66.2	69.2	70.9	(71.6)	-
20	L_1	60.5	57.5	(53.4)	-	-
	L_2	65.5	67.5	(68.4)	-	-
50	L_1	59.0	54.6	-	-	-
	L_2	64.0	64.6	-	-	-

For $p_2 = 0$, $L_1 = 62.0$ always, for p_2 100, $L_2 = 62.0$ always

TABLE 8

Values of L_1 and L_2 for L_{NP} = 70.5

p_2		$(L_2 - L_1)$				
		5	10	15	20	25
1	L_1	69.1	67.5	65.4	62.3	57.8
	L_2	74.1	77.5	80.4	82.3	82.8
2	L_1	68.5	66.2	63.0	58.5	52.8
	L_2	73.5	76.2	78.0	78.5	77.8
5	L_1	67.3	63.2	56.9	51.4	-
	L_2	72.3	73.2	71.9	71.4	-
10	L_1	65.8	60.0	52.7	-	-
	L_2	70.8	70.0	67.7	-	-
20	L_1	63.8	55.6	-	-	-
	L_2	68.8	65.6	-	-	-
50	L_1	61.0	50.1	-	-	-
	L_2	66.0	60.1	-	-	-

For p_2 = 0, L_1 = 70.5 always; for p_2 = 100, L_2 = 70.5 always

Table 9

Values of L_2 for $L_{eq} = 62.0$ when $L_0 = 50$

P_2	L_2
1	81.7
2	78.7
5	74.7
10	71.7
20	68.7
50	64.9
100	62.0

Table 10

Values of L_2 for $L_{NP} = 70.5$ when $L_0 = 50$

P_2	L_2
1	83.3
2	73.7
5	65.2
10	61.1
20	58.3
50	56.6
100	70.5

Table 11

Values of Corrected Noise Level (translation by $L_{eq} = 62.0$)

p_2	$(L_2 - L_1)$	CNL											
1	5	62	62	62	62	62	62						
	10	64	62	62	62	62	62						
	15	68	67	65	64	62	61						
	20	71	70	68	67	66	64						
	25	73	72	70	69	67	66						
2	5	62	62	62	62	62	62	62					
	10	66	65	64	63	61	61	61					
	15	69	68	67	66	65	63	62					
	20	72	71	70	68	67	66	64					
	25	73	72	71	69	68	67	66					
5	5	63	62	62	62	62	62	62	62				
	10	67	66	65	64	63	62	62	61				
	15	70	69	68	67	66	65	64	63				
	20	71	70	69	68	67	66	65	64				
10	5	64	64	63	62	62	61	61	61	61			
	10	67	67	66	65	65	64	63	62	62			
	15	69	68	68	67	66	65	65	64	63			
20	5	65	64	64	63	63	62	62	61	61	61		
	10	67	66	66	65	65	64	64	63	63	62		
50	5	64	64	63	63	63	63	62	62	62	62	62	
	10	65	64	64	64	64	63	63	63	63	63	62	
	$L_o = 50$												
1		74	73	71	70	68	67						
2		73	72	71	70	68	67	66					
5		72	71	70	69	68	67	66	65				
10		70	69	69	68	67	66	66	65	64			
20		68	67	67	66	66	66	65	64	64	63		
50		65	65	64	64	64	64	64	63	63	63	63	
100		62	62	62	62	62	62	62	62	62	62	62	62

TABLE 12

Values of Corrected Noise Level (translation by $L_{NP} = 70.5$)

P_2	(L_2-L_1)	CNL											
1		69	69	69	69	69	69						
	10	70	68	68	68	68	68						
	15	72	71	69	68	67	65						
	20	74	73	71	70	69	67						
	25	75	74	72	71	69	68						
2	5	69	69	69	69	69	69	69					
	10	71	69	68	67	66	66	66					
	15	72	71	70	69	68	67	65					
	20	73	72	71	69	68	67	66					
	25	72	71	70	69	67	66	65					
5	5	69	68	67	67	67	67	67	67				
	15	69	68	67	66	65	64	63	62				
	20	68	67	66	65	64	63	63	62				
10	5	69	68	68	67	66	66	66	66	66			
	10	68	68	67	66	65	65	64	63	62			
	15	66	65	64	64	63	62	62	61	60			
	20												
20	5	68	68	67	67	66	66	65	65	64	64		
	10	65	64	64	63	63	62	62	61	61	60		
	15												
50	5	66	66	65	65	65	65	65	64	64	64	64	
	10	60	60	60	59	59	59	59	59	58	58	58	
	$L_o = 50$												
1		75	74	72	71	70	68						
2		68	67	66	64	63	62	61					
5		62	61	60	59	62	57	56	55				
10		59	59	58	57	57	56	55	54	54			
20		58	57	57	56	56	55	55	54	54	53		
50		57	56	56	56	56	55	55	55	55	55	54	
100		71	71	71	71	71	71	71	71	71	71	71	71

TABLE 13

TYPICAL BACKGROUND NOISE LEVELS: RESIDENTIAL SUBURBAN AREAS

Source	Location	Description of Site/Area	Levels dB(A)	
			L_{50}	$L_{10} - L_{90}$
PARKIN et al. (1968) (London Noise Survey)	London, England	Minor roads; Gardens of houses, with traffic routes more than 100 yds distant.	55	9
		Residential roads, local traffic only.	61	9
MOCHIZUKE (1967)	Tokyo, Japan	Suburban	41	8
		Suburban	45	10
		Residential	50	11
SCHULTZ (1971)	Various cities USA	Quiet Residential	45	10
		Average Residential	55	10
		RANGE	41 to 61	8 to 11
		MEAN	50.3	9.6

TABLE 14

Values of Noise and Number Index

A. Translation by $L_{eq} = 67$

B. Translation by $L_{NP} = 76$

	Background Noise L_{50} dB(A)	Aircraft/Flight Path Combination								
		1	2	3	4	5	6	7	8	9
A. L_{eq}	40	49.2	49.4	50.5	50.2	49.2	50.8	49.4	51.2	50.0
	50	48.8	49.4	(50.0)	50.0	49.2	50.5	49.4	51.0	50.0
	60	47.2	47.0	(48.4)	48.0	47.2	48.6	47.0	49.0	48.8
B. L_{NP}	40	36.6	33.4	30.4	36.8	35.8	35.8	34.5	35.0	34.2
	50	39.6	37.3	-	40.6	39.2	40.0	38.0	39.2	38.0
	60	40.2	40.0	-	40.6	41.6	42.0	39.4	42.0	40.0

TABLE 15

Values of Noise and Number Index

A. Translation by L_{eq} = 62

B. Translation by L_{NP} = 70.5

	Background Noise L_{50} dB(A)	Aircraft/Flight Path Combination								
		1	2	3	4	5	6	7	8	9
A. L_{eq}	40	41.8	42.0	42.6	42.6	41.8	43.2	42.0	43.6	42.4
	50	41.2	41.3	42.0	42.0	41.2	42.6	41.3	42.8	42.0
	60	-	-	-	-	-	-	-	-	-
B. L_{NP}	40	32.6	29.6	27.2	32.8	31.8	32.0	30.8	31.5	30.5
	50	34.1	32.3	31.4	35.0	33.8	34.6	32.8	34.0	32.8
	60	-	-	-	-	-	-	-	-	-

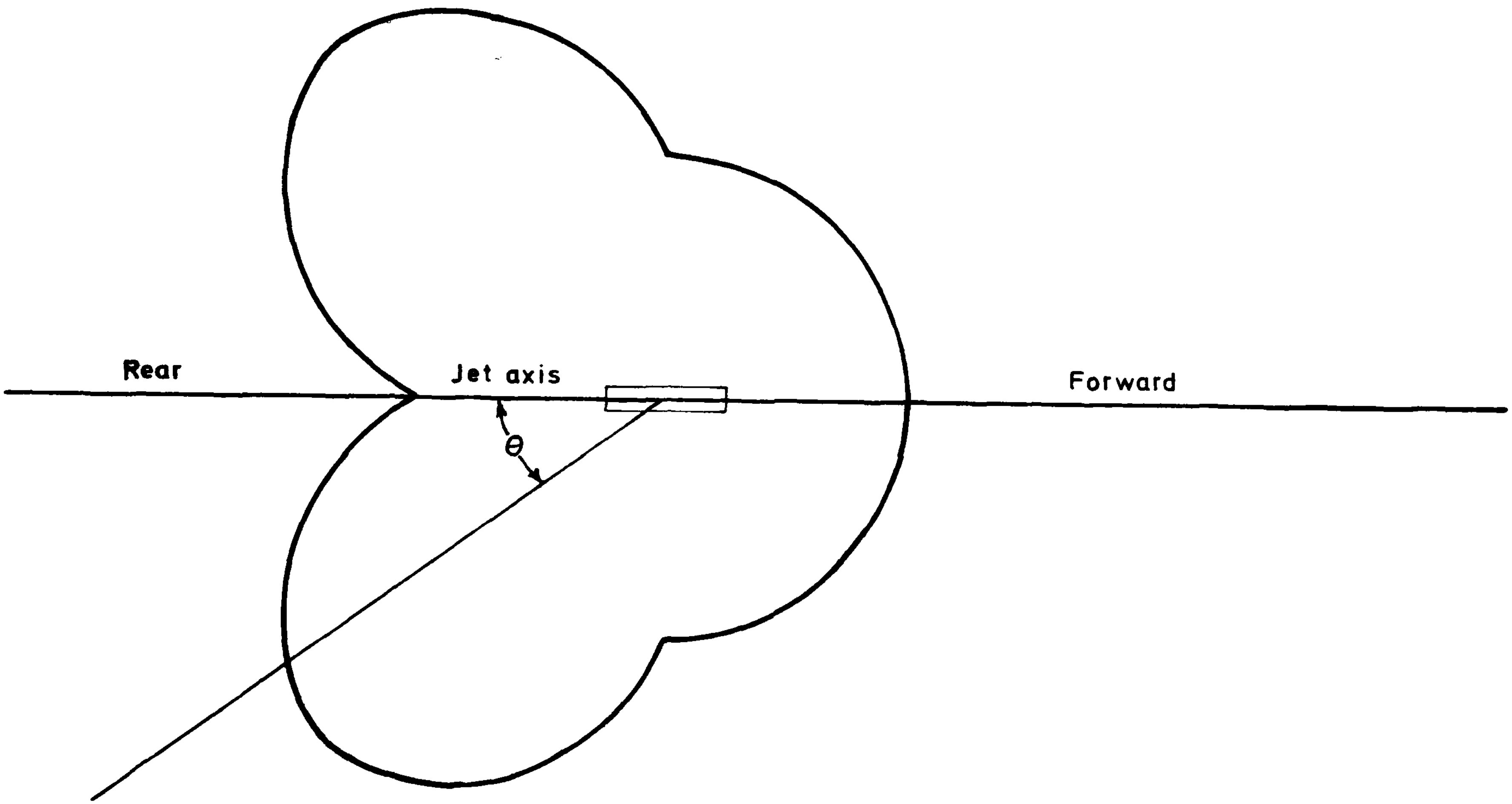

FIG.1 Assumed directivity of aircraft noise in climb

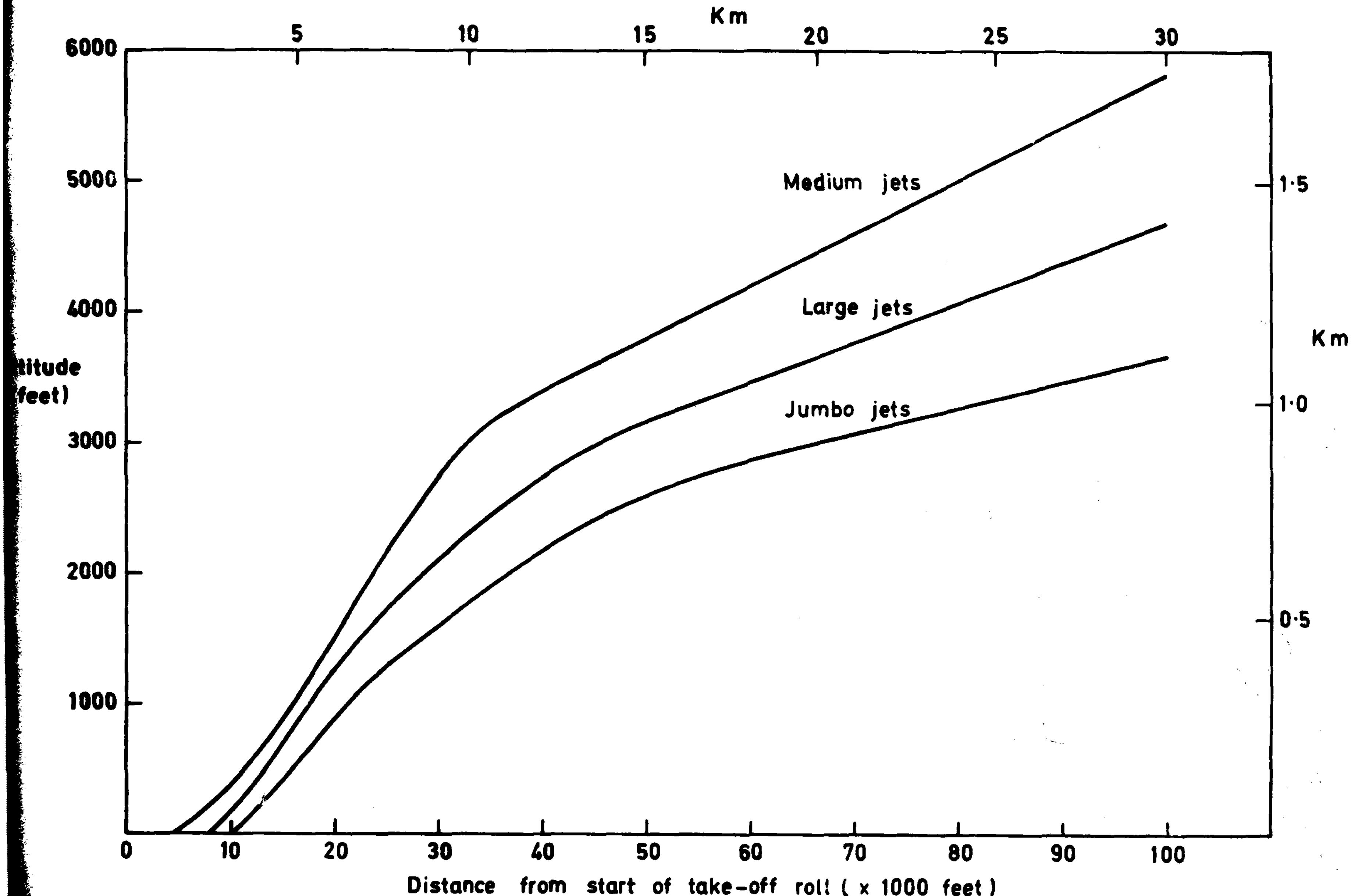

FIG. 2. Vertical flight profiles on take-off

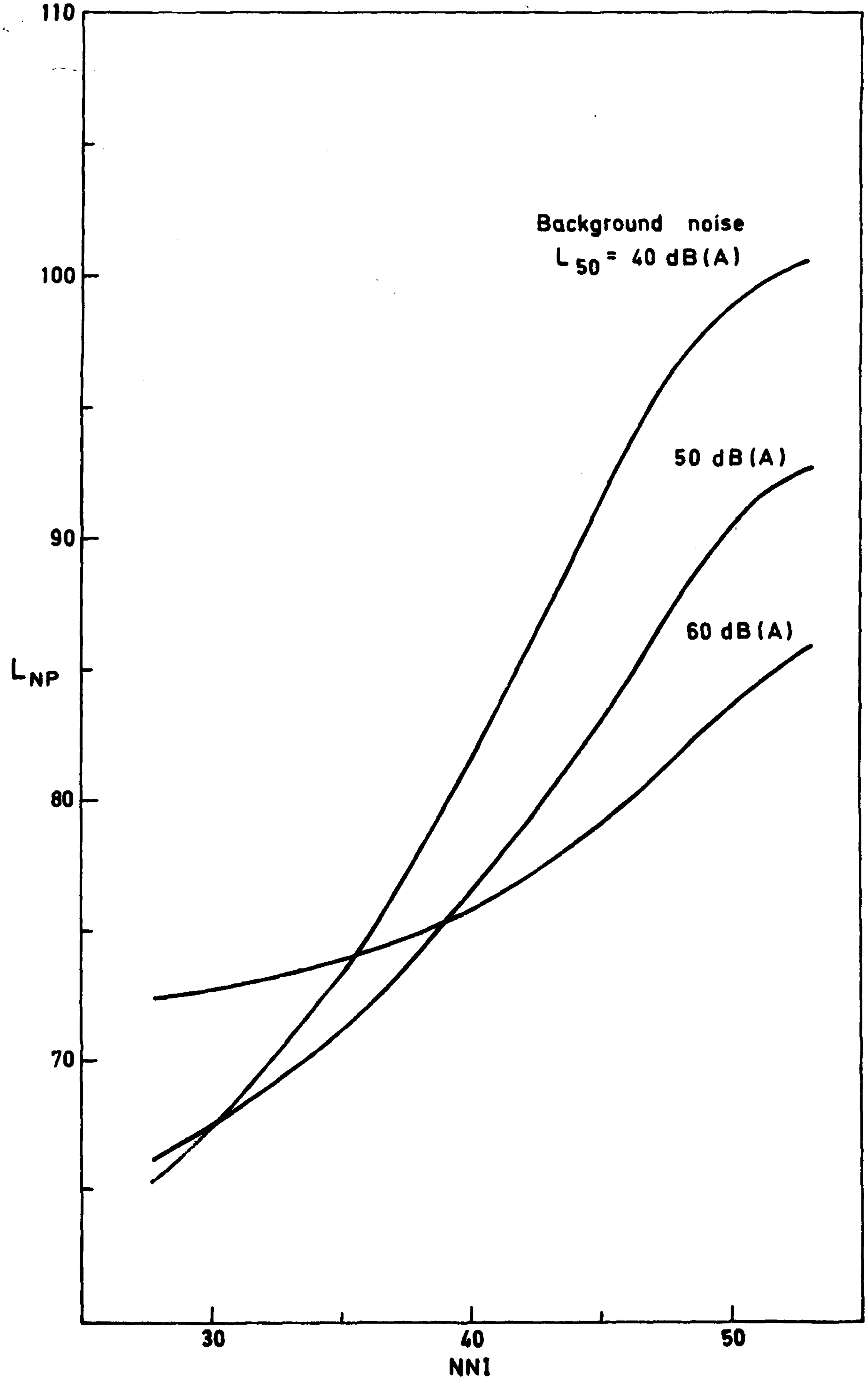

FIG.3. Noise pollution level and NNI

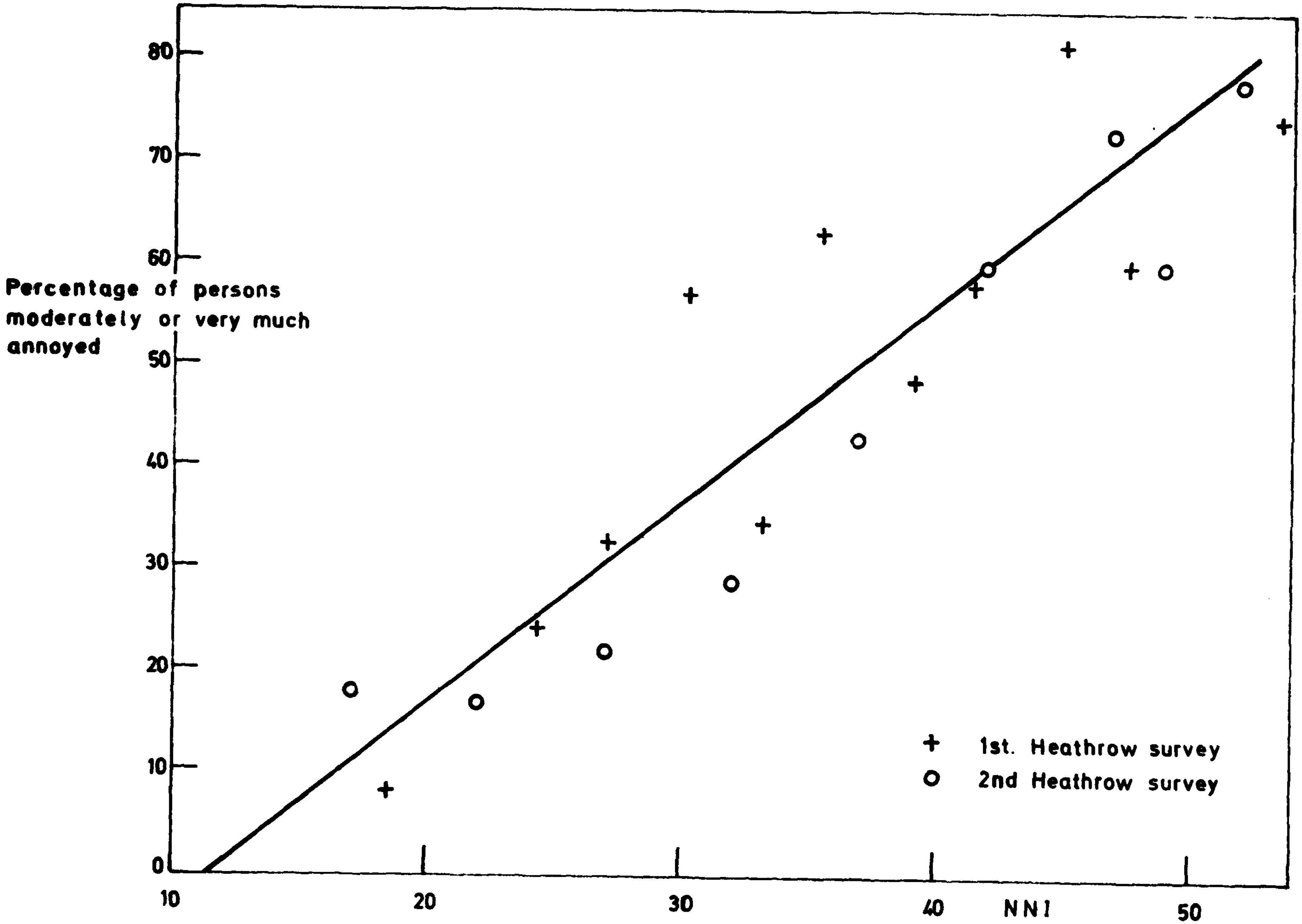

FIG. 4. Percentage annoyed and NNI