N-96-01
II-A-491

Synthesis of social surveys on noise annoyance

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(Received 17 December 1976; 10 March 1978)

Since noise was first recognized as a serious environmental pollutant, a number of social surveys have been conducted in order to assess the magnitude of the problem and to develop suitable noise ratings, such that, from a measurement of certain physical characteristics of community noise, one could reliably predict the community's subjective response to the noise. Recently, the author has reviewed the data from social surveys concerning the noise of aircraft, street traffic, expressway traffic, and railroads. Going back to the original published data, the various survey noise ratings were translated to day-night average sound level, and an independent judgment was made, where choice was possible, as to which respondents should be counted as "highly annoyed." The results of 11 of these surveys show a remarkable consistency. It is proposed that the average of these curves is the best currently available relationship for predicting community annoyance due to transportation noise of all kinds.

PACS numbers: 43.10.Ln, 43.50.Qp, 43.50.Sr

PART ONE: COMPARISON OF SURVEY RESULTS

INTRODUCTION

In late 1971, the United States Department of Housing and Urban Development (HUD) issued a nation-wide noise abatement and control policy.[1] The policy encourages noise control at the sources of noise, and, in order to provide incentive for compatible land use, it prohibits HUD's support to *new* construction on sites having unacceptable noise exposures. The standards for determining unacceptable noise exposure in HUD's noise abatement policy are based on information available in the late 1960's.

In the 15–20 years since noise was recognized as an environmental pollutant, a number of social surveys on noise annoyance have been conducted, in order to assess the magnitude of the problem and to develop suitable noise ratings, such that, from a measurement of the physical characteristics of community noise, one could reliably predict the community's subjective response to the noise. Many of these surveys have been published since the original HUD noise policy was adopted.

We recently decided to review the existing social surveys concerned with noise annoyance, reasoning as follows: If annoyance scales have *any* meaning, then, even though the various surveys used annoyance scales with different numbers of steps, and even though there were different (or even no) names for the scale steps, nevertheless a sensible person ought to be able to locate with useful accuracy the points on *all* the scales corresponding to the same degree of annoyance. Then one could go on to define what constitutes a "suitable living environment."

This paper describes the results of a study comparing the conclusions of more than eighteen social surveys on annoyance due to noise.

It will be useful first, however, to review the procedures used in those social surveys.

I. SOCIAL SURVEY PROCEDURES

The typical survey was addressed to a study of one particular source of noise, for example, aircraft or street traffic. The procedure was to subdivide a neighborhood, known to be significantly impacted by the noise in question, into sub-neighborhoods, each of which is more or less uniformly exposed to the noise, but in different degrees, either because of differing distances from the source or because of different traffic volumes. Interviews were conducted among the inhabitants of the various sub-neighborhoods to determine whether (and how much) they were annoyed by the noise in question, and (in some cases) whether the noise interferes with sleep, conversation, listening to radio or television, etc. It was expected that there would be a correlation between the degree of exposure to the noise and the intensity of annoyance felt by the subjects.

A. Correlation between noise exposure and subjective response

In fact, in each sub-neighborhood, all of whose inhabitants were presumed to be exposed to the same amount of noise, as recorded by the measurement equipment set up in that area, there was a wide range of subjective responses. For the same noise exposure, some people were nearly oblivous to the noise, some experienced various amounts of annoyance (or interference with activities such as conversation, sleep, or listening to radio or television), and some were extremely disturbed.

Even in the earliest surveys, it was observed that the correlation between the noise exposure and the *individual* subjective reactions was poor; typical correlation coefficients ran around 0.3 to 0.4. When the responses of the sub-neighborhoods were pooled, however, the correlation between the noise and the *median* response of the sub-neighborhood was much better, with correlation coefficients of the order of 0.8.[2]

Still, the limited predictability of individual response was regarded as a serious limitation, and considerable effort was devoted to improving different aspects of the survey techniques. Refinements were made in the interview instruments (e.g., open vs closed questionnaires), the noise measurement procedures (e.g., various sam-

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pling techniques), the noise ratings (e.g., peak levels vs background levels, frequency weightings, cumulative statistics), etc.

B. Annoyance scales

On one point there seemed to be agreement from the beginning[3]; namely, that people's subjective responses could be measured along a scale of annoyance running from (approximately) "not at all annoyed" to (approximately) "very much annoyed." (It will be seen that the name assigned to the upper end of the annoyance scale has a significant effect on the survey results. See particularly Section C of the Addendum.) Intermediate responses were arrayed along a numerical annoyance scale having four, five, six or seven (or more) steps, of which (usually) the two extreme responses, at least, were named. Having various degrees of subjective annoyance associated with numbers along an annoyance scale, it was then possible to analyze these numerical data mathematically.

The approach used for constructing the annoyance scale differed from one survey to another; in the early surveys it was built up from a combination of the subject's answers to a number of questions about activity interference, sleep interference, etc., or the spontaneous mention of noise as an especially annoying aspect of the neighborhood.

A number of recent surveys, however, have assumed that a person's degree of annoyance can be more simply and more reliably determined from his response to a direct question, asking how annoyed he is by the noise under investigation.[1,20,38] Often his response is invited in terms of where his annoyance lies along a "thermometer" of subjective reaction, ranging from "hot" to "cold"; the thermometer scale is then converted to a numerical scale for subsequent analysis.

C. Intervening nonacoustical variables

Study of the data from certain surveys seemed to indicate that nonacoustical variables play an important role in determining individual annoyance and complaint reactions.[4-6] At any given degree of noise exposure, for example, the subject's attitudes toward the source of noise, or toward the neighborhood in general, or toward noise in general, appear to affect whether or not he expresses annoyance and the amount of his annoyance.

It has even been suggested that noise exposure itself is one of the *least* important determinants of people's propensity for noise annoyance,[7] that one can more accurately predict whether an individual will be annoyed by noise from a study of his personal traits (fear, hostility, etc.) rather than by measurement of the noise to which he is exposed.

It appears to be well established (in the literature, at least) that, *if* annoyance is to be evaluated in terms of people's median response along a constructed annoyance scale, then the intervening, nonacoustical variables are highly influential. To the extent that this is true, it makes urban planning with respect to noise more difficult, because it implies that one cannot plan in terms the noise alone.

There is, however, good reason to question the grea importance that has been placed on the nonacoustical variables, in accounting for the variance in subjective response data. I do not mean that the nonacoustical variables are unimportant; rather, the *acoustical* variables have been poorly handled, so far, with the result that the effect of nonacoustical variables has been inflated.

D. "Percent highly annoyed"

It has been noted[8-10,38] that in subneighborhoods whe the noise exposure is extreme, there is less scatter in the responses. The author suggests that when people are highly annoyed by the noise, the effects of nonacou tical variables are reduced, and the correlation betwee the noise exposure and the expressed subjective reacti is high, both for individuals and for groups. In other words, when the noise exposure is felt to be extreme, people have little difficulty in sorting out their feelings about the noise from their other nonacoustical attitudes

An even more crucial matter has to do with whether or not the past surveys have correctly assessed the nois stimulus. Clearly, the outdoor noise "stimulus" can vary widely from subject to subject in the sub-neighbor hood, depending on distance from the measuring location, house orientation, shielding by other buildings or the terrain, etc. But more important, anyone who has simultaneously measured the noise just outside and inside a house knows that the exterior and interior noise exposure bear very little relation to one another.[11,12] The differences run 20–30 dB and fluctuate greatly with time. (These differences may be even greater when the outdoor noise is measured at some distance away, at the center of the sample neighborhood.) Thus, instead of each member of the test sample being exposed to the same noise, as measured at the survey microphone, the official "outdoor noise stimulus" may have little or nothing to do with the noise actually heard indoors by the subjects, because of noisy indoor activities

For example, in the recent survey of community response to noise in Belgium (Antwerp and Brussels), the correlation between the measured noise and the subjective response (in terms of disturbance of reading, and listening to television and radio) was 0.87 with windows open, and 0.44 to 0.52 with windows closed. In other words, if one wishes to increase dramatically the correlation between the measured noise and the subjective response of the subjects, one should open the windows so that the official survey microphone and the noise to which the subjects are actually exposed to the same noise.

It is at least arguable (with respect to past surveys), that the half of the sample population at each noise exposure who respond below the median have simply not heard the noise measured in the survey. For this group the survey's measured noise is a random variable! It is little wonder that their individual subjective responses correlate poorly with the noise!

With the "highly annoyed" part of the population, on the other hand, we know we are dealing with people who have attended to the outdoor noise, because they exhibit a definite and conscious response to it. With this group we have some hope of discovering a meaningful relation between outdoor noise exposure and annoyance.

There are, in fact, other reasons why the percentage of the population who are highly annoyed seems a better measure of community response than the median response of the sub-neighborhoods.

First, it must be remembered that the present purpose in reviewing the past noise surveys is to seek guidance for regulatory decisions about noise. In this context, the median response is much more difficult to translate from one annoyance scale to another, in everyday terms that are understood by politicians and policy makers, particularly for the scales with unnamed steps. By contrast, "percent highly annoyed" carries a commonsense import that is clear, even when it is not precisely defined, that "median response" completely lacks.

Furthermore, the median annoyance is diluted and thus is anchored by the responses of the continual complainers and the noise imperturbables [if any (see Sec. II G, below)] in the population, whom no noise ordinances or regulations can help. Since the median response does not adequately describe that part of the population whose expressed annoyance actually changes with differences in noise exposure, it is too sluggish and insensitive a statistic for regulatory purposes.

Finally, the median response to noise corresponds essentially to "no complaints." The median response is not dealing with a community noise "problem" at all.

Thus, while one can agree that studies of median response, based on factor analysis and multivariate regressions, may contribute substantially to our understanding of people's response to the noise environment and of how annoyance is generated, they are not of much use in guiding decisions about noise ordinances and other governmental acoustical regulation, because they tend to deflect attention to *non*acoustical matters. For regulatory purposes, any analysis that fails to focus on the noise itself muddies the issue.

For planning and monitoring purposes, then, the percentage of the population who are "highly annoyed," when plotted against some measure of the noise exposure, is proposed as a more useful indication of acceptable community noise exposure than the "median degree of annoyance" of the community.[10,38]

II. PURPOSE AND METHOD OF THE PRESENT STUDY

If we adopt the "percentage of the population highly annoyed" for the common annoyance rating, then, it becomes of interest to see how well the results of the various social surveys agree with each other, when all the data are analyzed in a uniform manner. In particular, we wish to determine whether or not a single relationship between noise exposure and annoyance can be found that is valid for all kinds of noise.

The difficulty with such an investigation is that the noise exposure in the various social surveys has been measured with different noise ratings; and the question of who is to be counted as "highly annoyed" has been dealt with differently in the different surveys. The present study attempts to translate the different noise ratings into a common measure of noise exposure and to develop a uniform assessment of the percentage of the survey population who were highly annoyed.

For this purpose, the author has gone back to the basic data, so far as possible, from eighteen social surveys dealing with the noise of aircraft, street traffic, expressway traffic and railway traffic, spanning a period of fourteen years and a range of nine countries. The various noise ratings were translated to day–night average A-weighted sound level, L_{dn}, as the common measure of noise exposure, according to methods that are described carefully for each survey in the second part of this report. (The rating, L_{dn}, is defined as $L_{dn} = 10\log\frac{1}{24}(15\times10^{L_d/10}+9\times10^{(L_n+10)/10})$, where L_d and L_n are the energy-averaged noise levels during the daytime (0700–2200) and nighttime (2200–0700) periods, respectively.[15])

Similarly, the author has tried to assess in a uniform manner the percentage of the population who were reported to be "highly annoyed" in the different surveys; the details for each survey are described later in the report. It will be seen that, given the survey data as published, the largest uncertainties in the results of this study are associated with the judgment as to who is counted as "highly annoyed."

A. Evaluation of the survey data

Since the annoyance scales used in the different surveys were rather different, the author originally decided to use his own personal judgment as to what point on each scale should be reckoned as the threshold of "high annoyance," and then counted people as "highly annoyed" who responded in the steps on the scale above this threshold.

Of the eighteen surveys initially studied, (An addendum to this paper presents the results from four surveys that became available after the synthesis was finished.) eleven presented the subjective response data in such a way that a consistent choice could be made of who were "highly annoyed" (see below). The results are shown in Fig. 1.

The degree to which these curves agree with one another was surprising and impressive, particularly since the noise ratings and interview methods were, in some cases, quite different.

When these results were first circulated for comment,[17] however, they drew severe criticism from sociologists on two grounds: (1) it was said that the eleven survey curves *appear* to agree with one another only because the author had made arbitrary judgments as to the thresholds of high annoyance on the different scales, in such a way as to force the data to agree; and (2) in the absence of a "scientific" definition of who should be counted as "highly annoyed," no other researcher

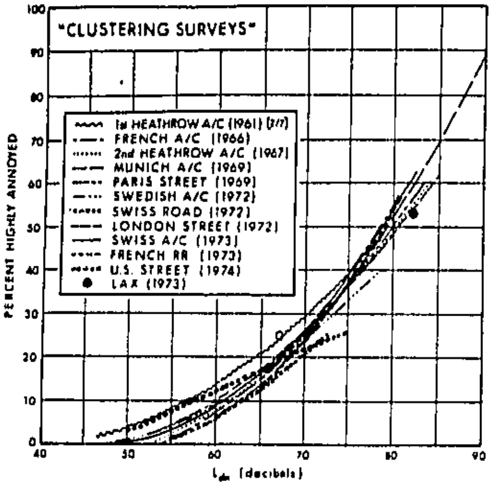

FIG. 1. Summary of annoyance data from eleven surveys that show close agreement and two points from a recent (BBN, unpublished) study of aircraft noise annoyance at Los Angeles International Airport (LAX).

would be able to repeat or confirm the author's personal decisions. It was implied that, by a different choice of whom to count as "highly annoyed," the conclusions would be significantly changed.

1. *Arbitrariness in counting the percent highly annoyed*

In reply, the author asserts that, because of the nature of the annoyance scales in question and the manner in which the data were published, there is not much latitude in the choice of whom to count, if we are to retain any reasonable concept of "highly annoyed."

If the data were always presented in fine steps, then the judgment of who is to be counted as highly annoyed is relatively free and may, indeed, be made arbitrarily. Another researcher might make a different choice and come to different conclusions.

But if the data are presented in only, say, seven steps along the annoyance scale, then the options as to who should be counted as *highly* annoyed are considerably restricted. If one counts only the top step, or 14.3% of the scale, one surely risks missing some of the highly annoyed population. Counting the top *two* categories out of seven (or 29% of the annoyance scale) seems more reasonable; but counting the top three categories (43%) includes almost the entire top half of the scale, and would surely exaggerate the count of people "highly annoyed."

In practice, the choice of whom to count as highly annoyed was pegged, more or less arbitrarily, by the two Swiss surveys, as described in the next section.

2. *The eleven annoyance scales*

Let us now consider the terms of the eleven scales of annoyance, as shown in Table I; they correspond to the surveys whose results are given in Fig. 1.

In the published reports of the two Swiss surveys, people were reported as highly annoyed who responded in the top three out of eleven categories, that is, in the top 27% of the annoyance scale; this seems to the author to be a reasonable definition of "high annoyance," and no other choice was offered.

The first and second Heathrow surveys, the London street traffic survey and the French railroad survey, on the other hand, all had seven-step annoyance scale with only the end steps named; the data were presented in enough detail in each case so that a number of choices were possible for whom to count as "highly annoyed." However, only by counting the top two of the seven categories (the top 29% of the annoyance scale) can we come close to agreeing with the counting method used in the Swiss reports.

(It is interesting that the agreement of the "self" ratings, from the surveys with named steps, supports the choice of counting the upper 27%–29% of the annoyance scale as highly annoyed.)

B. Original count of highly annoyed populations, based on the author's personal judgment

Thus, the basic rule adopted was to count as "highly annoyed" the people who responded on the upper 27%–29% of the annoyance scale, if the scale steps were *not* named; and, in the surveys using annoyance scales with all steps named, so that the respondent could state directly his degree of annoyance, those people were counted as "highly annoyed" who said they were highly annoyed. This basic rule was modified according to

TABLE I. Annoyance rating scales used in eleven social surveys concerning noise.

Swiss Road (Eleven-step annoyance scale, no steps named). Based on self-rating by reference to an "opinion thermometer" with eleven categories. Category 0 was regarded as corresponding to "Keine Störung"; categories 1, 2, and 3 as "geringe Störung"; and ca . . . es 8, 9, and 10 as "Stark Störung" (Ref. 23, Table 4.10, p. 132).

Swiss Aircraft (Eleven-step annoyance scale, no steps named). Same rating basis as for Swiss road traffic survey, given above (Ref. 23, Table 4.7, p. 114).

London Street Traffic (Seven-step annoyance scale, end steps named). Based on number of correspondents falling into seven categories along a semantic differential scale of annoyance, of which only the two extreme categories were named: "definitely satisfied" and "definitely unsatisfied".[11]

French Railroad (Seven-step annoyance scale, no steps named).[11] "*D'un point de vue général le bruit des trains est à votre avis*":

• 1 • 2 • 3 • 4 • 5 • 6 • 7 •

très supportable … *tout à fait intolérable*

U. S. Street Traffic (Five-step annoyance scale, all steps named). "How ANNOYING was the noise in your neighborhood over the past year? 1. Not at all; 2. slightly; 3. moderately; 4. very; 5. extremely" (Question No. 14 of questionnaire, Ref. 38, Appendix A).

Paris Street (special, see text). Based on response to a request to rank-order ten aspects of the neighborhood (amusements, nearness to workplace, public transport, street noise, noise in the building, schools, neighbors, shops, public services, doctors and pharmacies), from most to least satisfying. Those who put street noise in tenth place were counted as "highly annoyed" (Ref. 40, Fig. 12, p. 48).

Swedish Aircraft (Five-step annoyance scale, all steps named). Five categories: *Märker ej* (do not notice noise); *Märker, ej störd* (notice, but not annoyed); *störs ej särskilt mycket* (annoyed, but not much); *störs ganska mycket* (rather annoyed); *störs mycket* (highly annoyed) (Ref. 43, Table 5–5, p. 41).

First and Second Heathrow–Aircraft (Seven-step annoyance scale, response built up from answers to questions). One point scored if "at least a little annoyed by aircraft" and one additional point scored for each positive response to five questions:

"Does the noise of aircraft ever (a) wake you up, (b) interfere with listening to T. V. or radio, (c) make the house vibrate or shake, (d) interfere with conversation, (e) interfere with or disturb any other activity, or bother, annoy, or disturb you in any other way?" (Ref. 3, p. 205). For the Second Heathrow Survey, "N/2 was identical to the annoyance score used in 1961" (Ref. 14, p. 35).

French Aircraft (Four-step annoyance scale, all steps named). "*Est-ce que le bruit des avions vous gêne*;

pas de tout? un peu? assez? beaucoup?" (Ref. 18, p. 49; Ref. 19, p. 30).

Munich Aircraft (Five-stage annoyance scale, all steps named). "*Anteil der Gruppe der Stärker Betroffenen*. . ." (Ref. 41, Vol. I, Figs. 3–19, p. 130).

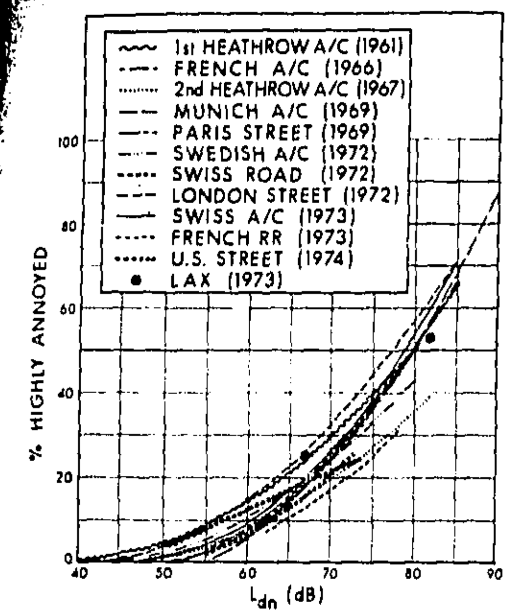

FIG. 2. Revised analysis of the clustering surveys using a rule for counting the percent highly annoyed that leaves out personal judgment in the individual surveys.

the author's personal judgment in a few cases, in the original analysis of the survey data.

The original count of percent highly annoyed, then, was straightforward, in six of the surveys: U.S. Street: "very" or "extremely annoyed"; Swedish Aircraft: *störs mycket*; French Aircraft: "beaucoup gêne"; Munich Aircraft: "Starker betröffenen"; Swiss road: $\frac{3}{11}$; Swiss Aircraft: $\frac{3}{11}$.

We now come to the question of the name given to the top step of the annoyance scale. In the London Street survey, the end steps of the annoyance scale were given neutral names: "definitely satisfied" and "definitely unsatisfied." The latter seemed a very mild description of the most extreme form of annoyance that a subject can feel, compared to the other surveys. In that context, one might conclude that the step *next* to the top must correspond to something like only "somewhat" or "moderately" unsatisfactory. In the author's original assessment, therefore, the percentage of people counted as highly annoyed was based on the average between those with scores in the first category only and those responding in the first and second categories: thus, effectively, $1\frac{1}{2}$ out of 7, or the upper 21% of the annoyance scale.

In the French Railroad survey, on the other hand, the designation "altogether intolerable" for the high end of the scale seemed so extreme a response, compared to the other survey scales, that people responding in the top *three* out of seven categories were originally counted as highly annoyed ($\frac{3}{7}$).

In the first and second Heathrow studies the annoyance scale was built up from responses to questions like "are you at least a little annoyed by aircraft noise?" or "have you *ever* been disturbed in conversation?" etc. A respondent thus could be reported in the highest category of annoyance, according to his built-up score, even if he was only rarely disturbed. (The last question, indeed, seems to be coaxing an annoyed response, in comparison with the other survey annoyance scales. See Table I and Part Two, Sec. II A.) One is tempted, for this reason, to count only the top category ($\frac{1}{7}$) as highly annoyed; but in view of the fact that the Heathrow survey reports, themselves, identify the threshold of high annoyance with about the third category down, the top *two* categories were counted as highly annoyed, consistent with the basic rule.

The Paris Street survey involves an entirely different kind of scale, not an annoyance scale at all. It is based on rank-ordering quite different aspects of the neighborhood, including noise. We judged that unless the respondent put noise into last place, he was not "highly annoyed" in a sense comparable with those in the other surveys.

The results of this original accounting of percent of populations "highly annoyed" are presented in Fig. 1, and, as stated above, this procedure drew criticism as being deliberately biased.

C. Unbiased count of percent highly annoyed

Now let us adopt, instead, an alternative counting rule that leaves out personal judgment on individual surveys, as follows: We count as "highly annoyed" those people who claim to be highly annoyed, when presented with annoyance scales whose steps are named, and those people who respond on the upper 27%–29% of the annoyance scales if the steps (except for the extremes) are un-named. The Paris Street survey is counted as before.

With this rule, the results for the eleven surveys are as shown in Fig. 2. The curves for these surveys cluster only slightly less well than in the original analysis. Also, because some surveys have moved up and others down, the *average* of these curves is the same as for the original analysis, as shown in Fig. 3.

The author, needless to say, prefers the original analysis of percent highly annoyed, as shown in Fig. 1.

D. Power-law behavior functions

If the average curve of Fig. 3 indicates *how* people behave, the same curve plotted in logarithmic form in Fig. 4 suggests an explanation for this behavior, in terms of two power-law functions.

If the intrusive noise is altogether masked, there is no response at all. As the noise exposure increases, an increasing number of people notice it and become aroused. Finally, when people actually attend to the noise, their annoyance increases at the same rate as the well-known loudness function.

This suggestion, of course, is unproved, but it deserves further study.

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E. The remaining surveys

For the surveys not included in the discussion above, the published data were not presented in such a way that one can count the top 27%–29% of the annoyance scale, or even anything close; nor, with one exception (see Part Two, Sec. II F), were the steps on the annoyance scales named, so as to permit the respondents to self-evaluate their annoyance. Thus, the results of these surveys cannot be compared meaningfully with those of the eleven surveys discussed above, simply because of the manner of reporting the subjective data.

If the curves for these remaining surveys are plotted together, anyway, using the best approximation to "percent highly annoyed" that the published data permit, it is seen from Fig. 5 that the curves scatter widely and appear to be unrelated to one another.

The author initially tried to account for these nonclustering data on the ground of seasonal differences, etc.; only later did it become apparent that great care is needed in accounting for the percentage of high annoyance: it is accounted quite differently in different survey reports.

The counting rules for all the survey data are summarized in Table II.

F. Accuracy of annoyance prediction

Even if we accept that the curve of average annoyance response in Fig. 3 represents the consensus of all comparable published surveys, one may still ask: How accurate a prediction of community response does it provide?

Figure 6 shows all the data points from the eleven clustering surveys. It also shows two regression

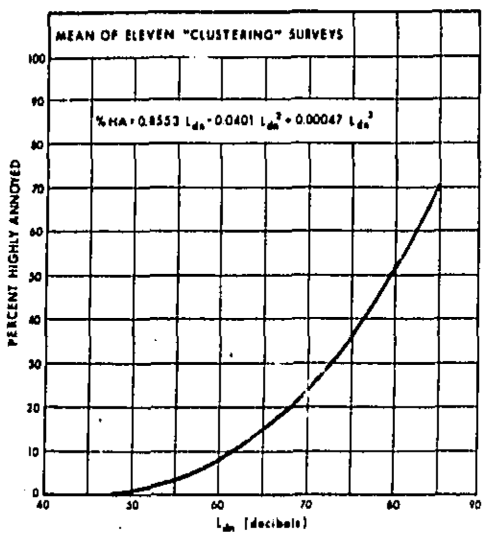

FIG. 3. Synthesis of all the clustering survey results. The mean of the "clustering surveys" data, shown here, is proposed as the best currently available estimate of public annoyance due to transportation noise of all kinds. It may also be applicable to community noise of other kinds.

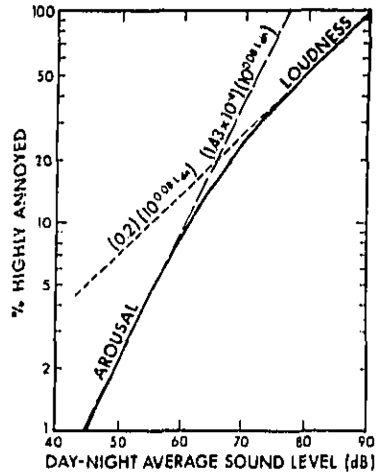

FIG. 4. Power function approximation to the cubic equation for relating annoyance to day–night average sound level.

curves, one in which all the individual regression curves from the eleven surveys are averaged together with equal weight, the other in which all the individual data points are given equal weight to form a single regression curve. These two regressions are practically identical with one another, and with the original average curve.

The shaded area contains 90% of the data points; its significance is simply that it hugs the main body of the

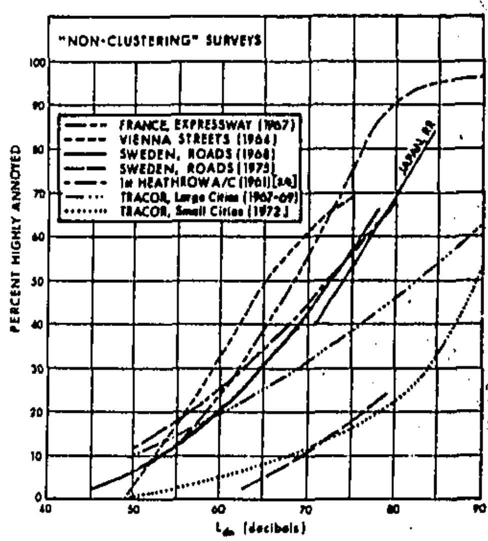

FIG. 5. Summary of annoyance data from seven surveys that exhibit wide scatter. See text for explanation of the scatter in some of these surveys. (The Japanese railroad noise survey is included here rather half-heartedly and is not even counted in the "seven," because of considerable uncertainty in adapting the original data.)

data, and leaves 5% of the points above and 5% below the shaded area.

The original set of clustering survey curves (Fig. 1) lies within ±4 percentage points of their average; and 90% of all the data points lie within ±10 percentage points of the average. Whether or not the survey average curve (Fig. 3) yields a useful prediction, then, depends on your purpose.

G. The "supersensitives" and the "imperturbables"

It has been claimed, and widely repeated, based mainly on the results of the noise surveys in the United Kingdom, that there is a supersensitive portion (about 20%) of the population who are always annoyed and who may complain of the noise even though they are exposed to very low noise levels; and that there is an "imperturbable" portion (about 25%) of the population who do not appear to be disturbed, no matter how much noise they are exposed to.

The results of noise surveys in other countries, however, do not bear out this claim. Alexandre has already expressed his doubts as to the validity of this conclusion,[8] and the author agrees with him, based on the results of the individual surveys presented in the second part of this paper. In general, there is always a threshold below which there is no part of the population who are *highly* annoyed; and there is no suggestion, even in the survey on French expressway noise, that the "highly annoyed" response levels off below 100%.

If, however, one is looking, not for "high annoyance," but for "any annoyance at all," there is, indeed, evidence for a supersensitive portion of the population, but not for "noise imperturbables."

TABLE II. Method of reckoning "percentage highly annoyed" in various social surveys. The entry "3/11," for example, means that people responding in the top three out of eleven categories were counted as highly annoyed; the designation "self" means that people were counted as highly annoyed who *said* they were highly annoyed.

Clustering Surveys	Counted as highly annoyed	% upper end of scale
Swedish Aircraft	Self	...
Swiss Aircraft	3/11	[illegible]
French Aircraft	Self	...
Second Heathrow Aircraft	2/7	29%
First Heathrow aircraft	2/7	29%
Munich Aircraft	Self	...
French Railroad	2/7	29%
Paris street Traffic	1/10	10%
Swiss Road Traffic	3/11	27%
BBN 24-Sites Street Traffic	Self	...
London Street Traffic	2/7	29%
Nonclustering Surveys		
Swedish Street Traffic	1/11 (1968)	9%
Swedish Street Traffic	Self (1975)	...
Vienna Street Traffic	2/5 (1964)	40%
French Expressways	2/4	50%
Tracor Large Cities	21/45	47%
Tracor Small Cities	21/45	47%
First Heathrow Aircraft	3/7	43%

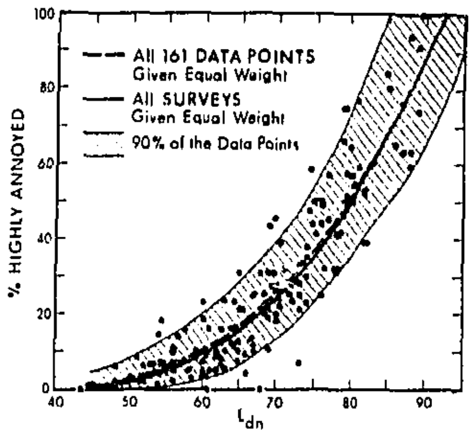

FIG. 6. Summary of all survey data points.

H. "Percent complaints" vs "percent highly annoyed"

The Tracor studies of community response to aircraft noise[45,46] have led to equations, expressed in a variety of formulations, that purport to relate the percent of people who are highly annoyed by noise to the percent of the population who actually complain of the noise in some official manner. A typical example is (% highly annoyed) = 20 + 2 × (% complaining).[18]

These relations must be regarded with suspicion, because of the manner in which the percent of the population who are "highly annoyed" were counted in the Tracor studies. Since people were regarded as highly annoyed if they score more than 21 out of 45 points on the annoyance score, it appears that the highly annoyed portion of the population is overestimated. Thus, if the complaint statistics from these studies are to be trusted, the number of complainants in a population is probably comparable with the number of people who are truly highly annoyed.

III. REASONS FOR THE DATA SCATTER

It is useful now to seek the reasons for the data scatter shown in Fig. 6.

Some of it, of course, comes from inaccuracies in the translation of the noise data from the original surveys to the day-night noise level used here. And, as suggested earlier, some may reflect differences between the measured noise and the noise to which the subjects were actually exposed.

Some scatter may depend on the time of year in which the survey was conducted. This effect may be indicated in the two Tracor surveys of U.S. annoyance due to aircraft noise, shown in Fig. 7. The upper curve is for a survey conducted in summer, the lower curve for a survey conducted in winter, when people tend to stay indoors where they are better protected from outdoor noise. If this effect *does* exist, it presumably affects all surveys to some extent and contributes to data scatter. (This also raises a question as to whether the same relationship between noise and annoyance can be valid for both hot and cold climates, even in the same country.)

There may also be an effect due to the *size* of the surveyed community, an alternative explanation of the results shown in Fig. 7.

Some response scatter may be due to differences in the noise attenuation of the exterior walls of the dwellings. The reported annoyance response to Japanese Railway noise, for a given noise level, is extremely high, as shown in the left-hand curve of Fig. 8. If, however, one notes that the typical noise attenuation (*A*-weighted) for railroad noise in Japanese houses is only 10 dB, compared to 28 dB in northern North America or Europe, one may be justified in shifting the original curve 18 dB to the right—which brings the survey results into closer agreement with the other surveys. These Japanese annoyance responses still lie above those of the clustering surveys, but this may be because the questions in the interviews asked "Have you *EVER* been annoyed by so and so?"

Finally, there is the effect of background noise. It is commonly believed that a given level of intrusive noise is less disturbing in locations with high background noise than in quiet locations. This notion has been embodied in a number of schemes for evaluating community noise, dating back to the original Composite Noise Rating (1953). It still appears in the current ISO standard for "Assessment of Noise with Respect to Community Response" (R1996).

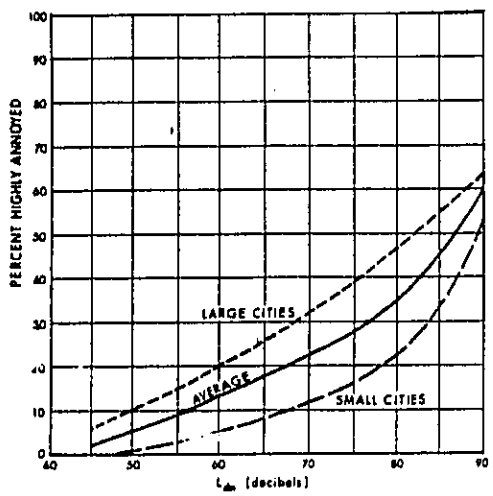

FIG. 7. The Tracor survey of aircraft noise in large cities was conducted in the summertime, while the survey in small cities were conducted in winter. Whether the differences in the results reflect a seasonal influence or an effect of the size of the community is unknown.

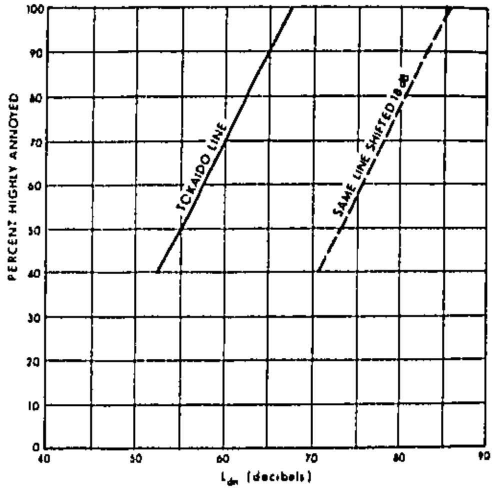

FIG. 8. Annoyance due to railroad noise in Japan (see text for explanation of 18-dB shift).

Thus, some of the data scatter in Fig. 6 may be due to differences between people's responses to the noise under study as it is heard in different background noise levels. Figure 9 seems to confirm this suggestion; it shows that the annoyance response to a given level of aircraft noise is less in neighborhoods with heavy road traffic than where the road traffic is light. That seems plausible enough: Either the heavy road traffic helps to mask the aircraft noise, or it attracts some of the annoyance to itself. A similar results was reported by Waters and Bottom.[39]

Moreover, in EPA's study of Community Noise (NTID

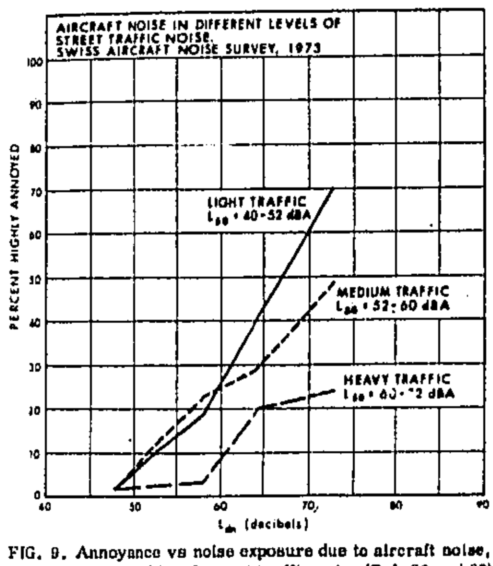

FIG. 9. Annoyance vs noise exposure due to aircraft noise, for different levels of local street traffic noise (Ref. 20 and 23).

300.3, Dec. 1971), the standard deviation of the noise level data about the mean relationship between community reaction and noise level was cut nearly in half (i.e., the data scatter was reduced) when the amount by which the intrusive noise exceeded the background noise was taken into account, rather than accounting simply for the intrusive noise level alone.

On the other hand, in the French study of response to railroad noise,[24] it was found that the annoyance due to the railroad was *greater* in areas with *higher* background noise from other sources, as though high background noise from other sources has the effect of sensitizing the community to the railroad noise. A similar result was found in a pilot study of railway noise in England.[54,55]

In addition, if the annoyance caused by an intrusive noise depends on how much that noise exceeds the background level, then we should expect to find a higher correlation between community annoyance and those noise ratings, such as the Traffic Noise Index (TNI) and Noise Pollution Level (NPL), which depend on the difference between the background noise level (L_{90}) and the quasi-peak noise level (L_{10}). Instead, in several recent surveys[40,62] these two ratings have correlated no better, and sometimes significantly less well, with community response than did simpler ratings like L_{eq}.

A final conclusion about the effect of background noise on the assessment of community noise is evidently premature. In fact, the facts of the matter, themselves, may be changing, with the increased publicity about noise as an environmental pollutant.

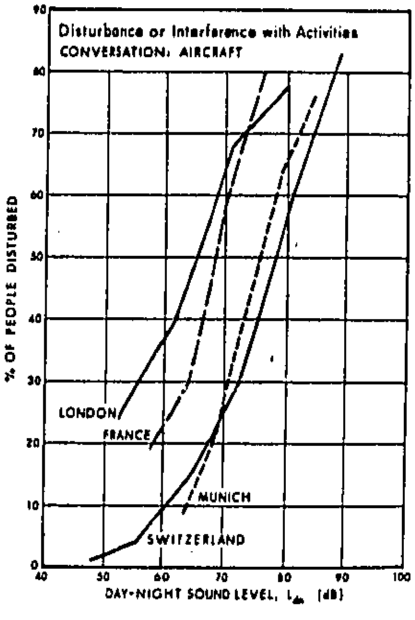

FIG. 10. Interference by aircraft noise with conversation.

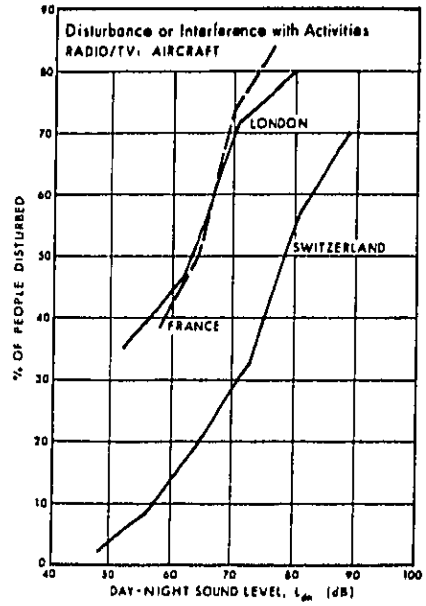

FIG. 11. Interference with radio or television listening by aircraft noise.

IV. DISTURBANCE OF VARIOUS ACTIVITIES BY NOISE

In addition to reporting general annoyance with noise in the community, the interviewed subjects in some of the surveys reported interference with specific activities, such as conversation (face-to-face or by telephone), listening to the radio or television, sleep, rest, or work, and disturbance due to the startle effect, or house vibration.

These disturbances undoubtedly contribute to the general annoyance, as reported above; but it is also interesting to examine these reports separately, for they throw some light on the question of which noise sources are most disturbing for different activities.

First, we consider aircraft noise. Figures 10–12 present data showing the percentage of the sub-populations exposed to various levels of L_{dn} who reported serious interference with conversation, radio or television listening, or sleep, in surveys carried out in London,[1] France,[18] Munich,[41] and Switzerland[20] concerning aircraft noise.

Speech activities are more seriously disturbed by aircraft noise than is sleep; and, with respect to sleep interference, being awakened by aircraft noise is more disturbing than being kept from falling asleep.

The apparent differences in amount of interference can be attributed to differences in what was counted as "serious interference." In the London survey, interference was reported for people who said they had *ever* been disturbed; the French survey counted, "sometimes" and "often" disturbed; the Swiss survey counted "rather often" and "very often" disturbed; the Munich survey counted "rather strong" and "very strong" disturbance. In other words, London counted mild disturbance, France moderate disturbance, and both Munich and Switzerland great disturbance. The apparent differences reported are thus understandable.

Figure 13 shows the interference with these same three activities due to road traffic noise.[21,22] In this case, by contrast, interference with sleep is more pronounced than interference with speech activities, particularly for the noise of street (as opposed to freeway) traffic.

Figure 14 presents the results for railroad noise[23]; it is seen that activity interference by railroads resembles that for aircraft. This is not surprising because the time patterns of the noise of railroad passages are quite similar to those for aircraft.

Figures 15 and 16 show the incidence of serious disturbance by aircraft and street traffic noise in terms of startle and house vibration.[3,18,21]

Figures 17–19 show activity interference by street traffic noise with conversation, with radio/TV listening, and with sleep, for 24 sites recently studied in the United States.[25]

Figures 20–22 summarize the activity interference due to various kinds of noise, under the categories of disturbance of conversation, listening to radio or television and sleep. These data do not cluster so closely as the curves concerning annoyance, for reasons having

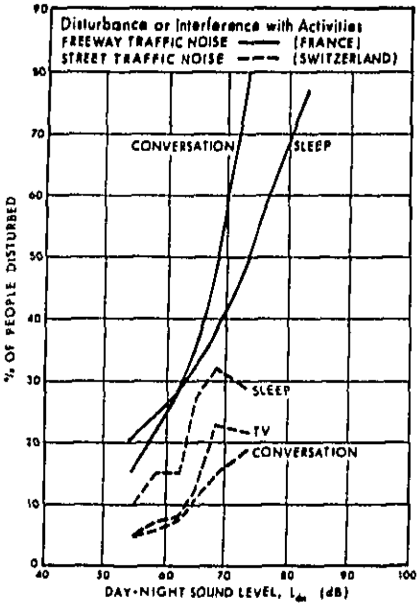

FIG. 13. Interference by street and freeway traffic noise with conversation, radio/television listening, and sleep.

to do with who was counted as seriously disturbed; but nevertheless it is possible to draw meaningful averages from the data, as shown by the heavy lines in each of the three figures. They indicate a threshold of inter-

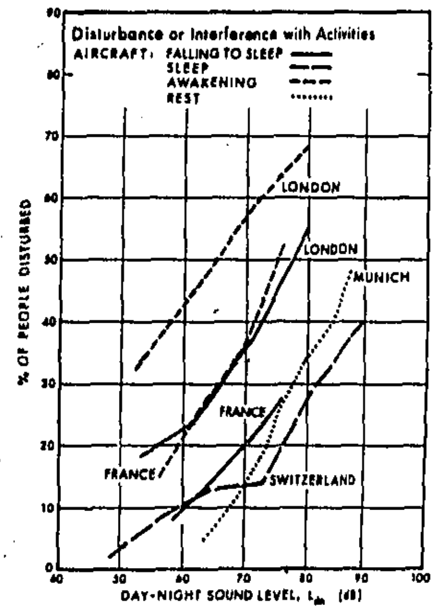

FIG. 12. Interference with sleep by aircraft noise.

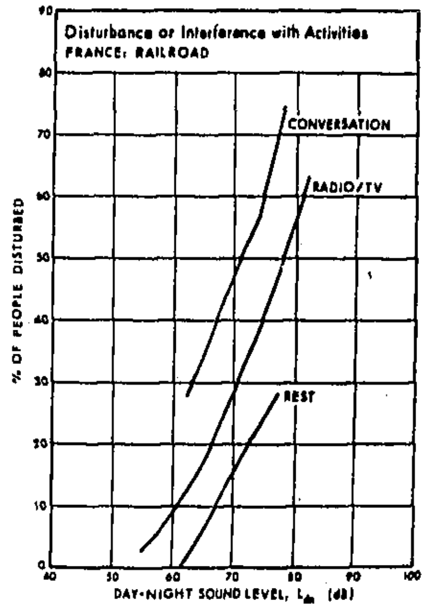

FIG. 14. Interference by railroad noise with conversation, radio/television listening, and rest.

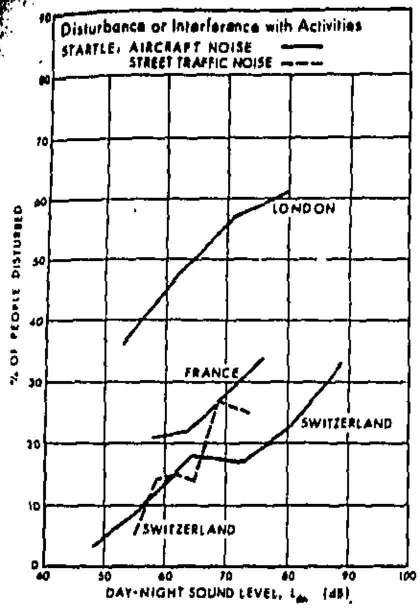

FIG. 15. Incidence of startle, and house vibration due to aircraft and street traffic noise.

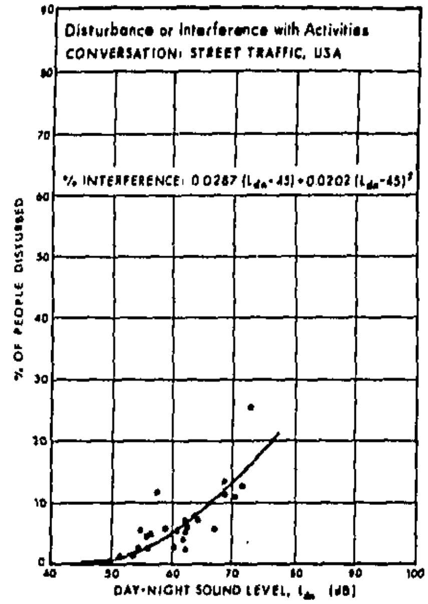

FIG. 17. Interference by street traffic noise in the U. S. A. with conversation.

ference for all three kinds of activity at around L_{dn} = 50 dB, high and comparable amounts of interference for speech activities, and somewhat less disturbance of sleep.

V. A SUITABLE LIVING ENVIRONMENT

Returning now to the original question of what constitutes a community noise level suitable for a living environment, it is not possible to base this decision on

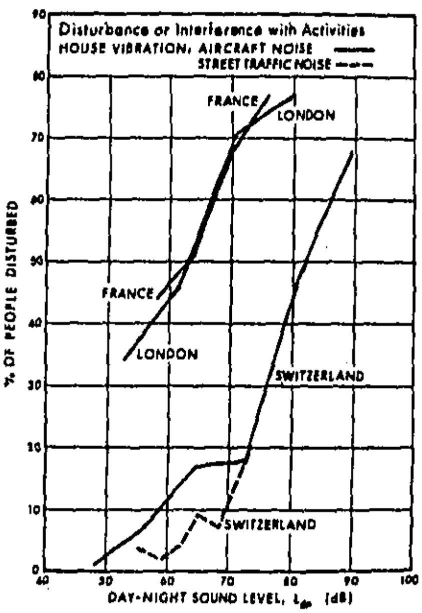

FIG. 16. Incidence of house vibration due to aircraft and street traffic noise.

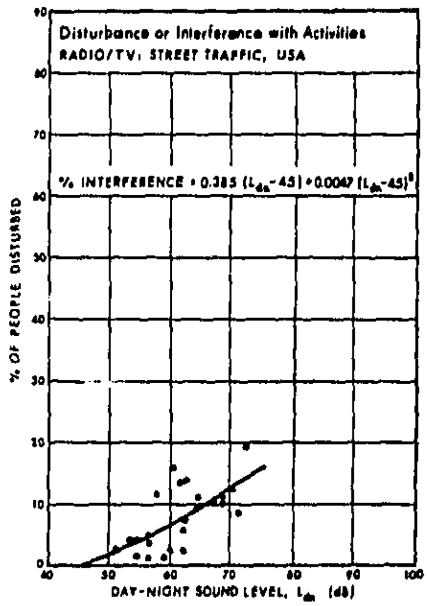

FIG. 18. Interference by street traffic noise in the U. S. A. with radio/television listening.

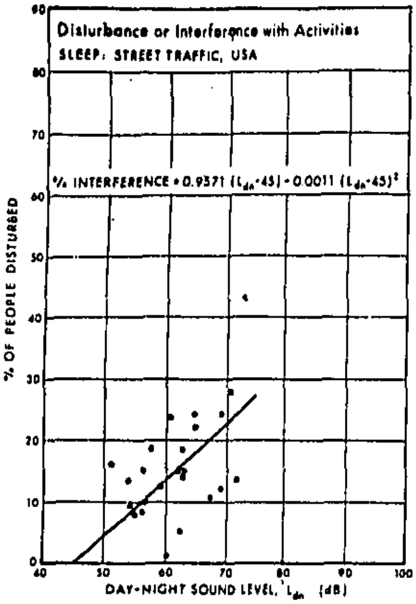

FIG. 19. Interference by street traffic noise in the U. S. A. with sleep.

the human response to the noise, alone. One must also take reasonable account of the noise that already exists in the community.

Figure 23 shows both the expected effects on the population, for different choices of a standard of accept-

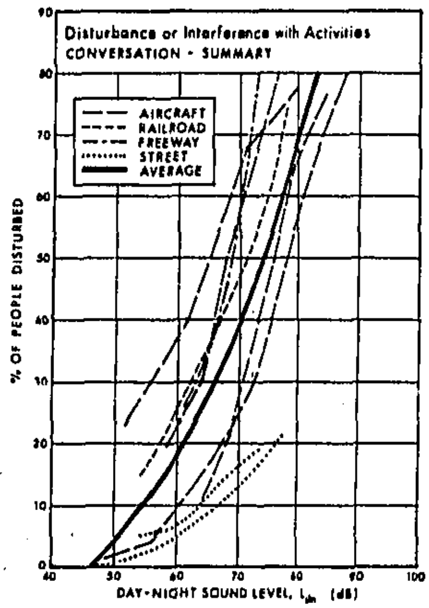

FIG. 20. Summary of interference by noise with conversation.

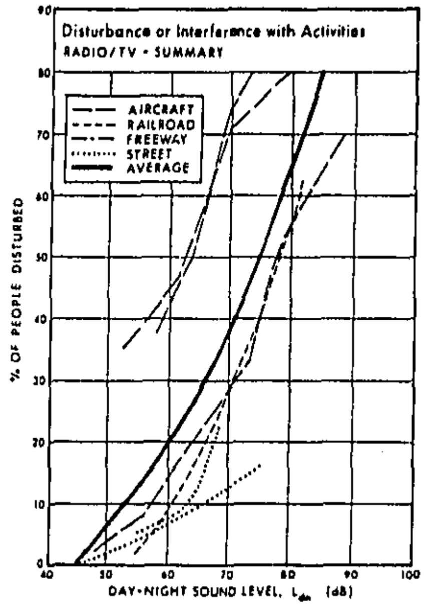

FIG. 21. Summary of interference by noise with radio/television listening.

able noise environment; and also the number of urban housing sites, or the percentage of the population, currently already exposed to higher noise levels than the standard in each case.

Suppose, for example, that a value of L_{dn} = 55 dB were to

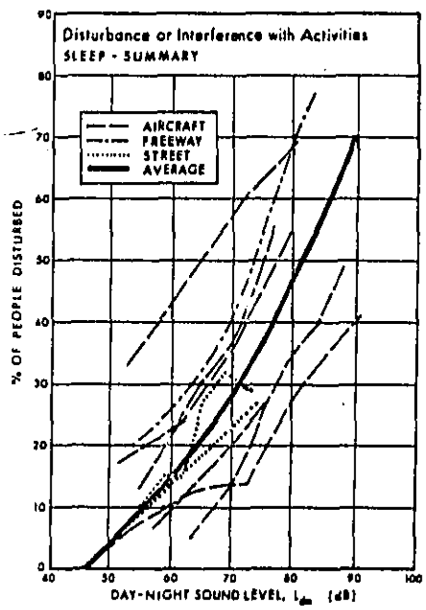

FIG. 22. Summary of interference by noise with sleep.

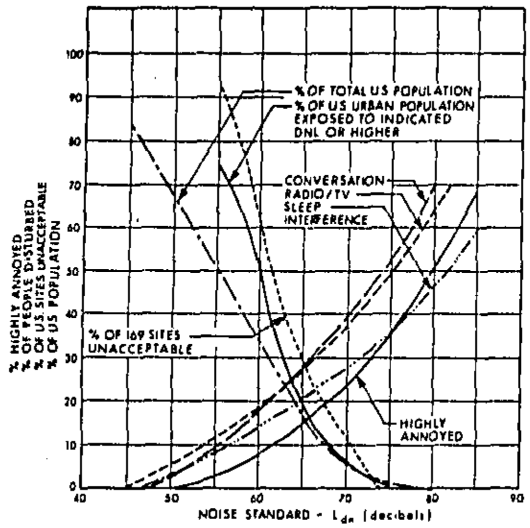

FIG. 23. Summary of data from eleven social surveys concerning noise from aircraft, street traffic, highway traffic and railroad traffic: percentage of the local population highly annoyed and activity interference. The consequences of various choices for noise standard are also shown in terms of the percentage of U. S. sites and of U. S. population currently exposed to higher levels.

be adopted as a standard of acceptable environmental noise exposure, nationwide, corresponding to the noise level identified by the U.S. EPA as "requisite to protect public health and welfare with an adequate margin of safety."[13] Then, according to Fig. 23, the percentage of the population highly annoyed by noise or seriously disturbed in various activities would be restricted to less than about 10%.

But this desirable condition could currently be met at only about 10% of U.S. urban sites; also, about 75% of the U.S. urban population, and about 50% of the entire U.S. population are already exposed to higher levels than this.

On the other hand, if, in the interest of categorizing more urban sites as "acceptable," one were to permit a higher level of environmental noise exposure, say $L_{dn} = 70$ dB, then one would find that nearly 90% of urban sites would be currently acceptable, but 25%–40% of the population would be highly annoyed by noise or seriously disturbed in important activities.

Thus, Fig. 23 provides a tool for the use of decision makers (in reaching conclusions about suitable sites for residential buildings, for example) that takes into account both the subjective effects of noise on people and the current prevailing noise levels in the United States.

VI. CAUTIONARY COMMENTS

One reviewer, commenting on an earlier draft of this paper, was candid enough to remark that he was taking a severely critical view of this synthesis on the ground that an inattentive reader, who reads only the conclusions, might well believe that the matter of community response to environmental noise is now settled, and no further comparative research is needed; moreover, these careless readers might even include the people from whom he was hoping to get funds for his own future studies!

Let such fears be laid to rest immediately. There is so much work yet to be done in understanding how people respond to noise that one might say the task has barely begun. The author hopes that the present paper, by juxtaposing the results and procedures of a number of quite different surveys, will help communities to mount more useful surveys in the future.

In particular, it seems clear that if we continue to be interested in the part of the population that is highly annoyed, the annoyance scale for future surveys should be standardized. There should be enough steps (at least seven) on the scale to allow the highly annoyed population to distinguish themselves from others; and we must agree on how to count the percentage of people highly annoyed; or, alternatively, to rely on self-judgments based on an annoyance scale with consistently named steps.

The most severe problem with past surveys, in the author's view, is the uncertainty about what noise the interviewed subjects were actually exposed to.

In past surveys, measurements of the noise to which the subjects were exposed were made by placing an outdoor microphone more or less centrally with respect to the homes of the interviewees and analyzing the data from this microphone. It was assumed that this account of the noise exposure would be approximately valid for all the subjects in that neighborhood; and, in the survey analysis, their responses, either individual or pooled, were tested for correlation with one or another measure of the noise signal recorded at the microphone position.

This approach rests on the assumption either that most of the noise indoors, where the subjects spend most of their time, comes from outdoors; or that most of the *annoying* noise comes from outdoors—and thus the central outdoor microphone could be used to gather the physical noise data. It is worthwhile to explore the validity of these assumptions.

If the indoor noise levels were coming mainly from outdoors, one would expect the outdoor-indoor noise level difference to remain nearly constant, even though the outdoor levels might fluctuate; this difference would correspond to the sound attenuation of the exterior walls of the dwelling.

Instead, the differences typically fluctuate wildly over a range of as much as 30 dB.[18,31] Evidently, a large part of the noise in a house is generated indoors and is independent of outdoor events. Consequently, it is doubtful that an outdoor microphone can correctly characterize the noise exposure of the subject indoors, at least with current noise ratings.

This is not the end of the problem, however. It must not be assumed that a microphone placed inside the house would yield a better approximation to the occupant's noise exposure than the outdoor microphone.

In order to investigate this question, a pilot experiment was run. The aim was to compare the exposure recorded by a fixed indoor microphone with the exposure recorded by a microphone mounted near the ear of the occupant. The results of subsequent statistical analysis for these two signals indicated that the cumulative distribution from the fixed microphone bears almost no relation to that from the moving microphone! The L_{10} levels differ by 17 dB, the L_1 levels by 21 dB; only for percentiles higher than about 50 (that is, the background events) do the two distributions agree.[33]

These results suggest that current noise ratings, based on data from a fixed microphone, no matter where it is placed, give a poor account of the actual noise exposure of active occupants of a dwelling.

This situation could be significantly improved if we agreed to measure, in addition to, say, the average sound level or the day-night average level, the occurrences (levels and numbers) of maximum (i.e., short-term rms) noise levels outdoors. These might be associated with identifiable events, such as a fire truck siren, an aircraft flyover, or a train or heavy truck passage. These noisy events are the *only* candidates likely to intrude indoors with sufficient intensity to attract the subject's attention and thus generate annoyance. Not even L_1 identifies such events with useful accuracy, so such a procedure would mean a drastic change in current noise measurement practice.

It may be asked: If the peaks of outdoor noise are the only acoustical events likely to penetrate indoors enough to cause annoyance, then why do the results of past surveys agree so well (Fig. 1)? The answer is that, more or less inadvertently, the surveys did attend to the maximum noise levels. For the aircraft surveys, the noise rating was NNI, NEF, or CNR, all of which depend on the mean maximum flyover level and the number of passages. Similar ratings were used for the railroad surveys. As for street, road, and expressway traffic noise, the noise level statistics are very well behaved, and all of the percentile levels (L_{50}, L_{10}, etc.) are so highly correlated among themselves that any one of them is a reasonably good measure of the maximum noise levels.

It is proposed here that more deliberate and careful attention to the population of *maximum* outdoor noise levels will lead to better correlation between outdoor noise and annoyance, and (perhaps) less need to rely on nonacoustical variables.

Thus, the scope for further research in comparative studies of community reaction to noise is not restricted in any way by the results presented here. There is much more study to be done.

In the meanwhile, however, the clustering of all the data points from past surveys (Fig. 6) suggests that the average curve of Fig. 3 is a reasonable account of the relation between transportation noise exposure and community response. Provided the noise exposure continues to be measured in terms of day-night average sound level and the definition adopted here for percent highly annoyed is retained, the results of future studies will not likely shift that curve very much.

PART TWO: TRANSLATION OF SOCIAL SURVEY DATA INTO COMMON TERMS

I. CURVE FITTING

Part Two of this report presents details of the methods by which the data of the various social surveys were translated into common terms so that they could be meaningfully compared. Slightly different methods had to be applied for each case, because the survey results were reported differently.

In each case, once the noise exposure rating was converted to L_{dn}, and the percentage of people highly annoyed at each noise level was determined, the data points were plotted and a "best fit" curve was drawn through the data points. A regression equation is given for each curve.

It will be helpful first, however, to comment on the use of least-squares methods of curve fitting in the interpretation of survey data, because such procedures, if used blindly, may have a profound influence on the appearance of the results.

Some data sets, such as those for the surveys of French and Swiss aircraft noise, define a function so clearly that they offer little or no option in fitting a curve to the data points (see Figs. 28 and 36). Other data sets, such as those from the Munich and Swedish aircraft noise surveys, are sufficiently scattered that fitting a curve by eye entails considerable uncertainty (see Figs. 31 and 34).

Least-squares curve-fitting procedures are extremely useful in fitting curves to ambiguous data sets, but even so the procedures must not be used uncritically. In the first place, there must be a decision as to the form of function to be fitted to the data: linear, quadratic, cubic, exponential, etc. The choice will be strongly influenced by fundamental views as to how annoyance is generated, and particularly about what happens in the region of the threshold of annoyance.

For example, if one believes that there is a hypersensitive residuum of the population that will be annoyed by noise however mild the exposure, then an exponential curve should be fitted to the data: it will not go to zero annoyance in the range of noise exposures of interest.

Most of the survey data, however, strongly suggest a threshold below which none of the population are *highly* annoyed. Furthermore, for the purposes of land-use planning and monitoring community noise, for example, accounting for the hypersensitive residuum simply muddles the issue: one wants to know the annoyance threshold of the part of the population that actually responds to *differences* in noise exposure. Thus, for these purposes, one should fit a function to the data that meets the zero-annoyance axis and defines the threshold.

Almost all the survey data clearly forbid a linear regression; therefore, the choice is between a quadratic or a cubic function. Here, again, one must be guided by judgment.

The choices embodied in the present study grew out of earlier views embodied in the Fractional Impact Method (FIM),[13] which envisioned a sharp threshold of noise exposure below which there was assumed to be no noise impact. This calls for an independent variable of the form $(L_{dn} - L_t)$, where L_t is the threshold or criterion level of noise exposure; by tacit agreement the function (whatever its form) is defined to be zero for values of L_{dn} less than L_0. The original version of Fractional Impact involved a linear function of $(L_{dn} - L_0)$ with $L_0 = 55$ dB.

The survey data collected here, however, demand a curvilinear function and a somewhat lower threshold. The choice of a cubic, rather than a quadratic, function might be made if the data set requires a more "curvy" function than can be obtained with a quadratic; in practice, the results also depend on the choice of L_0, and on whether and how far one expects to extrapolate the fitted curve beyond the range of the given data set (a practice that is strongly discouraged!).

In any case, least-squares curve-fitting is merely an aid, not an imperative; one should not hesitate to modify the function defined by least squares where it is clearly at variance with the data, as in the case of the French expressway survey at high noise levels (see Fig. 28).

The best fit to most of the data was found for a quadratic equation with a choice of $L_0 = 35$ dB; alternative choices of 40 and 45 dB for L_0 made very little difference, in the noise level range occupied by the data points, particularly for high noise levels. The greatest differences occurred outside the survey data range, between 35 and 50 dB, and had to do with how far the annoyance function dipped below zero (something that seemed undesirable but not very important, since the annoyance function is defined to be zero at noise levels below the greatest value for which it meets the zero axis).

Quadratic functions fitted almost all of the data sets well; exceptions are the Swiss aircraft noise survey and the summary curves, for which a cubic equation with no annoyance threshold was required, and the U.S. 24-site data, for which a linear equation gave the best fit.

There is, of course, a problem with fitting a quadratic function to the annoyance data, namely, that one expects an *S*-shaped response curve, tangent to "zero-percent annoyed" at low noise levels and to "100% annoyed" at high noise levels; instead, the quadratic functions continue to increase at high noise levels.

However, if one examines the data points in the individual surveys, one cannot find consistent evidence for leveling off at high noise levels, in the noise ranges studied. One must conclude that the leveling-off occurs suddenly, as suggested in the (arbitrary) treatment of the data from the French expressway noise survey (Fig. 28). Note, too, that Fig. 3 refrains from claiming a consensus at levels above 85 dB. Presumably, the expected leveling-off occurs above that level.

As for the response leveling off at low noise levels, the use of a quadratic function of $(L_{dn} - L_0)$, with L_0 constant at 35 dB, has the unfortunate effect that the annoyance curves sometimes tend to intersect the horizontal axis at a rather sharp angle (see Fig. 31, for example). Rather than being tangent to that axis, they dip below the axis, being forced to zero at $L_{dn} = 35$ dB. In each case, therefore, the regression curve has been confined to the range actually occupied by the data points.

The data from each survey might be better fitted, at the low end, by a curve with a different value chosen for L_0 in each case, forcing the curve to tangency with the horizontal axis just below the range of data points. But it is not clear how to choose that proper value for L_0; the data points themselves do not give clear guidance, so the choice would remain arbitrary.

In any case, the main result of the study is the *average* curve of Fig. 3, and it *does* exhibit the desired gradual approach to the zero-percent boundary. A more accurate fitting of curves to the data points in the individual surveys (based on the principle discussed above), would have the effect (on Fig. 3) only of making the approach very slightly more gradual.

II. THE INDIVIDUAL SURVEYS

A. First London (Heathrow) aircraft noise survey[3] (1961, 1731 respondents)

Table II of Ref. 3 lists the number of survey respondents with various annoyance ratings, classified according to their aircraft noise exposure in terms of maximum flyover noise level and number of aircraft per day. The annoyance scale covered a range of seven (unnamed) categories, from 0 to 6. (The annoyance scale that was actually used had seven steps, from 0 to 6; but so few people responded in category 6 that they were lumped into category 5 for the data analysis of the original report). It was based on a combination of the response to a direct question about annoyance (Does the noise of aircraft bother you very much, moderately, a little, not at all?) and the answers to five other questions that indirectly imply disturbance (Does the noise of aircraft ever (a) wake you up, (b) interfere with listening to TV or radio, (c) make the house vibrate or shake, (d) interfere with conversation, (e) interfere with or disturb any other activity, or bother, annoy, or disturb you in any other way?).

The informant scored one point toward his annoyance rating if he judged himself at least a little annoyed by aircraft in the direct question, and an additional point for each kind of disturbance from aircraft that he said ever annoyed him, a possible total of six points, which would place him in category 6 of the rating scale. If he was not at all annoyed and was never disturbed in any of the listed activities, his score was zero.

Given the phrasing of the questions (Does the noise *ever* disturb you?) and the method of scoring (one point if "at least a little annoyed" and one point for each positive disturbance answer), it is not clear that a high annoyance rating necessarily implies a *highly* annoyed subject. Even a score of 6 could be attained with only occasional annoyance.

Thus, an analysis, such as that of EPA,[29,30] which counts as "highly annoyed" the people falling in the Wilson Report's categories 4 and 5 (actually the top three of the seven steps on the annoyance scale) may significantly exaggerate the number of people who are actually highly annoyed. This analysis is plotted as the top curve in Fig. 24 and also with the nonclustering surveys in Fig. 5. If only the people in the Report's category 5 (the top two of the seven steps) are counted, the curve of percent highly annoyed people is given as the lower curve in Fig. 24; it falls much more closely in line with the results of the "clustering" surveys, as shown in Figs. 1 and 2.

> *EXAMPLE*: In the first cell of Table II of Ref. 3, there are 5 people counted in annoyance category 4 and 31 in category 5 (see column iii of the table); the total number of people in the stratum is listed as 512 (column v). The percentage of the population highly annoyed is calculated as
>
> $(5+31)/512 \times 100 = 7\%$
>
> if categories 4 and 5 are counted, and
>
> $31/512 \times 100 = 6\%$
>
> if only category 5 is counted.

The maximum [illegible] over perceived noise levels (PNdB) and daily numbers of aircraft operations listed in Table II of Ref. 3 can be used to calculate values of Noise and Number Index (NNI), which is the noise rating developed in this survey and used to report the results. The same data can be used to calculate values of day-night average sound level, L_{dn}, by means of the following equation[11]:

$$L_{dn} = (\text{PNL}_{max} - 13) + 10\log N + 10\log \tau/2 - 49.4 \text{ dB}, \qquad (1)$$

where PNL is the cell median value of perceived noise level; N is the effective number of flights per day ($= N_d + 10N_n$); N_d

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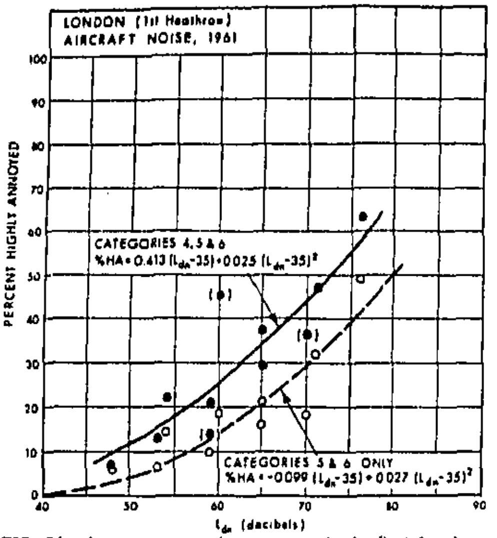

FIG. 24. Annoyance vs noise exposure in the first London (Heathrow) survey of response to aircraft noise (Ref. 3). The amount of annoyance depends on whether the top *three* out of seven categories of annoyance, or just the top two categories are counted as "highly annoyed."

and N_n are numbers of flights in the daytime and nighttime, respectively; 20% nighttime operations were assumed, so the value of N was 2.8 times the tabulated number; and τ is the duration between 10-dB-down points during a flyover.

The final constant (−49.4) corresponds to (−10 log$T$) where T is the observation period (24 h = 86 400 s).

The values of τ were estimated from a curve relating flyover duration and maximum flyover noise level, derived from the aircraft noise survey in Munich (see Fig. 32, below).

> *EXAMPLE*: For the first cell in Table II of Ref. 3, the average number of aircraft per day is 5.75, and the maximum flyover noise level range is from 84 to 90 PNdB, with an average value of 87 PNdB. Subtracting 13 dB to convert this perceived noise level to A-weighted sound level, and referring to Figure 32 for a maximum A-weighted flyover level of 74 dBA, yields an estimate for τ of 26 sec. Then L_{dn} is calculated as:
>
> $$L_{dn} = (87-13) + 10\log(2.8\times 5.75) + 10\log(26/2) - 49.4$$
> $$= \quad 74 \quad + \quad 12.1 \quad + \quad 11.1 \quad - 49.4$$
> $$= 47.8 \text{ dB}.$$

The regression equation between L_{dn} and NNI is $L_{dn} = 0.76\,NNI + 37.5$.

B. Viennese traffic noise survey[32] (1964, 400 respondents)

Table 10 of Ref. 32 presents, for various 5 dB ranges of *indoor* noise exposure (in terms of the Störindex, $\bar{Q}$), the percentages of the population who lie in three "reporting categories" of annoyance, which in turn are based on five *basic* annoyance categories, as follows:

(I) Includes basic annoyance categories 0 (not at all disturbed) and 1 (slightly disturbed);

(II) Includes the single basic category 2 (disturbed);

(III) Includes basic categories 3 (very disturbed) and 4 (unbearably disturbed).

For the purposes of the present study, Reporting category III, as tabulated, was counted as "highly annoyed."

However, the percentages in category III were given separately for day and for night, and separately for windows-open and windows-closed conditions: four different combinations. There was no plausible way of combining these data for a meaningful comparison with the results of other surveys. The "daytime, windows open" curve has been plotted with the nonclustering surveys in Fig. 5, merely as a matter of interest.

The means of translating the noise rating used in this survey to day-night average sound level is also not very satisfying. The German Störindex, $\bar{Q}$, is defined as follows:

$$\bar{Q} = 13.3\log(1/100)\sum_i F_i 10^{L_i/13.3}, \qquad (2)$$

where F_i is the percentage of the time that the time-varying sound level spends in the class interval L_i. This is a form of equivalent sound level commonly used in Germany for evaluating aircraft noise since about 1965. It is approximately, but not quite, equivalent to the L_{eq} currently used by the U.S. Environmental Protection Agency and other jurisdictions. (The difference is that L_{eq} uses the constant 10 where $\bar{Q}$ uses 13.3.)

In the absence of further information, the tabulated values of $\bar{Q}$ for this survey were simply interpreted as indoor L_{eq}. These values were first corrected to outdoor values, by the addition of 7 dB. (The indoor measurement location was 1.5 m. from the open window. The range of differences between outdoor and indoor A-weighted noise levels was stated to be 4.4 to 8.9 dB, with an average value of 7 dB.) The values were then further corrected to L_{dn}, based on tabulated values of the difference between daytime and nighttime noise levels. Specifically, Table II of Ref. 32 lists the differences at eleven measurement locations between daytime noise levels indoors with windows closed and the noise levels during the evening and nighttime periods (1800–0600). The average difference was 3.87 dB with a standard deviation of 2.7 dB. (It would have been preferable, for the purpose of calculating L_{dn}, if the difference between the day-and-evening period and the night period had been given. Presumably that difference would have been smaller than the one actually tabulated; the result would be slightly higher values of L_{dn} and the curve of annoyance vs L_{dn} would come a little closer to agreeing with the clustering surveys.) Taking the nighttime level to be, on average, 4 dB less than the daytime level leads to the conclusion that $L_{dn} = L_{eq} + 4.4$ dB. Thus, if the tabulated range of $\bar{Q}$ is 40–45, the average is 42.5 and L_{dn} is taken to be 42.5 + 7 + 4.4 = 54 dB outdoors.

The Viennese traffic noise survey data do not suggest a polynomial fit to the data points as in the other surveys. Instead, the curves shown in Fig. 25 simply connect the data points for the "daytime and nighttime windows-open" conditions. The corresponding curves for windows closed are very nearly the same; this seems puzzling, unless in both cases the annoyance was related to indoor noise level, but the report implies that this is not the case.

C. French aircraft noise survey[18,19] (1966, 2000 respondents)

This survey, carried out in a manner similar to that of the first London (Heathrow) study, involved four airports: Orly, Le Bourget, Lyon-Bron, and Marseille-Marignane, in the period from November 1965 to April 1966. The numbers of people interviewed at these airports was, respectively, 800, 500, 400 and 300.

The results are reported in Refs. 18 and 19, but the reader must be cautious in interpreting the data. Nominally the *same* noise rating is used to report the survey results in the two

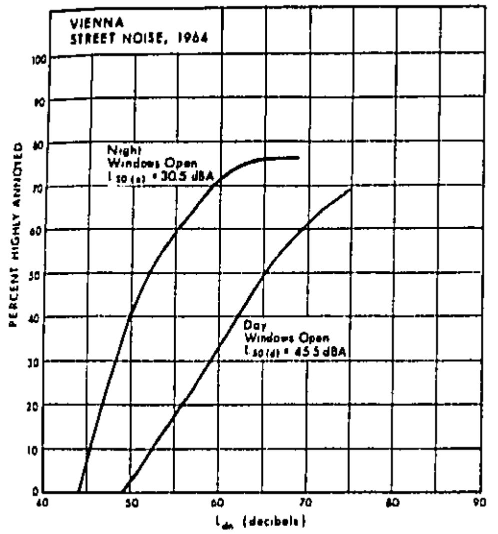

FIG. 25. Annoyance due to street traffic noise in Vienna, 1964. On average, the same amount of annoyance is caused at night by noise levels 10 dB lower than in the daytime.

references (the French isopsophic index, R), but it is defined differently in the two cases.

Josse (Ref. 18) gives:

$$R = \overline{L} + 10\log N - 34 \,, \tag{3}$$

while Alexandre (19) gives:

$$R = \overline{L} + 10\log N - 30 \,. \tag{4}$$

In both cases, $\overline{L}$ is the average maximum perceived noise level, in dB, during a flyover and N is the number of such flyovers per day.

One can get the value of L_{dn} as in Eq. (1). Assuming an average flyover duration of 20 s and 7% nighttime operations (based on operations at the Geneva and Zürich airports), the translation from R to L_{dn} is

$$L_{dn} = R - 16.4 \text{ (Josse)} \,, \tag{5}$$

$$L_{dn} = R - 20.4 \text{ (Alexandre)} \,. \tag{6}$$

(In reckoning the percentage of nighttime traffic, it is not wise to rely upon official airport records. For example, despite the general prohibition against flight operations between 11:30 pm and 6:00 am at Orly and Le Bourget airports near Paris, certain exceptions are permitted (for postal flights and "emergencies"); aircraft may officially receive authorization to land and sometimes even to take off during the nighttime. For example, in 1969, Alexandre counted 6000 "exceptional" nighttime operations at Orly and 4000 at Le Bourget; these operations did not figure in the official count, but amounted to about 3% of the total traffic at Orly and 5% at Le Bourget. Most of these flights were made with piston aircraft.[27])

NOTE ON THE DIFFERENCE BETWEEN L_{eq} AND L_{dn} DUE TO NIGHTTIME OPERATIONS: If k is the fraction of the total daily number (N) of operations occurring during the nighttime (2200–0700), then $N_n = kN$, $N_d = (1-k)N$ and:

$$L_{dn} = L_{eq} + 10\log(1 + 9k) \,. \tag{7}$$

For 7% nighttime operations ($k = 0.07$), the difference is 2 dB.

A slight refinement would have been to use flyover-level-dependent values for flyover duration, as in the first Heathrow noise level translation, but the published data do not report the flyover noise levels independently of the values of R. It would have made differences of only ±1 dB over the range of reported data, anyway.

The number of people counted as highly annoyed were those who said they were highly annoyed (Fig. 3 of Ref. 18; Fig. 5 of Ref. 19) as shown in Fig. 26 and Fig. 1.

As for activity interference, people were regarded as seriously disturbed who reported themselves "sometimes" and "fairly often" disturbed.

D. Second London (Heathrow) aircraft noise survey[16] (1967, 4699 respondents)

Annoyance was rated according to a Guttman scale similar to that used in the first London aircraft noise survey, with seven un-named categories from 0 to 6. The percentages of people counted as highly annoyed are those in the top two of the seven categories, averaged from Tables P-2 and P-4 (3 month total mode, day). They are plotted here in Fig. 27 and also with the results of the other clustering surveys in Fig. 2. No activity interference data as a function of noise exposure were reported.

The method of translating from Noise and Number Index (NNI) to day-night average sound level, L_{dn}, differs from that used for the first London aircraft study, because the flyover noise levels and number of flights were not reported separately in the second London study. Instead, the values of L_{dn} corresponding to tabulated ranges of NNI (15–19, 20–24, etc.) were found by taking the average value of NNI in each cell and referring to the average of two very similar linear regressions

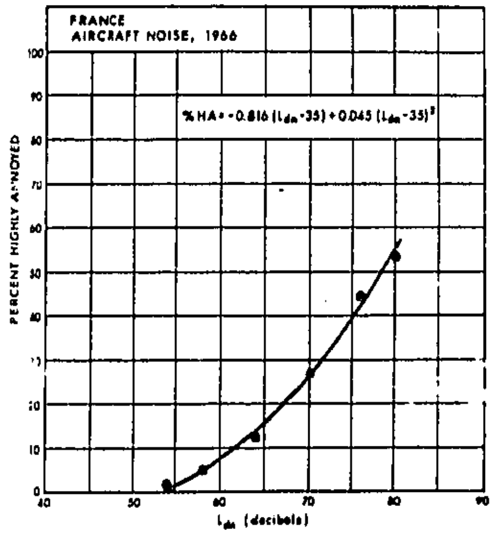

FIG. 26. Annoyance due to aircraft noise around four French airports, 1966.

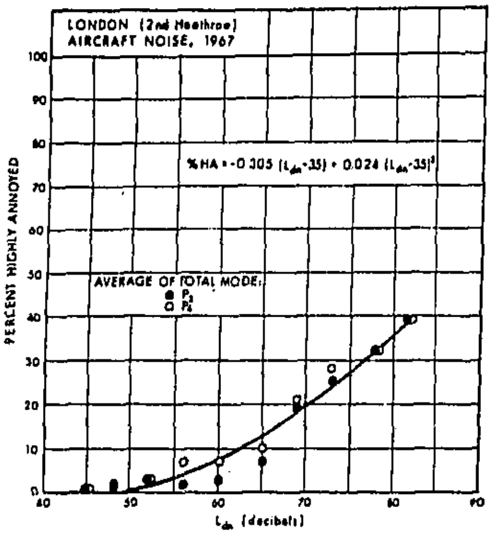

FIG. 27. Annoyance due to aircraft noise around London's chief airport, 1967.

relating L_{dn} and *NNI*, based on data from the Swedish and Swiss aircraft surveys.

The regression equation from the Swedish data is L_{dn} = 0.87 NNI + 31.7; the equation from the Swiss survey is L_{dn} = 0.833 NNI + 35.2; the average of these, used for translating the noise of the second London aircraft study, is

$$L_{dn} = 0.85\ NNI + 33.5 \tag{7}$$

E. French expressway noise survey[21] (1967, 400 respondents)

The percentage of annoyed population is taken from Fig. 2c of Ref. 21, which plots the percentage of responses in the top two of four annoyance categories, in response to a direct question about annoyance, as follows: *"Finalement, êtes-vous gênés, pas, peu, assez, beaucoup par l'autoroute?"* [Finally, are you not at all, a little, moderately or extremely annoyed by the expressway?] People were said to be "highly annoyed" if they responded in the third or fourth category. Such a procedure surely overestimates the highly annoyed part of the population, since it includes people who claim they are only moderately annoyed.

Activity interference data are presented in Fig. 2b of Ref. 21 in terms of the percentages of respondents who replied "yes" to direct questions, as follows: *"Êtes-vous réveillés la nuit par l'autoroute?"* [Are you awakened at night by the expressway?] and *"Êtes-vous obligés de fermer les fenêtres quand vous recevez des amis ou des parents?"* [Are you obliged to close the windows when friends or parents visit?]. Positive response to the latter question was taken to indicate serious interference with conversation.

The noise rating used for reporting noise exposure in the French expressway survey was the value of L_{50} measured during the hour between 11:00 a.m. and noon on weekdays. The method used to translate those data to L_{dn} is not altogether satisfactory, but no other way was available.

A later study of street traffic in central and suburban Paris[34] produced a large amount of noise level data from which values of L_{dn} could be calculated and values of L_{50} both for the daytime period and for the hour between 11:00 a.m. and noon could be determined.

Restricting attention to 28 suburban measurement locations near arterial roads (the closest approximation to expressway traffic), one can calculate a linear regression between L_{dn} and L_{50} for the daytime period (no hourly breakdown of noise levels was reported for the suburban locations), as follows:

$$L_{dn} = 1.20\ L_{50(d)} - 6.2 \tag{8}$$

$(r = 0.964,\ S_y = 1.17\ \text{dB})$.

Then, referring to 43 urban Paris sites, a linear regression was found to relate $L_{50(d)}$ to L_{50} for the hour between 11:00 a.m. and noon:

$$L_{50(d)} = 1.115\ L_{50(11:00-12:00)} - 9.1 \tag{9}$$

$(r = 0.980,\ S_y = 0.57\ \text{dB})$.

Equations (8) and (9) were then combined to give a relation between L_{dn} and L_{50} for the hourly period used in the survey, as follows:

$$L_{dn} = 1.34\ L_{50(11:00-12:00)} - 17.2\ . \tag{10}$$

The annoyance data are presented here in Fig. 28 and also as a matter of interest, with the non-clustering surveys in Fig. 5. However, because of the uncertainties of noise level translation and the interpretation of high annoyance (all people responding on the top half of the annoyance scale were reported as "highly annoyed"), this survey has been left out of account in the averages and the synthesis.

The single data point for L_{dn} = 89.5 was omitted in calculating the regression for this survey, since it obviously would not fit onto a quadratic regression curve; between that point and the regression curve at about L_{dn} = 77 the annoyance curve was completed by eye, as shown dashed in Fig. 28.

F. Swedish street traffic[35,36] (1966, 472 respondents; 1975, 564 respondents)

Two Swedish surveys of community response to traffic noise have been made recently by different teams of investigators.

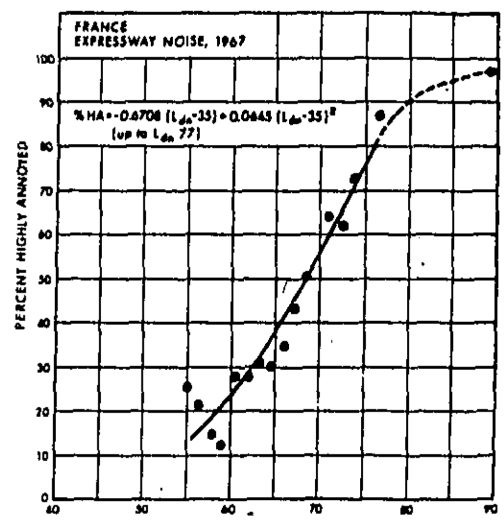

FIG. 28. Annoyance due to expressway noise around Paris, 1967.

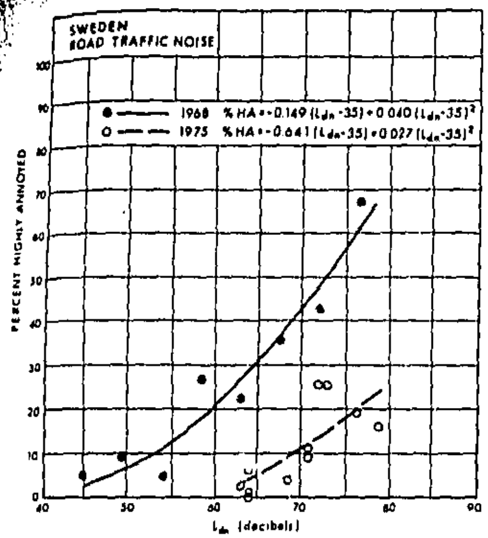

FIG. 29. Annoyance due to road traffic noise in several Swedish cities, 1968 and 1975.

They create a problem for the purposes of the present study because they disagree strongly with one another and with the results of the clustering surveys. The reasons are not clear.

The people counted as highly annoyed in the 1968 survey (carried out in Stockholm and Gothenburg) were those whose annoyance rating fell in the highest one out of 11 categories; these are tabulated against 24-h equivalent noise level, L_{eq}, in Table 13 of Ref. 35.

In order to translate from $L_{eq(24)}$ to L_{dn}, use was made of an earlier traffic noise study,[37] carried out in several Swedish cities, in which cumulative statistical distributions were given for the traffic noise at ... measurement locations, for the daytime, evening, and nighttime periods, and for the entire 24-h period. From these data, it was possible to calculate both $L_{eq(24)}$ and L_{dn} and to determine a linear regression relating them, as follows:

$$L_{dn} = 1.13 L_{eq(24)} - 4.9 \tag{11}$$

$$(r = 0.99,\ S_y = 0.9\ \text{dB})\ .$$

The results of this survey are plotted as the upper curve of Fig. 29. Even though only the top category of eleven on the annoyance scale was counted as highly annoyed, this curve lies considerably above those for the clustering surveys.

No activity interference data plotted against noise exposure were reported.

In the 1975 survey, the study was carried out in urban and suburban residential areas in Stockholm and Visby. Again the noise exposure was measured in terms of $L_{eq(24)}$ and the translation to L_{dn} was made with the use of Eq. (11), as for the earlier Swedish study.

In this survey, the people counted as highly annoyed were those who declared themselves to be "very annoyed." The results for eleven city areas (eight of them in Stockholm) are plotted in Table 2 of Ref. 36, and are plotted as the lower curve of Fig. 29. This time the curve falls significantly *below* those of the clustering surveys, and very much below that for the earlier Swedish road traffic study.

There seems to be nothing questionable about the translation to L_{dn} from the reported noise ratings used in the surveys, except, perhaps, that in the report of the second survey it was implied, but not explicitly stated, that the noise rating L_{eq} was the 24-h average.

Considerably greater question arises from the fact that in the first survey, the measurements were made over a 24-h period at locations near the roadway; but the noise exposure at the respondent's residence was calculated, based on level-vs-distance relations developed from previous studies and on an approximate calculation of barrier attenuation for partially shielded dwellings. In the second survey, the values of L_{eq}, instead of being measured, were calculated from measured mean pass-by noise levels and a traffic volume count based on "official statistics" for the previous year.

There appears to be sufficient question about the determination of the noise exposure in both surveys that, even though the annoyance of the subjects in the 1975 survey was self-rated, and, as such, qualifies for inclusion with the eleven clustering surveys, it was omitted from Fig. 1 and included in Fig. 5.

One (anonymous) reviewer of an early draft of this paper commented, with respect to the two Swedish traffic noise surveys: "The differences have never been discussed (unless within the cloisters of Gothenburg), but if they were to be discussed would not have been very difficult to explain. In the first place, the 1968 survey used a very peculiar 'cascade' type scale giving results which are themselves internally inconsistent, whereas the 1975 survey used a more conventional scale. Secondly, the 1975 survey did not measure the noise fully but used a computational procedure which probably grossly overestimates the noise levels."

Correcting (i.e., reducing) the noise levels might bring the results of this 1975 survey into better alignment with the clustering surveys.

G. French street traffic noise survey[40] (1969, 700 respondents)

Noise measurements were made in front of more than 100 buildings in urban (43 sites) and suburban (68 sites) areas of Paris, including arterial streets, one-way and two-way streets, distribution streets and connecting streets.

The noise rating used in this survey was L_{50} measured over 24 h. Based on the noise data from Ref. 34 for all of the 111 Paris measurement locations, a regression between L_{dn} and $L_{50(24)}$ was determined, as follows:

$$L_{dn} = 0.915 L_{50(24)} + 16.3 \tag{12}$$

by averaging the two regression curves for the urban and the suburban Parisian sites:

Urban	Suburban
$L_{dn} = 0.785 L_{50(24)} + 24$	$L_{dn} = 1.06 L_{50(24)} + 7.4$
$(r = 0.946,\ S_y = 1.01\ \text{dB})$	$(r = 0.92,\ S_y = 1.85\ \text{dB})$.

The people counted as highly annoyed were identified by their responses to a question that asked them to rank-order ten aspects of the neighborhood from the most to the least satisfying. These aspects include amusements, nearness to workplace, public transport, street noise, noise in the building, schools and high schools, neighbors, shops, public services (city hall, post office, etc.), and doctors and pharmacies. Those who put the street noise in tenth place (least satisfying), were regarded as highly annoyed, as shown in Fig. 12 of Ref. 40. Those data are plotted here in Fig. 30 and are also included with the results of the clustering surveys in Figs. 1 and 2. No activity interference data-vs-noise exposure were reported.

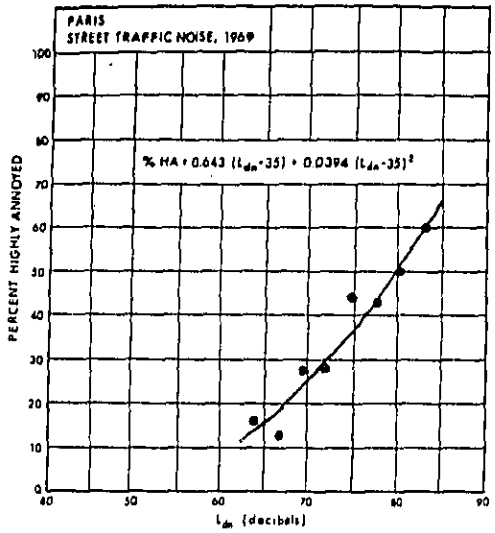

FIG. 30. Annoyance due to street traffic noise in urban and suburban Paris, 1969.

H. Munich aircraft noise survey[41] (1969, 660 respondents)

The results of this survey led to the proposal of a new German rating, FB1, for aircraft noise called "*Fluglärmbewertungsmass* 1" ["Aircraft Noise Rating Measure 1"], as follows:

$$FB1 = 10 \log \sum_{i=1}^{N} 10^{(L_{Ai}/10)} + 10 \log N - 50 \ . \qquad (13)$$

(Notice that the number of operations is taken into account once in the sum term, and again in the second (10 log$N$) term; thus, this rating has a 20 log$N$ dependence on number of operations, as in the Dutch "noise load.")

The survey results were mainly presented in terms of FB1,

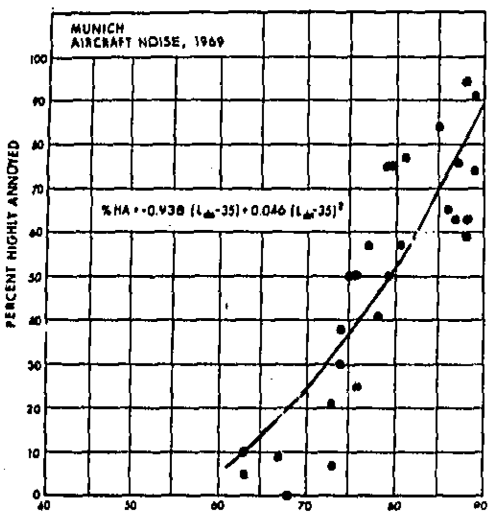

FIG. 31. Annoyance due to the noise of aircraft in Munich, 1969.

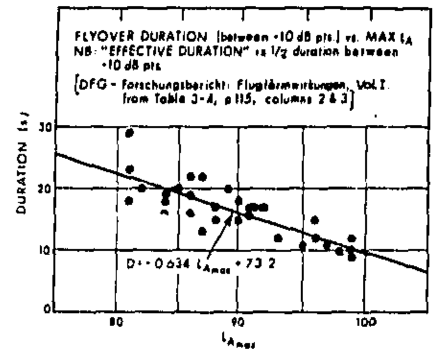

FIG. 32. The duration of aircraft flyovers as a function of the maximum A-weighted sound level occurring during the flyover; the louder the noise the shorter the duration.

but equivalences with other, more familiar, ratings were also given, in some cases. For the purpose of the present study, the data expressed in terms of Noise and Number Index (NNI) were used; these were translated to L_{dn} by means of the average of two nearly equal linear regressions of L_{dn} on NNI, derived from the Swedish and the Swiss aircraft noise studies. (The same procedure was also used for the second London aircraft noise study.)

This leads to the following relation:

$$L_{dn} = 0.817 \text{ FB1} + 14.5 \ . \qquad (14)$$

The annoyance data are summarized in Fig. 3–19 of the Main Report of Ref. 41 where the percentage of highly annoyed (stärker Betroffenen) population is plotted against several noise ratings, including FB1 and NNI. These data are plotted against L_{dn} here in Fig. 31 and also with the results of the clustering surveys in Fig. 1.

Tabulated values of the percentages of people disturbed in rest and conversation are presented in Fig. 6 of the Dubrovnik version of this report and in Fig. 11 of the So[illegible]mpton version (see comment at Ref. 41). They were derived by the respondents' self-ratings, based on a five-step scale as follows: Not at all, slightly, average, very, and strongly disturbed. Those responding in the "strongly disturbed" ("*ziemlich starke*") and "very disturbed" ("*sehr starke*") categories were counted as seriously disturbed.

Further results from the Munich aircraft noise survey have been helpful in translating to L_{dn} the noise data from the first London (Heathrow) survey. These give the relation between the maximum flyover sound level and the duration of the flyover, in terms of the time between instants when the noise level is 10 dB below the maximum value, as shown here in Fig. 32.

I. Swiss street traffic noise survey[20,23] (1972, 945 respondents)

In 1972–1973 a large survey studied the Swiss urban community response to aircraft noise and also considered the response to street traffic noise in the city of Basel, for comparison.

The annoyance data for street traffic are given in Table 4.18, p. 132, of Ref. 23. The noise exposure was rated in terms of L_{16} for the daytime period (0600–1800), in 4-dB windows (e.g., 64–68 dB, 68–72 dB, etc.). The mean level in each window was translated to L_{dn} by way of the average of five linear regressions of L_{dn} vs $L_{16(d)}$, based on street traffic noise data from Paris (urban and suburban,[34] 111 sites), Sweden[37] (26 sites), Belgium[42] (16 sites) and the United States[15] (100 sites) as follows:

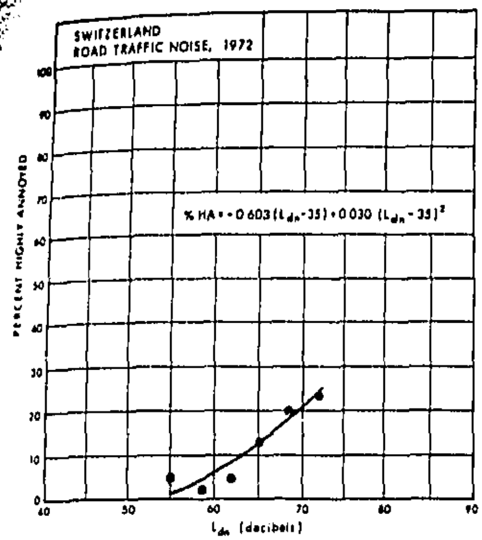

FIG. 33. Annoyance due to road traffic noise in Basel, 1972.

$$L_{dn} = 0.8428\ L_{50(d)} + 16.6\ . \tag{15}$$

The five individual regressions were as follows:

Paris (urban): (0730–2230) $L_{dn} = 0.95\,L_{50(d)} + 9.2$ ($r = 0.962$, $S_y = 0.95$ dB)

Paris (suburban): (0730–2230) $L_{dn} = 1.04\,L_{50(d)} + 3.7$ ($r = 0.94$, $S_y = 1.6$ dB)

Sweden: (0700–1800) $L_{dn} = 0.92\,L_{50(d)} + 10.6$ ($r = 0.92$, $S_y = 2.6$ dB)

Belgium: (0700–1900) $L_{dn} = 0.829\,L_{50(d)} + 16.1$ ($r = 0.756$, $S_y = 3.6$ dB)

United States: (0700–2200) $L_{dn} = 0.762\,L_{50(d)} + 22.0$ ($r = 0.934$, $S_y = 1.6$ dB)

The percentage of people counted as highly annoyed was based on the respondent's self-rating of annoyance by reference to an "opinion thermometer" with eleven categories; those rating themselves in the top three categories were reported as feeling "*starke Störung*" ("strong annoyance"). The results are plotted against L_{dn} here in Fig. 33, and with the results of the clustering surveys in Figs. 1 and 2.

J. Swedish aircraft noise survey[43,44] (1972, 2900 respondents)

Social surveys were conducted in 24 areas around 8 airports in three Scandinavian countries (Sweden, Denmark, and Norway). The noise exposure in each of the 24 areas was said to be homogeneous and was characterized in terms of PNL for the mean of individual flyovers, and by NNI, CNR, and NEF for overall aircraft noise exposure assessment. The values of NNI and CNR were calculated in two ways: once, taking into account only the noise from the runway that most strongly impacted the neighborhood, and a second time for the noise impacting the area from *all* runways. The latter data are used in the present report, taken from Table 4-2, p. 32, of Ref. 43.

The translation to L_{dn} of the values of noise exposure for this survey was slightly complicated. It was assumed that the correct values for both CNR and NEF had been calculated by the Swedish study team for the various areas, and that the best estimate of L_{dn} would be found by translating *both* of those reported ratings to L_{dn}, according to the approximation recommended in Ref. 29 (Appendix A):

$$L_{dn} = \mathrm{NEF} + 35 = \mathrm{CNR} - 35\ . \tag{16}$$

(There is actually no fixed relationship between CNR and NEF, because of differences in frequency weighting between *A*-weighting (used in the CNR) and perceived noise level (used in the NEF), the allowance for flyover duration in the NEF, and minor differences in handling nighttime adjustements. Thus, both equivalences expressed in Eq. (16) are approximate.)

There is a further slight complication, however, because CNR, but not NEF, was calculated for the impact of noise from *all* the runways. Accordingly, L_{dn} was approximated once by subtracting 35 from the value of CNR for *all* runaways. Then, the difference in CNR for the "all-runways" and the "dominating-runway" conditions was determined, and this difference was used to correct the second approximation to L_{dn}, formed by adding 35 to the value of NEF for the "dominant-runway" condition. The mean of the two approximations was used for the value of L_{dn} in this report.

In addition, a regression was determined between this approximation for L_{dn} and the reported values of NNI for the various study areas, as follows:

$$L_{dn} = 0.877\ \mathrm{NNI} + 31.7\ . \tag{17}$$

This agrees very closely with the regression determined from the data of the Swiss aircraft noise survey; the two regressions give each other mutual support, and lend confidence to the use of these regressions in the analysis of data from other aircraft noise surveys that used NNI for the noise rating.

The annoyance data are tabulated for the various study areas in Table 6-1, p. 45, of Ref. 43. People were counted as highly annoyed who stated that they were highly annoyed ("*mycket störda*"). (The categories were five in number, as follows: "do not notice," "notice, but not annoyed," "a little annoyed," "rather annoyed," and "highly annoyed.") Of those who claimed to be highly annoyed, 49% spontaneously mentioned aircraft noise as a serious source of discomfort, and 85% said the annoyance happened daily, 81% reported difficulty in listening to radio or television, 70% reported interference with conversation, 60% were awakened by the noise, etc.

The annoyance results are plotted here in Fig. 34, and also with the results of the clustering surveys in Figs. 1 and 2.

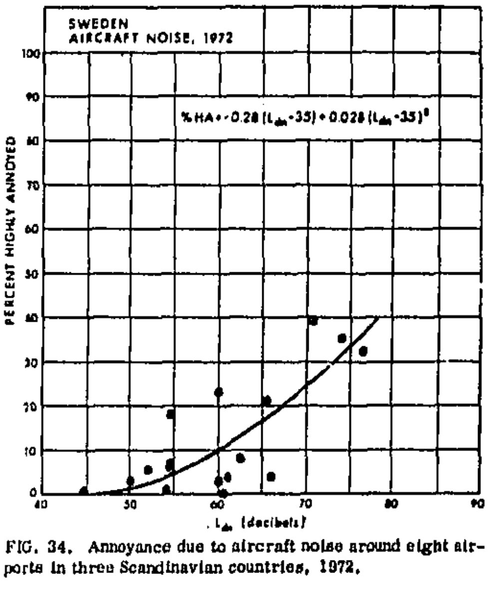

FIG. 34. Annoyance due to aircraft noise around eight airports in three Scandinavian countries, 1972.

K. U.S. aircraft noise surveys (Tracor)[45,46] (1967–1969, 6502 respondents in seven large cities; 1970–1971, 1960 respondents in two small cities)

The annoyance data are summarized separately for the large and small cities in Fig. 1 of Ref. 45. The noise exposure is rated in terms of CNR, which was translated to L_{dn} for this study by subtracting 35 dB.

The definition of what was meant by "Percent Highly Annoyed" in that figure is not given in Ref. 45, but it *is* explained in Ref. 47. The description of the scoring procedure is ambiguous, however:

> "When the respondent indicated disturbance of a particular activity, he was asked how much he was bothered. The response, obtained with a graphic aid called an 'opinion thermometer' had a range of 0–4 for each activity. This range was scored on a scale of 1–5 and the value 0 was assigned when no disturbance of the activity was reported. The scores for all nine activities were added to produce a summated rating which thus had a value of 0 representing no disturbance of any activity and a range of 1–45 for those respondents who were disturbed."

The ambiguity arises from the fact that the zero step on the opinion thermometer was labeled "not at all" disturbed, which would earn a score of 1, not 0, as stated.

In any case, activity interference, not annoyance, was assessed by this means for each respondent, but those whose total rating was between 21 and 45 on this scale were regarded as "highly annoyed." Apart from the fact that it does not directly rate annoyance, *per se*, this procedure (of counting everyone scoring on the upper half of the rating scale as "highly annoyed") seems likely to include in the highly annoyed category many people who are actually *not* highly annoyed, at least in the sense intended in most of the other surveys. It would be more interesting to know how many people indicated point 4 on the opinion thermometer at the various noise exposures!

The annoyance data, plotted against L_{dn}, have already been presented in Fig. 7. The large discrepancy between the results for large and small cities may be explained in part by the fact that the large cities were surve[illegible]d in the summertime, when people spend a lot of time out[illegible]s or with their windows open; this is always a period of high complaint about noise. (For example, the mean monthly complaint rate at Kennedy International Airport during the period of the small city survey (October through January) was only 1.6%; for the large city survey period (May through September) it was 16.6%.) The small cities were studied in the wintertime, when people indoors had significantly better effective protection from the noise. The average of the two curves probably gives a better idea of *annual average* community response.

There remains, ho[illegible]r, the problem o[illegible] counting as highly annoyed all the people who rated on the upper half of the activity interference scale. It is surprising that the reported percentage of high annoyance is not greater!

L. Japanese railroad noise survey[48,49] (1972, 424 respondents)

This railroad noise survey is included here, despite serious difficulties in reconciling the results, chiefly because there is so little quantitative information, to date, a[illegible]ut community response to railroad noise. These data are not included with those of the other surveys in formulating the averages.

The annoyance data are presented in Tables 1 and 3 (last column) of Ref. 49 (or 50). The noise exposure is rated in terms of maximum *A*-weighted sound level during the passby of the railroad train.

The translation to L_{dn} was made in accordance with a formula similar to that given incorrectly in Ref. 51. The correct form is

$$L_{eq} = L_{max} + 10\log\left(\frac{N}{2.3T}\right)(\tau + 2.3\,\delta),$$

where N is the number of trains per day, T is the observatio[n] period (1 day = 24 hrs = 86 400 s), τ is the duration of the peri[od] in a train passby when the noise level is below, but within 10 dB of, the maximum value and δ is the duration of the maximum level.

Based on the standard 16 cars per train for these Japanese Shinkansen trains, and an assumed car length of 20 m, the train length is 320 m. At the cruising speed of 210 km/h, the value of δ, the duration of a passage, is 5.5 s. The value of τ is found from

$$\tau = 5.4\,d^{0.8}/58.3\,, \qquad (1[illegible])$$

where the distance, d, from the railroad track is estimated from the reported maximum passby level, based on Fig. 1 of Ref. 49 (or 50). The reported number of trains per day is 200. Thus, for example, where the reported maximum passby level is 80 dB, the value of L_{eq} ($= L_{dn}$ because there are no nighttime passages) is

$$L_{eq} = 80 + 10\log\left(\frac{200}{2.3\times 86400}\right)(2.12 + 2.3\times 5.5) = 61.8\ \text{dB}\,.$$

Neither of the references clearly states how the percentage of people who were "annoyed" was determined. It is not even stated which of the listed survey questions is the source of the annoyance data. But the general *form* of many of the questions used in the interviews (Does railroad noise *ever* keep you from going to sleep? Have you *ever* been disturbed in conversation by the railroad noise? etc. [emphasis added]), suggests that people responding affirmatively are not necessarily *highly* annoyed. Thus, we may expect a rather large percentage of the population to be reported as annoyed for a given noise exposure in this survey.

Even taking this into account, the results indicate an astoni[sh]ingly high incidence of annoyance, as already shown in Fig. [illegible] (solid line).

It appears, however, that this anomalous result may depe[nd] in part on the fact that the noise attenuation from outdoors [to] indoors in Japanese houses is much different than in Europ[ean] and American buildings. For example, the attenuation (in A-weighted sound level) for a railroad noise spectrum by cold[-]climate American houses with closed windows is about 28 d[B]. In Ref. 49, a value of only 10 dB attenuation is given for Japanese houses. Thus, a shift of some 18 dB toward high[er] noise exposure may be appropriate in comparing these Japa[nese] survey results with the others, as shown in Fig. 9 (dashed li[ne]). (A similar shift is needed to make the Japanese data on acti[vity] interference by the "bullet train", by ordinary railroad trai[ns] and by road traffic noise come into agreement with data from the other surveys.[46,47]) The lightly drawn line for "Japan R[R]" in Fig. 5 represents the original data shifted 18 dB to the rig[ht]. Considering the phrasing of the interview questions, these re[]sults are perhaps not far out of line with the other surveys.

M. French railroad noise survey[34,52,53] (1973, 350 re[sp]ondents)

The annoyance data are presented in Ref. 52 (page 63) in terms of the response to the direct question:

> #57. "From a general point of view, in your opinion the noise of the trains is:
>
> quite tolerable . . . . altogether intolerable
>
> (The respondent was asked to indicate his response along a scale with seven categories, of which only the two extremes were named, as above.)

The noise exposure was expressed in terms of L_{eq} at the house facades during the daytime; since there were no nighttime train passages, the same noise level can be used as L_{dn}.

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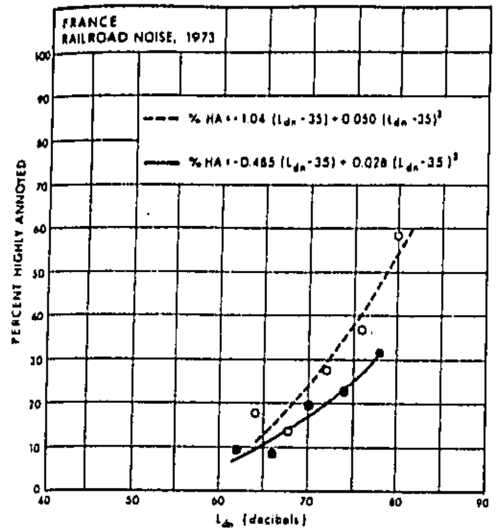

FIG. 35. Annoyance due to railroad noise in France around Paris, 1973.

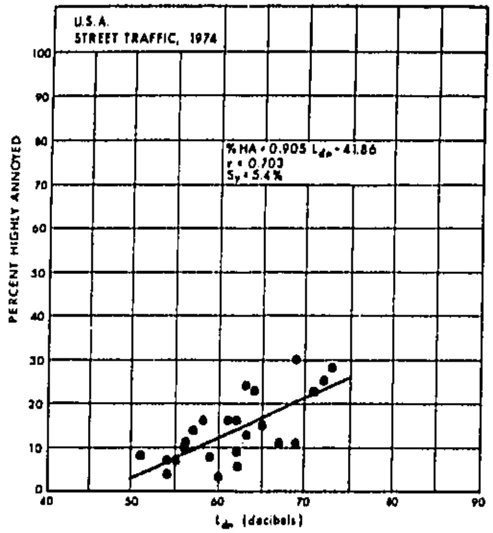

FIG. 37. Annoyance due to street traffic noise in the United States, 1964.

Because the name given to the top step on the annoyance scale in this survey appeared to be so extreme in comparison with those in the other surveys, the author originally chose to count as highly annoyed those people responding in the top three categories, instead of following the basic rule of counting the top two categories. This yields the upper curve of Fig. 35, which falls near the center of the clustering surveys of Fig. 1. If one adopts the basic rule and counts only the top two categories as highly annoyed, one gets the lower curve of Fig. 35, which still lies in the range of the clustering curves but near the lower part of the range (see Fig. 2).

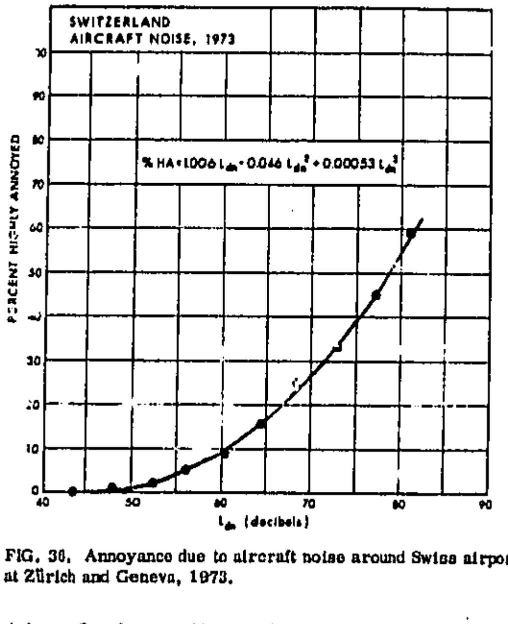

FIG. 36. Annoyance due to aircraft noise around Swiss airports at Zürich and Geneva, 1973.

N. Swiss aircraft noise survey[20,23] (1973, 2995 respondents)

The annoyance data are given in Fig. 4.8 of Ref. 23, as a plot of "percent highly annoyed" ("*stark gestört*) against noise exposure in NNI. The respondents self-rated their annoyance on an eleven-category scale, and those who fell into the top three categories were counted as highly annoyed.

The regression equation between L_{eq} and NNI for the data in this survey was found to be (Ref. 23, page 94):

$$L_{eq} = 0.833\,\mathrm{NNI} + 33.3 \quad (r = 0.513)\,.$$

Assuming 7% nighttime flights, the value of L_{dn} would be 2 dB greater than L_{eq} in each case:

$$L_{dn} = 0.833\,\mathrm{NNI} + 35.3\,. \tag{20}$$

The data from Fig. 4.8 of Ref. 23 are plotted here as Fig. 36, and also in Figs. 1 and 2 with the results of the clustering surveys.

This regression agrees very well with a similar regression based on data from the Swedish aircraft noise survey. The mean of those two relations was used to translate the data from other surveys that used NNI into corresponding values of L_{dn}.

O. United States street traffic noise survey[25] (1974, 1843 respondents)

The annoyance results came from the responses to a direct question: "How ANNOYING was the noise in your neighborhood over the past year?" The five named response categories were as follows:

1. Not at all; 2. Slightly; 3. Moderately; 4. Very; and 5. Extremely. (People responding in categories 4 and 5 were counted here as highly annoyed.)

As for the noise exposure, it was measured directly in L_{dn}.

The results of the survey are plotted here in Fig. 37, and also in Figs. 1 and 2 with the results of the clustering surveys.

P. London street traffic noise survey[11] (1972, 1359 respondents)

An earlier survey of street traffic noise in London was conducted in 1966. The results are not reported here because the

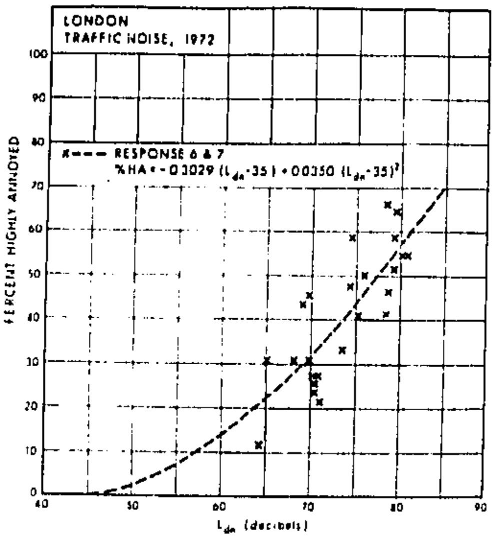

FIG. 38. Annoyance due to street traffic noise in London, 1972.

relevant data concerned the *average annoyance* of groups of individuals with various noise exposures. It is not possible to derive the percentage of highly annoyed population from the published results. The same is true for the recent street noise survey reported in Ref. 11.

However, Dr. F. J. Langdon has kindly supplied noise exposure and subjective response data for the 24 sites of this survey at which the traffic was freely flowing. He has calculated the noise exposure in terms of L_{dn} and has tabulated the number of respondents falling into each of seven categories along a semantic differential scale of annoyance, of which the two extreme categories were named: "definitely satisfied" and "definitely unsatisfied."

In the author's original analysis of this survey, people were counted as highly annoyed based on the average between those with scores in the top two categories and those responding in only the top category: thus 1½/7. The results are plotted in Fig. 1. In a revised analysis, the people responding in the top two categories were counted as highly annoyed, as shown in the curve of Fig. 38, also plotted with the clustering surveys in Fig. 2.

ADDENDUM

Most of the author's analysis of surveys reported in this paper was done in the autumn of 1976. The data from comparable surveys that were available at that time are presented as a synthesis of community response to noise in Figs. 1–3.

Since that time, several other surveys have been published. The results are described in this addendum, but they have not been taken into account to update the average curve of Fig. 3. In fact, however, the three surveys that are comparable with the others (from Copenhagen, Brussels and Antwerp) agree closely with the clustering surveys of Figs. 1 and 2, and their inclusion would hardly change the synthesis curve of Fig. 3 at all.

A. Danish street traffic noise survey[59] (1972, 960 respondents)

The annoyance data are given in Table 8, Annex 1.7, of Ref. 59, in terms of the percentage of the interviewed persons at each of the 28 sites who answered that they are "much annoyed" by the noise of street traffic. The two other steps on the three-step annoyance scale were "a little annoyed" and "not at all annoyed."

Appendix B of Ref. 60 gives for each site in this survey the values of measured L_{eq} for the periods from 0700–1800, from 1800–2200 and from 2200–0700, as well as the 24-h L_{eq}. Since these data concerned the noise level *at* the facade of the dwelling, 5 dB were subtracted for the purposes of this study, according to the recommendation of the author of Ref. 60. Corresponding values of L_{dn} were calculated from these data.

The regression between L_{dn} and $L_{eq(24)}$ for these sites is

$$L_{dn} = 1.0024\,L_{eq(24)} + 3.36\ ,$$

with $r = 0.9963$ and $S_y = 0.76$; this agrees very closely with the regressions found in the surveys in Paris, Leuven, Sweden and the U.S.A.

The percentage of the population highly annoyed by street traffic noise is plotted against L_{dn} in Fig. 39.

B. Viennese street traffic noise survey[61] (1975, 2642 respondents)

The recent Viennese street traffic noise survey results cannot be compared with the "clustering" surveys of Figs. 1 and 2, because only one question in the interview concerned annoyance and it asked simply, *"Sind Sie in Ihrer Wohnung erheblichen Lärmbelastigungen von aussen ausgesetzt?"* ["Are you considerably disturbed in your dwelling by noise from outdoors?"] The permitted answers were either "no" or "yes."

In the latter case, the interviewer determined whether the source of the "considerable disturbance" was street traffic, heavy trucks, industrial noise, construction noise, or "other source."

Thus, there is no scale of annoyance in the sense of the other surveys, nor is an opportunity allowed for self-rating annoyance like the others, for no range is suggested, against which the subject can "calibrate" his response.

The results of this survey are shown in Fig. 40; one curve indicates the responses only for individuals whose dwellings face the street, the other curve shows the responses irrespective of dwelling orientation. This survey confirms the results found in both the Japanese railway noise survey[43,44] and the

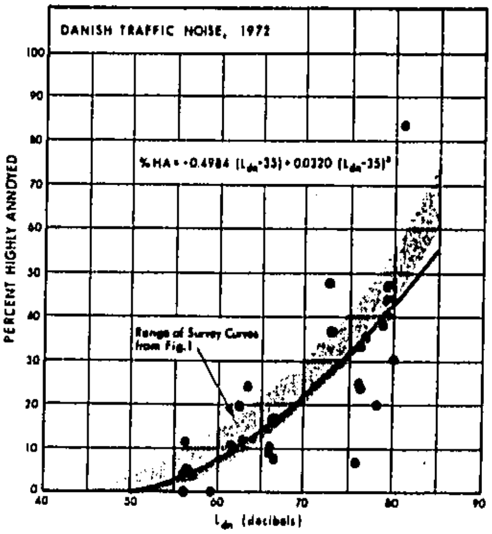

FIG. 39. Annoyance due to street traffic noise in Copenhagen, 1972.

French expressway noise survey,[31] that if there is an "escape room" available in the dwelling, to which one can retreat from the side of the dwelling exposed to the noise, the noise level can be 3 to 5 dB higher for the same annoyance.

The noise measurements in this survey were reported in terms of $L_{eq(24)}$; they were converted to L_{dn} by means of the average of six regressions between L_{dn} and $L_{eq(24)}$ from various other cities, as mentioned in the previous section. The annoyance data come from Table 5 and 6 of Ref. 61.

C. Belgian street traffic noise survey[62-64] (1974-1976, 2062 respondents)

The annoyance data and the activity interference data for the survey in Antwerp are given in Table 32, Vol. 5 of Ref. 62. People were counted as "highly annoyed" who responded in the top three of ten categories on the annoyance scale.

Similar data are given in Table V3a, Vol. 12, of Ref. 62 for the survey in Brussels.

The traffic noise in the Antwerp survey was measured in terms of L_{eq} separately for the daytime, evening and nighttime periods and reported in Vols. 2 and 3 of Ref. 62; the corresponding values of L_{dn} were calculated from these data for the forty measurement sites.

In Brussels, the noise measurements were less completely carried out, but at each site the value of L_{eq} was given for a substantial part of the daytime period. Thus, based on a regression between daytime L_{eq} and the corresponding values of L_{dn} fr m the Antwerp survey data, the daytime noise data from Brussels were used to determine values of L_{dn} for the 25 Brussels sites. These values agreed very closely with values of L_{dn} calculated directly for sites in Brussels for which both daytime and nighttime noise measurements were reported.

Two questions in the Antwerp survey (see Volume 6 of Ref. 62 concerned annoyance due to the noise of street traffic. They are of special interest for this synthesis of responses to environmental noise, for they show clearly the effect of how the upper endpoint of the annoyance scale is named.

Question 5 asked, *"Wij hadden graag uw opinie gekend over het verkeerslawaai dat U hoort wanneer U overdag in uw woning is?"* [We would like to know your opinion of the traffic noise that y u hear in your residence during the day.] The endpoints of the annoyance scale for this question were named *"Helemaal niet storend"* (not at all disturbing) and *"zeer storend"* (very disturbing). In Brussels, the interviews were conducted in both Dutch and in French; the corresponding text for question 5 in French was *"Nous voudrions bien connaître votre opinion sur le bruit du trafic que vous entendez chez vous pendant la journée;"* and the endpoints were named *"Ne pas gênant du tout"* (not at all annoying) and *"Très gênant"* (Very annoying). (See Volume 11 of Ref. 62).

When the responses to question 5 are plotted against day-night average noise level, the results agree fairly well with the results of the clustering surveys, as shown in Fig. 41.

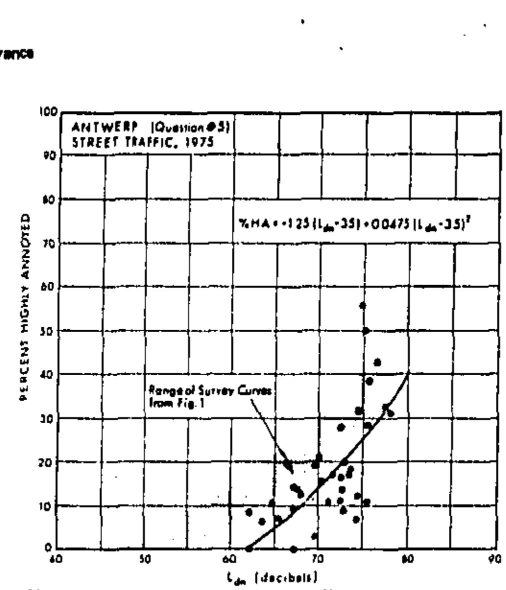

FIG. 41. Annoyance due to street traffic noise in Antwerp, 1975: Question 5. The difference between this figure and Fig. 42 is attributed to differences in the names of the endpoints of the annoyance scale, see text.

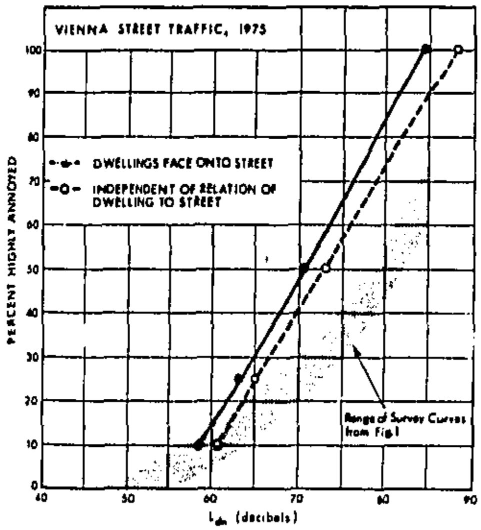

FIG. 40. Annoyance due to street noise in Vienna, 1975. See text for discussion.

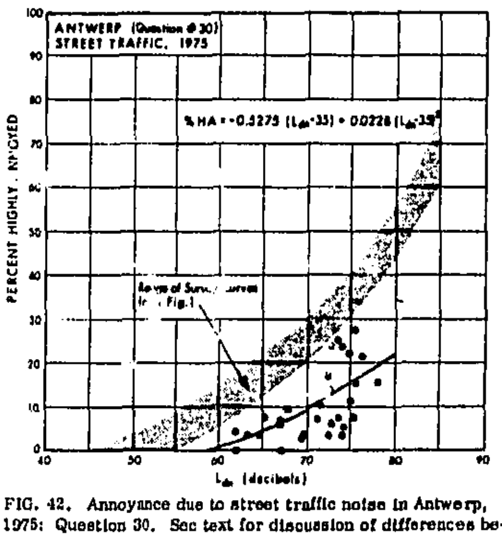

FIG. 42. Annoyance due to street traffic noise in Antwerp, 1975: Question 30. See text for discussion of differences between this figure and Fig. 41.

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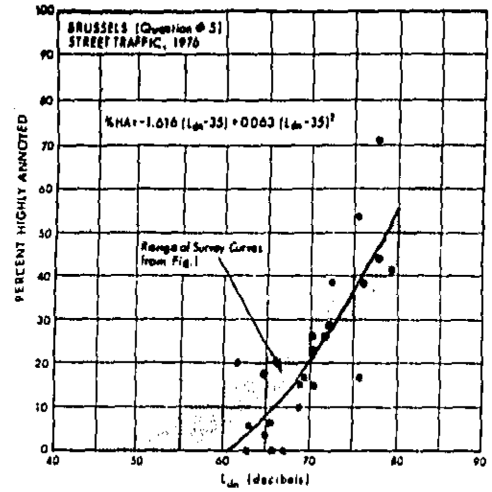

FIG. 43. Annoyance due to street traffic noise in Brussels, 1976.

The second question about annoyance in the Antwerp survey (No. 30) was quite similar: *"Het verkeerslawaai dat U over het algemeen in uw woning hoort overdag is volgens U: Niet hinderlijk. . . . . Erg onverdraaglijk"* [The traffic noise that you generally hear in your residence during the day is, in your opinion, not annoying. . . . . quite unbearable.]

Note that the upper step on the annoyance scale for this question carries a much more extreme name than for question 5: "quite unbearable" vs "very disturbing." If the responses in the top three out of ten categories for this question are plotted against the noise exposure, the curve lies significantly below those for question 5, as shown in Fig. 42. In order to get a proper estimate of the highly annoyed population with this question, it would be necessary to count as highly annoyed those people responding in the top four (or more) of the ten categori on the annoyance scale. A similar result was found in the survey on French railway noise (cf. Part II, Sec. M).

Question 30 was dropped from the interview used the next year in the Brussels survey. The results from Question No. in Brussels are shown in Fig. 43; they lie somewhat higher than the Antwerp results but still more or less within the region defined by the eleven surveys shown in Fig. 1.

The activity interference data from the Belgian survey on street traffic noise are also quite enlightening, particularly with respect to the validity of using outdoor noise measuremen to assess the noise that the residents are exposed to inside their dwellings. The data from Antwerp on interference with radio listening are typical (similar results occurred for television listening in both Antwerp and Brussels.)

As shown in Fig. 44(a), one would have little hesitation in sketching by eye a curve showing a relation between percent of people reporting serious disturance and the measured noise exposure: the data for the open-window conditions do not allow much leeway for improvisation. On the other hand, as seen in Fig. 44(b), the data points with windows closed hardly suggest a relationship at all. The interference with people's radio listening is not well predicted by noise measurements made outside the dwelling.

D. Canadian road traffic[1,46] (1976, 410 respondents)

Reference 65 gives an account of a recent survey of community response to road traffic noise in southern Ontario. Unfortunately, this reference presents no data that permit comparing the results with the other surveys here. However, one of the authors has provided[66] a plot against L_{dn} of the percentage of people responding in the top two of the nine categories of the annoyance scale, as shown in Fig. 45. Since all the categories were named, the subjects were self-rating their own annoyance

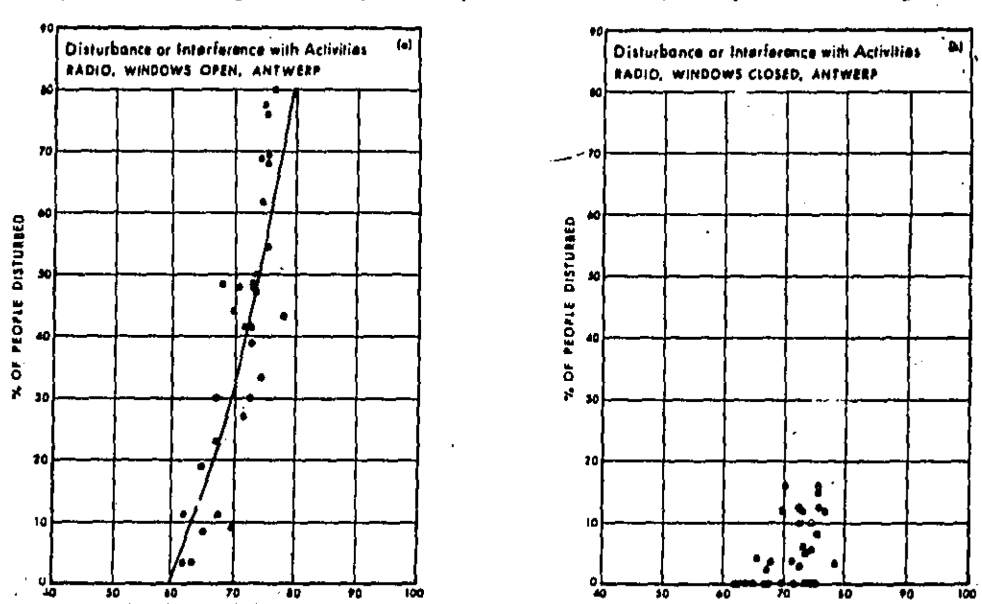

FIG. 44. Interference by road traffic noise with radio listening. Note the difference in correlation between noise and interference, depending on whether the windows were (a) open or (b) closed, see text.

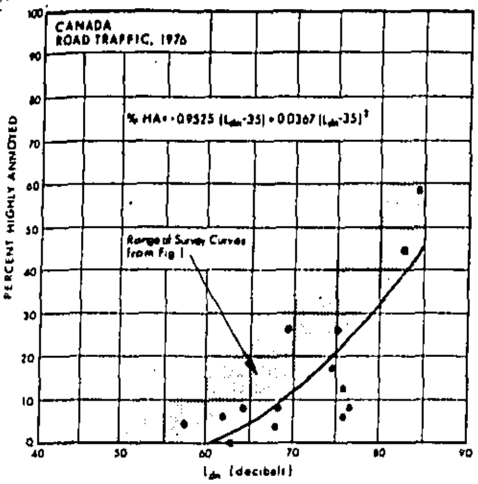

FIG. 45. Annoyance due to road traffic noise in southern Ontario, 1975 (7).

It can be seen that the curve defined by the data points falls below the clustering surveys of Fig. 1. The reason for this is not clear but, once more, it may have to do with the fact that the question and the corresponding annoyance scale were not comparable with those of the other surveys. They were as follows: "Considering all you have mentioned, how would you rate the overall noise?" 1. Extremely agreeable; 2. Considerably agreeable; 3. Moderately agreeable; 4. Slightly agreeable; 5. Neutral; 6. Slightly disturbing; 7. Moderately disturbing; 8. Considerably disturbing; 9. Extremely disturbing.

This is the only survey questionnaire that suggests to the subject that the road noise may actually be agreeable, rather than annoying. In fact, the bipolar scale given above was adopted after the results of a pilot study indicated that people seemed to like some kinds of noise, for example, the noise of children or of railways (provided that there were not too many pass-bys per day).

Nevertheless, such a scale may tend to bias the responses toward a more favorable view of the road noise than annoyance scales that focus on the unpleasant aspects, and this could account for a smaller percentage of people claiming high annoyance at each level of noise.

Note added in proof: The author has found a previously overlooked question with a bipolar scale of annoyance in the French railroad noise survey. The highly annoyed responses to that question are significantly lower than to a similar question with the usual unipolar scale.

It has been suggested that the names "definitely satisfied" and "definitely unsatisfied" in the London surveys imply a bipolar scale with a neutral response somewhere near the middle of the scale. Dr. Langdon, however, states that either he or his interviewed subjects made this interpretation.

ACKNOWLEDGMENT

This study was supported in part by the U. S. Department of Housing and Urban Development. The views, conclusions, and recommendations contained in this paper, are those of the author, who is solely responsible for this accuracy and the completeness of all data presented. The contents of this paper do not reflect the official views and policies, expressed or implied, of the Department of Housing and Urban Development or the U. S. Government.

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Updating a dosage–effect relationship for the prevalence of annoyance due to general transportation noise

N-96-01
II-A-492

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(Received 1 December 1989; accepted for publication 25 September 1990)

More than a decade has passed since a relationship between community noise exposure and the prevalence of annoyance was synthesized by Schultz [T. J. Schultz, J. Acoust. Soc. Am. 64, 377–405 (1978)] from the findings of a dozen social surveys. This quantitative dosage–effect relationship has been adopted as a standard means for predicting noise-induced annoyance in environmental assessment documents. The present effort updates the 1978 relationship with findings of social surveys conducted since its publication. Although the number of data points from which a new relationship was inferred more than tripled, the 1978 relationship still provides a reasonable fit to the data.

PACS numbers: 43.50.Ba, 43.50.Lj, 43.50.Qp

INTRODUCTION

It has been more than a decade since Schultz (1978) synthesized a relationship between transportation noise exposure and the prevalence of annoyance in communities from the findings of a dozen social surveys. Although initially greeted with considerable controversy, the relationship has become a mainstay of assessments of the effects of noise exposure on communities, and has gained widespread currency as the most thorough and well-documented dosage–effect relationship available to environmental planners.

One concern expressed at the time of publication of Schultz's synthesis was that it might have a chilling effect on the conduct of further social surveys of noise-induced annoyance, since some believed that agencies which fund such studies might erroneously conclude that the synthesis represented a definitive solution to many of the problems of assessing effects of noise exposure on communities. The abundance of surveys conducted since preparation of the synthesis (cf. Borsky, 1985; Fidell *et al.*, 1985; Fields and Walker, 1982; Hall and Taylor, 1977; Hall *et al.*, 1981; Hede and Bullen, 1982; Rylander, 1977; Schomer, 1983b; Sorensen and Hammar, 1983, *inter alia*) demonstrates that such concerns were unfounded.

In fact, so many measurements have been made of the prevalence of noise-induced annoyance in various communities since publication of the synthesis paper that it is now worth reviewing the dosage–effect relationship derived in 1978 in the light of evidence published since.

I. METHOD

Table I lists 15 social surveys of the annoyance of transportation noise exposure published since the preparation of the 1978 Schultz synthesis paper that were judged sufficiently similar in design to those considered by Schultz to be comparable for present purposes. Five criteria for comparability were adopted: (1) At least one questionnaire item had to inquire directly about long-term annoyance *per se*, rather than activity interference or other noise effects from which annoyance might arguably be inferred; (2) the noise source under study had to be a transportation noise source, and actual acoustic measurements of noise exposure were strongly preferred; (3) acoustic measurements, if not reported in units of day-night average sound level (DNL), had to be convertible into such units with reasonable confidence; (4) sample sizes had to be adequate for estimating

TABLE I. Summary of social surveys reviewed.

Mnemonic	Authors(s)	No. of data points
1978 addenda, new surveys:		
(1) U. S. AIRBASE	Borsky, 1985	25
(2) ANTWERP STREET	Myncke *et al.*, 1977	31
(3) BRUSSELS STREET	Myncke *et al.*, 1977	23
(4) BURBANK AIRPORT	Fidell *et al.*, 1985	20
(5) CANADIAN ROAD	Hall and Taylor, 1977	14
(6) DANISH STREET	Relster, 1975	28
(7) BRITISH RAIL	Fields and Walker, 1982	11
(8) AIRCRAFT/TRAFFIC	Hall *et al.*, 1977	21
(9) ORANGE COUNTY AIRPORT	Fidell *et al.*, 1985	12
(10) AUSTRALIAN AIRCRAFT	Hede and Bullen, 1982	42
(11) TRAMWAY/TRAFFIC	Rylander, 1977	12
(12) DECATUR AIRPORT	Schomer, 1983	4
(13) SWEDISH RAILROAD	Sorensen and Hammar, 1983	15
(14) WESTCHESTER AIRPORT	Fidell *et al.*, 1985	8
(15) DANISH RAILROAD	Andersen *et al.*, 1982	26
	total:	292

prevalence of annoyance with reasonable precision; and (5) the scale used for quantification of annoyance had to permit identification of numbers of respondents describing themselves as "highly annoyed" in a manner comparable to that devised by Schultz (1978).

Specifically excluded from present consideration were laboratory studies of noise-induced annoyance, field studies of community reaction to impulsive noise sources (gunfire, blasting, helicopters, sonic booms, etc.), and studies of community response to other nontransportation sources (e.g., construction).

A. Treatment of data from studies meeting selection criteria

Since the major goal of the present effort was to preserve comparability of analyses with those conducted by Schultz (1978), the conventions adopted by Schultz for deriving paired values of noise exposure and prevalence of annoyance were retained. For example, the definition of "highly annoyed" respondents adopted by Schultz (those respondents whose self-described annoyance fell within the upper 27%–29% of the response scale, except when category labels unambiguously dictated otherwise) was retained. Likewise, it was necessary to transform noise measurements reported in units other than L_{dn} to units of L_{dn} in several cases. Treatments of the data of individual studies are described below.

1. Australian aircraft (Hede and Bullen, 1982; 3575 interviews)

Hede and Bullen report a conventional social survey of the annoyance of aircraft noise. Noise levels were reported in units of L_{dn} for field measurements made at various locations around the commercial airports at Sydney, Perth, Adelaide, Melbourne, and the Royal Australian Air Force Base at Richmond. Personal interviews were conducted with 45 to 115 respondents per site. The physical measurements used in the present analysis are reported in Hede and Bullen's Tables 3.3 and D.9 and Fig. 6.4. Twenty-four-hour noise measurements were made for approximately 2 weeks per site. These values were then compared to existing noise exposure forecast (NEF) contours for accuracy.

The percentages of respondents highly annoyed were tabulated from responses to questionnaire item 36 by the authors (Bullen, 1988). The item was worded "How would you describe your 'general feelings' about the aircraft noise in this neighborhood?" Respondents were constrained to select one of the following categories: (1) highly annoyed, (2) considerably annoyed, (3) moderately annoyed, (4) slightly annoyed, or (5) not at all annoyed.

A total of 42 paired values of measured noise levels and percentages of respondents highly annoyed were available in this data set. Respondents describing themselves as "highly annoyed" were considered highly annoyed for present purposes to conform with the convention adopted by Schultz (1978, p. 381) for dealing with named response categories.

Ninety-five percent confidence intervals were calculated for the estimated percentages of respondents highly annoyed at each interviewing site by assuming that the self-reports of annoyance in the categories "highly annoyed" and all other categories were binomially distributed:

$$1.96(PQ/N)^{0.5}$$

where P is the proportion of respondents highly annoyed, Q is the proportion of respondents not highly annoyed, and N is the number of respondents per site. Figure 1 displays the 95% confidence intervals for the data points reported by Hede and Bullen in relation to the dose–response curve synthesized by Schultz (1978).

2. Aircraft–traffic comparison (Hall et al., 1981; 673 interviews)

This social survey compared the annoyance from aircraft noise to the annoyance of road traffic noise at nine sites around Toronto International Airport (Canada). Inter-

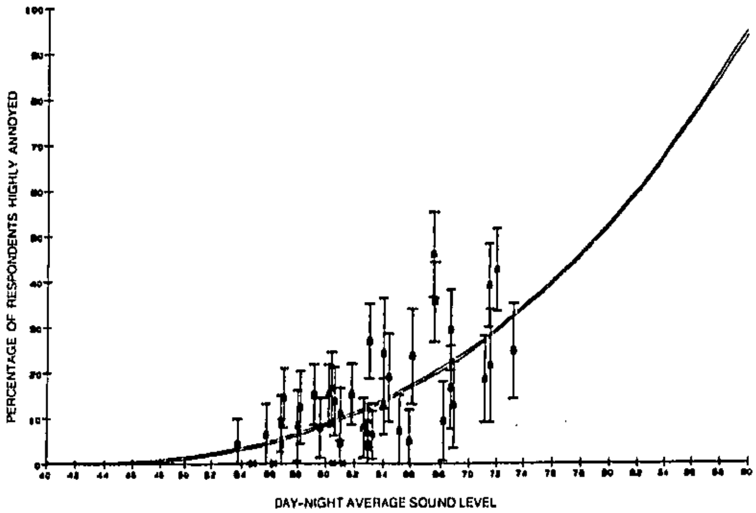

FIG. 1. Relationship of data from Australian Aircraft Study to 1978 synthesis curve.

views were conducted with 10 to 180 respondents per site. Noise levels were reported in units of L_{dn}. The data analyzed for present purposes are those reported in Table III (road traffic) and Table IV (aircraft) of Hall *et al.* (1981).

Data for road traffic noise were collected by automated equipment during 24-h periods during weekdays, at one location per site. Aircraft noise exposure was predicted by use of the Integrated Noise Model software. Control tower records for 1977 were used as the source of operational information for the predictions.

Hall *et al.* solicited judgments of the annoyance of transportation noise sources with a direct question ("How do you rate each of the sounds you have mentioned?") and a bipolar response scale composed of the following categories: (1) extremely agreeable, (2) moderately agreeable, (3) considerably agreeable, (4) slightly agreeable, (5) neutral, (6) slightly disturbing, (7) moderately disturbing, (8) considerably disturbing, and (9) extremely disturbing.

Nine data points for aircraft noise and 12 data points for traffic noise were reported. Hall *et al.* suggested that "... the appropriate cutoff point for high annoyance on the response scale is between moderately and considerably disturbing... ." This criterion represents the top two of the nine response categories of the bipolar scale. If the "neutral" category is considered to be equivalent to "not at all annoyed," however, Hall *et al.* in effect counted the top 40% of a five-point scale. Thus the authors' criterion overestimates the percentage of respondents highly annoyed relative to the percentages counted by the criteria adopted for the 12 clustering surveys. Figure 2 shows 95% confidence intervals for both the aircraft and traffic noise data.

3. Burbank Airport survey (Fidell et al., 1985; 5041 interviews)

Fidell *et al.* describe a social survey of aircraft noise annoyance involving multiple rounds of interviews in the vicinity of a mixed-use civil airport located in Southern California [reported as "study 1" in Fidell et al. (1985)] at which noise levels changed considerably over time due to changing runway use patterns. Noise levels were monitored continuously for a week prior to interviewing at multiple microphone positions within the boundaries of each site, and calibrated against exposure gradients from aircraft noise exposure contours. *De facto* panel samples of 220 to 330 respondents per site were interviewed five times in person or by telephone. Table II of Fidell *et al.* (1985) presents the annoyance and noise data for five rounds of interviews in four airport neighborhoods. The percentage of respondents highly annoyed was derived from responses to questionnaire item 4, which asked respondents if they had been (1) not at all annoyed, (2) slightly annoyed, (3) moderately annoyed, (4) very annoyed, or (5) extremely annoyed by the noise of aircraft over the past year.

Twenty data points resulted from this assessment of long-term noise exposure. (Another questionnaire item that solicited judgments of the annoyance of aircraft noise exposure over the past week was not considered for present purposes to preserve comparability with the time scales of other surveys.) Respondents describing themselves as "extremely annoyed" or "very annoyed" were considered to be highly annoyed. Figure 3 displays 95% confidence intervals for the data points.

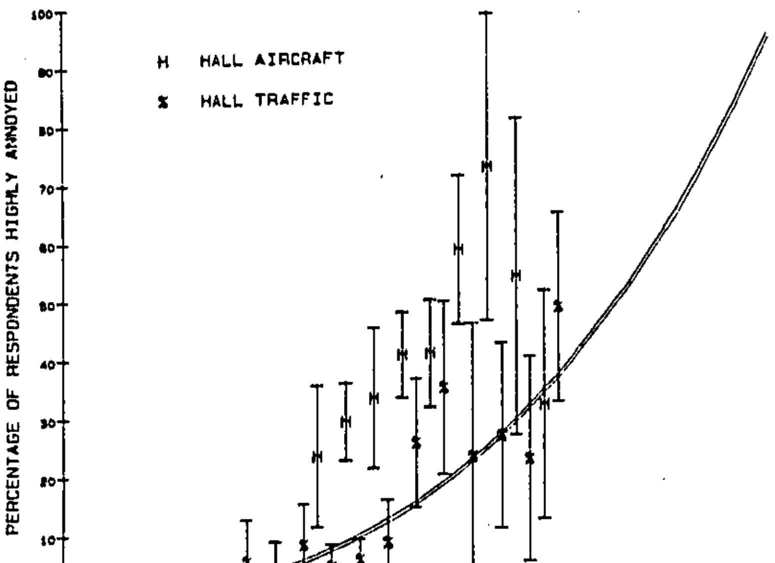

FIG. 2. Relationship of data from Aircraft–Traffic comparison to 1978 synthesis curve.

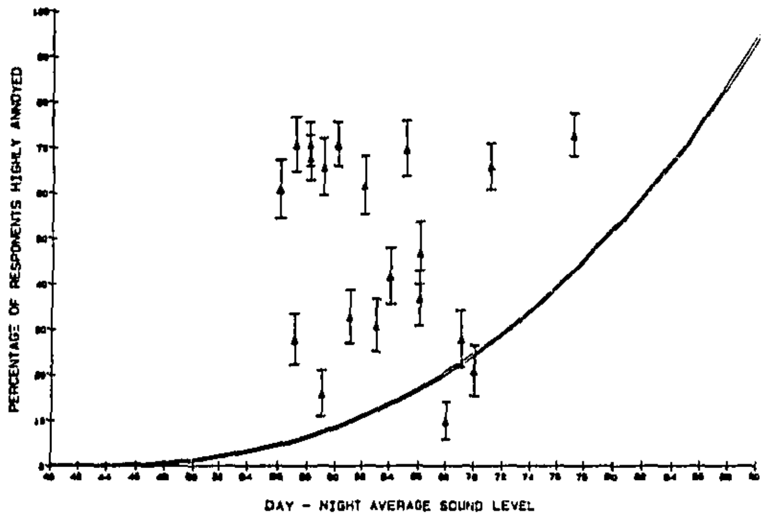

FIG. 3. Relationship of data from Burbank Airport Study to 1978 synthesis curve.

4. Orange County Airport (Fidell et al., 1985; 3103 interviews)

This social survey was reported as "study 2" in Fidell *et al.* (1985). Noise exposure measurements were made by the existing monitoring system installed at Orange County Airport located in Southern California. The data were energy-averaged over week-long intervals from six microphone positions and were compared with known aircraft noise contours to estimate area-weighted noise exposure levels. These sites were part of the airport's installed noise monitoring system. Face-to-face and telephone interviews were conducted with 200 to 330 respondents per site. Table IV of Fidell *et al.* (1985) summarizes the long-term annoyance data produced in four rounds of interviews in three interviewing areas in airport environs. The percentage of respondents highly annoyed was compiled from responses to questionnaire item 5, which asked respondents "While you've been at home over the past year, since last (season of year), have you been bothered or annoyed by the noise from larger airliners?" The named categories for the response scale were: (1) not at all annoyed, (2) slightly annoyed, (3) moderately annoyed, (4) very annoyed, or (5) extremely annoyed. Twelve paired values of percentages of respondents highly annoyed and measured sound levels were reported. These data points may be seen in Fig. 4.

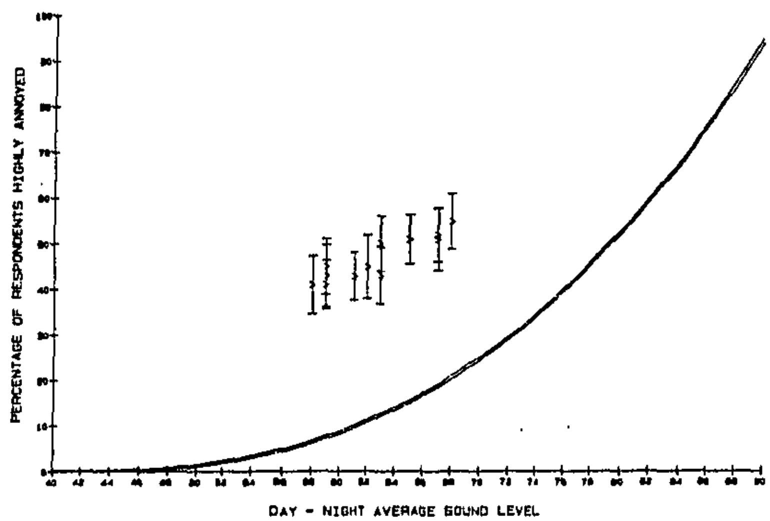

FIG. 4. Relationship of data from Orange County Airport Study to 1978 synthesis curve.

5. Tramway and traffic survey (Rylander et al., 1977; 464 interviews)

Rylander *et al.* report a survey of differences in respondents' reactions to tramway and city traffic noise. Interviews were conducted with approximately 75 respondents at each of 12 sites in Gothenburg, Sweden, along streets supporting mixed motor vehicle and tramway traffic. Noise measurements were collected on tape recorders at 1-h intervals during afternoons, and were later analyzed using a statistical distribution analyzer. Specific details regarding the period of time over which these measurements were taken were not reported.

Noise levels reported in units of 24-h L_{eq} for both tramway and traffic noise were converted to L_{dn} values by taking the average of two different conversion procedures. The conversion equation for the first method (Galloway, 1977) was

$$L_{dn} = L_{eq(24)} + 3.38 \text{ dB}.$$

The conversion equation for the second method used by Schultz (1978) was

$$L_{dn} = 1.13 L_{eq(24)} - 4.9 \text{ dB}.$$

The differences between the conversions ranged from 0.3–0.8 dB.

Respondents were provided with three response categories from which to select an answer to the question "Are you annoyed by tramway or traffic noise?": (1) a little annoyed, (2) rather annoyed, and (3) very annoyed. Rylander *et al.* (1977) present the noise exposure and response data in Tables 1 and 2 for respondents who described themselves as "very annoyed." Respondents considered to be very annoyed by Rylander *et al.* (1977) were counted as highly annoyed for present purposes.

A total of 12 data points consisting of noise levels and percentages of respondents highly annoyed (six for tramway and six for traffic) were reported by Rylander *et al.* Figures 5 and 6 display 95% confidence intervals in relation to the Schultz Curve for both tramway and traffic noise respectively.

6. Decatur Airport (Schomer, 1983a,b; 231 interviews)

Schomer (1983b) reports a noise survey of attitudes toward aircraft noise conducted near Decatur, Illinois Airport. Noise measurements were made in units of L_{dn}. Field measurements of noise exposure were compared against exposure levels predicted by Integrated Noise Model Version 2.6. Details regarding the measurement methods were not specified. Personal interviews were conducted at four sites with 22 to 99 respondents per site.

Questionnaire item 7a inquired about noises heard at home that respondents preferred not to hear. For each undesired noise source heard in the home, questionnaire item 7f asked respondents to rate their annoyance using the following scale: (1) extremely annoyed, (2) very much annoyed, (3) moderately annoyed, or (4) slightly annoyed. Schomer considered respondents who described themselves as "very much" or "extremely" annoyed as highly annoyed. Schomer presents the noise source and response data in his Fig. 3 and Table IV for respondents he considered highly annoyed.

Respondents who spontaneously mentioned some type of noise annoyance were considered to be at least "slightly annoyed" by the noise source. It is assumed that respondents were "not at all annoyed" by noise sources that escaped mention, yielding a five-category response scale. Schomer's study yielded four paired observations of measured noise levels and percentages of respondents highly annoyed. These are plotted in Fig. 7.

7. British railroad (Fields and Walker, 1982; 1399 interviews)

Fields and Walker conducted an attitudinal survey of railroad noise in Great Britain. They made more than 2000 noise measurements at 403 locations in units of 24-h L_{eq}, noise and number index (NNI), community noise equivalent level (CNEL), and L_{dn}. Personal interviews were conducted with 45 to 220 respondents per site.

The authors tabulated percentages of respondents high-

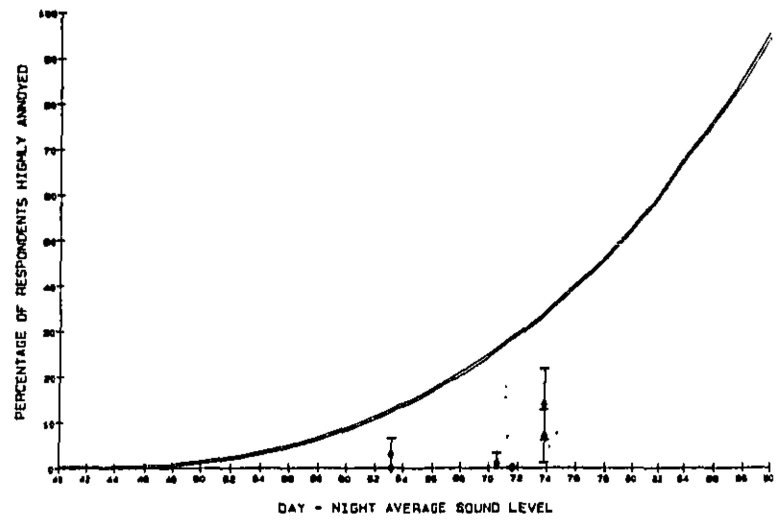

FIG. 5. Relationship of tramway data from Tramway and Traffic Study to 1978 synthesis curve.

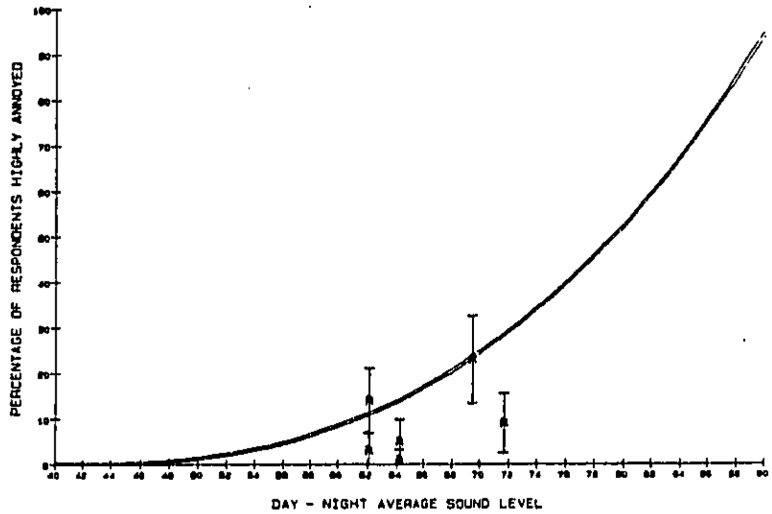

FIG. 6. Relationship of traffic data from Tramway and Traffic Study to 1978 synthesis curve.

ly annoyed to a direct question (questionnaire item 17b) worded as follows: "Does the noise of trains bother or annoy you: (1) very much, (2) moderately, (3) a little, or (4) not at all." Respondents describing themselves as "very much" annoyed by train noise were considered to be highly annoyed for current purposes. Figure 8 shows 95% confidence intervals for the British Railroad data.

8. Swedish railroad (Sorensen and Hammar, 1983; 1125 interviews)

Sorensen and Hammar report an investigation performed during 1978–1980 of reactions to railroad train noise in areas surrounding the cities of Malmo and Stockholm. The authors interviewed 50 to 100 respondents at each of 15 sites. Noise was measured in units of 24-h L_{eq} for each passing train. The conversion from the reported units of L_{eq} to L_{dn} was performed as described for the Rylander (1977) survey.

The data used in the present analysis are found in Fig. 1 of Sorensen and Hammar (1983). Since the data were not tabulated, a grid was overlaid on Sorensen and Hammar's Fig. 1 to estimate values of pairs of noise exposure levels and percentages of highly annoyed respondents.

Sorensen and Hammar did not report the labels of response categories used for eliciting annoyance judgments. They did, however, claim close similarity of annoyance measurement techniques with an earlier survey (Rylander *et al.*,

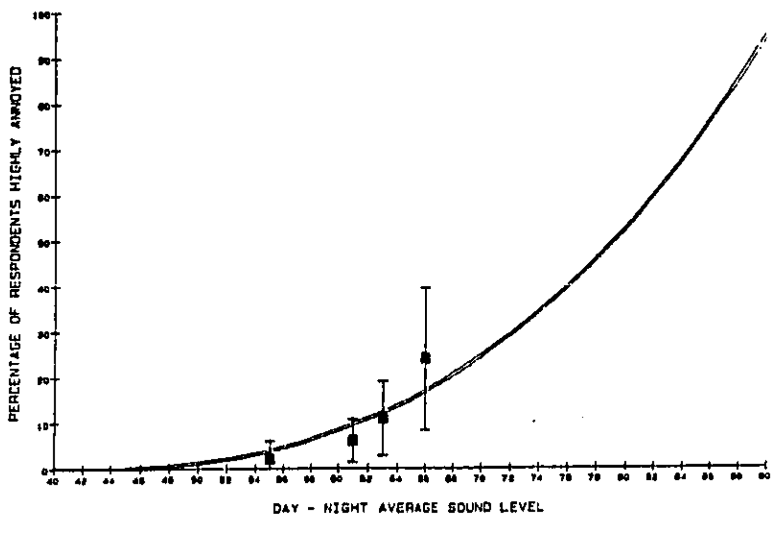

FIG. 7. Relationship of data from Decatur Airport Study to 1978 synthesis curve.

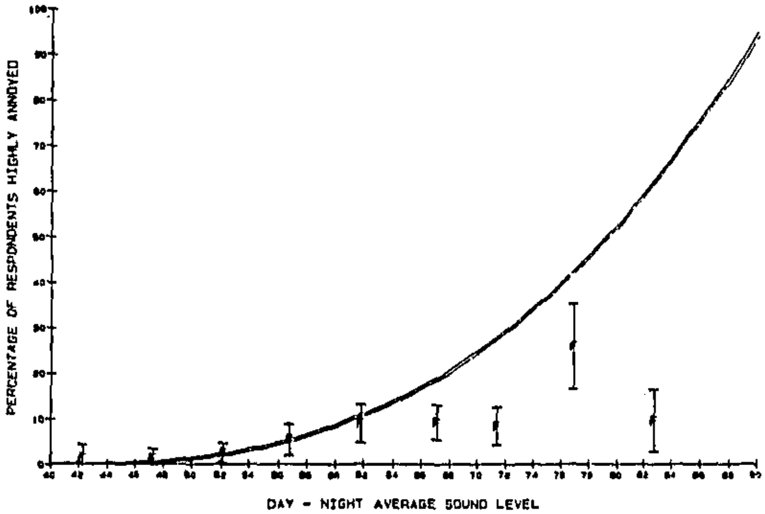

FIG. 8. Relationship of data from British Railroad Study to 1978 synthesis curve.

1980), which used four named response categories: (1) not annoyed, (2) a little annoyed, (3) rather annoyed, and (4) very annoyed. In the present analysis, "very annoyed" was used to describe high annoyance. Figure 9 shows 95% confidence intervals for the 15 data points from this study.

9. U.S. Airbase (Borsky, 1983, 1985; 874 interviews)

Personal interviews were conducted with 27 to 45 respondents per site at 25 sites near seven U.S. Air Force bases. Borsky used automatic equipment to measure exposure in units of L_{dn} for approximately 10 days per site. A threshold of 65 dBA was used for these measurements. It is unclear how levels of exposure lower than this threshold value were estimated.

The data used in the present analysis are based on a questionnaire item that asked "How much does noise from aircraft disturb, bother, or annoy you?" Respondents selected a response category from an "opinion thermometer" composed of ten gradations with named end points, as follows:

"not at all 0 1 2 3 4 5 6 7 8 9 extremely"

Respondents were considered highly annoyed for present purposes if they selected categories 7, 8, or 9 (30% of the response scale). Figure 10 shows the 95% confidence intervals calculated for the 25 sites.

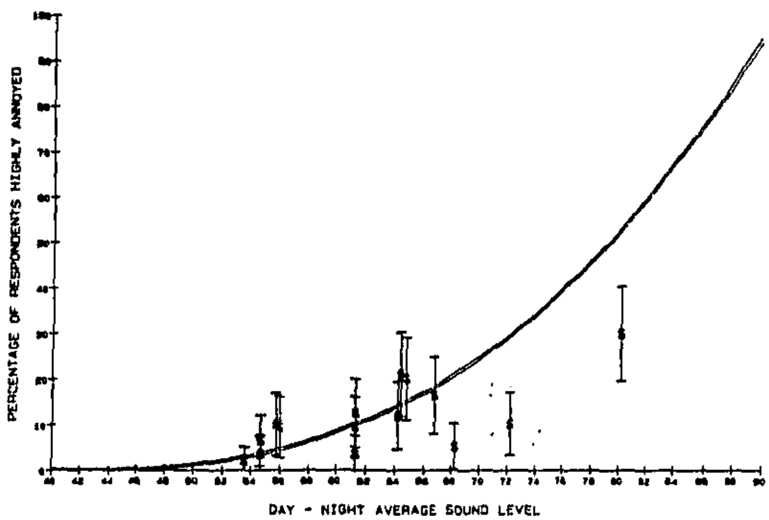

FIG. 9. Relationship of data from Swedish Railroad Study to 1978 synthesis curve.

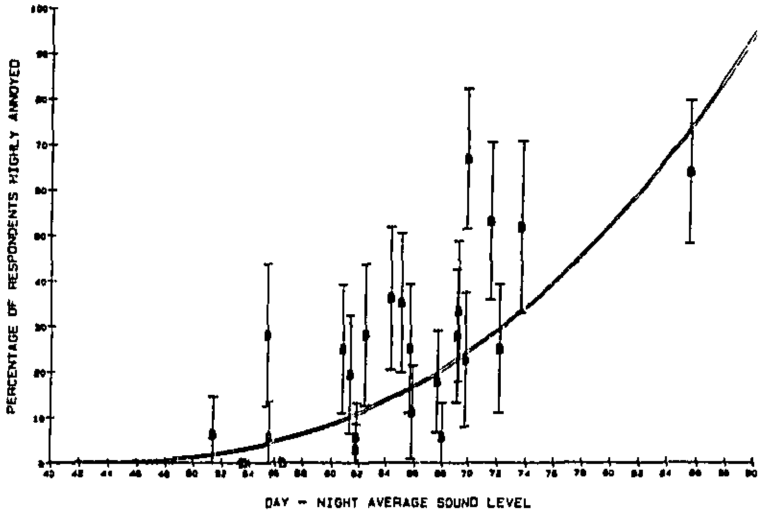

FIG. 10. Relationship of data from U. S. Airbase Study to 1978 synthesis curve.

10. *Westchester County Airport (Fidell et al., 1985; 1465 interviews)*

Fidell *et al.* report a social survey of the annoyance of aircraft noise at four sites around Westchester County Airport located in New York state. Both personal and telephone interviews were conducted twice with samples of 100 to 250 respondents per site. Noise measurements were made by automatic equipment at multiple microphone locations within each site for a week prior to interviewing, and were reported in units of L_{dn}.

Table VI of Fidell *et al.* (1985) summarizes the percentage of respondents highly annoyed and measured noise levels. Questionnaire item 4 asked respondents "And how about this past (season of year): Have you been bothered or annoyed by noise from airplanes while you've been at home during these months?" Respondents were allowed to choose one of the following categories: (1) not at all annoyed, (2) slightly annoyed, (3) moderately annoyed, (4) very annoyed, or (5) extremely annoyed. Respondents describing themselves as either "very" or "extremely" annoyed were considered highly annoyed for current purposes. Figure 11 presents the 95% confidence intervals for the eight data points reported by Fidell *et al.* in relation to the dose–response curve generated by Schultz (1978).

11. *Danish railroad (Andersen et al., 1983; 615 interviews)*

Andersen *et al.* report a survey conducted near seven Danish railways with traffic volumes ranging from 30–300

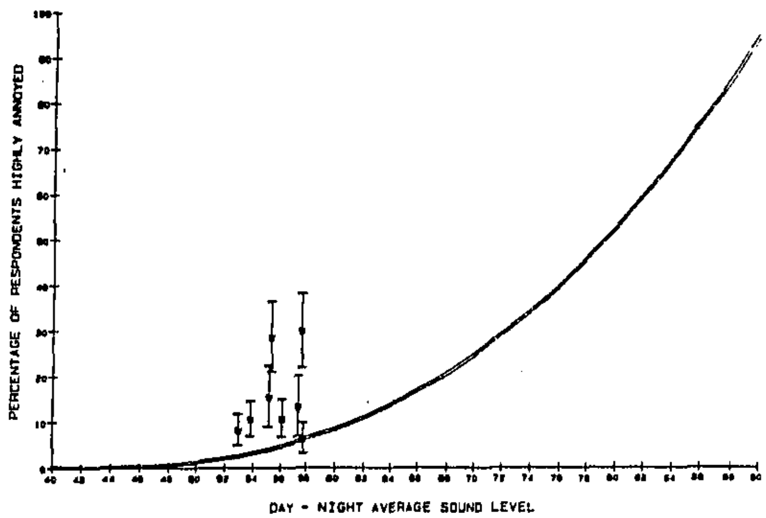

FIG. 11. Relationship of data from Westchester County Airport Study to 1978 synthesis curve.

trains per hour. Numbers of respondents ranged from 1–55 at each of 26 sites. Noise measurements were reported by Andersen *et al.* in units of L_{eq} and were converted to L_{dn} by using the method described for the Rylander (1977) survey.

Andersen *et al.* directly asked respondents "Does railway noise annoy [you]?" Respondents indicated that they were (1) strongly annoyed, (2) somewhat annoyed, (3) slightly annoyed, (4) very little annoyed, or (5) not annoyed at all. Respondents rating themselves as "strongly annoyed" were considered to be highly annoyed for present purposes. This represents 20% of the response scale, slightly underestimating high annoyance as defined by the 27%–29% criteria.

A grid was overlaid on Figure 1 of Andersen *et al.* (1983) to estimate values of pairs of noise exposure levels and percentages of highly annoyed respondents. Figure 12 shows 95% confidence intervals for the 26 points from this study.

12. Other studies

Data from the following studies [considered as part of the original clustering surveys or four addenda by Schultz (1978)] are included in the present analysis as well. The reader is referred to Schultz (1978) for a detailed explanation of the treatment accorded the data of these studies.

French Aircraft (Alexandre, 1970)
Second Heathrow Airport (MIL Research, 1971)
First Heathrow Airport (McKennell, 1963)
London Traffic (Langdon, 1976)
Munich Airport (Rohrman *et al.*, 1974)
Paris Street (Aubree *et al.*, 1971)
French Rail (Aubree, 1975)
Swedish Aircraft (Rylander *et al.*, 1972)
Swiss Road (Grandjean *et al.*, 1973)
Swiss Aircraft (Grandjean *et al.*, 1973)
USA 24 Site (Fidell, 1978)
Los Angeles Airport (LAX 2 SITE) (Fidell and Jones, 1975)
Antwerp Street (Myncke *et al.*, 1977)
Brussels Street (Myncke *et al.*, 1977)
Canadian Road (Hall and Taylor, 1977)
Danish Street (Relster, 1975)

B. Derivation of a fitting function

The studies summarized above yielded a total of 292 new data points. Figure 13 combines the data from the individual studies described above into a single plot, along with the 161 data points from the clustering surveys of Schultz (1978). A least-squares quadratic fit to the data points is also shown.

Figure 14 compares the third-order polynomial function Schultz chose to fit the data of the 1978 synthesis with a second-order fitting function for all 453 data points. As can be seen, the quadratic fit to the new data points is several decibels higher (about 4 dB higher at an L_{dn} value of 57.5 dB, and about 1.5 dB higher at an L_{dn} value of 70 dB), indicating greater annoyance than the 1978 synthesis over a large part of the range of interest for most purposes.

II. DISCUSSION

A. Relationship between third-order polynomial and least-squares quadratic fit

Schultz (1978) selected a third-order polynomial forced to predict zero prevalence of high annoyance at an L_{dn} value of 45 dB for the 1978 dosage–effect relationship. Figure 15 compares the 1978 dosage–effect relationship with (1) the (unconstrained) least-squares quadratic fitting function shown in the previous figures and (2) with quadrat-

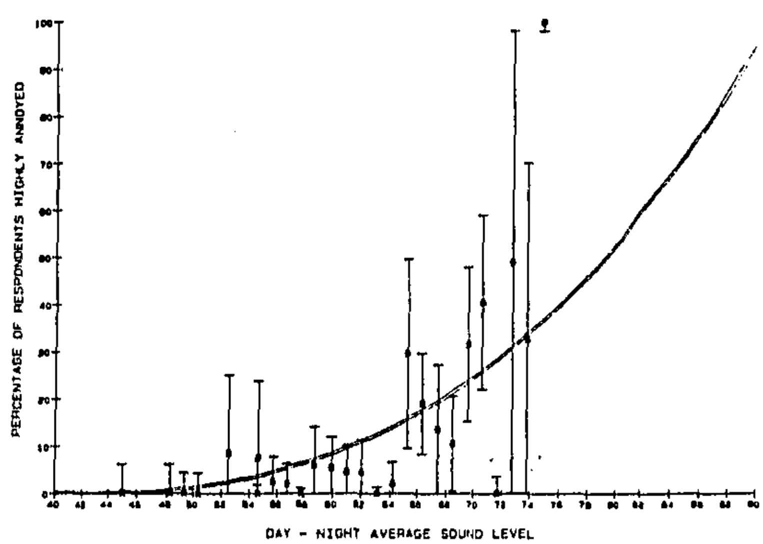

FIG. 12. Relationship of data from Danish Railroad Study to 1978 synthesis curve.

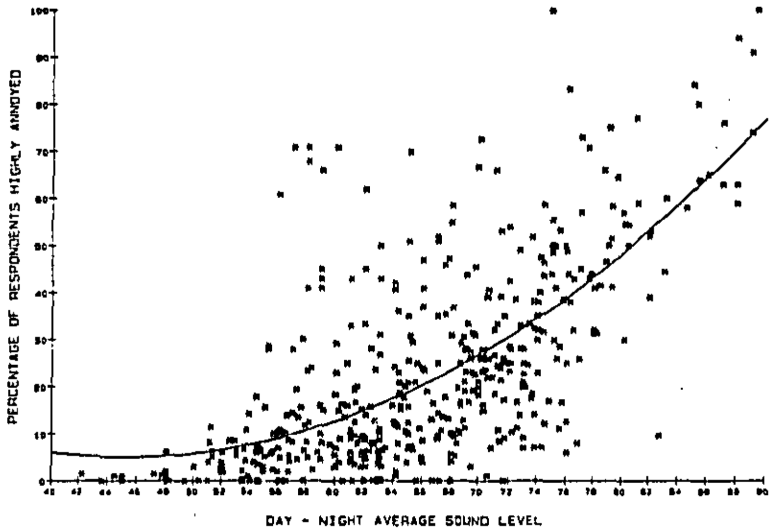

FIG. 13. Quadratic fit to all 453 data points.

ic least-squares fits to the upper and lower boundaries of the 95% confidence intervals for all data points. Note that the 1978 relationship lies within these limits over virtually all of its range.

The equation of the quadratic fitting function is

$$\%HA = 0.0360L_{dn}^2 - 3.2645L_{dn} + 78.9181.$$

The quadratic fit accounts for 44% of the variance in the data points. Since the best-fitting (least-squares criterion) cubic relationship accounts for only 1% more variance, and in the absence of any theoretical imperative in favor of either one, the quadratic is preferred over the cubic fit for reasons of parsimony.

The information on which both the 1978 and the quadratic fitting functions are based is not error-free. Indeed, there is uncertainty in quantification of both the dependent and independent variables of the dosage–effect relationship. Influences of errors of several types on the relationship are discussed briefly here, and from a different perspective, by Green and Fidell (1991).

B. Bias errors in definitions of high annoyance

One obvious influence on the shape of the fitting function is the definition adopted for high annoyance in each of the data sets. Table II compares the percentages of the response alternatives included in the definition of "high annoyance" in the 11 studies not considered in the 1978 synth-

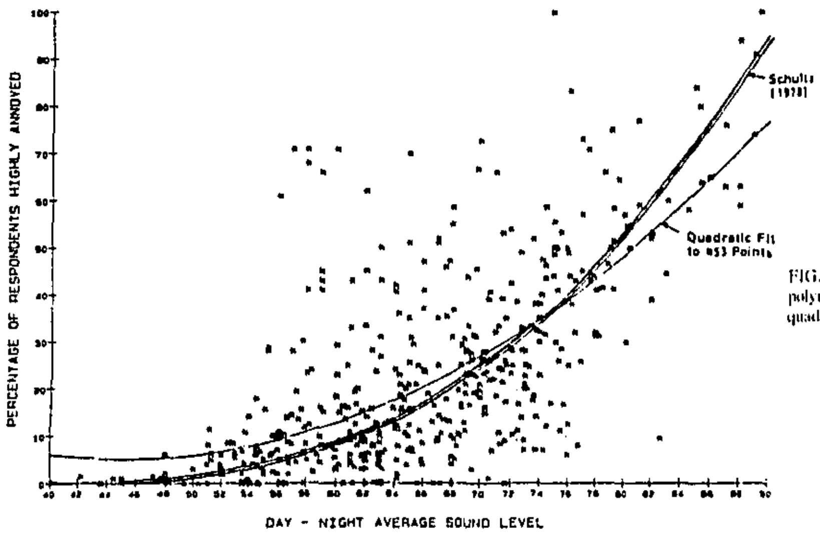

FIG. 14. Comparison of 1978 third-order polynomial fitting function with present quadratic fit to 453 data points.

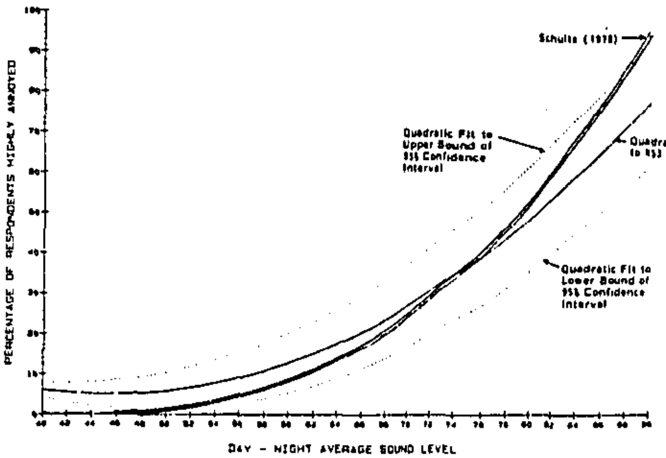

FIG. 15. Comparison of third-order polynomial and quadratic fitting functions sources of error in data.

esis.On average, self-reports of annoyance in the upper 31.4% of the response alternatives in these studies were considered to meet criteria for "high annoyance." This figure is slightly higher than the 27%–29% average for the 12 clustering surveys on which the 1978 dosage-effect relationship is based. About half (45.5%) of the data points underestimate "high annoyance" by 5%, while 54.5% of the data points overestimate "high annoyance" by 10.3%. Even these figures do not suggest the extent to which the dosage–effect relationship is sensitive to the definition of high annoyance in separate surveys. Because the present data set of 453 points is composed of a relatively large number of surveys each contributing a relatively small number of data points, changing the definition of high annoyance adopted in any one survey is unlikely to produce a meaningful change in the dosage–effect relationship.

For example, changing the definition of high annoyance adopted for the Burbank Airport data points from 40% of the response scale to 30% of the response scale as shown in Fig. 16 changes the quadratic fit hardly at all.

C. Uncertainty in measurements of percentages of respondents highly annoyed

Table III displays the sizes of the average estimated 95% confidence intervals for percentages of highly annoyed respondents for each of the 29 data sets. When published reports contained sufficient information, these estimates were made by calculating confidence intervals for each interviewing site and averaging them within studies. When the published reports indicated only total numbers of respondents and interviewing sites, the estimates were made by assuming equal numbers of respondents per site. As can be seen, there is considerable uncertainty in some of the survey data about percentages of respondents highly annoyed. The average width of the estimated 95% confidence intervals of the 29 studies is 16.5%. Given that the slope of the 1978 dosage–effect relationship is about 2%–3% highly annoyed per decibel of noise exposure through much of its range, the uncertainty in the original survey data corresponds to a change in noise exposure of nearly an order of magnitude.

TABLE II. Percentage of response alternatives considered "highly annoying" in surveys not considered in the 1978 synthesis.

Survey	% of response scale considered "highly annoying"	Comparison of percentages % of total data points	% of new data points
Australian Aircraft	20%	9.3%	21.4%
Aircraft/Traffic	40%	4.6%	10.7%
Burbank Airport	40%	4.4%	10.2%
Orange County Airport	40%	2.7%	6.1%
Tramway/Traffic	25%	2.7%	6.1%
Decatur Airport	40%	0.9%	2.0%
British Railroad	25%	2.4%	5.6%
Swedish Railroad	25%	3.3%	7.7%
U.S. Airbase	30%	5.5%	12.8%
Westchester Airport	40%	1.8%	4.1%
Danish Railroad	20%	5.7%	13.3%

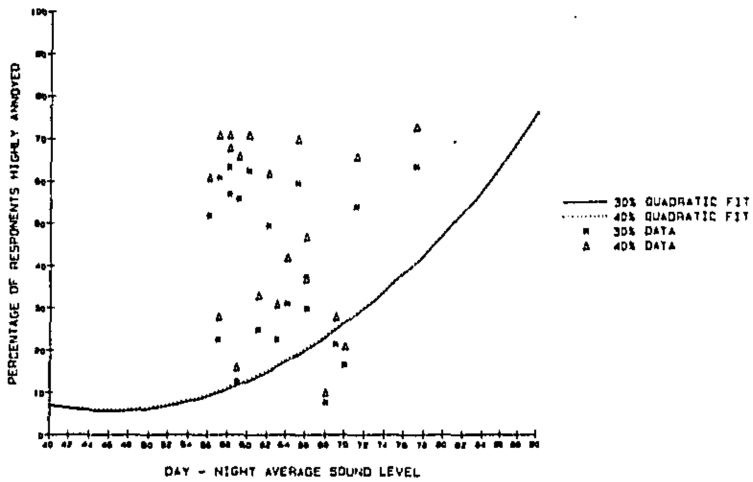

FIG. 16. Effect of changing definition of high annoyance for Burbank data.

Since this uncertainty represents the fundamental level of precision of measurement on the ordinate of the dosage–effect relationship, it is unproductive to seek explanations for smaller differences among potential fitting functions for these data.

TABLE III. Ninety-five confidence intervals for determinations of percentages of respondents highly annoyed.

Rank ordering of studies by average estimated confidence intervals	
Width of 95% confidence interval (%)	Study
7.1	Swiss Aircraft (Grandjean *et al.*, 1973)
7.2	Traffic/Tramway (Traffic only, Rylander, 1977)
7.4	Second Heathrow Airport (MIL Research, 1971)
7.5	British Rail (Fields and Walker, 1982)
7.6	French Aircraft (Alexandre, 1970)
9.0	Swiss Road (Grandjean *et al.*, 1973)
10.9	First Heathrow Airport (McKennel, 1963)
10.9	Westchester Airport (Fidell *et al.*, 1985)
11.3	Burbank Airport (Fidell *et al.*, 1985)
11.4	Traffic/Tramway (Tramway only, Rylander, 1977)
12.3	Orange County Airport (Fidell *et al.*, 1985)
12.5	Los Angeles Airport (Fidell and Jones, 1975)
13.5	Swedish Rail (Sorensen and Hammar, 1983)
14.3	Australian Aircraft (Hede and Bullen, 1982)
14.5	Brussels Street (Myncke *et al.*, 1977)
14.8	USA 24 Site (Fidell, 1978)
16.3	Antwerp Street (Myncke *et al.*, 1977)
16.3	Decatur Airport (Schomer, 1983)
17.3	French Rail (Aubree, 1975)
18.7	Paris Street (Aubree, *et al.*, 1971)
20.2	Danish Railroad (Andersen *et al.*, 1982)
22.1	Traffic/Aircraft Comparison (Traffic only, Hall *et al.*, 1977)
22.4	Canadian Road (Hall and Taylor, 1977)
23.4	U.S. Airbase (Borsky, 1985)
23.9	Danish Street (Relster, 1975)
24.4	London Traffic (Langdon, 1976)
29.5	Traffic/Aircraft Comparison (Aircraft only, Hall *et al.*, 1977)
32.0	Munich Airport (Rohrman *et al.*,1974)
40.3	Swedish Aircraft (Rylander *et al.*, 1972)

D. Errors in estimating noise exposure

A more difficult matter to address is uncertainty in reported measurements of noise exposure. Few of the studies reviewed provide sufficient detail to permit estimation of confidence intervals for such measurements. In general, the numbers of microphone locations, durations of measurement, calibration of measurements against other information, and homogeneity of exposure across interviewing sites are not well reported.

One exception is the measurements made at Burbank Airport. In this case, noise measurements were made at five locations within each interviewing site for a full week prior to interviewing, and the obtained measurements were calibrated against noise exposure gradients derived from aircraft noise contouring software. Even in this case, however, exposure varied by about ± 2.5 dB within interviewing sites. This figure is probably close to the greatest precision of physical measurement of any of the studies in the present data set. Thus the position of any fitting function developed for this data set probably cannot withstand any closer scrutiny of its relationship to the abscissa than 3 dB.

E. Reliability of dosage–effect relationship

One major implication of the preceding discussion of sources of error in the data set is that the relatively small differences between the current dosage–effect relationship and the one synthesized in 1978 should not be overinterpreted. The differences are minor ones that could be attributed as persuasively to errors of measurement of various sorts as to substantive effects. Another implication is that more sophisticated curve fitting procedures could be employed to deal with uncertainty on both axes of the relationship. For example, if the goal were to weight the salience of each data point by the magnitude of its likely errors of both physical and psychological measurement, a dosage–effect relationship with a rather different shape might well emerge.

Another limitation of both the 1978 polynomial approximation and the current quadratic fitting function is that they are both simply convenient data fitting functions, devoid of physical meaning. Both functions are positively accelerated within the range of DNL values of greatest interest, and both are nonmonotonic. Care is therefore necessary to avoid using these relationships outside their intended ranges. Common sense strongly suggests that in reality the function relating exposure to annoyance must be a sigmoid asymptotic to values of the prevalence of annoyance in the vicinity of 0% and 100%.

The next article in this issue develops a theoretically based alternative approach to the purely empirical curve fitting described above.

ACKNOWLEDGMENTS

The authors thank Dr. C. Stanley Harris of Armstrong Aerospace Medical Research Laboratory for suggesting the effort described herein. We are also grateful to Dr. David M. Green for discussions of various analyses described in this report, and to the authors of the reviewed studies for their assistance in providing unpublished information. Lawrence Finegold served as the contract monitor for this effort, which was sponsored under Contract F33615-86-C-0530 of the U. S. Air Force Noise and Sonic Boom Impact Technology (NSBIT) program, directed by Major Robert Kull.

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CORRECTION!

THE PREVIOUS DOCUMENT(S) MAY HAVE BEEN FILMED INCORRECTLY . . .

RESHOOT FOLLOWS!

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