ACOUSTICS AND NOISE CONTROL IN CANADA

THE CANADIAN ACOUSTICAL ASSOCIATION

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CONTRIBUTIONS

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NOTICE BOARD

CAA MEETING

The fourteenth annual meeting of the Association will be held in Vancouver on the 6, 7 and 8th of October, 1976. Contributions on all aspects of acoustics and noise control are invited and abstracts should be sent by July 1 to Doug Whicker, Barron and Strachan, 3284 Heather Street, Vancouver, B.C. V5Z 3K5.

These abstracts will be organized by an ad-hoc editorial committee and it is planned to include a few invited papers on selected topics. For those members in eastern or central Canada it is hoped a group flight can be arranged from Toronto to Vancouver and return so as to reduce transportation costs. More information in the next newsletter.

INTER-NOISE 76

The 1976 International Conference on Noise Control Engineering (INTER-NOISE 76) will be sponsored by the International Institute of Noise Control Engineering (INTERNATIONAL/INCE), and organized by the Institute of Noise Control Engineering, U.S.A. (INCE/U.S.A.) in cooperation with the Acoustical Society of America (ASA). It will be held at the Shoreham-Americana Hotel in Washington, DC on 5-7 April 1976, concurrent with the Spring 1976 Meeting of the ASA at the Statler Hilton Hotel, Washington, DC, 5-9 April 1976.

CRITERIA FOR AIRBORNE SOUND INSULATION BETWEEN DWELLINGS

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(Summary of paper presented at meeting of Canadian Acoustical Association, 8 October 1975.)

Experience indicates that the most disturbing of intrusive sounds in apartment dwellings are voices, either live or by way of radio or television. Closely related are other airborne sounds including music reproduced on radio, TV or stereo. Next on the list are impact sounds including slamming of doors and footsteps on the floor adjacent or above. Finally there are mechanical or plumbing noises. [1,2] All of these need consideration, but only the first topic, insulation against airborne sounds, is considered here.

1. The Sound Transmission Process

The physical process of sound transmission is epitomized in the familiar formula:

$$TL = NR + 10 \log (S/A_2) \qquad (1)$$

This equation applies to the case of a partition separating two rooms, one of which contains a sound source.

- TL is the sound transmission loss, which is defined as the ratio of incident sound power on the source side to the radiated sound power on the other side of the assumed partition
- NR is the noise reduction or difference in average sound pressure level in the two rooms
- S is the area of the transmitting surface
- A_2 is the absorption in the receiving room.

A number of assumptions are implicit in this formula: for example, the sound fields are assumed to be relatively uniform and diffuse; in particular, the sound field incident on the partition is assumed to consist of a uniform distribution of sound waves from all possible directions. Published values of sound transmission loss are usually obtained in a special laboratory facility where the environment is made to fit the theoretical assumptions as closely as possible.

In typical dwellings the rooms may be too small for the theory to apply. They may contain so much sound absorption that the assumption of a "reverberant field" is not met; indeed there may not even be well-defined rooms or a well-defined partition. Another complication is the fact that sound may be transmitted by paths other than through the nominal partition. For these reasons, although the level difference between two spaces can be measured in a defined way, one should be cautious about inferring the transmission loss of the nominal partition. In sum, laboratory measurements can provide definitive information about the primary separating elements in a building, whereas field measurements provide information on the assembly comprising a specific building.

The interest of the building occupant is, in any case, two stages removed from the mere question of transmission loss of partitions. He is interested in the extent to which he is bothered by intrusive noises. This depends on the sound insulation between his neighbour and himself, and also the range of noise levels in the two places. Whether there is a sound insulation problem may thus depend on the specific building and on the occupants thereof. Nevertheless the first step in providing adequate sound insulation is to provide adequate separating walls and floors.

Simple homogeneous wall

The transmission loss of a simple homogeneous wall is well understood theoretically, at least for the infinite wall case. For reasonably large partitions, experimental evidence fits the theory quite well if one makes an appropriate adjustment for the finite dimensions of the partition and the associated rooms. Typically the transmission loss increases with frequency by about 5 dB per octave, except for a "coincidence dip," at the frequency for which the velocity of transverse flexural waves in the wall equals the velocity of sound in air. Above the coincidence dip the transmission loss again increases with frequency at a rate dependent on internal damping in the wall.

Doubling the thickness or mass of a single wall increases the TL by about 5 dB. On the other hand, two or more leaves, relatively independent of each other, can provide substantially higher transmission loss for the same total weight of material.

An important type of wall in Canada is the two-leaf wall consisting of gypsum board on either side of a framing system. Then sound is transmitted in two stages: through the first leaf into the cavity and then from the cavity through the second leaf. The best walls provide a structural break in the framing system (flexible metal studs or flexible furring over wood studs) together with sound absorbing material in the cavity. There is no simple theoretical approach to this rather complicated system, but there is sufficient empirical information that most constructions of this type can be accurately predicted. When well constructed, they give very good performance for relatively light weight at low cost.

In the ensuing discussion four representative walls, shown in Fig. 1, will be used for illustrative purposes. The brick wall has a slow monotonic frequency characteristic, whereas the gypsum-faced masonry is spoiled by a coincidence dip in the mid-frequencies. The two-leaf gypsum walls, although quite good in the mid-frequency range, drop off rapidly toward the lower frequencies and are limited by coincidence dips at high frequencies. The numbers given correspond to the single-figure rating known as the sound transmission class (STC).

2. Subjective Assessment of Sound Insulation

All attempts to deal quantitatively with sound insulation requirements face the fact that requirements differ widely with time, place and people. A practical criterion might be limited to satisfying a reasonably large proportion of the occupants at least to the point where lack of sound insulation is not a major complaint.

A number of ways of assessing the problem will be considered. One of these is to examine the record of complaints from occupants of multidwelling buildings. The material derived in this way is limited, of course, to a study of existing structures and does not permit a detailed identification of the various physical parameters.

A series of British social surveys involving buildings where the party walls were of 9-in. brick indicated that about one quarter of the occupants of such buildings are disturbed by intrusive noise.[2] Hence the 9-in. brick wall might be regarded as an example of fairly adequate sound insulation. In considering other types of construction, however, there is a problem in knowing how to make a detailed comparison with the 9-in. brick wall: specifically, how should the insulation vary as a function of frequency? Auxiliary studies of this question [3,4,5] support the view that in fact the TL curve for the brick wall provides about the right frequency weighting. A slightly better criterion would give more emphasis to the middle frequencies as, for example, in the contour used in deriving the ASTM sound transmission class (Fig. 1).

In terms of the STC rating system, the brick wall rates STC 53, and one can infer from British social surveys of row housing that STC 53 would satisfy about three-quarters of the building occupants. Surveys of apartment buildings[2] showed that insulation as low as STC 47 resulted in disturbance of about 36 per cent and noise intrusion moved from being a minor dissatisfaction to a major one.

One source of Canadian evidence consists of a compilation of complaints investigated by NRC. These data reflect in part the fact that the legal minimum in many parts of Canada is STC 45, which is therefore the design objective for much Canadian dwelling construction. The compilation shows a relatively small number of complaints for separations better than STC 50 and none above STC 55. By far the most complaints are in the category from STC 45 to 50. The evidence is thus consistent with that of the British social surveys: complaints about intrusive noise are common when sound insulation is below STC 50.

Other approaches to the problem involve calculations for the kinds of noise known to be troublesome. Briefly, one considers the extent to which intrusive sounds are perceived above the existing accepted "background noise." Background noise is itself very similar in character to the noises identified as disturbing, differing mainly in that it is sufficiently garbled that it does not carry a specific message. Studies of domestic noise levels suggest that during quiet periods, which are the periods when intrusive noise is likely to be objectionable, the background level may fluctuate from about 25 to 35 dB A, the latter figure being applicable when there is a certain amount of outdoor traffic and minor indoor sounds such as a refrigerator. For purposes of this discussion a reference spectrum of background noise will be assumed to correspond to the NC-25 contour, which is equivalent to an A-weighted level of 35 dB. This level is just low enough that most quiet activities are not normally interfered with.

An important noise is speech and an important criterion of disturbance is the extent to which transmitted speech is intelligible. Speech sounds may be considered to fluctuate over a range of about 30 dB and to comprise important frequency components from 200 to about 4000 Hz. It is the fluctuations that carry the intelligence in speech; the proportion of these fluctuating sounds that protrudes above background noise is a measure of speech intelligibility. There is an established procedure for calculating the Articulation Index (AI), but the application of this procedure near the threshold of intelligibility is in some doubt. For purposes of this analysis it will be simpler and nearly equivalent to assume that transmitted speech is not disturbing if no more than the top 5 per cent of speech sounds protrudes above background.

Calculations for the four representative walls shown in Fig. 1 and for typical room configurations yield results given in Table I, where what is calculated is the level of background noise required to mask all but the top 5 per cent of speech sounds. For a background level of 35 dB A, all four walls are seen to be adequate to mask "conversational" speech, but only Walls A and C are adequate protection against "loud" speech.

TABLE I - BACKGROUND NOISE REQUIRED TO MASK TRANSMITTED CONVERSATIONAL SPEECH

Wall	STC	Required Masking Level: Conversational Speech	Required Masking Level: Loud Speech
A	53	24	34
B	45	33	43
C	50	25	35
D	47	30	40

A similar approach by van den Eijk[3] considered the transmission of typical radio and TV sounds from which it appeared that the STC 50 wall would reduce transmission to the point that only the top 5 per cent peaks emerged above the reference background level.

Nowadays it is found that the noise from stereo recording equipment is a major source of complaint. An analysis of such sounds indicates that the main difference as compared to radio and TV sounds is the operating level, the implication being that users of such equipment tend to play it at higher levels than is normal for radio or TV. Certainly the commercially available equipment has the potential of producing very high levels, and some users will choose to exercise this potential. Data suggest that a wall corresponding to about STC 60 would be necessary to bring typical levels of stereo sound down to the background level of 35 dB A.

These are but a sampling of studies suggesting that a modest objective for separation of dwellings would be a sound insulation corresponding on the average to STC 50. This might be apportioned so as to provide higher insulation, say 53 to 55 for protection of bedrooms, and perhaps about STC 45 for separation of noncritical spaces such as kitchens, bathrooms and utility spaces. These requirements would not eliminate all noise problems, but perhaps three quarters of dwelling occupants would be satisfied most of the time. A common noise source not adequately guarded against by these requirements would be a stereo system played at high level.

Specification of Sound Insulation

Having established sound insulation criteria, the next step is to try to achieve them in buildings. The usual mechanism for specifying the properties of buildings, especially multi-unit dwellings, is a set of building specifications or regulations administered by municipal building authorities, lending institutions or other agencies. Generally the control point is the issuance of a building permit or equivalent, which is done on the basis of a set of plans and specifications. At this stage one cannot guarantee that the difference in sound level between units in the finished building will conform to a particular requirement, but one can at least require that the major separating components -- the party walls and floors -- are potentially adequate. To ensure that these potentials are realized in the final construction is somewhat more difficult. It seems possible, however, to introduce some qualitative requirements to prevent the partitions being ruined by service openings, lack of caulking and similar defects.

Finally it should be reiterated that, in addition to airborne sound insulation which is the subject of this note, similar considerations now apply also to the impact noise insulation provided by floors. Plumbing noise, which is also of major importance, cannot yet be handled by quantitative noise limits, but at least it might be possible to specify installation of the plumbing equipment in such a way as to minimize transmission from one dwelling unit to another.

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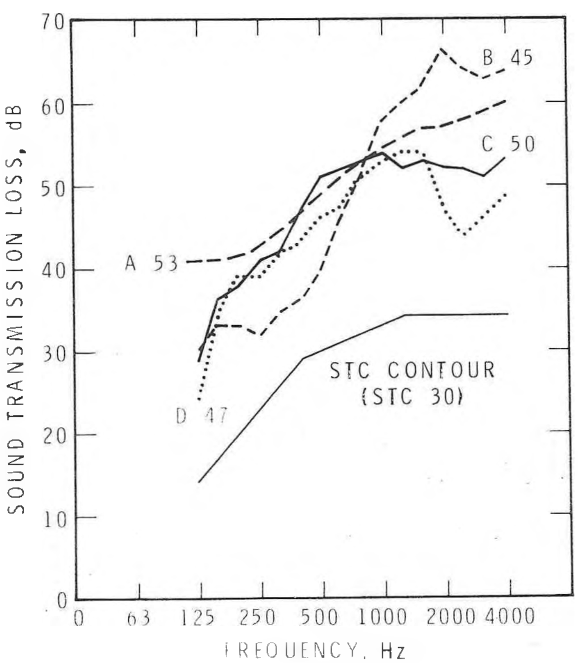

FIG. 1. SOUND TRANSMISSION LOSS CURVE OF FOUR REPRESENTATIVE WALLS.

A. 9-in. block wall, plastered both sides. 80 lb/sq ft.

B. 6-in. lightweight block, aggregate, gypsum board adhered to both sides. 46 lb/sq ft.

C. Two leaves, 1/2-in. and 2- x 1/2-in. gypsum board, metal studs, absorption. 6.7 lb/sq ft.

D. Two leaves, 5/8-in. gypsum board, metal studs, absorption. 5.4 lb/sq ft.

PREDICTING COMMUNITY RESPONSE TO SURFACE TRANSPORTATION NOISE: PRELIMINARY FINDINGS FROM THE HAMILTON-TORONTO URBAN CORRIDOR

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The purpose of this paper is to identify a means for predicting, for residential neighbourhoods, the percentage of the population likely to be disturbed by any given transportation noise environment. The equation to be developed will depend only on those characteristics of the noise environment which can be predicted with the present state of the art. The reason for this is that the most fruitful applications of such an equation are in predicting the impact of possible future actions. For existing situations, it is almost as simple to survey personal reactions as it is to monitor noise levels.

The paper focuses on residential neighbourhood noise resulting primarily from ground transportation systems. This means noise caused by expressways, arterial roads, rail lines, and combinations of these. In an attempt to determine whether reliable predictions can be made without reference to the specific noise source (given that it is a ground transportation source), this paper will report results based on sites representing all of the sources. It is expected that subsequent work will test these general findings on larger, source specific data sets.

The reader may wish to object at this point, that at best this paper will add yet another set of initials to an already extensive list (TNI, NPL, (or L_{NP}), NNI, CNEL, L_{eq}, etc.), or less optimistically, will simply replicate what has already been done. Our aim is not derive a measure of noise, which would have units of, e.g. dBA, but to produce a measure of community reaction to noise, which will have units of percent of population disturbed. Our measure will be based on the physical measures of noise, certainly. However, it goes beyond them to permit a statement of results in terms of total number of people disturbed, so that it is possible to compare more easily a variety of proposed plans. (See Hall and Allen (1) for elaboration of this point.)

In the following sections, we describe work leading to several plausible equations for the proposed measure. The first section briefly describes the data on which the analysis is based. The next section deals with the simple correlations among the several variables, which served as essential starting information for the regression analysis reported in the third section. The final part of the paper briefly compares this work with that on which TNI and NPL are based.

Description of the data base

The data analysed here represent part of that collected during the summer of 1975, with support of the Ontario Ministry of the Environment and the National Research Council. A total of 28 sites were surveyed, in the Hamilton, Burlington, and Mississauga areas. Survey procedures consisted of

(1) identifying a site, based on its characteristics with respect to a particular transportation noise source;

(2) conducting a household interview with a target of roughly 30 interviews per site;

(3) monitoring the noise levels at the site for at least one and preferably three days.

The interviewing was carried out from May 23rd to July 18th, resulting in a total of 837 individual interviews. Due to weather and equipment problems, the monitoring was not so successful, and in fact is still in process. As a result, only 25 monitor days, representing 14 sites, were available for analysis for this paper. Discussion of each of the three survey components is helpful for an understanding of the analysis.

Site selection is critical for this kind of study. Ideally, every housing unit in the site should be exposed to an identical external noise environment, a requirement which has led to poor results in some previous studies (2, 3). This normally means only a small number of units can be included in each site. On the other hand, if the interview data obtained at the site are to have any statistical reliability as representative of response to that noise environment, then the number of interviews at each site should be reasonably large. There will usually be a non-response problem in household interviewing, either because people are not at home, or because they choose not to participate. Hence the site should, for practical reasons, contain at least 50%, and possibly 100% more housing units than one intends to interview.

Fortunately, the types of noise source of interest for this paper are essentially linear, rather than point. This means that it is theoretically possible to satisfy both of the apparently contradictory selection criteria just identified, by taking a single row of housing paralleling a specific source. Problems still arose, however, in finding 50 housing units in such a row. Table 1 identifies the housing and noise environment characteristics for the 14 sites used in this analysis.

The item in the questionnaire on which most of this paper is based is a nine-point rating scale used in response to the question, "How would you rate the overall noise in this neighbourhood?" The nine points of the scale consisted of labels, as follows:

extremely	agreeable
considerably	agreeable
moderately	agreeable
slightly	agreeable
neutral	
slightly	disturbing
moderately	disturbing
considerably	disturbing
extremely	disturbing

This, of course, represents an ordinal scale, and while one can number the scale points, the numbers will contain information only on the order of the responses, not on intervals between them. Consequently, only limited arithmetic operations are valid. This point should be obvious, but has proved in the past to be a stumbling block for similar studies (4).

The fact of ordinal data poses a particular problem given that we wish to aggregate the data at each site, and then to compare findings across sites. Two approaches are possible. The first is to calculate the median response score at each site, which permits rank-order correlations between physical and social data, but not regression analysis. The second is to dichotomize the scale, to disturbed and not disturbed categories, and to determine the percent disturbed at each site (3). This would permit a regression analysis, although it is dubious in that it collapses a meaningful nine-point scale into an artificial two-point scale. In fact, it appears that there are two recognizable types of disturbance response in the data. The advantages gained by allowing legitimate regression analyses outweigh the damage done to the scale however, and tests against two other questions from the survey indicated a high degree of reliability for this approach. Some information has been lost by using it, nevertheless.

All of the monitoring for this study was carried out using a timer-activated analog recording unit, with the timer set to record roughly 10 seconds every 2 1/2 minutes. Although 25 days of monitor information are available, the analysis will be restricted to a single tape per site, or 14 days. The primary reason for this is that we have only one measurement of overall response to the noise at each site. Hence to use all 25 days would mean repeating the same response data for two or three sets of physical data. The effect of this would be to weight those sites for which multiple tapes are available more heavily in the results, for which there is no justification. Fortunately, preliminary analyses of all 25 days indicated a very close correspondence among the several days of record for each single site. Selection, for those sites with more than one monitoring day, was accomplished by deleting Saturdays and Sundays, and selecting randomly if more than one weekday remained. The day of the week for the monitor record used in the analysis is shown for each site in Table 1.

Correlation of physical and social data

Two facts stand out upon inspection of the simple bivariate correlation coefficients. First, the response data correlate strongly with many of the direct measures of noise levels, not simply with one or two. And second, the direct measures of the noise distribution generally give better correlations with the response data than do several of the more involved measures which have been developed in the literature. Table 2 presents the correlations in support of these statements.

Five direct measures of the distribution of noise levels over time were used for this study: L_{90}, L_{75}, L_{50}, L_{25}, and L_{10}. Separate time-varying distributions were calculated for daytime (0700-1900), evening (1900-2300), and night (2300-0700), resulting in a total of 15 direct measures of noise level. Of these, 13 produce correlation coefficients with the response variable which are significant at the .05 level. The correlations for all five measures for the daytime are significant at .001, with the lowest coefficient being r = 0.758, for L_{10}.

The fact that all of the measures correlate highly with the response variable indicates that there is a high degree of correlation among the direct physical measures. While this is not surprising, it is important to keep in mind the fact that any conclusions from this study will necessarily apply only to situations in which the noise measures are so highly correlated.

The other point to be extracted from Table 2 is that the L_i measures in general perform much better than the more complicated measures which have been suggested for assessing the community impact of traffic noise. Because of the significance of this finding, we shall deal with each measure separately.

Two measures of the 'average' noise were used: the arithmetic mean of the dBA readings, μ, and the equivalent sound level, L_{eq}. The mean dBA level did correlate roughly as well as the direct measures, such as L_{50}, but did not improve on them. L_{eq}, on the other hand, did not do so well as the direct measures. Except for the night period, when L_{90} and L_{75} did not produce significant correlations with response, the L_{eq} correlation was lower than any of the direct measures.

Building on L_{eq} and μ are the L_{NP} measure (L_{eq} + 2.56 σ) proposed by Robinson (5) and a measure consisting of μ + 0.5 σ, recently proposed by Johnston and Carothers (6) as an improvement on L_{NP}. Our data support the findings of Johnston and Carothers, that μ + 0.5 σ gives better correlations with response data than does L_{NP}. However, our data also suggest that the σ term makes little if any improvement on the correlation of μ alone.

The remaining measure for road traffic noise is the Traffic Noise Index (TNI = $4(L_{10} - L_{90}) + L_{90} - 30$) proposed by Griffiths and Langdon (4).

With our data, it is among the weakest correlates for day and evening, and among the best for night. If we attempt to replicate the conditions under which TNI was developed, by using data from only the 8 road traffic sites, and aggregating the three time periods to produce a single 24-hour record, the measure still does not do well. L_{50}, L_{25}, and L_{10} all correlate with the response variable at greater than $r = 0.7$, while TNI correlates at only $r = 0.605$, as opposed to the $r = 0.88$ which Griffiths and Langdon report.

Development of a regression equation to predict disturbance

In attempting to identify a good equation for predicting the percentage of population disturbed, we made use of several criteria, as follows.

1. The independent variables in the equation should not be highly correlated with each other. (Regression analysis assumes they are statistically independent, which would mean zero correlation.)

2. The combination of coefficients (including sign) and variables must make sense, not merely provide a statistically good fit.

3. The variables used in the equation should all be significant at the .05 level in that particular combination.

In order to better understand the available data, partial correlations were calculated for all variables against the response data, while holding each other variable constant. The most striking finding from this was that when the night measures were held constant, the daytime L_{75} had the strongest partial correlation in all but two cases. For those, the daytime L_{50} was strongest. For evening measures held constant, L_{75}, L_{50}, and μ for the daytime were always the top three partial correlates. When the daytime measures were held constant, slightly more variation appeared in the partial correlates, although for the two measures of variation (σ and $L_{10} - L_{90}$), and for L_{eq} the same three measures were again the top correlates.

This means then, that in a stepwise multiple regression equation, no matter what variable is entered first (with the exception of the daytime L_{90}, L_{25}, and L_{10}) one of the measures L_{75}, L_{50}, or μ for daytime will enter next. It seems sensible therefore to focus on those three plus the three exceptions just noted.

Three of these six can be very quickly dealt with. If L_{90}, L_{75}, or L_{50} is placed in a regression equation, no other variable will yield a coefficient significant at the .05 level. Hence by the third criterion listed above, we are limited to single-variable equations. Table 3 contains the relevant data about each equation. The remaining three variables, in addition to the univariate equations, yield two multi-variate equations with significant coefficients, which are also listed in Table 3.

Equation 7, based on L_{25}, does not meet the second criterion, in that the constant term is positive, predicting high annoyance even if there is no noise. Equation 8 also conflicts with the second criterion, because it is difficult to understand why, if average daytime noise levels are held constant, disturbance will decrease as average night-time noise increases. In fact, the second criterion rules out any two-variable equation involving L_{75}, L_{50}, L_{25}, or μ for the daytime. Once one of them is held constant, the partial correlation coefficient is negative for each variable outside that group. The only plausible (in terms of criterion 2) two variable equation involves L_{90} and L_{10} (equation 9). This equation does not meet the first criterion, as L_{10} and L_{90} are closely correlated (0.873).

While it is of course possible to try many other combinations of variables, any plausible ones we have tested have either produced worse results than equations 1 to 6, or have resulted in coefficients which do not fulfill criterion 2. The choice of a predictive equation would appear then to be limited to the first six listed in Table 3. On the basis of both the coefficient of multiple determination and the standard error, the equation based on L_{75} would seem best. If other criteria are important as well, either of the equations based on L_{50} or on μ is almost as good.

Although the equations reported here yield good statistical fits, it is important to be aware of their limitations. For two reasons, they should not be used to estimate changes in the reactions of a single group to a change in the noise environment. They can be used only to estimate responses to reasonably stable noise environments. The primary reason for this limitation is that the data report the reactions of different groups of people in different noise environments, not changes in the reactions of a single group as the noise situation changes. The second reason is an extension of this: once people are accustomed to a particular noise environment, changes in any of several parameters may affect the degree of disturbance they report. These single-variable equations are obviously not sensitive enough to incorporate that.

A second limitation on the equations deals with their predictive reliability, and can be judged by inspecting the statistics reported in Table 3. The value of R for the equations based on L_{75}, L_{50}, and μ ranges from 0.838 to 0.819, indicating that these equations explain only from 67 to 70 percent of the variation in the percent disturbed. In addition, the fact that the standard error of the estimate is between 10.3 and 10.8 means that confidence limits on the prediction need to be fairly broad. The 95% interval, for example, would be the actual estimate $\pm$ 20. While this is not a particularly narrow band, the fact that the actual percent disturbed ranged from 9 to 61 does serve to increase one's confidence in the estimates. Although one should be aware of this limitation, it is reasonable to use one of these equations to estimate the number of people likely to be disturbed by a particular noise environment.

Comparison with previous studies

For two reasons, the principal comparison in this section will be with the Griffiths and Langdon study (4). Both the Traffic Noise Index and the Noise Pollution Level were derived from that particular data set, and the description of the work is sufficiently complete to allow a detailed comparison of approach, techniques, and findings. The results reported in the present paper differ considerably from those Griffiths and Langdon report, both in the degree of correlation between physical and social measures (they obtained at best $r = 0.60$ for the direct physical measures), and in the form of the equation which best matched the response data. Explanations for these differences can be found in both the questionnaire and the analysis techniques.

The question Griffiths and Langdon used dealt specifically with traffic noise, while our results are based on a question about overall neighbourhood noise. That these two questions yield different responses can be seen from another question in our study, which asked about reaction to specific noise sources, as well as reaction to the overall neighbourhood noise. For expressway traffic, the correlation (Kendall's tau for ordinal variables) between responses to the two questions was only 0.4026. We focused on the rating of overall noise for two reasons. First, it is rarely the case that only a single noise affects people, although people can certainly identify different noise sources, and talk about them separately. Second, any physical measure we could provide would be of ambient noise, not of noise from a single source. It seemed most legitimate to match overall noise records against reaction to overall noise.

The questionnaire used in the present study was introduced to respondents as a general neighbourhood survey, and the first two questions asked were, "What are the important things you like (don't like) about living in this neighbourhood?" Thus noise could be, and was, voluntarily mentioned before the study had been identified as focusing on noise. In a case such as this it is good practice to obtain some indication of the respondent's concern about noise before telling him or her that it is the interviewer's concern. It is not clear whether the survey Griffiths and Langdon report was able to do this.

The final point of difference is the interpretation of the response scale. There is some confusion in the analytical treatment of the Griffiths and Langdon scale. For example, they interpret the mid-point as "don't know", and then exclude such responses from subsequent analysis (4:21). They appear subsequently to calculate the arithmetic mean of responses for each site, in which case surely the scale mid-point should be included. The average score for each site is then used in a regression analysis, which requires an interval scale, and also argues for inclusion of the mid-point. Because of these analytical problems, the formula for TNI is necessarily questionable. In that L_{NP}, the noise pollution level, is based on the same set of data treated in the same way (5:282), so likewise is it questionable.

Conclusions

The study reported in this paper indicates that it is possible to predict, with a fair degree of reliability, the percentage of a group of people likely to be annoyed by noise from surface transportation solely on the basis of the daytime L_{75}, L_{50}, or μ. Because this is a surprising finding, several possible explanations for the difference between these and previously reported results have been explored, all of which appear to argue for the improved reliability of the results reported in this study.

Grounds for hesitation in accepting these results stem from two sources. First, the fact that only a single parameter of the noise profile is included means that the findings will be of use only in those areas where the set of noise profile parameters varies in the same way they have here. For example, if driving trucks at night were suddenly restricted, the noise profile of most highways would change drastically, and it is doubtful whether these results would still hold. Second, the selection of households at some of the sites included in this analysis deviates too far from the ideal. As additional data become available, they will be used to replace the faulty sites, to improve the analysis.

Nevertheless, the equations reported here represent reasonable ways to identify or predict the social impact of the noise from a road or rail line. This appears to represent a significant advance in our treatment of ground transportation noise.

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TABLE 1

Description of sample sites by noise source

Site	Housing Placement	Shielding	Day Monitored	Daytime L_{50} (dBA)	% Disturbed
Expressway					
1	ideal	light industry	Friday	48	17
2	ideal	none	Tuesday	68	56
3	ideal	housing row	Wednesday	59	57
4	fair	wooded area	Tuesday	62	43
5	bad	housing	Thursday	63	38
Arterial					
1	ideal	none	Wednesday	68	61
2	good	none	Friday	53	14
3	good	housing row	Thursday	48	36
Rail					
1	good	none	Monday	51	26
2	ideal	none	Thursday	45	19
Rail & Expressway					
1	ideal	none	Tuesday	53	17
2	ideal	commercial row	Tuesday	50	9
Control (quiet) areas					
1	–	–	Thursday	49	26
2	–	–	Tuesday	47	9

TABLE 2

Correlations of physical data with percentage of respondents expressing disturbance at noise

Noise measure	Time of Day: Daytime (0700-1900)	Evening (1900-2300)	Night (2300-0700)
L_{90}	.799[c]	.661[b]	NS
L_{75}	.838[c]	.681[b]	NS
L_{50}	.827[c]	.717[b]	.548
L_{25}	.797[c]	.711[b]	.675[b]
L_{10}	.758[c]	.622[b]	.658[b]
μ	.819[c]	.712[b]	.580
L_{eq}	.743[c]	.553	.548
σ	NS[a]	NS	.610[b]
$L_{10}-L_{90}$	NS	NS	.645[b]
L_{NP}	.660[b]	.493	.586
$\mu + 0.5\sigma$	.810[c]	.702[b]	.617[b]
TNI	.530	NS	.658[b]

NOTES:

[a]NS = coefficient not significant at the .05 level.
[b]coefficient significant at the .01 level.
[c]coefficient significant at the .001 level.

TABLE 3

Candidate regression equations for predicting percentage of population disturbed by noise

	Equation	R	Standard Error
(1)	$Y = -86 + 2.4\ L_{90}$ (day)	.799	11.3
(2)	$Y = -80 + 2.2\ L_{75}$ (day)	.838	10.3
(3)	$Y = -73 + 1.9\ L_{50}$ (day)	.827	10.6
(4)	$Y = -67 + 1.7\ L_{25}$ (day)	.797	11.4
(5)	$Y = -74 + 1.7\ L_{10}$ (day)	.758	12.3
(6)	$Y = -83 + 2.1\ \mu$ (day)	.819	10.8
(7)	$Y = 44 + 11.9\ L_{25}$ (day) $- 9.7\ L_{10}$ (day) $- 2.1\ \mu$ (night)	.904	8.8
(8)	$Y = -44 + 9.8\ \mu$ (day) $- 5.7\ L_{10}$ (day) $- 2.2\ \mu$ (night)	.922	8.0
(9)	$Y = -89 + 1.7\ L_{90} + 0.6\ L_{10}$	.808	11.6

NOISE CONTROL IN ALBERTA

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ABSTRACT

The Provincial and Municipal Governments of Alberta have attempted a variety of measures for the abatment and control of environmental noise. The origins, contents and effectiveness of the measures are outlined and commented on. Several major studies have and are being conducted by both levels of government in their attempts to improve their ability to deal with these problems. This work is described in outline and the special difficulties related to the conduct of this work because of the lack of sufficient professionally trained man-power will be described. The difficulties of finding the appropriate solutions to particular problems especially in regard to urban planning, economic impact and the fostering of good public relations is discussed by reference to the role of the acoustician in a multi-discipline team. The problems which exist for Municipal and Provincial Governments because of the presently inadequate national regulations relating to some aspects of noise control is also discussed.

Alberta has two cities which are home to about half its population, consequently the problems of noise mainly relate to the cities of Edmonton and Calgary. Both of these cities, in separate and independent initiatives, formulated by-laws for noise control which were eventually passed in Calgary in 1968, and in Edmonton in 1970. The by-laws in their presently amended forms constitute the main legislation on noise abatement and control in the province, and are the first topic considered in this discussion.

Table 1 summarized the relative positions of Calgary and Edmonton regarding vehicle noise emission.

TABLE 1

CALGARY BY-LAW (Figures in Parenthesis are for the original bylaw)

VEHICLE CLASS	LAWFUL SPEED LIMIT (in miles per hour)	MAXIMUM NOISE INTENSITY (dbA)
Light Motor Vehicle (Passenger vehicle, light truck, power bicycle, motor scooter)	not more than 30	80
	More than 30 and not more than 45	85
	more than 45	88
	Edmonton 40 mph or less	83

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TABLE 1 (continued)

VEHICLE CLASS	LAWFUL SPEED LIMIT (in miles per hour)	MAXIMUM NOISE INTENSITY (dbA)
Motorcycle	not more than 30	(80) 85 (in daytime)
		82 (in night)
	more than 30	(88) 90 (all times)
	Edmonton < 40	83
Motor Truck	not more than 30	87
	more than 30 and not more than 45	91
	more than 45	95
	Edmonton < 40	90
Tractor Trailer and Concrete Mixer	not more than 30	(88) 92
	more than 30 and not more than 45	94
	more than 45	98
	Edmonton < 40	92

Clearly there is some considerable discrepancy between the requirements of the two cities; one city enforces levels which are regarded as impractical by the other. It is to be noted that the Edmonton by-law specifies noise emissions at 40 miles an hour and less, above 40 miles an hour there is no restriction.

The two by-laws are quite divergent in their content and philosophy. The Calgary by-law introduces a series of particular prohibitions against a variety of noise sources. For example, 'unloading trucks at night', advertising, lawn mowers, powered snow clearing devices, model aircraft, dogs and air conditioning. Table II summarizes some of these conditions.

TABLE II

(1) No person shall operate a power or hand lawn mower in any area designated as a Residential District between the hours of

(a) ten o'clock in the evening and eight o'clock of the next forenoon on weekdays or

(b) ten o'clock in the evening and nine o'clock in the morning of the following day which is a Sunday or holiday.

(2) No person shall operate a model aircraft driven by an internal combustion engine of any description during the hours when the use of a lawn mower is prohibited by subsection (1) in any Residential District.

(3) No person shall operate a snow clearing device powered by an engine of any type during the hours when the use of a lawn mower is prohibited by subsection (1).

(4) In addition to but not is substitution for any penalty which a person may incur by a contravention of any provision of the Dog By-law a person who owns, keeps, houses, harbours or allows to stay on his premises a dog which by reason of barking or howling disturbs persons in the vicinity of his home is guilty of an offence under this By-law.

(5) No person shall operate an air conditioner, fan or similar device at more than the following levels measured at any location on the lot line;

July 1, 1973	60db A (Day or night)
July 1, 1974	55db A (Day)
	50db A (Night)
July 1, 1977	50db A (Day)
	45db A (Night)

There is an unusual statement on the measuring techniques to be used in Calgary. This requires the use of a B and K meter, Aweighted, on the fast response, so that it appears that the legal unit for the measurement of noise is a "B and K Aweighted decibel" (which is the result of an amendment of the by-law, causing the replacement of the ISO 123 standard).

Edmonton chooses to set noise standards for different zones in the city. These are given in the table below for the residential, commercial and industrial zones.

TABEL III

Noise Level in Residential Zones

10. No person shall cause or permit to be caused in a residential zone within the City during the day, a noise level in dbA recorded on a sound level meter operated as directed herein greater than 65 dbA unless the noise level:

(a) results from an emergency situation, or
(b) has been approved by a special permit issued by the City Commissioners, or
(c) is included in Part 4 hereof, or
(d) is of a temporary and intermittent nature to the extent hereinafter set forth, namely,

dbA	70	75	80	83
Time	2 hours	1 hour	30 minutes	15 minutes

Noise in Commerical or Industrial Zones

12. No person shall cause or permit to be caused in a commercial or industrial zone within the City, a noise level in dbA recorded on a sound level meter operated as directed herein greater than 75 dbA unless the noise level:

(a) results from an emergency situation, or
(b) has been approved by a special permit issued by the City Commissioners, or
(c) is included in Part 4 hereof, or
(d) is of a temporary and intermittent nature to the extent hereinafter set forth, namely,

dbA	80	85
Time	2 hours	1 hour or less

A general abatement provision is included in the by-law which prohibits 'unnecessary or unusual noise which disturbs the comfort or repose of other persons'.

Enforcement is not without its difficulties. In Calgary this task is mainly undertaken by the police who, apparently, have little enthusiasm for duty with a B and K sound level meter. There is a variety of reasons for the reaction of the police. They feel that the noise enforcement duty is less essential than some of their other tasks. For example, they feel that their efforts to stem the road traffic casualty rate is a more imperative duty. Some difficulty has been experienced in obtaining convictions under the by-law. The sound level meters are used less frequently than hitherto. The Police tend to stop a noisy vehicle and have it examined under the provisions of the Highway Traffic Act. The findings of this examination can lead to a prosecution.

Edmonton approaches the problem in a different manner. The police department uses a special noise enforcement team. Consequently, the majority of police officers are not concerned with enforcing the by-law. It seems that the opinion of the police is that difficulties arise because of the lack of a Provincial standard for motor vehicle emission. The police feel quite strongly that test stations should be established for the static testing of vehicle noise. The police have found difficulties in using noise level meters in compliance with the by-law. The by-law requires that no sound level reading shall be taken if the background is within 10 dB of the permitted noise level, or when the wind velocity is greater than 25 miles per hours.

It can hardly be said that either of the by-laws attempt to legislate a comprehensive noise control package. In practice, they serve to deal with the worst excesses only.

This situation is fairly well recognized in the Province and has lead to consideration of alternative approaches to the problem. A second attempt was made by the Provincial Department of the Environment, which funded two noise surveys. These called for a comprehensive study of the problem in both cities[1~2]. The results of these surveys were published about 18 months ago and reported in detail on the various problems of the cities. Reaction to these reports and other related pressures had led to attempts to avoid reproducing the conditions which occurred at some of the more unsatisfactory existing situations. These attempts have been made at several levels of Government. At one level, trucks have been re-routed in several parts of the Cities, so that the impact of their noise on residential areas has been reduced. Questions of re-routing are raised often as a result of public pressure. The published noise measurement data has been very influential in assisting objective decisions. At another level, new major highways have in many cases been designed so that the noise inflicted on local communities has been kept within reasonable limits. Now it is quite usual for a noise assessment study to be part of the planning process for the siting and layout of new highways and residential subdivisions. A recent example of such a study is that done for the small town of Leduc. This small community, which is just south of Edmonton, is close to a major airport and sandwiched between the Province's main north-south highesy and a railway line. Developers and the town council looked for opportunities for expansion. The Provincial Government called for a detailed study of the preliminary proposals. The study, Reference 3, presented the facts of the situation very graphically. A public inquiry followed the study and all the facts relating to the proposed development have been thoroughly discussed.

The noise problem in multiple dwellings have received some attention, particularly when there was a 15-20% vacancy rate. At that time, developers were anxious to make their property more attractive to renters. Unfortunately, more recently the vacancy rate has declined dramatically and although the problem remains it is not always treated with the same urgency nowadays. One of the major acoustical consultants in the Province still receives quite a few inquires related to this problem. Unfortunately building codes are not satisfactory and no effective government action appears to be forthcoming.

Airport noise is a well recognized problem. In Calgary development around the airport has been limited to commercial and light industrial buildings. As the Leduc study showed, Edmonton is trying to keep the approaches of its International Airport free of housing.[4] There has been discussion of the need for more frequent updating of the Department of Transport/NEF contours; but I do not know if an approach has been made to the Federal Department on this matter. Developers have approached consultants and asked for noise measurements in the approach lanes to the airport. Clearly there is pressure to develop housing in these areas.

The Provincial government has initiated a $300,000 study of transportation noise. This work is being conducted by a civil engineering firm, De Leuw, Cather, Bolt, Beranek, and Newman, and the University of Calgary Acoustics Group. The study has concerned itself mainly with the problems of urban highway noise. In particular, its scope is mainly limited to the design and assessment of barriers along major highways. The testing of the validity of the predictions of the design guide prepared for the U.S. Government by Bolt, Beranek and Newman is the major activity of the study.[5] Berms and walls will be built and their effectiveness measured both physically and by the response of the public to the changed conditions. The economic viability of this method of noise control will receive some consideration. The University of Calgary Group is concerned with (i) field measurements of traffic noise, (ii) studies of the public reaction to noise and (iii) the establishing of a scaling law facility.[6] This project is being reviewed by a board set up under the chairmanship of the ex-lieutenant governor of the Province, Dr. Grant MacEwan, and has among its membership Dr. E.A.G. Shaw for NRC and Mr. Walton of CMHC.

A difficulty with advancement of legislation arises from the fact that there are no professionaly trained or experienced acousticians in Provincial government employment, apart from those concerned with industrial hearing hazards. A similar situation exists in both the City governments. The three governments are aware of this problem, and have sought the advice of those who have expertise in the area. It is very probable that a public advisory subcommittee will be set up by the Provincial government and that this committee will be given the task of producing a comprehensive and detailed report for consideration.

Clearly, Provincial and Municipal government take the problem of noise seriously. Some of the goodwill and effort, however, has been wasted because of the lack of understanding of the technical problems which exist. There appears to be a need for a close study of all the implications of the noise problem. This study should not only deal with engineering problems but should also discuss the legislative requirements which have to be satisfied for a noise abatement act to be effective. It seems to be clear that close cooperation between the three levels of government is essential if really substantial progress is to be made.

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MODELLING APPLIED TO ENVIRONMENTAL ACOUSTICS

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NOTE

This is an abbreviated form of a contribution presented to the October 1975 meeting of the C.A.A. A few copies of a slightly more detailed version are available.

Introduction

In spite of the advent of modern digital computers, there are occasions when analogue methods are still the best approach to solving problems. Much interest in acoustic modelling exists around the world demonstrating that there is a commonly held opinion that the technique is prospectively a competitor to the numerical method and also that the numerical method has many shortcomings. It is possible to itemize the expected advantages of modelling. They are:

(a) Low cost, since cheap materials and simple measurements will be sufficient to provide satisfactory data;

(b) It should be more flexible than computing, i.e., able to deal with the most complex situations quickly and accurately;

(c) It will allow novel solutions to problems to be tried out and their effectiveness explored[1].

(d) In many cases it will be cheaper to use than numerical methods and will probably be able to deal with problems which would be beyond computational methods because of the complexities involved.

The first and most natural use of modelling is for the solution of barrier problems. This is a complex physical problem which is reviewed in detail in reference 2. It is a topic of interest to nearly all the major urban communities of the wealthier nations. It is not necessarily the most economic or effective solution to the control of traffic noise but undoubtedly it has its place and it is much used.

The nature of the physical problem is well understood. It is the application of diffraction theory which was first developed for the solution of optical problems. The basic problem can be stated to be that of solving Kirchhoff's equation, i.e.

$$\psi = \int_A a_1 \frac{fs}{dd_1} \left[\exp -ik(d+d_1)\right] dA \qquad (1)$$

(See Figure 1 for definition of symbols). Equation 1 can be directly applied to acoustics if air absorption is not important, simply by using the wavelengths and velocity of sound.

If we require a solution for many sources, then we look for the time averaged vector sum of their effects at P, i.e.,

$$\psi = \sqrt{\sum_m \int_A a \frac{fs}{d_m d_1} \exp\left[ik(d_m + d_1)\right] dA} \qquad (1a)$$

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If the sources are self coherent but incoherent with their fellows, if they are of varying strengths and of a complex frequency structure, these effects must be accounted for. In practice it is very difficult to solve the Kirchoff equation even for single point sources for anything but a relatively limited number of circumstances. S. W. Redfearn[3] solved the barrier problem using a solution to a similar equation from Carslaw's "Conduction of Heat".[4] His solution is not easily applied in practice and it neglects the presence of the ground.

Maekawa[5], in a series of papers, compared a theoretical treatment with the results of model experiments. His work is briefly summarized in Figure 2. Figure 3 shows a comparison of Maekawa's predictions with the field results obtained by J.M. Rapin[6]. A British Standard[7] gives charts based on treatment which solved the diffraction problem for a receiver and source both close to reflecting ground on which the barrier was built. Field assessments of this standard (and its later development) have been made and published by Scholes et al[8,9].

It is apparent that "semi-infinite" barriers make only a very rough approximation to the real state of affairs. In practice the barrier may be semi-continuous (e.g., with breaks for side roads, etc.). It might be built on undulating absorbing ground with multiple scattering effects of houses and other buildings and so on. These effects cause any theoretical treatment based on simple geometry to break down. The discovery that the prediction of one design procedure was inadequate was the major outcome of a study in Ontario by Harmelink[10]. In principle, we can deal numerically with any problem to any degree of accuracy (provided that sufficient time and trouble is taken). For many cases the complexity of the process involved almost defies description. Quasi-analytical solutions have their application to simple circumstances. Probably it is sensible economically to seek solutions by analogue methods for many if not most real circumstances.

Modelling Criteria

It is important to discuss what scaling laws must be satisfied in order to carry out satisfactory modelling. These are:

(a) Geometric similarity requires generally that λ/d for the prototype and the model must be the same. If λ/d is very large, as in the case of surface roughness for example, failure to preserve this ratio may not be significant.

(b) Time (t), for example, the passage of a vehicle between two points. If the linear scaling factor is given by:

$$S = \frac{d_M}{d_P} \qquad (2)$$

Using the suffix M for the model and P for the prototype, table Ia shows relationships for some quantities.

Table Ia

Quantity	Distance	Time	Velocity	Frequency
Scaling Factor	$d_M = d_P . s$	$t_M = s . t_P$	$V_M = V_P$	$f_M = f_P / S$

If time is scaled so that $t_M = t_P$ then the scheme shown in Ib occurs:

Table Ib

Quantity	Time	Velocity	Frequency
Scaling Factor	$t_M = t_P$	$V_M = SV_P$	$f_M = f_P$

Thus, if air is used for both prototype and the model then the velocity in each must be the same. Consequently the time for an event in the model is reduced. It follows that the model frequency must be increased*.

(c) Change of Medium. If for some reason another gas was used in the model then by writing

$$s' = \frac{C_P}{C_M} \quad (12) \qquad \text{it follows that} \qquad f_M = \frac{f_P}{ss'} \quad (13)$$

Two cases exist as s' can be greater or smaller than I; the case that $s' > 1$ is, perhaps, more interesting. For example if we use a heavy gas such as krypton or freon 12, the model frequency can be reduced. Suppose $S = 1/80$, and air is replaced by freon 12 in the model:

$$S' = \frac{C_{air}}{C_{F12}} = 2.22 \quad .. \quad f_M = \frac{f_P}{2.22\ S} = 36\ f_P \text{ instead of } 80\ f_P.$$

Alternatively if f_M/f_P was maintained at 80, the model area available would be nearly five times more than would be obtained by using air. Similarly, if krypton is used $S' = 1.54$, $f_M = 52\ f_P$ and

if xenon is used, $S' = 1.92$; $f_M = 42\ f_P$.

(d) Surface effects in the model must represent their full scale equivalent. This means that the acoustic impedances in the model for the higher frequencies must be the same as in the prototype for the lower frequencies. Typically, two classes of materials are of interest in modelling urban environments:

(a) Hard materials of low absorption coefficient such as roads, pavements, and building facings.

(b) Porous materials of greater absorption coefficient such as the ground with its associated vegetation.

Delany, et al.[11] in their 1/30th scale model used the rough side of 3 mm hardboard to simulate the facing brickwork on buildings (the buildings themselves were constructed of 9 mm plywood). Roads and pavements (good sound reflectors) were simulated by using sheet aluminum. Absorbing ground with near-grazing propagation of sound[13] was simulated by 11 mm thick fibreboard. P.R. Donavan[12] in his 1/64th model of a city used plywood for the buildings which were constructed on a linoleum-covered concrete floor. Cann[1] tested the following materials and found them suitable: tree foliage, finely shredded paper; houses, painted styrofoam; roads, heavy flexible vinyl; ground, velour-covered fibreboard; and walls, heavy cardboard (covered with foam for absorption when needed).

(e) Air absorption presents a difficulty for modelling. Absorption is strongly dependent on frequency and humidity, Knudsen[14,15]. Delany et al.[11] and Donavan[12] all took account of this problem by correcting their model data for the extra absorption at high frequencies.

If we write $[\alpha d]_P$ and note that it scales to give $[\alpha d]_m$ then the ratio of these quantities gives the scaled classical absorption, these with related quantities are shown in table 1.

Acoustic Sources for Modelling

The spectrum of interest in traffic noise studies ranges from 50 to 2500 Hz, ref. Olsen[21], which for a model of 1/80th scale would convert to 4 to 200 KHz. A variety of noise sources have been been used for modelling. Cann[1], Delany et al.[11], Donavan[12], Lyon[22] have used broad band sources. Two of them used air jets, either impinging on each other or on vanes, while the others used spark discharges (which obviates the need for an anechoic chamber). Such devices suffer from the disadvantage that the frequency-amplitude relationship is fixed and uncontrolled. This inadequacy causes difficulties in obtaining a satisfactory correlation with the prototype, ref (11).

In order that the adequacy of the model may be fully investigated, and to have a better control over the noise source spectra, modulated whistles of the Hartmann type[23] are being developed for this project. With such devices intense sound of good tonal quality is easily obtained. Figure 4 shows a cross section of the prototype whistle. The essential features are (a) an over-expanded nozzle supplied with compressed air (typically about 600 kN/m^2 absolute), (b) an adjustable depth-cavity of 0.5 mm diameter bore, and (c) a means for adjusting the gap between the nozzle lip and cavity lip. Nozzle and cavity are the same bore and can easily be replaced with a different sized pair. The cavity needle allows the depth to be adjusted so that an octave-change of frequency can be obtained with nearly pure tone.

The performance of the whistle has been explored to find the effect of changes of;air pressure, gap size between the nozzle and cavity, and the cavity depth. Data has been obtained for whistles with 0.5 mm and 1 mm bore cavities. Figure 6 shows that nearly spherical emission is achieved by the whistle but some effect from the presence of the supports is apparent. The final design changes will be made to reduce their influence. Figures 7 and 8 show the variation of the frequency f and the whistle output L_T with cavity depth. The value of f calculated from $\lambda = 4(\ell + 0.3d)$[24] is in good agreement with experimental data. Figure 9, for a fixed geometry indicates that f varies little with pressure whereas L_T is strongly affected (with a maximum at 60 $lb\ f/in^2$).

These results show that it will be possible to span the required frequency range using fixed geometry, variable cavity depth, whistles producing a very adequate power level. It is intended to modulate the cavity needles by means of an electrically driven piezo-electric bimorph element. In this way it should easily be possible to produce any time averaged sound spectrum which is required.

The Calgary Model Facility

Since continuous ultrasonic noise sources will be used in this facility, it is necessary to find suitable materials for a high frequency anechoic enclosure of the model. To this end a 1 m^3 steel reverberation chamber was built (see Figure 10). The prototype whistle was used as a source. Proposed materials for the anechoic chamber were placed in the reverberation apparatus and their absorption coefficients found. Figure 11 shows the completed chamber. It should be noted that most of the wall panels can be removed in order to have free access and consequently the whole of the chamber floor space can be filled by the model.

Conclusions

This paper outlines a literature review which has been conducted; the review indicates that modelling probably will be a useful and successful technique. The application of scaling laws to the problem have been reviewed and commented on. The need for a thorough and careful approach to the problem in which all the material properties are measured and in which a controlled sound source is employed appears to be indicated. The development of a well-controlled high frequency source is described, together with some description of the first measurements of material properties. Experience to date indicates that modelling should provide a low cost method for obtaining solutions to propagation problems.

Acknowledgement

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Table 1

CLASSICAL ATTENUATION AT ≈15°C, 1 ATMOSPHERE

	CONDUCTION $\alpha_c/f^2 x10^{11}$ s^2/m	VISCOUS $\alpha_v/f^2 x10^{11}$ s^2/m	TOTAL $\alpha/f^2 x10^{11}$ s^2/m	C sound speed m/s	$(\alpha d)_M/(\alpha d)_P$
AIR (DRY)	0.38	0.99	1.37	332	80
NITROGEN	0.39	0.96	1.35	334	80
HELIUM	0.22	0.31	0.53	965	90
KRYPTON	1.25	1.80	3.05	219	117
XENON	1.43	2.06	3.49	175	107
FREON-12	0.24	1.95	2.19	150	58

Effects relating to molecular relaxation processes may modify some of the values given in the table. Some data relating to this effect is not available and none is listed. It is to be noted that the effects of molecular absorption can be reduced either by drying the air used in the model or replacing it with a nitrogen atmosphere. Figure 12 shows the values of α/f^2 for wet and dry air and nitrogen. More information on this topic can be found in references 14 to 20.

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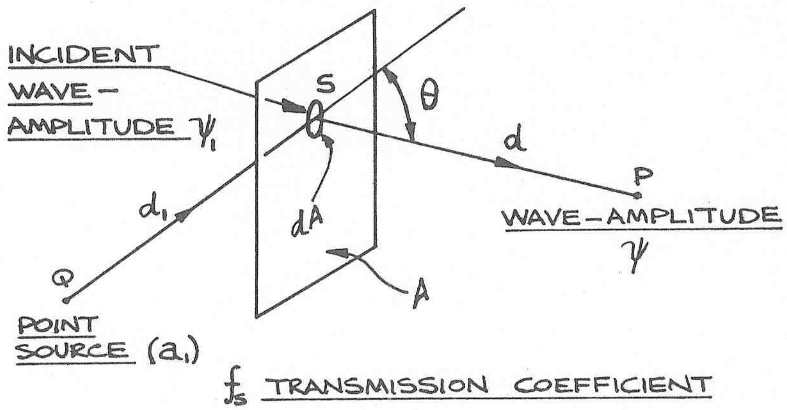
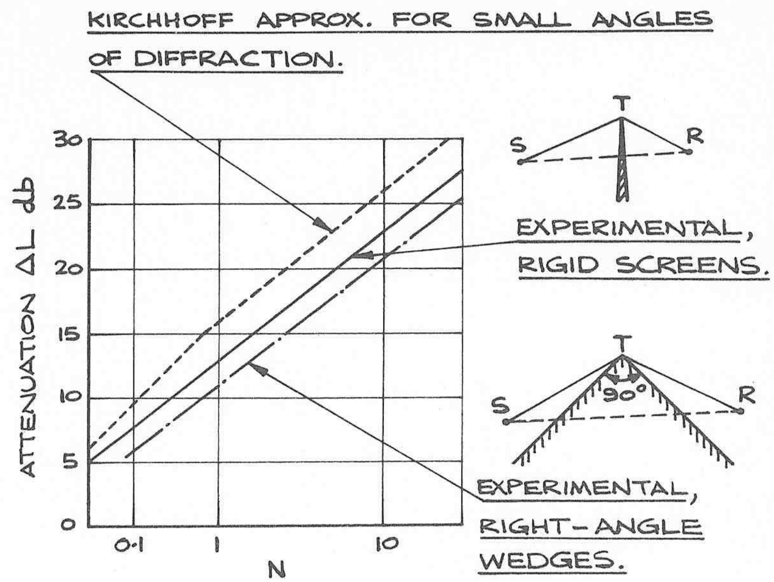


FIGURE 1



$N = \frac{2\delta}{\lambda}$ δ = PATH DIFFERENCE = STR – SR

FIGURE 2

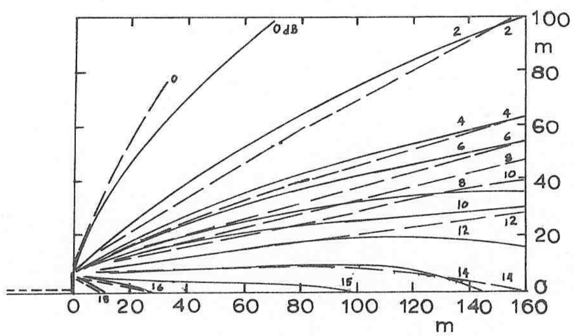


FIGURE 3

Section normal to eight-lane highway. —— Data from model test by Rapin[6]. ---- Calculation wtih Mackawa's procedure.

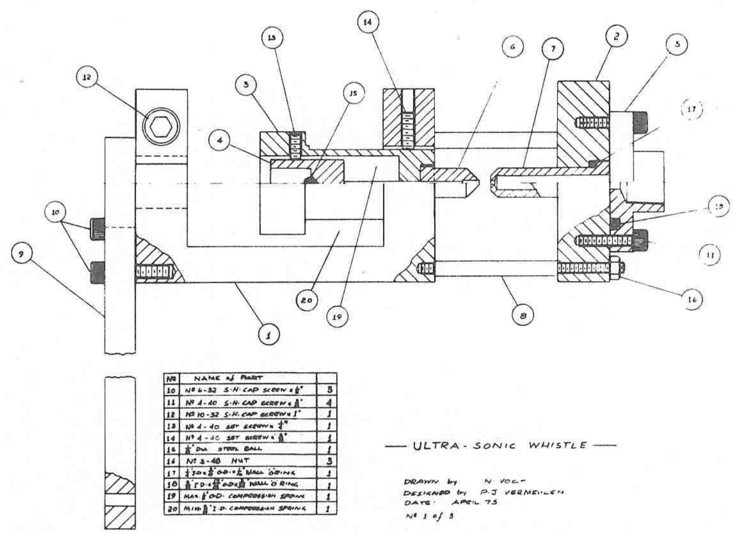


FIGURE 4

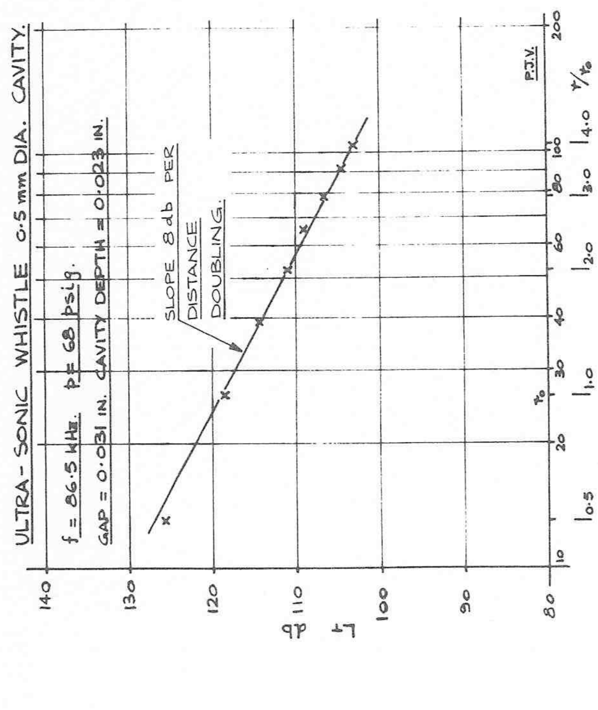


FIGURE 5

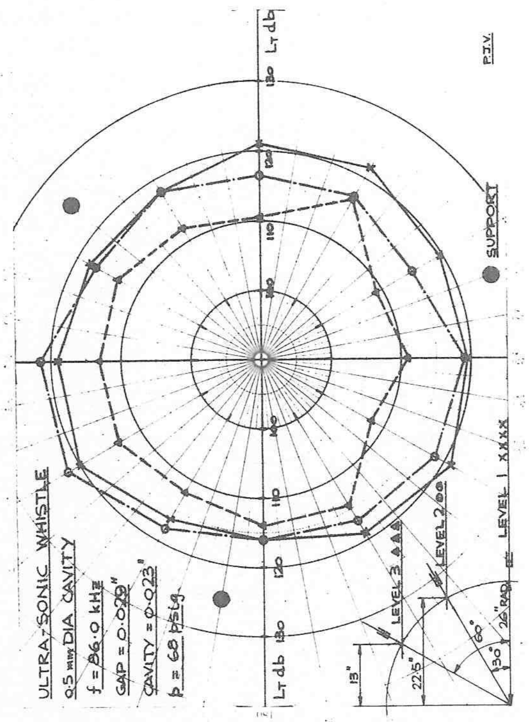
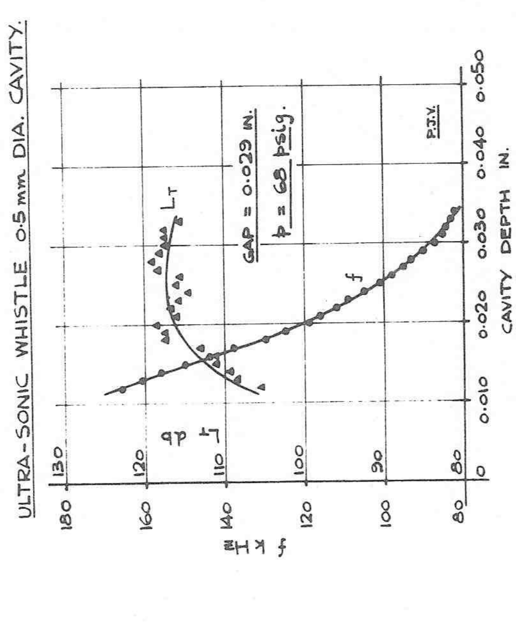


FIGURE 6



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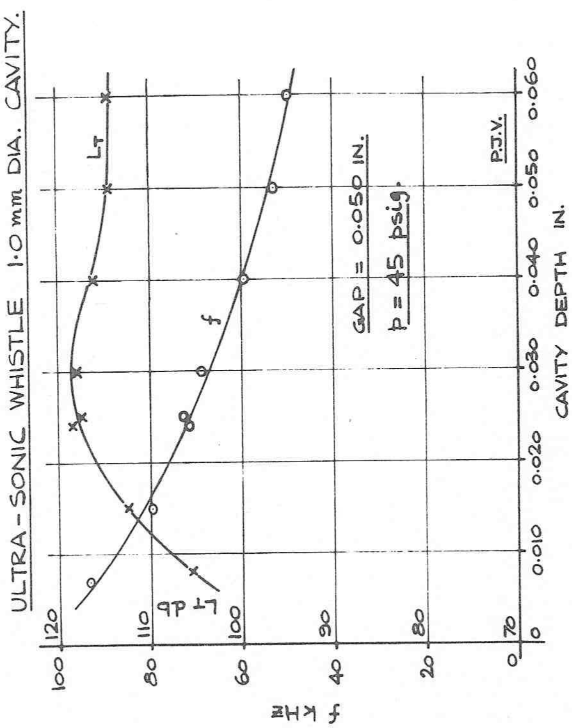

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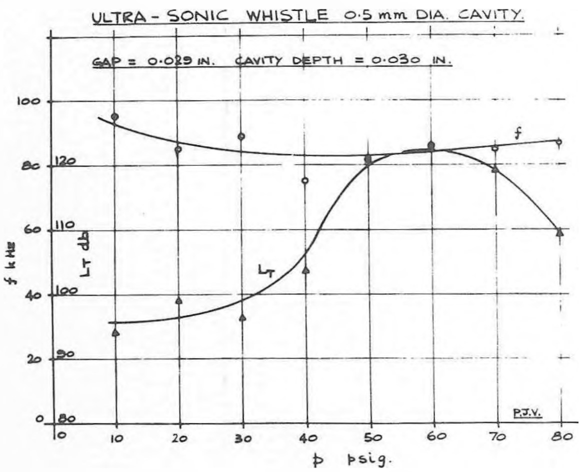

FIGURE 9

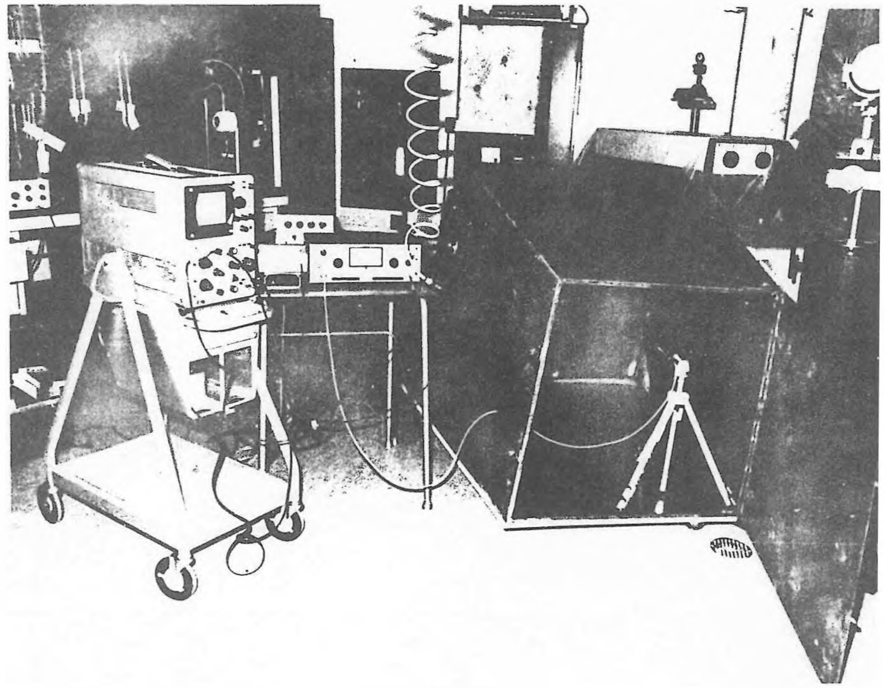

FIGURE 10

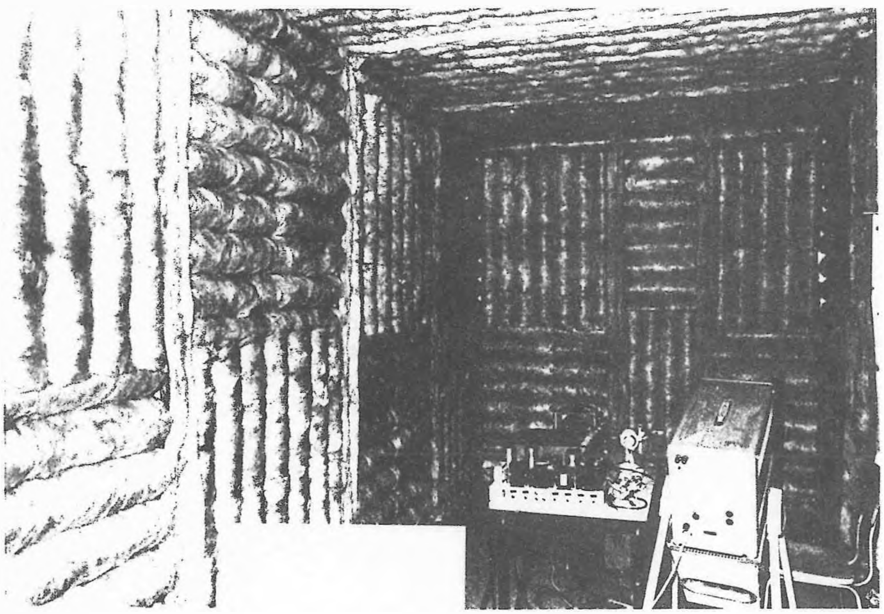

FIGURE 11

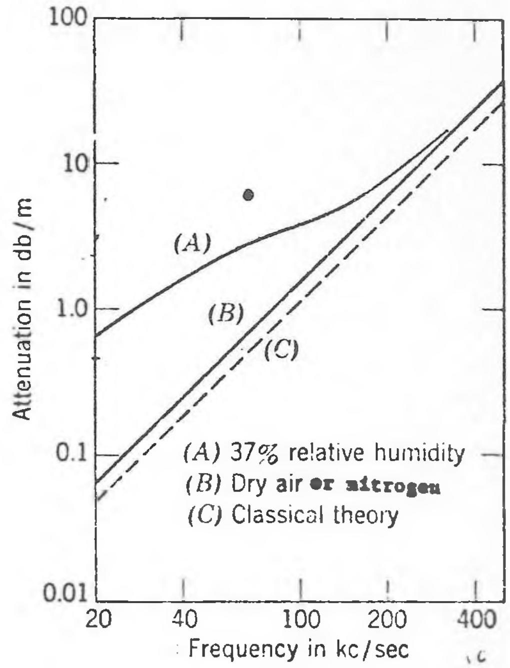

FIGURE 12