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BUILDING ACOUSTICS DESIGN CRITERIA

C O N T E N T S

PAPER 1

Noise Measures

C.E. Mather, Chief Noise Control Officer, Environment Protection Authority of Victoria.

1. Introduction

Concern about noise has reached the point where measures for describing its effects abound. In Australia, for example, each State's noise laws include measures to quantify noise in relation to the response(s) it arouses, and many other measures are also used, depending on the situation being examined.

This paper commences by distinguishing between the various terms applied to noise measures, followed by a review of the measures presently in use. It then looks at whether there is a need for such a variety, and concludes with some observations about the directions in which noise measures may develop.

2. Terminology

Before discussing the noise measures, it is necessary to distinguish between the various terms applied to them, i.e., scale, index, criterion, guide, goal and standard.

Firstly, scale. A scale is derived from measurement, i.e. from the assignment of numerals to a property of an object or event, *according to rules*. It is common to distinguish between four levels of measurement - nominal, ordinal, interval and ratio, as shown in Table 1.

There are two types of noise scale - those relating only to the physical properties of the sound, sometimes called direct measures (e.g. Decibel scale), and those relating to people's perception of those physical properties, sometimes called derived measures (e.g., the Loudness scale).

Secondly, index. An index is a scale adjusted to make allowance for certain additional factors not included in the scale's derivation. A noise index usually comprises a scale value and additional factors to allow for differences in people's perception, depending on the circumstances and on the time(s) of occurrence of the noise. Noise indices are measured over a given time period and are used in planning or in regulations to rate or assess particular situations. Examples of noise indices are the Noise Exposure Forecast (NEF) for commercial air traffic (used in Australia and U.S.A.), and the L_{10} (18 hour) index for road traffic noise (United Kingdom).

Thirdly, criterion. In general terms, a criterion is a means for judging or estimating a property of something. The World Health Organisation (WHO) recently produced a more specific definition for its environmental studies which, when applied to noise, means a *set of tests* selected to numerically relate the physical properties of noise to human responses (8). According to this definition, the tests from which the psycho-acoustic scales were derived (loudness, pitch, perceived noise level, etc.) would be *criteria*. However, this is not the commonly accepted meaning of criterion, at least in acoustics. Rather, it is used to mean a desirable or maximum permissible noise level, or set of levels. In this sense a noise index or scale value, or a noise index itself may be a criterion, as may a noise guide, goal or standard.

Fourthly, guide(line) and goal. Generally, 'guide'(line) means showing the way or leading in the right direction, while 'goal' means the object or end-point of effort. In acoustics, these meanings are sometimes interchanged*, however the generally accepted meaning of goal is an *identified level* of noise, below which public health and welfare will be protected with an adequate margin of safety. Goals can be either quantitative or qualitative. Examples of quantitative goals are: for hearing conservation $L_{eq(24)} \leq 70$ dB(A), and for residential areas indoors $L_{dn} \leq 45$ dB(A).

Lastly, standard. A standard is a legally enforceable limit, which must not be exceeded. Noise standards are usually set by taking into account technical, political and economic factors, as well as noise goals.

3. The Current Noise Measures

3.1 Efforts in noise abatement have been, and continue to be in three main directions:

(a) the elimination of health damage, particularly to hearing;

(b) the minimization of interference with peoples' activities; and

(c) the improvement of the perceived quality of acoustic environments.

Some of this effort has involved many countries in numerous research programs, that have resulted in measures of peoples' responses to noise. There are now probably hundreds of such measures (it has been reported that there are about 100 noise indices alone), but there seems to be fair agreement between many of them (2).

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* WHO defines 'guide' as a recommended (noise) limit, at or below which an undesirable effect does not appear (8).

3.2 Some of the major noise measures in current use are reviewed briefly below. The review is in two parts; part 1 covers measures dealing generally with activity interference and part 2 covers measures dealing with specific noise sources.

3.2.1 Part 1

(i) Sleep

Noise can adversely affect sleep by:

(a) causing difficulty in falling to sleep;

(b) shortening one or more stages of sleep;

(c) causing awakening, and

(d) causing autonomous arousal.

While there is no scale or index relating noise exposure to the extent of sleep disturbance, there are some provisional criteria. These are indoor night-time equivalent noise levels (L_{eq}) of:

$\leqslant$ 35 dB(A) for no sleep disturbance at all (this level seems to be particularly important for falling to sleep);

$\leqslant$ 45 dB(A) for maintaining the normal durations of the 'light' stages of sleep; and

$\leqslant$ 50 dB(A) for maintaining the normal durations of the 'deep' stages of sleep.

In addition, the average maximum level should not exceed these levels by more than 10 dB(A). Similar values are contained, or implied in a number of Australian guidelines and standards.

(ii) Speech Interference

A large body of data exists on speech interference caused by noise; the interference is given by the percentage of simple phrases understood (their intelligibility), in a given noise environment. Three acoustic measures have been developed to determine speech intelligibility:

Articulation Index, A.1. (which is really a 'scale'),

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Speech Interference Level SIL (also a 'scale') and

Equivalent Sound Level, in dB(A).

The Articulation Index is a complex measure, and runs from 0 (zero intelligibility) to 1.0 (100% intelligibility).*

The Speech Interference Level is a much simpler measure and is expressed as the level of vocal effort required, depending on the distance between the source (another person, TV, radio etc.) and the listener.

The Equivalent Sound Level in dB(A) usually gives an adequate indication of speech interference for day-to-day activities. Normal conversation outdoors at a distance of one metre can be achieved with a noise level of less than 65 dB(A) L_{eq}. Indoors, the same intelligibility can only be achieved with a noise level 15 dB(A) L_{eq} lower. For medical consultations, tutorials and the like, where reduced conversation levels are used, a further reduction of 5 to 10 dB(A) lower would be required.

Again, similar values are implied in a number of Australian guidelines and standards.

(iii) Relaxation

There are no scales or indices directly relating the effects of noise to rest and relaxation, but again many values are implied in Australian standards and guidelines. Large (6) has suggested criteria for the sick and convalescent of 45 dB(A) L_{eq} for daytime, and 5 to 10 dB(A) lower for night-time.

(iv) Task Interference

Task interference has been mainly examined under laboratory conditions, and the tentative conclusion is that there does not seem to be any significant interference with non-auditory tasks, if the noise is steady and does not exceed 90 dB(A) L_{eq}. (Of course, this obviously can not be regarded as a

* To compute an A1, a signal to noise ratio has to be determined in each of 20 especially selected frequency bands, and then converted to give its fractional contribution to the A1; these contributions are then summed to give the overall A1.

criterion for working conditions; some noise level guidelines for various activities are given in the Standards Association of Australia publication AS 2107).

(v) Health Damage

(a) Autonomous Arousal. A number of studies have been undertaken in this area, for example on cardiovascular, respiratory and hormonal responses. However, because the results have generally been obtained from very limited surveys, no scales, indices or criteria presently exist.

(b) Hearing Damage. A great deal of work has been done over the past thirty years to quantify the relationship between noise exposure and hearing damage. An important hypothesis arising from this work was the "equal energy principle", ie, equal amounts of noise energy cause equal amounts of hearing loss. This means that a doubling of exposure time is only acceptable if the noise level is reduced by 3 dB, and this forms the basis for the hearing conservation criteria used in a number of countries, including Australia. Here, the standard used for occupational situations in all States is a maximum of 90 dB(A) L_{eq} for an 8 hour working day.

The United States Environmental Protection Agency has issued goals for hearing conservation that take into account the voluntary and involuntary exposures to noise 24 hours per day, 365 days per year. It is claimed that these levels would protect the entire population from receiving more than a 5 dB noise induced hearing loss. The maximum equivalent noise levels are:

70 dB(A) for 8 hours per day in an occupational situation; this may be increased to 75 dB(A) provided the exposure over the remaining 16 hours is $\not>$ 60 dB(A).

71.4 dB(A) for 24 hours per day exposure to intermittent noise; and

66.4 dB(A) for 24 hours per day exposure to continuous noise.

(vi) General Annoyance

Noise can annoy people in a general sense because of its various interference effects, several of which may be present at once. A scale that is receiving increasing support as a noise measure (for hearing damage as well as annoyance and disturbance) is the Equivalent Sound Level, L_{eq}, quoted in previous paragraphs. This scale represents the level of constant sound which, in a given situation and time period, has the same sound energy as does a time-varying sound. It is usual to give this measure in dB(A). The United States Environmental Protection Agency has published some goals, based on L_{eq} measures, to minimize noise annoyance generally. Two of these goals are given as day-night average sound levels (L_{dn}); this value is the 24 hour A-weighted equivalent sound level, with a 10 decibel penalty for night-time, defined as 2200 to 0700 hours. (Because of this penalty, L_{dn} may be regarded as an index). The goals are:

for outdoors in residential and other 'quiet' areas,	$L_{dn} \leqslant 55$ dB(A)
other outdoor areas, where people spend limited amounts of time,	$L_{eq(24)} \leqslant 55$ dB(A)
for indoors, in residential areas,	$L_{dn} \leqslant 45$ dB(A)
other indoor areas	$L_{eq(24)} \leqslant 45$ dB(A)

3.2.2 Part 2

(i) Traffic Noise

In Australia, there are no standards for overall traffic noise, only for noise from individual, new and in-service motor vehicles (3) (4). In the United Kingdom, an L_{10} (18 hour) index is used, mainly as the assessment measure in The Noise Insulation Regulations, 1973. This index gives a measure of the level of noise exceeded for 10 per-cent of the time, as determined by the traffic noise peaks, between 0600 and 2400 hours. The index criterion at which compensation becomes payable under The Noise Insulation Regulations of the Land Compensation Act 1973, is 68 dB(A).

(ii) Air Traffic

In Australia and the USA, the index used to assess and predict the noise effects from commercial aircraft is the Noise Exposure Forecast (NEF). The scale used in this index is the Effective Perceived Noise Level, L_{EPN} which takes into account people's perception of the duration of the noisiest part of an aircraft fly-over and of any tones in the noise spectrum, as well their perception of the overall level. The other factor considered in this index is the number of aircraft movements during the day and night, for each flight path. The total NEF at a given position on the ground is determined by the energy summation of all individual NEF values for each class of aircraft and each flight path.

In the United Kingdom, the index used is the Noise and Number Index (NNI). The scale used in this index is the Perceived Noise Level (the predecessor to the Effective Perceived Noise Level, that does not allow for the accurate prediction of the noise's duration or tonal effects). The other factor considered in this index is also the number of aircraft exceeding 80 perceived noise decibels from 0600 to 1800 hours.

(iii) Noise from Fixed Installations

In Australia various standards, or proposed standards, exist for assessing and predicting noise from fixed installations, such as industry, as received in residential areas; e.g., Victoria's draft Policy "Control of Noise from Commercial, Industrial or Trade Premises within the Melbourne Metropolitan Area", proposed under the Environment Protection Act, and Western Australia's "Noise Abatement (Annoyance of Residents) Regulations 1974", made under the Noise Abatement Act. There are also a number of guidelines, such as those given in Australian Standard 1055, "Noise Assessment in Residential Areas".

The annoying characteristics of noise from industrial premises include its loudness, its particular spectral shape, its time(s) of occurrence and its duration. The standards and guidelines in use seek to take these factors into account, as well as the type of residential neighbourhood in which the noise is heard.

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4. The Need for Multiple Noise Measures

The need to have so many noise measures has been questioned. For example, von Gierke (9) believes that it "is not enough to have measures which show how one type of noise interferes with one type of human activity" and that there should be "one yardstick to measure the integrated effect of environmental noise on human health and well-being". Based on von Gierke's work, the United States Environmental Protection Agency issued the goals given in paragraphs 3 (1)(v) and 3(1)(vi) above. This approach assumes that exposure to equal L_{dn} values from different noise sources, or from a combination of noise sources, causes equal annoyance responses. Further, the L_{dn} assumes that these annoyance responses can be adequately described by the 'percentage of people highly annoyed'.

In England, a Working Party of The Noise Advisory Council also reported that the diversity of noise measures was "seen to have limitations" (7), and suggested that a solution might be to develop a single noise measure from which separate noise indices for daytime and night-time could be derived. (As an alternative, it suggested the development of separate noise scales for various noise sources). The Working Party concluded that one scale, the Equivalent Sound Level, should be adopted "for the present" as the scale to be applied to all noise sources; it also concluded that, for practical reasons, it would be necessary to continue to use existing noise indices "for the time being".

As mentioned earlier, noise measures need to take into account effects on health, effects on activities and effects on the quality of the acoustic environment. At this stage, it seems unlikely that one single noise measure could account for all of these factors. It should be noted that, even the U.S. EPA have given two measures in their goals - L_{dn} and L_{eq}, although both are closely related. It should also be noted that the British Noise Advisory Council only recommended the adoption of L_{eq} as a 'universal' noise scale, and stated that the present, separate noise indices should remain. Large (6) has pointed out that, while it might be scientifically and administratively desirable to have an unique noise measure for all sources and circumstances, the scientific data presently available are insufficient to completely specify the form such a measure should take. He stated that, although studies for given noise sources had suggested that an index using the L_{eq} scale explained peoples' reactions just as well as any other common index, equal L_{eq} values of different noises *did not* evoke equal annoyance reactions. This is at least partly because different situations can cause significantly different annoyance reactions.

Hence, for the time being at least, it seems desirable for the multiple noise measure situation to continue.

5. The Future

The area of noise abatement which has not received very much attention so far is the overall improvement of the perceived quality of acoustic environments. This is not only a matter of eliminating the adverse effects noise has on peoples' health and activities, but of creating an acoustic environment that people will find *enjoyable,* i.e. one in which people hear sounds that they like. Large (6) sees this requiring a different approach from that used to derive the health and activity interference measures, with noise environments being ranked subjectively for their relative quality. He goes on to stress that the setting of criteria in such a situation will not be just a matter of quantifying an 'acceptable' level and making it a standard, but of implementing *practical* improvements to acoustic environments, in terms of current technical and economic constraints. As these latter factors change, so should the standards for acoustical environments.

6. Conclusions

While indices incorporating the L_{eq} dB(A) based scale are becoming more widely used and are gaining international recognition, recent studies indicate that a unique noise measure is not yet available. This is at least partly because peoples' reactions to noise are strongly influenced by other acoustical and non-acoustical factors, not included in the measure, which can vary from situation to situation.

More work on peoples' reactions to their *overall* acoustic environment, as well as on peoples' reactions to specific noise sources, is needed.

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TABLE 1*

Scale	Scale Characteristics	Example
Nominal	Numbers assigned result in labels, indicating a class or category	Numbering school grades, team players, etc.
Ordinal	Numbers assigned result in a rank order.	Pleasantness of odours. Hardness of minerals. Quality of products, etc.
Interval	Numbers assigned result in empirically equal distances between them; the zero point set for convenience or by convention.	Temperature Energy Calendar
Ratio	Numbers assigned result in empirically equal ratios among them; the zero point is absolute, i.e., neither more or less than none of the property represented by the scale.	Numerosity Length, Weight, Density, Resistance etc. Loudness Pitch

* after Stevens, S.S. Handbook of Experimental Psychology, John Wiley & Sons, Inc., 1951.

Traffic Noise Prediction, and Traffic Noise Levels in Melbourne: Summary of a paper given on Saturday, September 22nd, 1979 at the Annual Conference of the Australian Acoustical Society.

J.D. Modra, Environment Protection Authority, Victoria

1. Introduction

The Report of the Committee of Inquiry into Town Planning Compensation attracted much attention when it was presented to the Premier of Victoria in March 1978. This report, generally known as the Gobbo report after the Chairman of the Committee, recommended that "Compensation should be payable for reduction in value caused by reason of injurious affection to property due to noise emanating from the use of a freeway or railway or any road widening. This would include the addition of a carriageway within an existing road reserve". [1]

A Bill for the Public Works and Planning Compensation Act 1978 was tabled in the Spring Session of Parliament 1978 [2]. This arose from the Government's acceptance in principle of the Gobbo Report. The traffic noise compensation provisions of this Bill (which has not yet become law) were based on provisions under the U.K. Land Compensation Act 1973. Both the Victorian Bill and the U.K. Legislation use the L_{10} (18 hour) scale for the assessment of traffic noise. In the Bill, compensation is to be payable when the level of noise is 68 dB(A) L_{10} (18 hour), or more. This is one of three conditions for eligibility under the U.K. Legislation. Naturally, the tabling of this Bill in the Victorian Parliament caused widespread public debate. At the closing of the Spring session of Parliament 1978 the Bill lapsed. At the time of writing, the Ministry for Planning was reviewing the Bill in the light of comment received, with a view to re-introducing it at a later date.

Since November 1976 it has been Environment Protection Authority policy that "... when considering the impact on residential areas of noise from freeways, due consideration must be given to the standards specified in the British Noise Insulation Regulations 1975, in the absence of relevant Victorian legislation". The Authority has published a booklet which explains the provisions of these Regulations, which were made for the purposes of the U.K. Land Compensation Act 1973 [3].

This paper, therefore, has two main aims: to draw attention to the implications of adopting here in Victoria the traffic noise prediction method and eligibility criterion from the U.K. Legislation; and to briefly describe the noise climate here in Melbourne.

It should be noted that the Authority is responsible for administering the Environment Protection (Motor Car Noise) Regulations 1976 and the Environment Protection (Truck, Omnibus and Motor Cycle Noise) Regulations 1978. These Regulations specify maximum permissible noise levels for in-service motor vehicles. Also, officers of the Authority are actively involved in setting revised maximum permissible noise levels for new (i.e. unsold) vehicles through the V.E.N.S.A.C. committee of the Australian Environment Council. This work is the Authority's main contribution to reduced road traffic noise levels.

2. The Implications of Adopting the U.K. Traffic Noise Prediction Method and Eligibility Criterion here in Victoria

If the U.K. scheme is to be "imported" into Australia, it is important that people realise exactly what it is they are importing.

The first Noise Insulation Regulations came into effect in 1973 and were made for the purposes of Section 20 of the U.K. Land Compensation Act 1973. The L_{10} (18 hour) level at one metre from the facade of a particular building could either be predicted or measured, although prediction was the preferred method and was to be used unless considered "inappropriate in the circumstances of the case". The document "New Housing and Road Traffic Noise" (Design Bulletin 26 H.M.S.O. 1972) was to be used for traffic noise prediction.

Amended regulations were introduced in 1975. The Noise Insulation Regulations 1975 (Statutory Instrument No. 1763) include an improved noise prediction method, clarify entitlement to noise insulation and add some flexibility to the specification for insulation work. The publication "Calculation of Road Traffic Noise" (HMSO 1975) is to be used when determining noise levels. This document specifies a prediction method and a measurement method. The prediction method is the preferred calculation technique and is intended to apply to both free and non-free flowing traffic.

The salient features of this legislation are;

1. the L_{10} (18 hour) scale is used,
2. prediction is the preferred method for determining noise levels,
3. one of the three criteria for eligibility for noise insulation is that the traffic noise level (within 15 years of opening a new road or widening an existing one) must be 68 dB(A) L_{10} (18 hour), or more.

The following questions therefore need to be asked;

1. Does the L_{10} (18 hour) scale adequately describe the community's response to traffic noise?

2. Does the empirically derived prediction method work with sufficient accuracy?

3. Is the 68 dB(A) eligibility criterion a reasonable one?

The answers for the U.K. appear to be;

1. Estimates of the correlation between L_{10} (18 hour) values and median community annoyance scores vary from .51 [4] to .70 [7]. The L_{10} (18 hour) scale does not predict annoyance caused by non-free flowing traffic as well as annoyance caused by free flowing traffic [5]. Because of its very nature the scale is unable to include the effect of vehicles passing a residence between midnight and 6 a.m. These problems are not overcome simply by using L_{10} (24 hour) or L_{eq} (24 hour). Various "extended" units have been developed which improve the correlation with annoyance. [5, 6, 7]

2. Yes, the prediction method is sufficiently accurate [8]. (i.e. there is good agreement between predicted and measured noise levels).

3. Evaluation of the 68 dB(A) eligibility criterion depends on what level of community dissatisfaction is considered acceptable. Annoyance surveys in the U.K. indicate that 68 dB(A) corresponds to a score of just over 4 on an annoyance scale ranging from 1 to 7. [4]. A score of 1 represents "definitely satisfactory" and a score of 7 represents "definitely unsatisfactory". (The annoyance scores mentioned here are median community responses not individual responses). The politicians in the U.K. recognize that the 68 dB(A) level is a trade-off. [9].

   (It should be noted that a Working Party has been set up in the U.K. to review the 1975 Noise Insulation Regulations. The first meeting was held in March 1979).

The answers for Australia appear to be;

1. The adequacy of the L_{10} (18 hour) scale has been investigated here in Australia but the investigation was on a smaller scale than those carried out in the U.K. and the results were inconclusive. [10].

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2. The U.K. prediction method is probably sufficiently accurate for Australian conditions although more work needs to be done. [11, 12, 13].

3. The 68 dB(A) eligibility criterion has been investigated (indirectly) here in Australia but the results are inconclusive and there is a need for more work to be done. However it does appear that "L_{10} (18 hour) free field levels of less than about 60 dB(A) would generally be regarded as acceptable" [10].

3. The Magnitude of the Traffic Noise Problem in Melbourne

The Country Roads Board publish an Annual Traffic Census for Victoria, copies of which are available to the public for a nominal charge. Traffic flow data for Greater Melbourne can be aggregated from data in the sections of the Census devoted to Highways, the Metropolitan Division and the Dandenong Division.

Using the data in the 1978 Census for all 332 sites in Greater Melbourne, and the traffic noise prediction method currently used in the U.K., it is possible to calculate likely traffic noise levels at these sites. The assumptions used in these calculations were;

- the mean vehicle speed was 60 km/hour (except for freeways where 100 km/hour was used).
- house facades were located 10 metres from the edge of the nearside carriageway.
- at the sites concerned there were no facades on the opposite side of the road to further increase the noise level.
- at all survey sites the roads were level.

The actual percentage of heavy vehicles in the traffic flow can be calculated from the data given in the Census.

The results are displayed in Figure 1. At 85% of sites the noise level probably exceeded 68 dB(A) L_{10} (18 hour). It must be emphasized that the Annual Traffic Census contains traffic flow data for a sample of major thoroughfares. The noise levels displayed in Figure 1 should therefore be regarded as typical for noisy roads in Melbourne rather than for Melbourne roads in general.

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4. Conclusions

1. If the U.K. noise insulation Legislation is "imported" into Australia it should be understood that;

   (a) there are now better scales available than the L_{10} (18 hour) scale.

   (b) the U.K. prediction method may need some modification for Australian conditions.

   (c) the 68 dB(A) eligibility criterion used in the U.K. appears to be a trade-off between economic and environmental considerations. From a strictly environmental point of view the level should be below 60 dB(A) L_{10} (18 hour).

   It is the author's view, however, that these problems are not so serious that it would be irresponsible to introduce Legislation here based on the U.K. Regulations. Nevertheless it would be essential to examine very closely the recommendations of the U.K. Working Party currently reviewing the 1975 Noise Insulation Regulations, and to continue the research effort here in Australia to establish what refinements, if any, are needed to adapt the U.K. Legislation to Australian conditions.

2. There are many roads in Melbourne where the level of traffic noise exceeds 68 dB(A) L_{10} (18 hour). (Of course it must be realised that eligibility for insulation in the U.K. is restricted to houses near new or altered roads. A similar eligibility clause is proposed for Victoria).

5. Acknowledgements

I would like to acknowledge the assistance of David Meagher of the E.P.A. Noise Control Branch who performed the calculations necessary to construct Figure 1.

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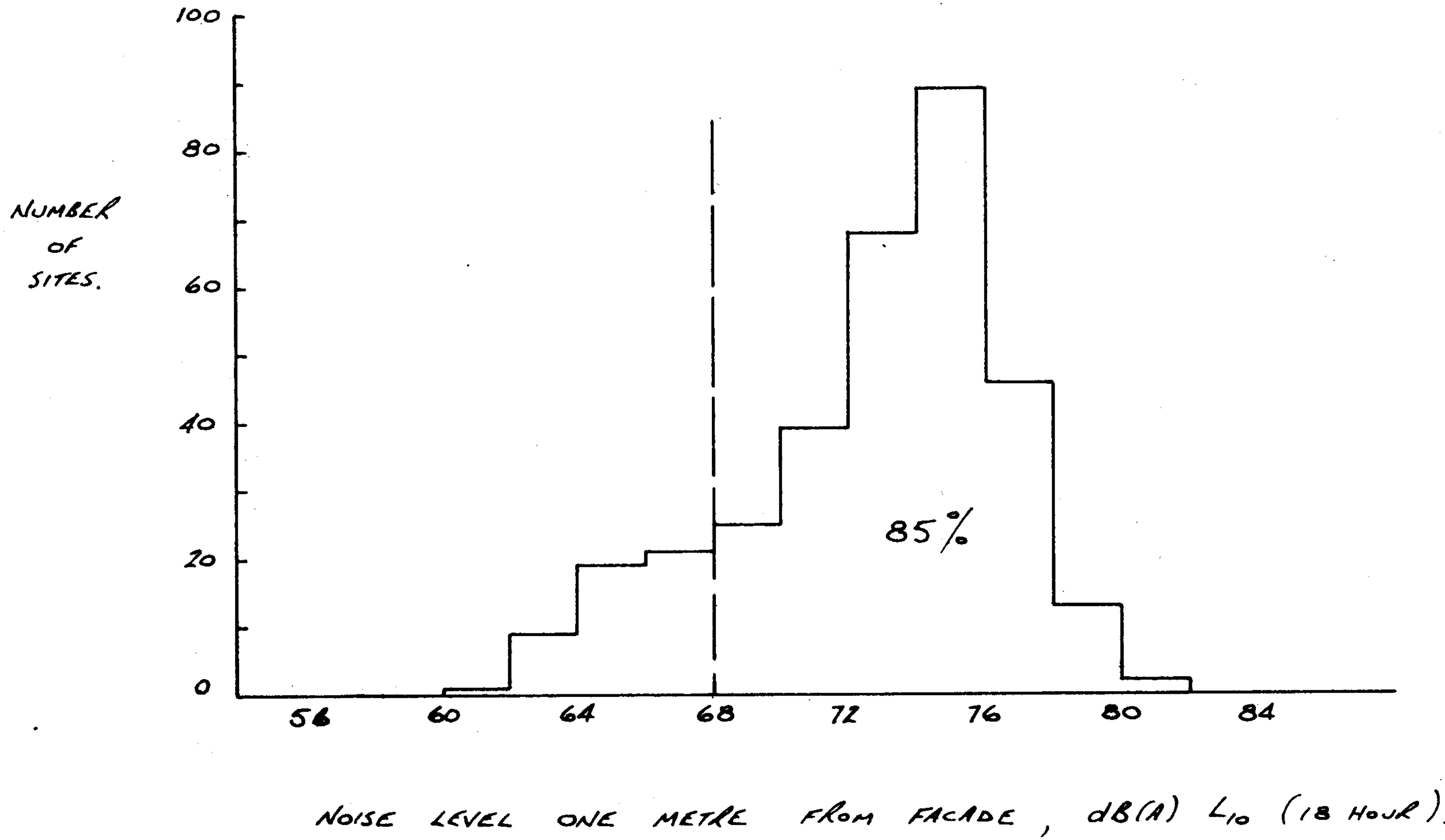
PREDICTED NOISE LEVELS FOR 332 SITES ON BUSY THOROUGHFARES IN MELBOURNE.



J.D.M.

PRESENT AND LIKELY FUTURE AIRCRAFT NOISE LEVELS IN THE COMMUNITY

by B.G. Harris, Department of Transport
Airways Operations Division.

Introduction

In the late 1960s and early 70s, community reaction to aircraft noise led initially to the introduction of noise limits and monitoring at major airports, followed by intensified control and the adoption of complex international Standards for the noise certification of aircraft as they are manufactured (Annex 16 to the Convention on International Civil Aviation). As a result of these actions and because of advances in engine and acoustic technology, substantial noise reductions have been achieved. Without the combination of improved technology and the enforcement of noise control the airport community noise environment would have reached levels far in excess of those prevailing today. Noise standards have now been defined for subsonic transport aircraft to a degree of stringency allowed by available technology sufficient to ensure that the airport community noise environment does not in general deteriorate. Additionally, with the continued introduction of new types of aircraft into the airline fleets substantial improvements in airport noise environments can be expected.

This paper reviews the extent of jet aircraft noise level reductions over the past twenty years and provides some indication of the likely extent of future reductions.

Fleet Replacement by New Technology Aircraft

It is certain that, in the first half of the next decade, one or more types of the 1970/80 technology aircraft will be introduced into Australian domestic airlines service to replace the 1960s technology aircraft. This fleet replacement will provide a gradual but continuing improvement in the noise levels around airports (as shown in Figure 1) over the next 15 years. The engines of these new aircraft are, or will be, derivatives of the existing high by-pass ratio turbofan engines of 1970s technology. However, the discussion later in this paper on engine and airframe noise indicates that, following completion of the fleet replacement of noisy types, no further substantial noise reductions can be anticipated.

Examples of commercial jet aircraft satisfying various mission requirements are shown in Figure 2. Also listed are some of the new generation aircraft expected to enter the short and medium range market during the 1980s. A comparison of the area exposed to noise for these aircraft within a given range class provides an estimate of the noise benefits for each operation that has occurred (and in some cases is expected to occur) with the introduction of advanced technology aircraft. Contour areas of 100 EPNdB are compared in Figure 3 to demonstrate these noise reductions. In the short and medium range aircraft categories, which represent the major portion of the current commercial airline fleet, only a limited number of aircraft incorporate the engine technology of the 1970s. It is expected that most of the replacement fleet for this market will incorporate engines derived from 1970s versions.

As shown by Figure 2, airport communities have experienced reductions in the 100 EPNdB contour area of the order of 80% during single event take-off and approach operations with the 1970s technology long range aircraft relative to the original long range commercial jets. Noise impact area reductions provided by current technology medium range aircraft, relative to the early jets, are in the order of 90 per cent. New type aircraft expected to enter the short range market will provide noise area reductions of the order of 60 per cent relative to the 1960 technology aircraft currently operating.

In addition to some of the existing types, the new types of aircraft forecast to be in operation in Australia by the 1990s are Advanced Boeing 747 and McDonnel-Douglas DC10 types, one or more of the Airbus A300, A310 or Boeing 757 or 767 types. A study of the effect of introduction of these types of aircraft on the extent of areas exposed to aircraft noise has been carried out by the writer for Sydney's Kingsford-Smith Airport. The results of this study, in terms of the likely reductions in numbers of people annoyed by aircraft noise in the period between now and the year 2000, are shown in Figure 4 which indicates that about 50% of people now annoyed will be relieved by the year 2000. A similar study carried out by the Federal Aviation Agency in the United States for two major airports produced similar results (see Fig. 5).

The noise exposure reductions shown in these figures are brought about by the markedly reduced noise levels of the 1970s/1980s technology aircraft as compared with earlier technology types and are despite an anticipated traffic growth of heavy aircraft in the order of 70% (at Sydney) over the next twenty years.

Turbofan Engine Noise - Future Technical Possibility of Noise Reduction

From the days of the early straight turbo-jet engines the quest for higher and higher operating efficiencies has led to the introduction of higher and higher by-pass ratio engines. The prime noise sources in engines are the jet, turbo-machinery and internal (combustor) noise sources. In general, the externally generated noise (i.e. that from the jet) reduces with increasing by-pass ratio whereas the increased work demanded from the rotating machinery causes more internal noise with increasing by-pass ratio. It is only as a result of noise control technology and use of noise absorbent materials that the higher by-pass ratio engines have emerged significantly quieter than those of lower by-pass ratios.

Compared on a common basis of size and performance, engine noise has been progressively reduced over the past twenty years from the combined effects of increasing by-pass ratio and improved noise suppression technology. As shown in Fig. 6, there has been a downward trend in jet noise and an upward trend in machinery noise from the fan, compressor and turbine. The latter has been offset by improvements in suppression technology to produce an overall reducing trend over the by-pass ratio range 0 to 6. The overall impact of the change from low to high by-pass ratio engine cycles in the 1970s has been dramatic, but the slope of the noise curve is already very shallow in the by-pass ratio region of 4 to 6.

The evidence from measured aircraft noise data also supports this general trend, but varies, of course, according to power setting. In Fig. 7 curves representing the "technology best" over the years have been drawn as the lower limit of the data at the 3 international noise certification points.

Beyond a by-pass ratio of 6 it is difficult to make a quantitative assessment of the trends, because of the lack of technological evidence. However, the prospects, as seen today, for noise benefit from by-pass ratios beyond those of current engines is considered to be extremely small in the absence of any unforeseen developments in both engine and noise control technology (Ref 1).

Furthermore, total aircraft system considerations, assuming cruise speeds remain in the 0.8 to 0.9 Mach Number range, tend to indicate that the overall optimum falls in the range encompassed by current high by-pass ratio engines. These considerations include installed engine fuel consumption and the manageability of the increased engines sizes and weights that even higher by-pass ratio engines would demand.

Consequently, under the assumption that major noise improvements are unlikely to be afforded by further changes in engine cycle, manufacturers have examined individual noise components of the current generation of engines to see what prospects for noise reduction are possible. These components are indicated in Fig. 8, and are, for a high by-pass ratio turbofan engine :

(a) jet noise,

(b) fan noise,

(c) turbine noise,

(d) core noise, and

(e) compressor noise.

It can be seen in Figure 8 that each of these components are similar in level, so that to achieve any further overall reductions all sources must be attached. Conversely, if suppression attempts on one of the components induces increases in one or more of the other components, the overall noise level will rise. As well, it can also be seen that airframe noise is of similar magnitude, and so engine noise reductions of any magnitude could be offset by this component.

Exhaust (or jet) noise at high jet velocities is predominantly due to the mixing process. The lower jet velocities of the HBPR engines has significantly reduced this component, however, with this reduction the internal noise source known as core noise, or tailpipe noise, which is associated with the actual combustion process has become more important.

The principal noise sources from the fan, which now provides most of the propulsive energy, are interaction tones and buzzsaw noise. The mechanisms which produce interaction tones are well understood and in modern engines appropriate numbers of blades and rotor/stator blade spacings are selected to suppress the tones. Buzzsaw noise is likely to be a permanent feature associated with supersonic tip speed of the fan blades. Acoustic treatment of the fan casing has provided some suppression.

Other components of the turbo-machinery noise arise from the compressor and the turbine. The scope of reducing compressor source noise by optimizing the configuration is limited mechanically by the need to carry engine loads and services to and from the compressor interior and by the aerodynamic disturbances generated by the roots of the fan blading. Compressor noise has thus been contained by acoustic treatment of intakes and ducts and this is likely to continue.

As improvements in propulsive efficiency are sought through higher by-pass ratios, compression ratios and turbine temperatures, turbine noise will become more significant. Turbine noise is less well understood than compressor noise and the environment is more severe and more complex. Now that most other sources are better controlled, turbine noise will tend to become more dominant. Compressor design techniques for noise are at present applied to turbines and it is probable that reduction techniques in the turbine field will improve. Improved control through acoustic liners may be possible, but although the noise suppression effects are likely to be more favourable, the safety and temperature conditions to be met are more severe than in other parts of the power plant.

Briefly, all the research carried out by the three leading jet engine manufacturers in the western world has indicated that their current range of high by-pass ratio engines are substantially within the optimum region from acoustic and performance viewpoints, that no single noise source is now dominant, and that there is no likelihood of a major advance in noise technology in the near future. Any minor noise reductions could involve weight/drag, fuel or cost penalties.

Airframe Noise

As a consequence of the reduction of engine noise, aircraft noise levels in the approach operation are becoming significantly close (within 5-7 dB) to the values which would be obtained with the airframe alone. Figure 9 indicates the current situation. The principal sources of airframe noise are thought to be :

(a) Undercarriage

(b) Leading and trailing edge high lift devices

(c) Cavities

(d) Protuberances such as jacks, tracks, antennae, etc.

Airframe noise is not significant during take-off where engine noise is far greater than on approach.

Present indications are that during approach, powerplant and airframe noise are similar in magnitude, so that reduction in total approach noise requires an attack on both aspects; reducing one without the other requires a disproportionate effort.

Although some proposals have been made to enclose the landing gear in streamlined fairings, to apply acoustic treatment to leading and trailing edges of aerodynamic surfaces, and to close or modify cavities, such changes may involve degradation of the performance of devices, the functions of which are to generate left in critical phases of operation. In the short term no great reductions in airframe noise are likely.

Summary

All new aircraft are now required to meet stringent international noise certification limits set by the International Civil Aviation Organisation. The replacement by the airlines of aircraft powered by low by-pass ratio engines with noise certified aircraft powered by the quieter high by-pass ratio engines of existing technology, over the next twenty years will provide a gradual, substantial benefit to communities near major airports.

The large improvement in aircraft noise technology in this decade cannot be repeated by simply increasing engine by-pass ratios or the amounts of sound absorbent treatment installed. Every further decibel of improvement is going to get progressively more difficult and expensive to achieve. This, coupled with the knowledge that a lower aircraft noise barrier, due to airframe noise, exists at a noise level not greatly below that of the modern turbofan engined aircraft's approach noise level indicates that even by the year 2000, air transport will still create noise around airports, and the installation of noise reduction features in new homes located near airports will still be necessary.

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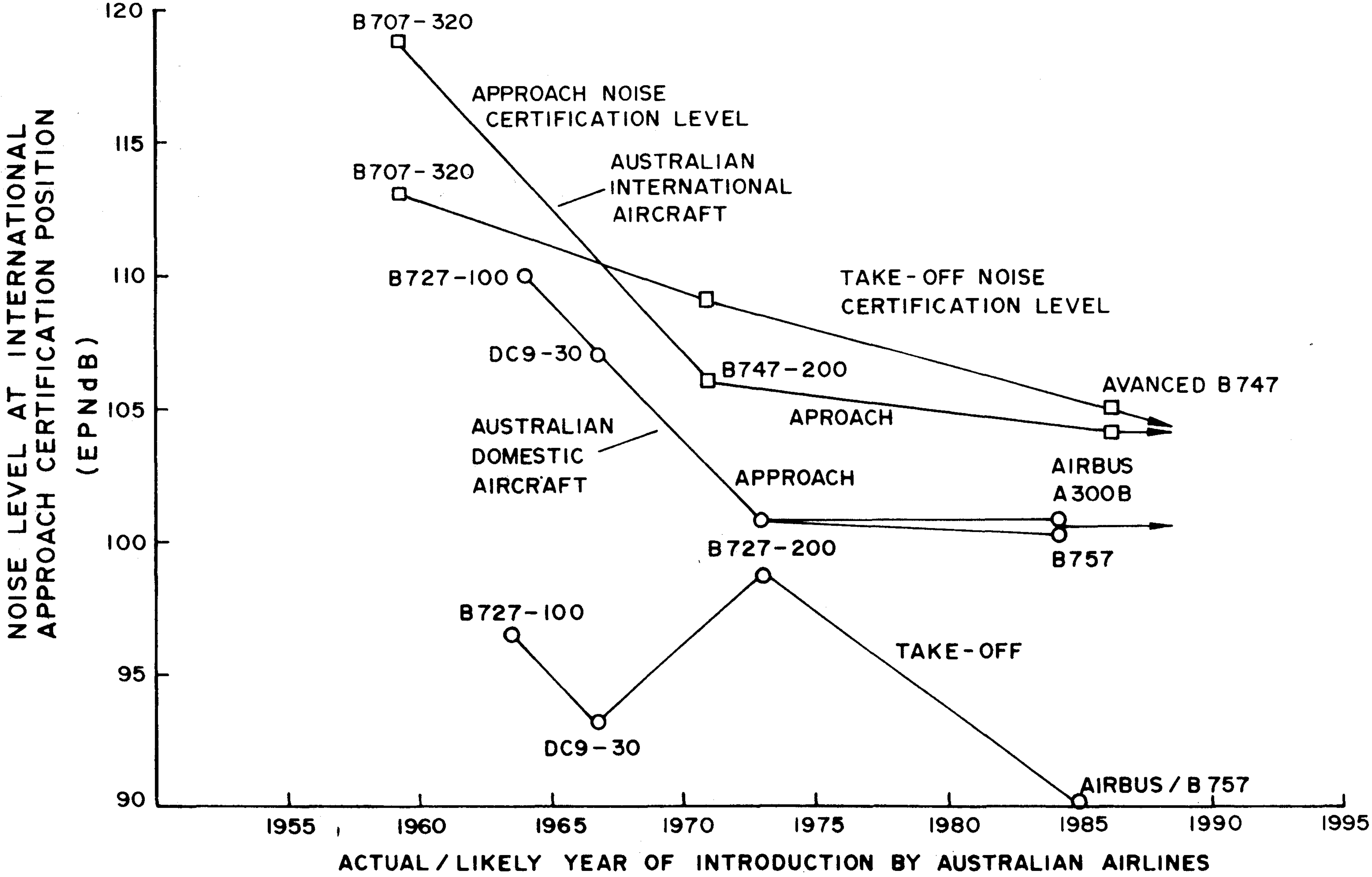


FIG. 1 NOISE REDUCTION TREND

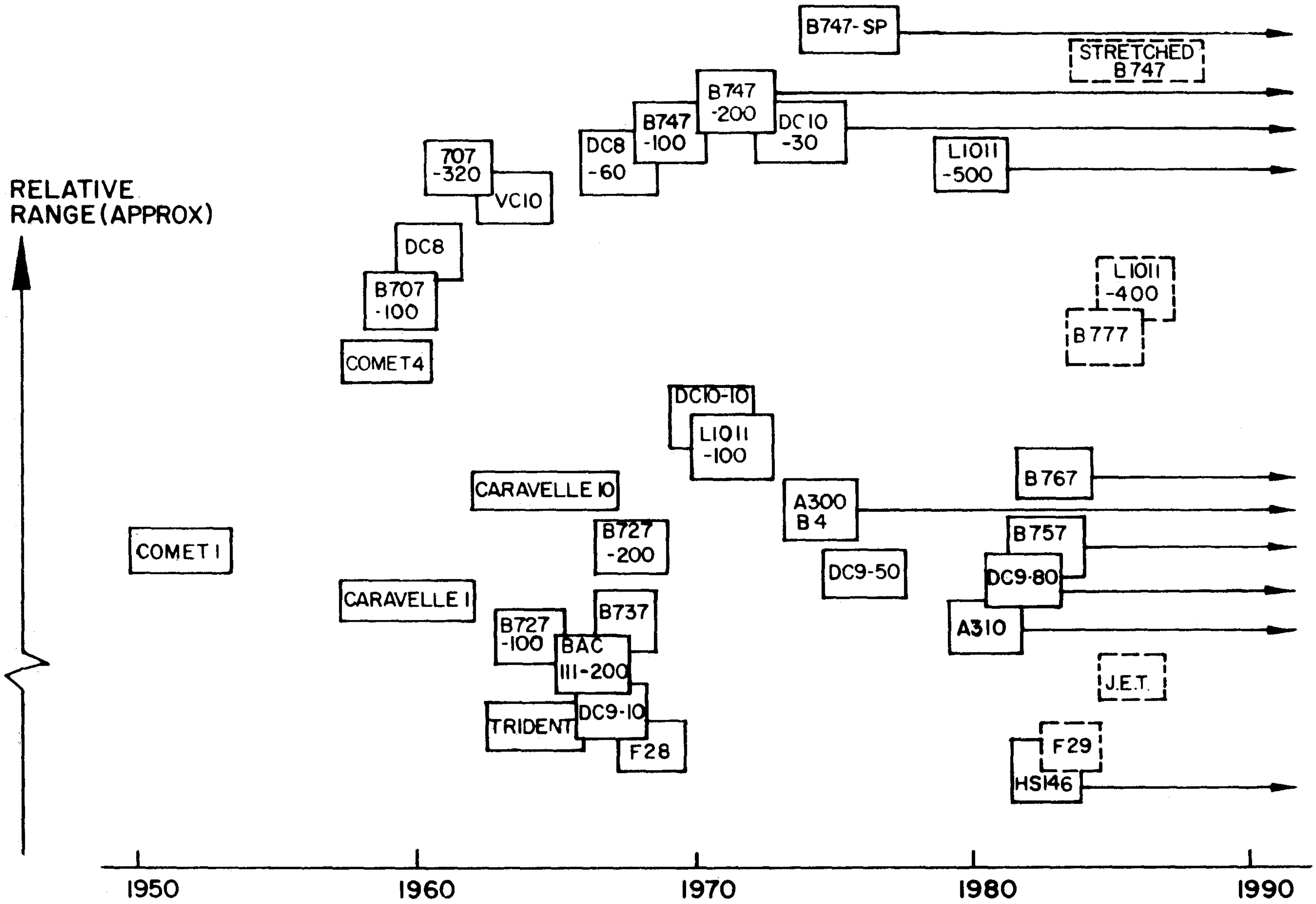


FIG.2. EVOLUTION OF COMMERCIAL JET AIRCRAFT

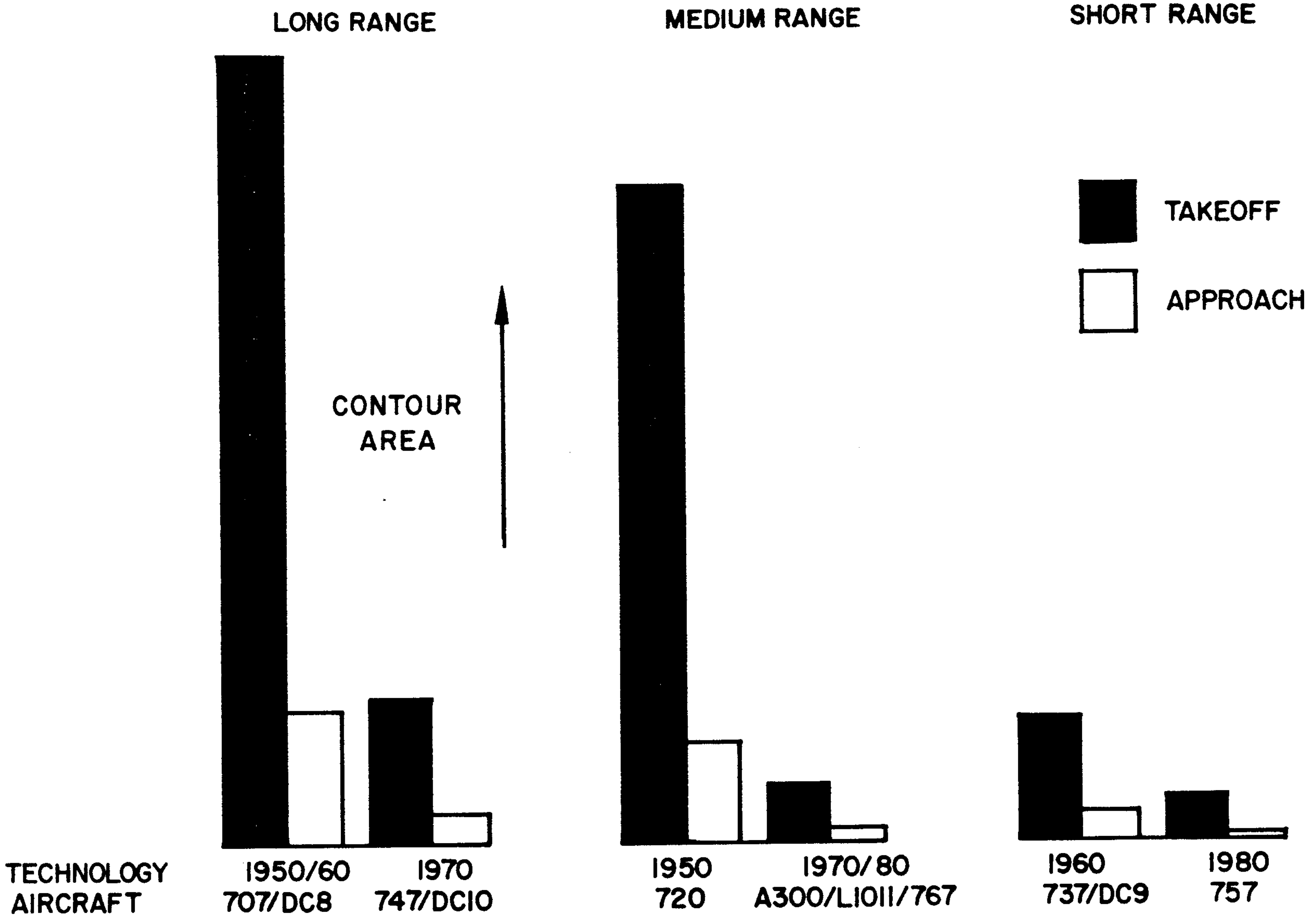


FIG.3. RELATIVE CHANGES IN 100 EPNL SINGLE EVENT NOISE CONTOUR AREAS FOR REPRESENTATIVE OPERATIONAL CONDITIONS.

SYDNEY (K/S) AIRPORT
FORECAST OF NUMBERS OF PEOPLE
ANNOYED BY AIRCRAFT NOISE: 1976-1995

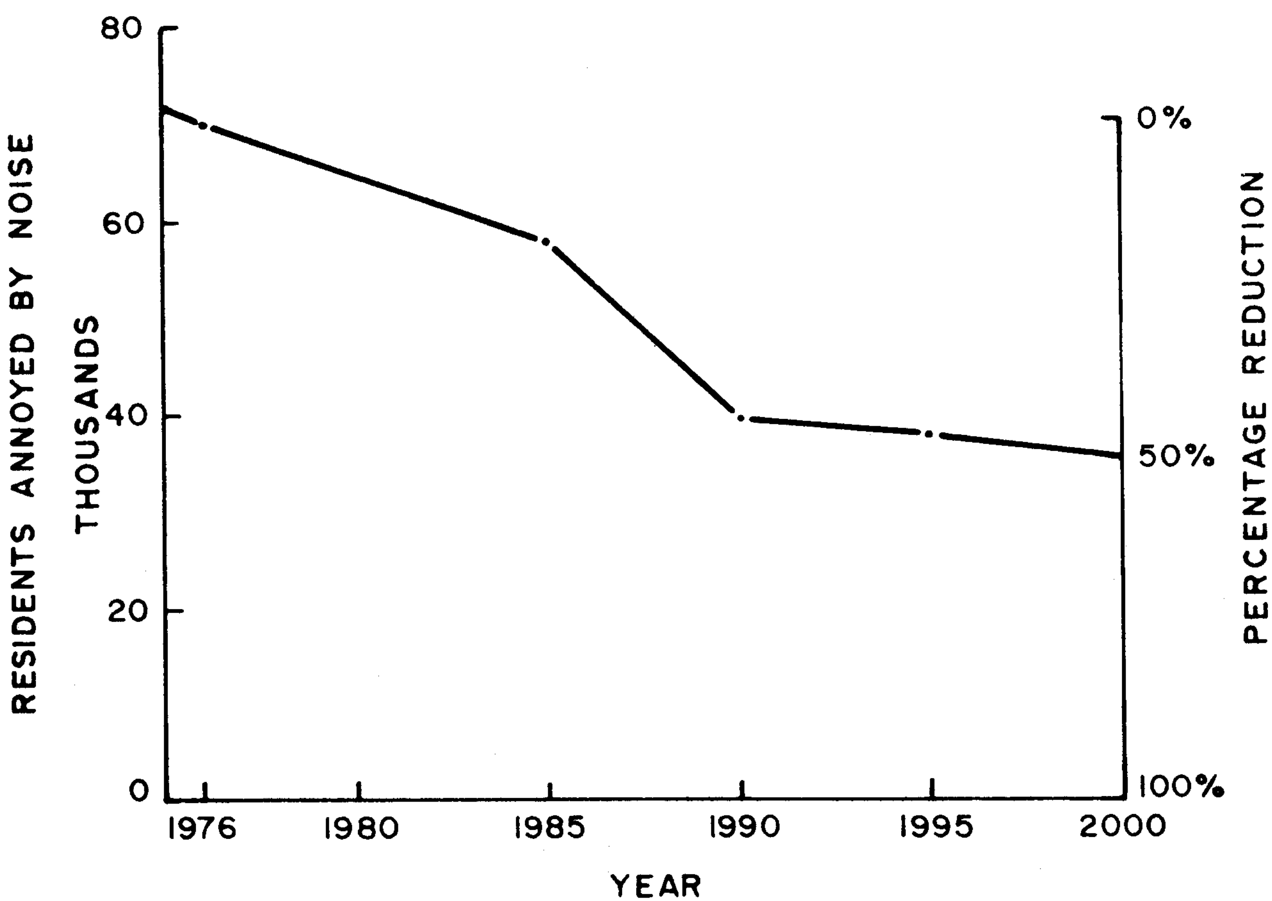


FIG. 4

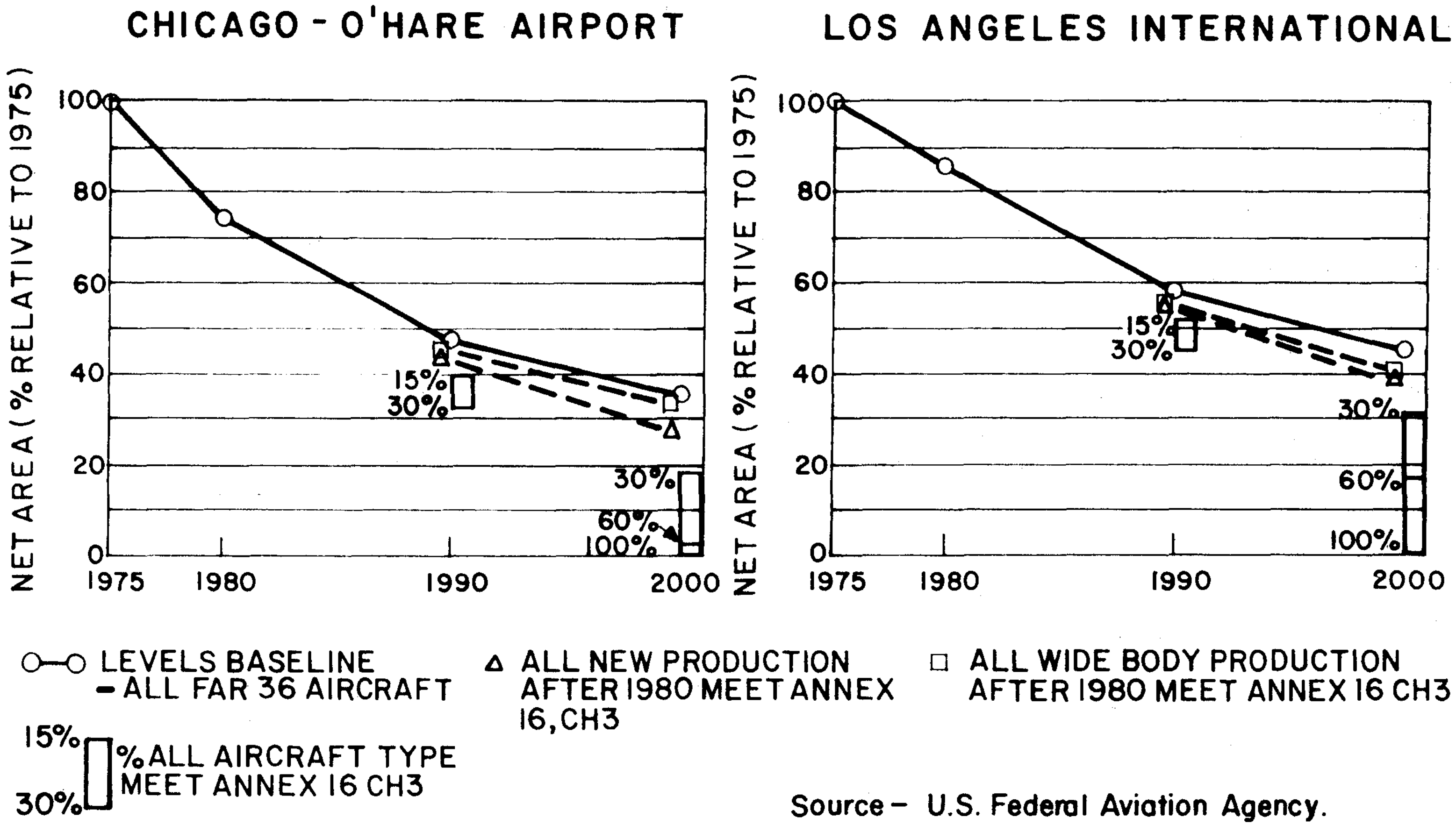
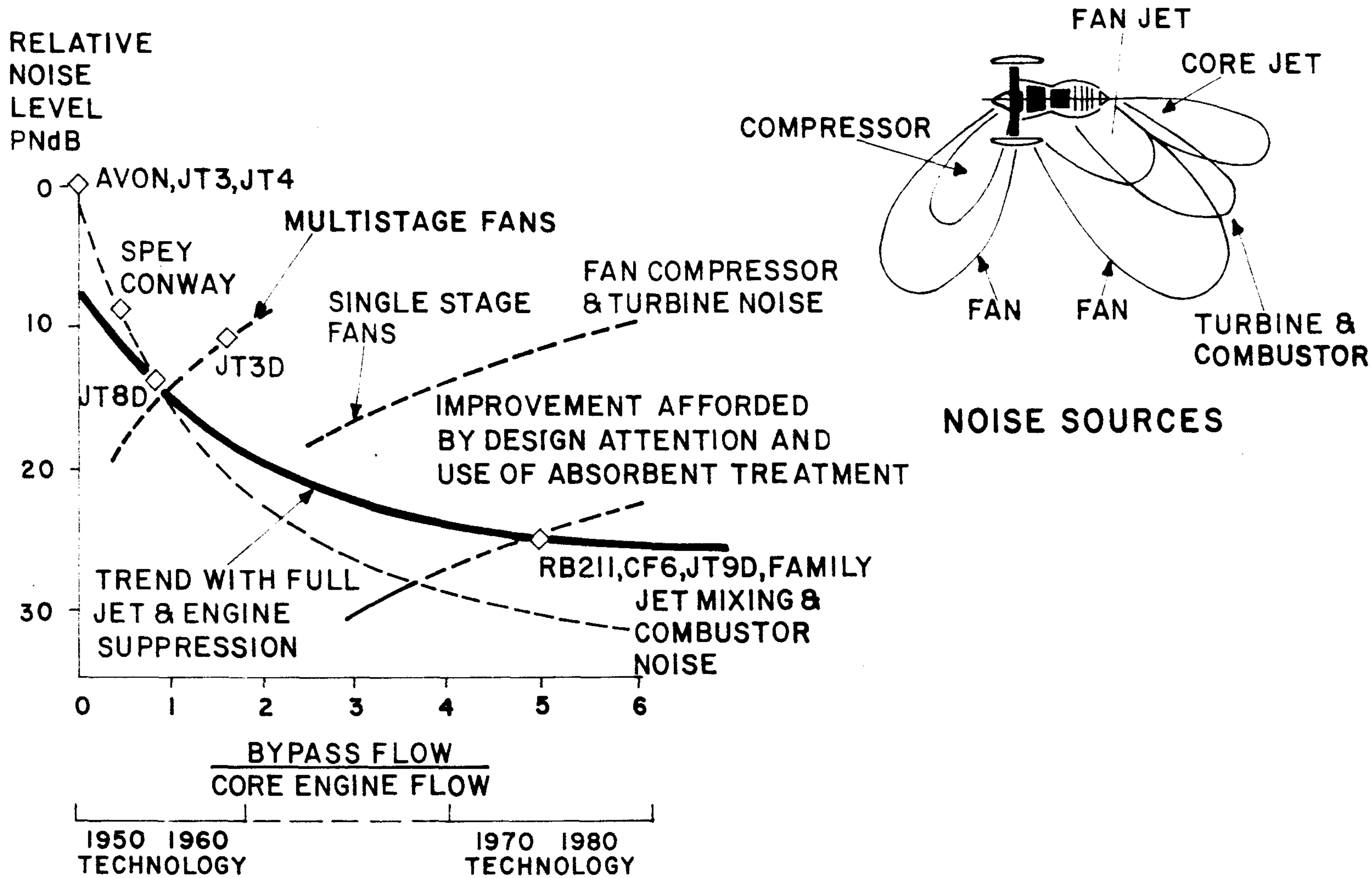


FIG.5 NET IMPACT AREA WITHIN NEF 40 FOR 2 MAJOR AIRPORTS



Source – Reference 1

FIG. 6 ENGINE NOISE SOURCES AND VARIATION WITH BY-PASS RATIO

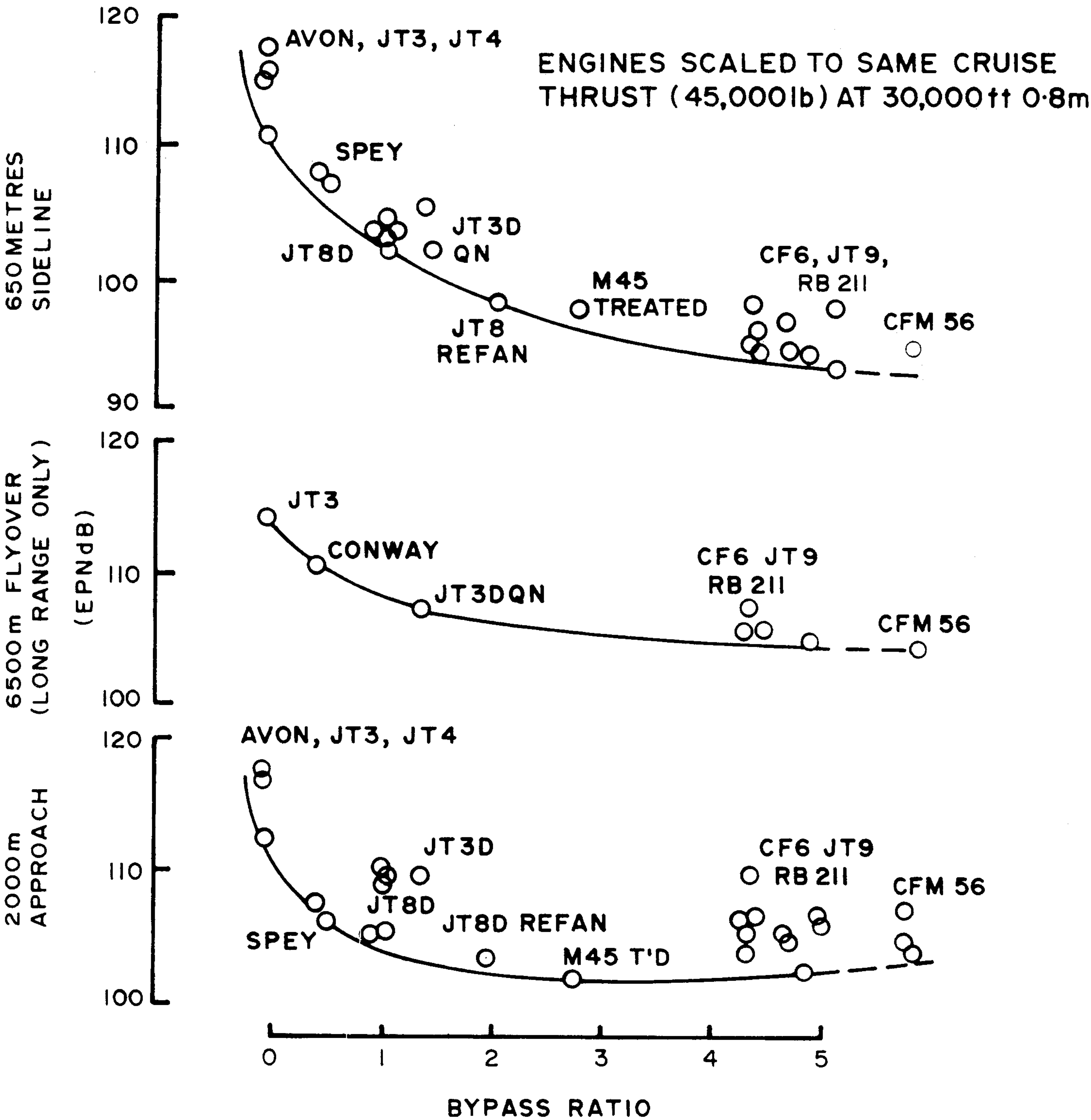


FIG. 7 CERTIFICATION NOISE LEVELS OF JET ENGINES–VARIATION WITH BY PASS RATIO

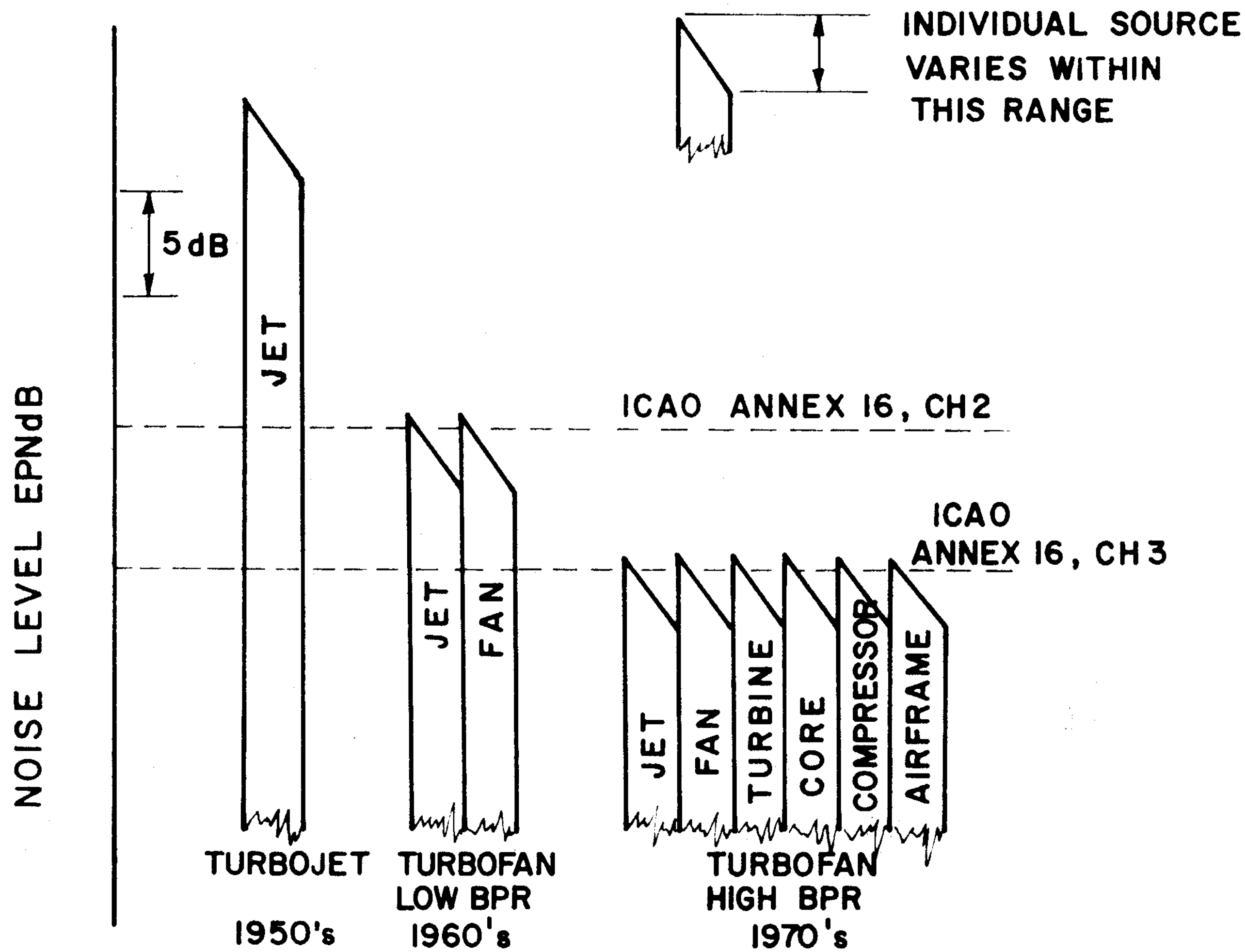


FIG. 8 RELATIVE IMPORTANCE OF NOISE SOURCES IN RELATION TO ANNEX 16, CHAPTERS 2 & 3. DIAGRAMMATIC REPRESENTATION.

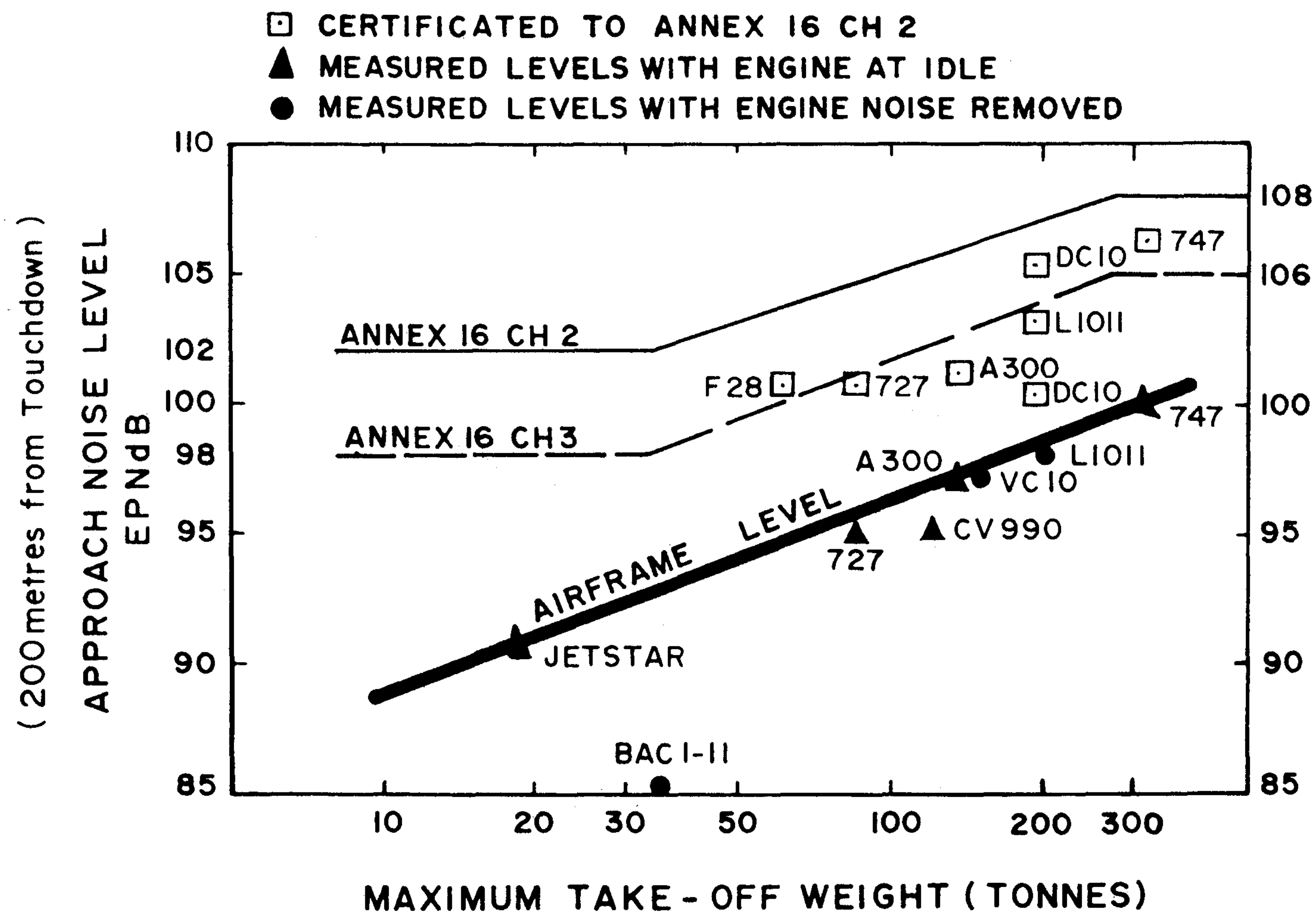


FIG. 9 AIRFRAME NOISE

Paper 4. Descriptors and Criteria of Performance of Building Partitions and Envelopes

P DUBOUT

CSIRO-Division of Building Research

Introduction

People expect certain acoustical performance characteristics of their buildings. Expressed in qualitative terms, in relation to dwellings the most important expectations include:

(a) a quiet place for sleeping;

(b) assurance that neighbours cannot hear what one does and says, and vice versa; and

(c) no interference with speech communication or listening to entertainment, and no distraction of thought, by noise from inside or outside.

As discussed in Paper 1, acousticians and legislators often proceed on the assumption that the achievement of subjective goals such as the above can be pre-judged in terms of the achievement of objectively quantifiable physical characteristics of the sound field in which a person, the ultimate judge, will be placed. Briefly, the argument runs as follows.

The relevant physical measures of the sound field include sound pressure level, spectrum, and time dependence of these. The target values of these physical measures, to satisfy one or more of the several criteria implicit in (a), (b) and (c) above, have to be determined by experiments in which human reactions to measured and analyzed sound fields are systematically studied. Human psychophysical functions can be derived in some cases to properly "weight" all future data gathered on sound fields. Such weighted data sets can sometimes be used to form single-number descriptors of a given sound field. The numerical value of the descriptor rates the sound field on the psychophysical scale applying to the particular aspect of human perception under consideration. Conversely, the original subjective criterion of acceptability of that aspect of perception can now be expressed as a maximum (or minimum) permissible value of the objective descriptor.

Descriptors developed specifically to rate loudness, noisiness, speech interference, speech intelligibility, etc. for sound fields that vary little with time, are well known. Of these, only L_A and PNL, which relate level and spectrum to loudness or noisiness, have evolved further into descriptors which also cope with variation of level over long periods of time, e.g. L_{eq} and EPNL. It is interesting to note that no specific descriptor for rating sleep interference potential has yet been devised.

Once the characteristics of the sound in the receiving space can be rated by an appropriate objective descriptor, and if the characteristics of the airborne sound produced in adjoining spaces are known or assumed, then an appropriate descriptor may be derived for rating the airborne sound insulating abilities of the building components that separate such spaces.

This paper discusses the derivation and applicability of two such descriptors, one already well known for rating the performance of indoor partitions, and the other recently proposed for rating performance of building envelope components.

Sound Insulation of Partitions Between Indoor Spaces

The Sound Transmission Class (STC) procedure for rating performance of partititons, as adopted in Australia [1] and earlier in America, has evolved with little change from the procedure adopted in Germany in the early 1950's for comparing the curve of STL versus frequency for a given partition with that of a reference grading curve, for regulatory purposes.

In particular, the shape of the reference grading curve has remained unchanged. It would be fair to say that when that arbitrary shape was chosen a quarter of a century ago, more attention was paid to constructing a stylized depiction of the field STL curve of the proven-in-usage 230 mm solid brick wall, than to the analytical processes described in the introduction above.

Since that time however there have been numerous attempts to deduce analytically the shape (and level) of the STL curve required to produce desirable characteristics of the sound field in the receiving room, under specific assumptions concerning the characteristics of the sound field in the source space. Several of these are summarized and discussed in reference [2], a comprehensive review and reassessment of this subject. Four examples are given here in Table 1.

In the first three examples, it was assumed that if the sound of a radio on the other side of the partition could be made acceptable, all would be well. All three cases, rather unrealistically, assumed zero masking noise on the receiving side. In the first case, if the radio was to be absolutely inaudible for 95% of the time, a curve of STL some 20 dB higher than an STC52 curve over most of the frequency range would be needed. Secondly, if the radio were to intrude at only 20 phon in each octave (exceeding about 37 phon total for only 5% of time), a curve somewhat like STC52 would be derived, but much less demanding at the lowest frequencies. Thirdly if instead of loudness the newer descriptor regarding noisiness were used to set a criterion corresponding to the previous one (at 1000 Hz), the curve so derived would interlace the STC52 contour with discrepancies of only ± 5 dB.

However Northwood in 1964 had already shown that if a somewhat more realistic blend of domestic noises were assumed at source, and a particular spectrum and level of continuous background masking noise were assumed on the receiving side, then to render the neighbour's noises inaudible for about 90% of the time(and therefore little to blame for upsetting expectations (a), (b) and (c) in the introduction), the required STL curve would agree with STC52 at 250 Hz, and droop below it by only 3 dB at 125 Hz, and 5 dB at 4000 Hz. If inaudibility were required for an even larger percentage of the time, the curves would interlace quite closely.

This was a rather close analytical vindication of the choice of the brick-wall-based STC52 criterion for party walls made a decade earlier. It might be made even more plausible today if a powerful wide range "hi-fi" music reproduction set were added to Northwood's 1964 blend of domestic sources.

However, Yaniv and Flynn [2] went on themselves to determine the required STL curves when other different criteria for the received sound were applied, couched in terms of 5 other descriptors (viz., 3 different forms of computed loudness, L_A, and PNL), again assuming van den Eijk's radio as the source. They also considered Northwood's household noise blend, speech alone, and a food blender alone, applying similar new criteria.

A wide variety of shapes of required STL curves was obtained. Few of the shapes added particularly close support to the shape of the STC contour. They did illustrate the point that there are as many possible criterion curves for STL of partitions as there are combinations of reasonable assumptions regarding:

(i) level and spectrum of unwanted sound in the source space;

(ii) level and spectrum of background sound in the receiving space and

(iii) what is the most appropriate descriptor, and criterion value thereof, to be satisfied in the receiving space. (They did not discuss the fact that it might be quite reasonable to demand that several criteria be met simultaneously).

It is clearly unreasonable to expect any single rating curve to be appropriate for all sets of assumptions. It would probably be uneconomic to choose a rating curve being the upper envelope of all curves satisfying all reasonable assumptions, as after all, the goal must be to satisfy most of the people most of the time at lowest cost. On the other hand, for regulatory purposes, it is undesirable to allow a proliferation of rating procedures, each conditional on sets of circumstances.

Even if the STC procedure were to be replaced with a small set of specialized alternatives in the future, it would be desirable for one of these to retain a curve shape, if not the fitting procedure, almost identical to that in the STC procedure. This would ensure some continuity with the past, and could also be justified on the following grounds.

The present STC transmission loss reference curve is, perhaps by chance, a good approximation to the inverse of the A-weighting transmission curve. If the algorithm for selecting the STC contour that a given STL curve corresponds to is regarded as a crude form of best-fitting, then it can be expected that the STC rating number of a given partition will be a good numerical approximation to the reduction in decibels (ΔL) of the A-weighted sound level between the two sides of the partition when the source room noise spectrum is pink, and the receiving room absorption area equals the partition area at all frequencies.

This expectation is borne out in practice. In a survey of 104 panels (mostly for building envelopes) conducted to assist in preparing AS 2021-1977 [3], it was found that the mean of the 104 values of (STC-ΔL) was only -0.6 dB(A) and the standard deviation 1.6 dB(A), for an assumed pink noise source.

The present audience may also be interested to know that the curve of minimum 1/3 octave band STL values specified by the acoustical consultant for the movable walls which separate this auditorium from its two neighbours in this National Science Centre, Melbourne, was very similar to an STC contour in shape. Its derivation assumed a lecturer, 16 mm movie sound, and audience reactions as the source blend, and background noise to be due to audience and air conditioning only. Two criteria were to be met for audience in the rear seats, speech from their own lecturer was to be highly intelligible over noise from all sources, and that from the lecturer next door not at all. The STL curve arrived at, after smoothing into three straight lines, closely matched the STC 46 contour, being 1.5 dB below it at 125 Hz, 3 dB above it at 400 Hz, and right on it from 1250 Hz to 4000 Hz.

Sound Insulation of the Building Envelope

In the case of devising a rating procedure for the sound insulating ability of the external components of a building against outdoor noise, investigations and proposals have been reported from many parts of the world in the last decade or so. The approach has differed from the foregoing rating of indoor partitions in two respects.

Firstly, the majority of workers have assumed that a measure of the difference of A-weighted sound pressure level (ΔL, in dB(A)) between the outdoor noise field and the one resulting from it indoors, provided by the building component for some standardized condition of absorption in the room considered, is a sufficiently sophisticated descriptor. This is approximately equivalent to rating components simply by the loudness reduction they will cause to a noise intruding from outdoors, without explicit and detailed consideration of the resulting absolute speech interference, etc. etc, for occupants of the room. However, because outdoor noise climates are nearly always measured and reported in terms of descriptors based on A-weighted level, it is natural to try to describe envelope performance in terms of its single valued effect upon such descriptors.

Secondly, many workers have been concerned at the wide variety of shapes of the spectra of outdoor noise that may be encountered, and have doubted the ability of a single rating procedure based on one average shape of spectrum of outdoor noise, to rate components appropriately for all particular situations. For example, after the survey carried out for AS 2021 referred to above, it was concluded that even for the restricted purpose of rating components by the noise reduction ΔL they could provide against aircraft noise, it would be necessary to take account of the aircraft type and operation to which the building would be mainly exposed.

In the same survey, the usefulness of the STC partition rating for predicting noise reductions against the various spectra of aircraft noise (and other real and hypothetical outdoor spectra) was also assessed. It was shown to be an unsuitable descriptor for rating performance against several important outdoor noise spectra [4]. Surprisingly, the Federal Republic of Germany has adopted the similar I_a in regulations for insulating buildings against aircraft noise [5].

Because the STC rating has often been provided in published collections of data on STL versus frequency, for external building components as well as for internal partitions, it was retained as the primary search index recommended in AS 2021, for a user seeking components likely to provide sufficient insulation for a building to be erected at a site of known exposure to aircraft noise. However, simple approximate allowances are first made for the type of spectrum of aircraft noise expected to dominate the exposure, to compensate for the shortcomings of the STC rating when applied to spectra for which its numerical value is not a good approximation to ΔL.

More recent work in U S A [6], conducted on similar lines but on a much wider basis, has come to rather different conclusions. In this work the transmission characteristics of over 500 components usable in building envelopes were surveyed, coupled with 27 representative spectra of outdoor transportation noise comprised of 11 highway, 11 railway, and 5 aircraft noise spectra. Three different rating procedures were statistically assessed for accuracy as predictors of ΔL over all possible component/spectrum combinations. The ΔL values were calculated for three different standardized curves of absorption in the hypothetical room. The three rating procedures included the well-known STC, the other two being similar to it but embodying differently shaped reference contours of STL versus frequency.

The conclusions were that none of the rating procedures assessed was very sensitive to variation of shapes of spectrum over the sample of transportation noises, but one was judged to correlate slightly better with computed ΔL values. In their Design Guide the authors have adopted this procedure for rating components against all forms of transportation noise, denoting it the Shell Isolation Rating (SIR). In it, the reference contour to which the actual curve of STL of the component is fitted is a straight line of STL versus frequency, increasing at 3 dB per octave.

This is tantamount to adopting a single arbitrary spectrum to typify all transportation noise, although in this case the shape of the single spectrum thereby implied does not appear to closely approximate to the mean shape of the sample of 27 spectra used in the assessments. In particular, the SIR rating procedure may be over-demanding of performance of components at high frequencies. Despite this, and other possible shortcomings discussed by the authors, the resulting inaccuracies of the SIR rating for particular spectral cases, divergent from the implied reference spectrum, were judged by them to be acceptably small.

Summary and Conclusion

It may seem strange that while a number of authors have used the difference of A-weighted level, ΔL, as a yardstick to judge the merits of various proposed reference-curve-fitting procedures, there appears reluctance to adopt ΔL in its own right as a standard type of descriptor for airborne sound insulation. Most descriptors of outdoor noise climate (except NEI and NEF near airports) are based on A-weighted level, so ΔL as descriptor for performance of building envelope components would be a natural extension. Yaniv and Flynn have shown that A-weighted indoor level is not a very good descriptor to predict human reactions, and if indoor descriptors are used which purport to be more relevant, significantly different curves of STL are required. This criticism also applies to STC for indoor partitions.

The use of ΔL as a descriptor for panel insulation would suffer, just as badly as any other descriptor, from inability to cope accurately with a wide variety of source spectra. A small number of ΔL rating procedures would be needed, one for each of a small number of stylized source spectra. The choice of the number, and shapes, and recommended applicabilities of such a set of source spectra is open for discussion. Pink noise is one obvious candidate for inclusion in the set, as the existing STC partition rating system would thereby be embraced in the system.

Pallet and co-authors, in recommending the SIR rating procedure, imply that one additional standard spectrum would be sufficient to typify all transportation noise, but they retain the full curve-matching concept. This is a safeguard against the spectrum of transmitted noise being very peaky, despite its overall level being low enough. The ΔL rating would not guard against this happening.

While in Australia we do have a standard rating procedure for partitions, which in Northwood's terms "is about the right shape", we have yet to adopt one for rating building envelope components. If building regulations are to include requirements for insulation against outside noise, (a trend already under way in Europe and North America), such an envelope rating procedure will be required. The choice is not a simple one. All parties concerned need to be well informed, but highly technical considerations are not likely to be the major determinants in any decision.

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Table 1. Comparison of Some Deduced Partition Insulation Criterion Curves with an STC Contour (STC52)

Year	Authors	Assumptions: Source	Assumptions: Rec. Room Background Noise	Receiving Room Criterion	Required STL Curve: Excess over STC52
1961	van den Eijk	Typical neighbour's radio	nil	Radio inaudible, (Loudness level = 0 phon), in any octave, 95% of time.	0 dB at 125 Hz 10 " " 200 Hz 22 " " 500 Hz 20 " " 630 Hz 20 " " 3150 Hz
"	"	"	"	Radio audible, but only 5% time, 20 phon allowed in any octave.	-15 dB at 125 Hz 0 " " 400 Hz 5 " " 630 Hz 0 " " 1250 Hz 0 " " 3150 Hz
1974	Pearsons and Bennett	" (same data)	"	Similar previous, but 0.16 noy allowed in any octave	-5 dB at 125 Hz 0 " " 200 Hz 5 " " 400 Hz 0 " " 800 Hz 0 " " 1250 Hz 3 " " 3150 Hz
1964	Northwood	Blend of TV, radio, speech and domestic appliances.	Octave band levels all on NC25 contour	No neighbour's noise audible in any octave ≃ 90% of time	-3 dB at 125 Hz 0 " " 250 Hz -1 " " 500 Hz -1 " " 1000 Hz -3 " " 2000 Hz -5 " " 4000 Hz

AUSTRALIAN ACOUSTICAL SOCIETY

1979 CONFERENCE

REVERBERATION EFFECTS

BY: Peter R. Knowland,
Director,
Knowland, Harding & Fitzell,
Acoustical Consultants,
Melbourne.

Every enclosed space that we occupy has some degree of acoustic reverberance. The effect is not only limited to enclosed spaces but can be experienced many times in outdoor situations.

The return of acoustic energy caused by boundary conditions has a significant effect on the subjective impression of that environment.

The effects can give rise to excessive noise and human discomfort. The effects can also manifest themselves where noise levels are not excessive, and yet discomfort is still experienced. Whilst in the beginning it appears that reverberation may have some bad effects, overall it is an everyday part of our lives and we enjoy a good reverberant environment.

What constitutes a good reverberant environment is highly subjective. Some people because of musical associations may enjoy a lively space, and yet in many other cases people for a multitude of reasons, some medical, prefer an environment which is relatively dead.

Therefore control of reverberation is very important but it is equally important to determine what degree of control is required for the environment which is to be created.

There is a misinformed belief that reverberation must be reduced in all cases where a problem exists, and this therefore provides a profitable industry for acoustic material manufacturers. Reduction of reverberation is not always necessarily required and the problem must be carefully analysed to determine what are the correct measures for the solution.

There are three essential elements in reverberation:-

1. The reverberation time in respect to frequency.

2. The smoothness of the reverberation in respect to frequency. The degree of frequency resolution required in the control of the overall reverberation curve.

3. The nature of the sound field, and this principally involves the diffusion of the field.

1. REVERBERATION WITH RESPECT TO FREQUENCY

Tonal balance is very important in the acceptance of a sound level. (1) Similarly, tonal balance is very important in the reverberation curve and in fact the two are obviously directly related. An environment where excessive high frequency absorbtion has occurred is dull and lifeless, and may be a very poor space for carrying out human communication. On the other hand, if excessive high frequency energy is present due to long reverberation times in the high frequencies, the space is hard and brittle, and can be a very fatiguing space for human leisure.

It is very important that the high frequencies are always kept in balance with the low and mid frequencies.

2. RESOLUTION OF THE REVERBERATION CURVE

In the early days of acoustics, consideration was given to the mid frequency reverberation time as a design criteria. Then in more recent times the practice adopted was to carry out calculations at 125, 500 and 2KHz octave bands. This condition at least gave some chance of examining tonal balance and is consistent with the requirements of (1) above. It was considered where a critical space was involved, i.e. for the use of music, that octave bands from 125 to 4KHz should be used for the basis of calculations.

Our experience with a number of projects has indicated that one-third octave bands must be used for calculation and measurement of reverberation, and this has been adopted as an office standard. At this stage it is difficult to acquire sufficient data on absorption coefficients in one-third octave bands, and a plea goes out to all ears to encourage laboratory and field measurement of one-third octave band coefficients.

Contained later in this paper is a case history which indicates one of the examples where one-third octave band resolution was necessary to solve a design problem.

3. THE NATURE OF THE SOUND FIELD

The nature of the sound field has a very important influence on our acceptability of the space. Most of us are familiar with double slope curves for reverberation but it is not this condition that we are talking about. Double slopes on reverberation can be extremely useful and has been exploited by a number of acoustic design firms in the design of auditoria. A number of textbooks cite double curves as acoustic no-no's. This is nonsense and illustrates a complete lack of understanding of the control of reverberation in auditoria design.

The condition with which we are principally concerned is acoustic diffusion and the elimination of harsh or delayed discrete reflections. These discrete reflections can either cause discomfort, or severely mask intelligibility.

Diffusion involves mixing the sound field to provide a homogenous condition. Diffusion techniques for the high frequencies are different to those applied to the mid and low frequencies. Diffusion does not involve the use of large, randomly spaced reflectors as one often sees in acoustic laboratories. It involves the nature and placement of three dimensional objects on the perimeter boundaries of the sound field. An essential element in diffusion is variation of the elements in respect to size.

Many times spaces that are considered to be noisy can be converted to being pleasantly reverberant simply by improving the diffusion. The reverberation time itself does not change but our psychological response to that room is different.

The condition of diffusion can be very easily seen from lighting analogy. A simple rectangular room with plasterboard walls and a concrete ceiling and floor slab provides the same condition as a room with mirrors on every surface. If one attempts to light a room with these mirrors, glare results, and a condition of diffusion or soft lighting is non-existent. Diffusion is not achieved by hanging a number of mirrors in a random manner around the room, to interrupt the light beam, as the glare still exists.

This is a direct analogy to the technique used in some measuring laboratories.

If we wish to achieve lighting diffusion, reradiation of the light at the boundary conditions is an essential element, and the use of textured paint over the mirrors can greatly soften the lighting.

When we go back to our acoustic situation, our textured paint has to be significantly large as our wave lengths are large in comparison to light. Our textured paint must vary in particle size as there is broad variation in wave lengths.

The careful application of 'acoustic paint' to the perimeter walls can soften the sound and a comfortable environment can be achieved without changing the reverberation times.

REVERBERATION IN AUDITORIUM DESIGN

For too long, reverberation time has been considered as an important element in auditorium design. As far as I am concerned, the main purpose of reverberation time in auditoria is for achieving tonal balance, and it basically represents Item 9 on a 10 point check list for auditorium design.

When we talk of musical auditoria, the musicians have no concept of reverberation, but commonly use the term 'resonance'. Their term is far more meaningful as a subjective description, and it is a term that I prefer to use, rather than 'reverberation'.

I do not intend to discuss musical acoustics but rather to explore the area of intelligibility.

REVERBERATION AND INTELLIGIBILITY

Too often, reverberation time is related to intelligibility of a space. Intelligibility is influenced by a great number of factors, of which reverberation is only a part.

I fondly remember some experiments carried out in 1966 with a very large space of which we could control the reverberation. The intelligibility in that space improved when we went up from 4 secs. to 5.2 secs. What had happened in this instance is that the 5.2 secs. condition offered much better diffusion of the sound field.

In the experimental work which we carried out on the Sydney Town Hall in 1972, we were able to achieve a very high degree of improvement in clarity of the orchestral sound without changing the reverberation time at all. In this instance the stage on which the orchestra performed was changed to remove the barrier effect of certain sections of the Sydney Symphony Orchestra.

To blandly suggest that a reverberation time of 1 sec. will give good intelligibility, and say 2 secs. will give poor intelligibility is nonsense. Yet, reverberation time certainly can influence intelligibility.

We again refer to Case History No. 1 below, where the overall reverberation time was in the order of .9 secs. and yet intelligibility was nearly impossible over a distance of 3 m. against a very low ambient sound level. In that case the correction of the reverberation curve solved the problem and allowed communication to occur over large distances.

Intelligibility is affected by:

1. The reverberation time and the fine resolution of the overall reverberation balance.

2. The ambient sound level, which is probably the most significant factor.

3. The diffusion of the sound field with obvious lack of masking discrete reflections.

MEASUREMENT OF REVERBERATION

There are many techniques of measuring reverberation, and people are still arguing the relative merits of tone bursts versus impulsive versus traditional methods. In auditoria work, the impulsive method is preferred by myself - but in auditoria work I am really looking at that magic quality 'resonance' and it is not essentially reverberation time that is being pursued.

However when we are involved with problem spaces, and we are trying to determine why people are discomforted, or a studio fails to have a correct sound, the technique of using a calibrated noise source and a one-third octave band real time analyser and a calibrated noise source given as instant picture and helps formulate a direction for investigation.

The point at which the microphone is placed in respect to the calibrated noise source is important.

Fig. 3 shows the reduction in sound pressure level with distance from a source as a function of the effective room constant. The best measurements are made at the point just as the curve flattens out. This point can be simply determined by sound pressure level measurements quickly measuring the rate of reduction from the source. The point at which the flattening out of the curve occurs can be easily determined. This point is where you have left the direct field and entered into the reverberant field.

The use of the real time analyser also allows you to see the uniformity of reverberation and whether peculiar diffusion problems exist.

Simplification of the diagnostic work can occur if a transparent lay-over of the calibrated sound power level spectrum of the noise source is used.

CASE HISTORY 1

The writer was involved in the design of a large space which had to provide a market-place type environment. Intelligibility of speech was very important so that bids could be clearly heard.

When the building was first complete, the reverberation time had departed from the design value and the actual reverberation time is shown in Figure 1. The intelligibility within the space under these conditions was very poor and it was extremely difficult to communicate from distances of more than 3 m. With reference to Figure 1, two factors are observable:-

(a) The 1600 Hz one-third octave band is notched out.

(b) The 250Hz one-third octave band is predominant.

The average reverberation time is in the order of .9 seconds and would be normally considered a condition for good intelligibility. The notching at 1600 Hz one-third octave band is occurring in a critical area of the human voice range, whilst the predominant peak at 250 Hz is providing a masking component which rides over an emaciated voice.

In the early stages it was difficult to determine why the acoustic absorbency had failed to perform in the manner predicted during design. A number of experiments were carried out to establish the acoustical performance of elements within the space and it was determined that the variation in performance was attributed to a series of carpet-covered panels scattered in an extensive area throughout the space. Research was carried out on the panels, and it was decided that the acoustic performance could be changed by a series of modifications. During the modifications it was accirdently discovered that the panels had been incorrectly constructed by the contractor, which had resulted in the panels acquiring unity absorbency at 1600 Hz and negating the low frequency diaphragms incorporated within the treatment.

The incorrect construction was an interesting situation where a manufacturer had rationalised the manufacture of a fibreglass absorbent panel but unfortunately the contractor had a stock of pre-rationalised panels which were used in the construction.

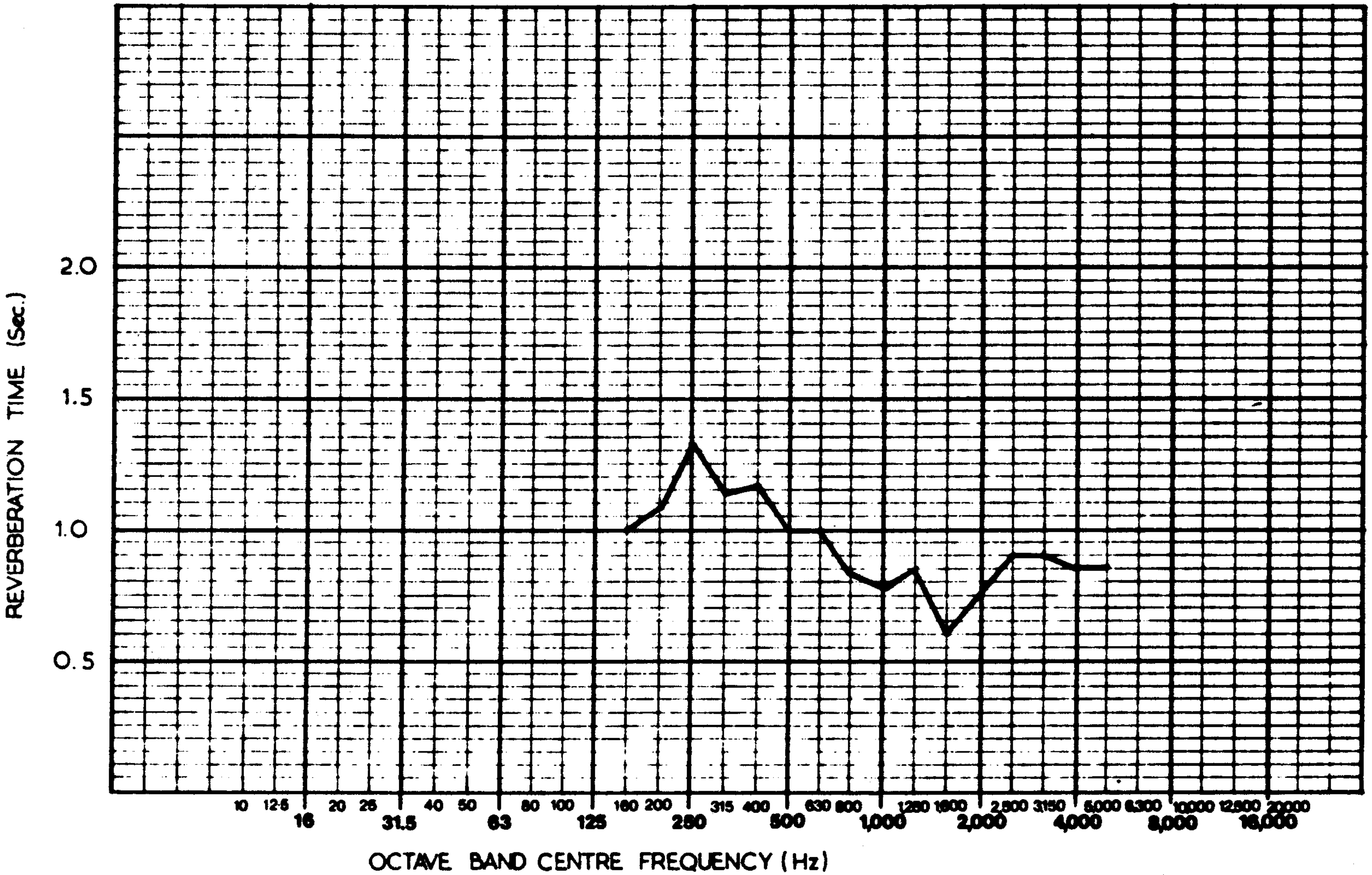
Unfortunately there were two ways the panels could be applied, and the contractor on his own initiative applied them the wrong way.

The cost of returning the panels back to the original design condition was high, and it was decided to go along with the modification as initially suggested. This achieved very close to the original design criteria and the intelligibility improved by a very large amoung.

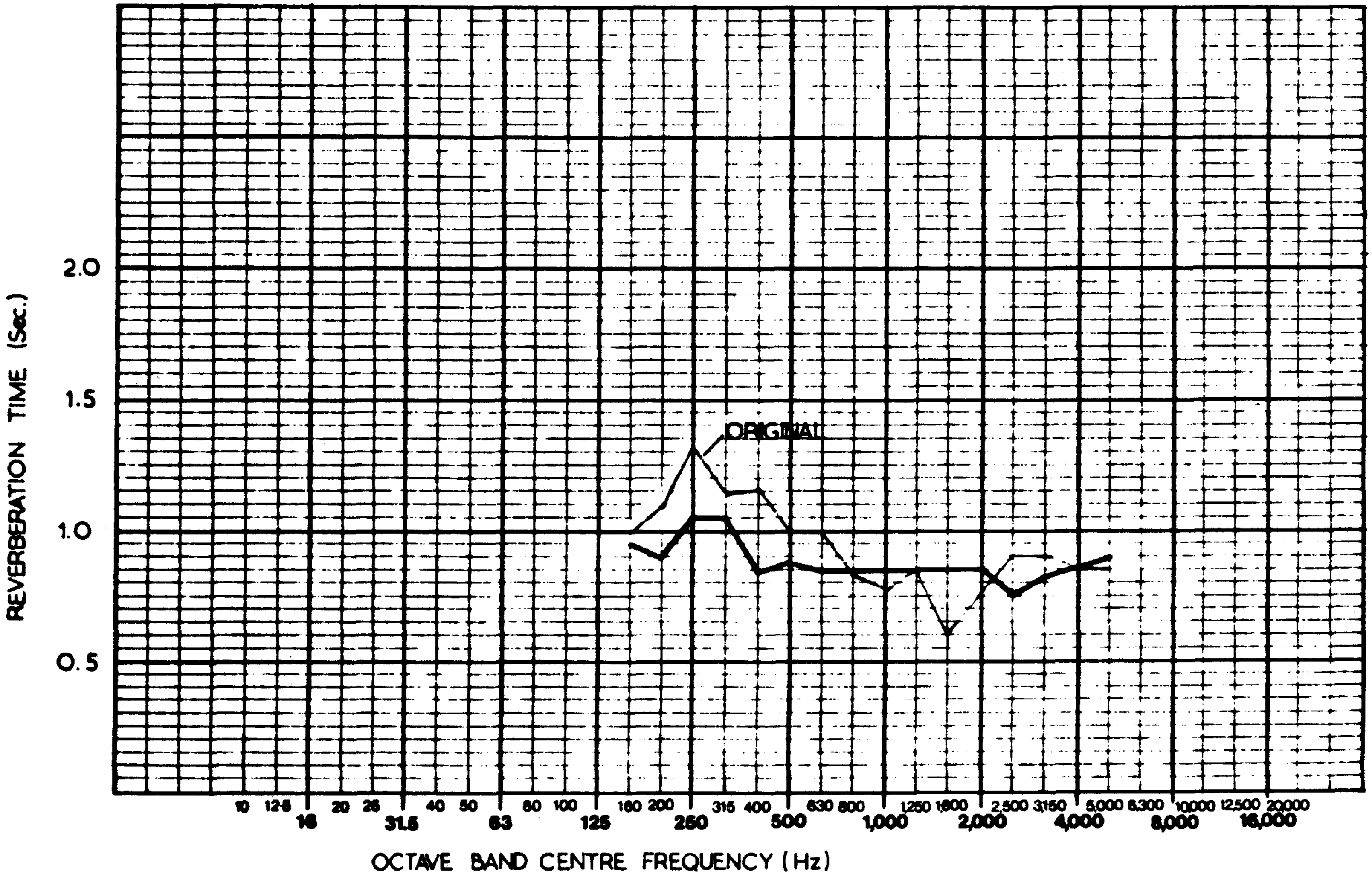
Two important lessons were learned from this exercise:

(a) Every stage of construction, whether on site or at the factory, must be supervised by the acoustic designer.

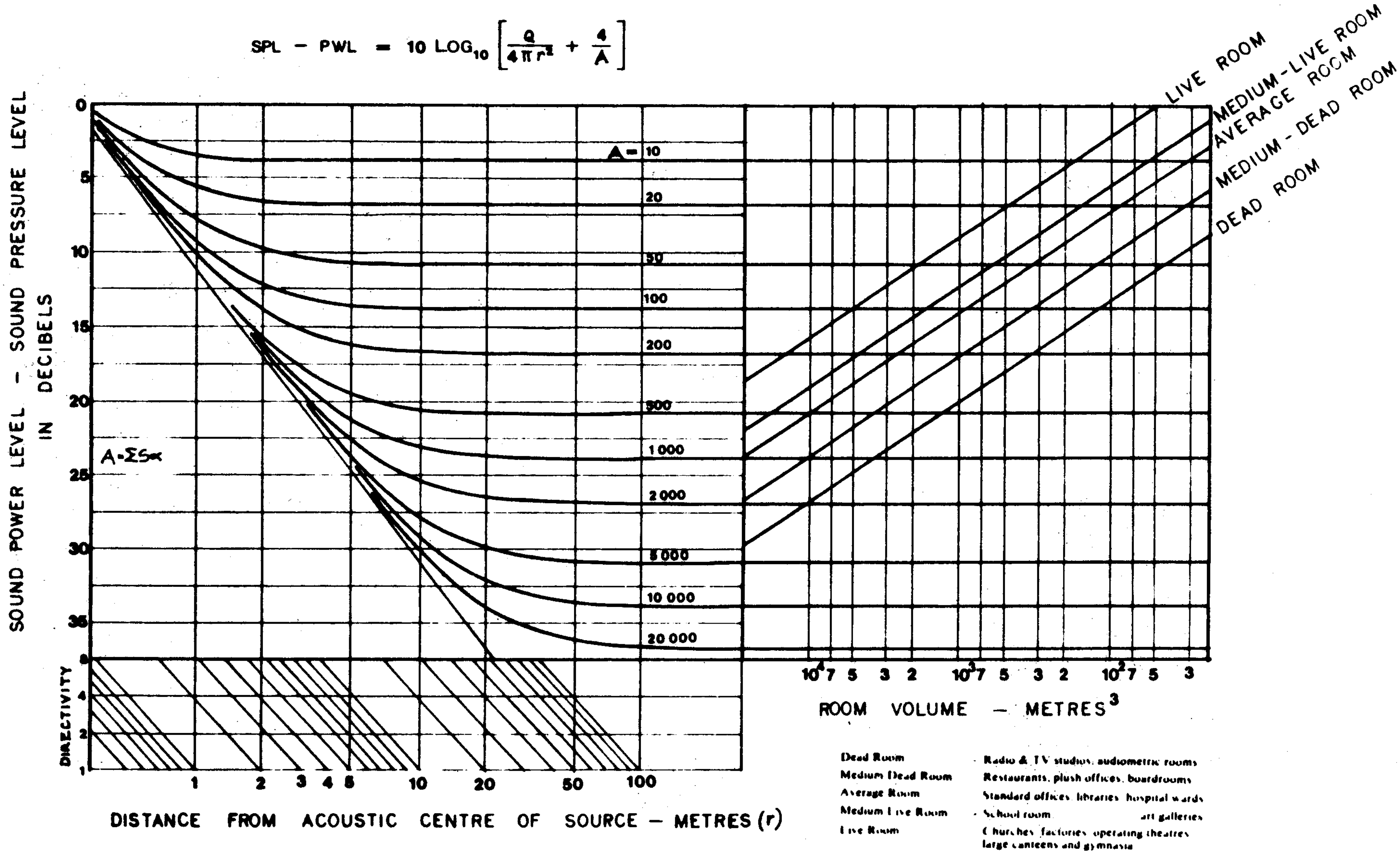
(b) One-third octave band resolution is important when studying reverberation characteristics.



CASE HISTORY - FIG. 1 - ORIGINAL REVERBERATION



CASE HISTORY - FIG. 2 - MODIFIED REVERBERATION



Relationship between sound power and sound pressure at a distance from a source, for various room types

Fig. 3

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Paper 6: GUIDELINES FOR ARCHITECTS AND BUILDERS IN THE SELECTION OF MATERIALS FOR SOUND CONTROL

Robert Burton, H. Vivian Taylor - Architect and Acoustic Consultant.

1.0 INTRODUCTION

Working in an Acoustic Consultancy, one becomes increasingly aware that many of the problems encountered in the field are the result of lack of foresight and/or lack of a working knowledge in building acoustics. With this problem in mind, this paper has been directed towards the practical aspects of insulation and absorption using commonly used building materials.

The aspects of structure borne sound will not be considered in this paper. Emphasis will be placed upon the clarification of the common misconception that sound absorptive materials will solve all noise problems.

2.0 SOUND INSULATION

The major concern of Architects and Builders is how to contain noise within the source space, be this the plant room, the typing pool or the managing director's office. That is to insulate, make into an island, acoustically detach from surroundings, to allow individual building spaces to operate without causing interference to the usage of other spaces.

When a sound wave strikes a surface some of it is reflected, some dissipated and converted into heat, and some is admitted by the surface. By conservation of energy, these components must equal the energy of the original sound wave.

The sound insulative characteristic of a material or panel is expressed in terms of its transmission loss in decibels. The transmission loss is equal to the number of decibels by which sound energy which is incidental on a panel is reduced in transmission through it. Transmission loss is dependent upon the frequency of the impinging sound wave. Transmission loss can be expressed as a value at each octave or third octave interval. Single number systems have been evolved and have been the topic of earlier papers.

2.1 SINGLE PANELS

At very low frequencies sound transmission is controlled by panel stiffness, that is the unwillingness of the panel to vibrate with the incoming sound wave and consequently to re-radiate sound. Above stiffness controlled frequencies, the resonate frequency of the panel becomes important. The transmission loss characteristics of panels in this area are controlled by mass, stiffness and internal damping.

For frequencies above about 100 Hz, the mass of the panel becomes of prime importance in the calculation of transmission loss. The mass law shows (see Figure 1) that an increase in transmission loss of 5 dB can be anticipated from a doubling of panel mass. In addition a 5 dB increase occurs for each doubling of frequency. The mass law will generally be accurate between the frequencies of 100 and 1500 Hz.

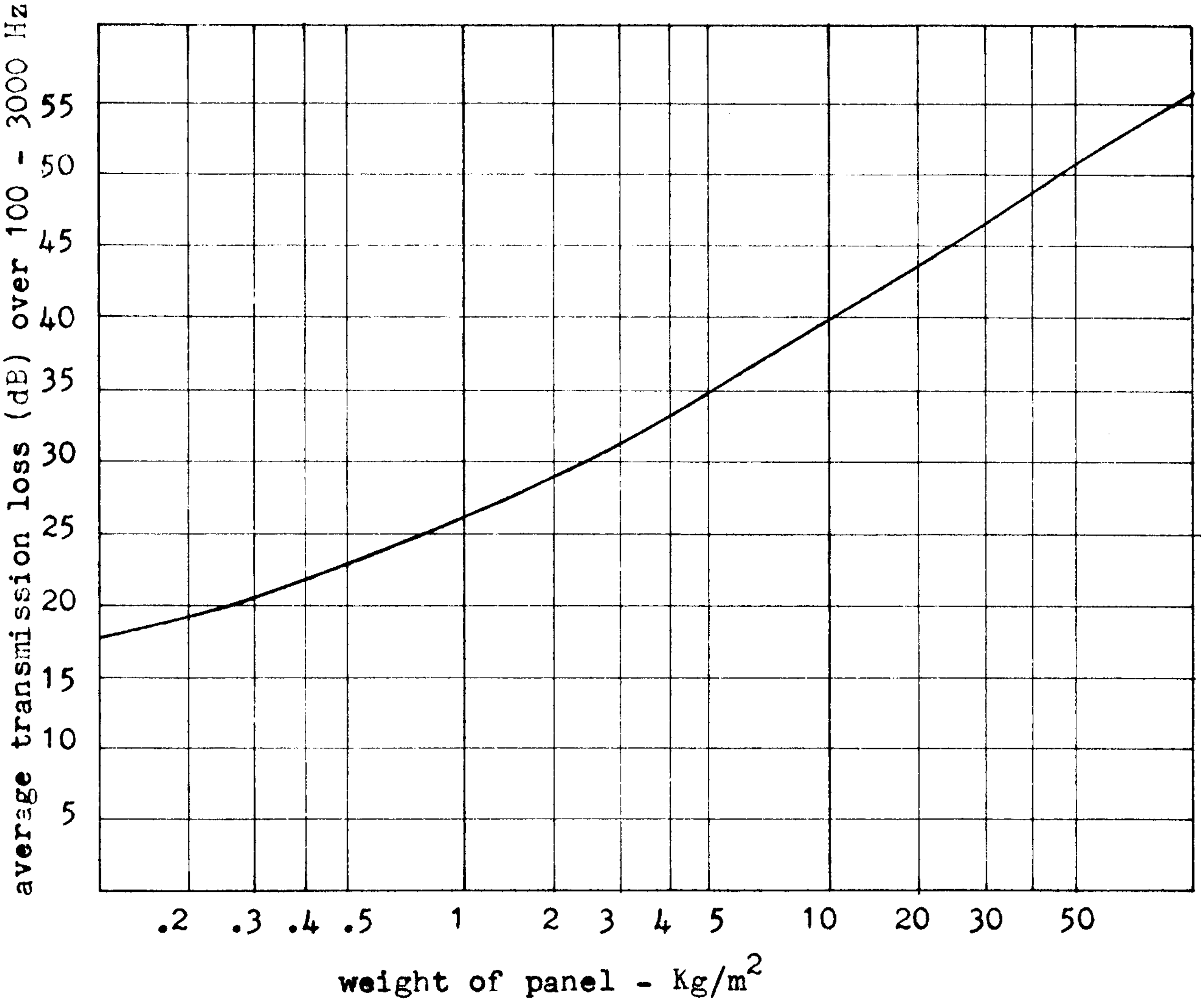


FIGURE 1 MASS LAW

Above 1500 Hz the possibility of wave coincidence becomes more likely. The critical frequency is defined as the lowest frequency at which wave coincidence occurs, that is when at a certain angle of incidence the wavelength of a sound in air coincides with wavelength in the panel. Transmission loss values of conventional building panels can drop as much as 10-20 dB below the mass law at coincident frequency, and remain 5-10 dB below throughout the rest of the audio-frequency range.

The most practical way of avoiding the reduction in transmission loss due to resonance and coincidence is to increase the panel mass. This will effectively lower the resonant frequency and raise the critical frequence into subjectively less important areas of the audio-frequency range. Increasing panel damping will cause the same effect of lowering resonance and increasing coincidence frequencies. This is particularly useful in sheet metal panels and the like.

Now with single panels, we can only go so far from an economic point of view, each doubling of mass can have a substantial effect on building costs. The following section will cover the benefits of double skin panels.

2.2 DOUBLE PANELS

Double wall construction frequently offers the most practical means of obtaining high insulation at moderate cost and reasonable dead loads.

Theoretically maximum benefit is obtained by large air spaces and structural independence of the two leaves. The transmission loss approaches the sum of each individual panel when the air space enclosed is much greater than the wavelength of the transmitted sound. Structural ties between the separate panels, however, tend to convert the compound partition into a single panel and consequently reducing the sound insulation.

The problem of resonance can be removed by the addition of an absorbent layer in the cavity. Figure 2 shows the increase in T.L. of a double wall over a single wall of equal weight as air space increases.

Methods of obtaining panel isolation in work partition with increasing efficiency are as follows:-

(1) Staggering studs on single plate, with alternate studs fixed to opposite diaphrams.

(2) Using separated plates for each skin.

(3) Using resilient fixings to one skin.

(4) Using self supporting panels.

Cavity brickwork should be constructed with as few ties as possible and without any bridging mortar droppings. Increasing the cavity width beyond the conventional 50 mm will result in better transmission loss figures.

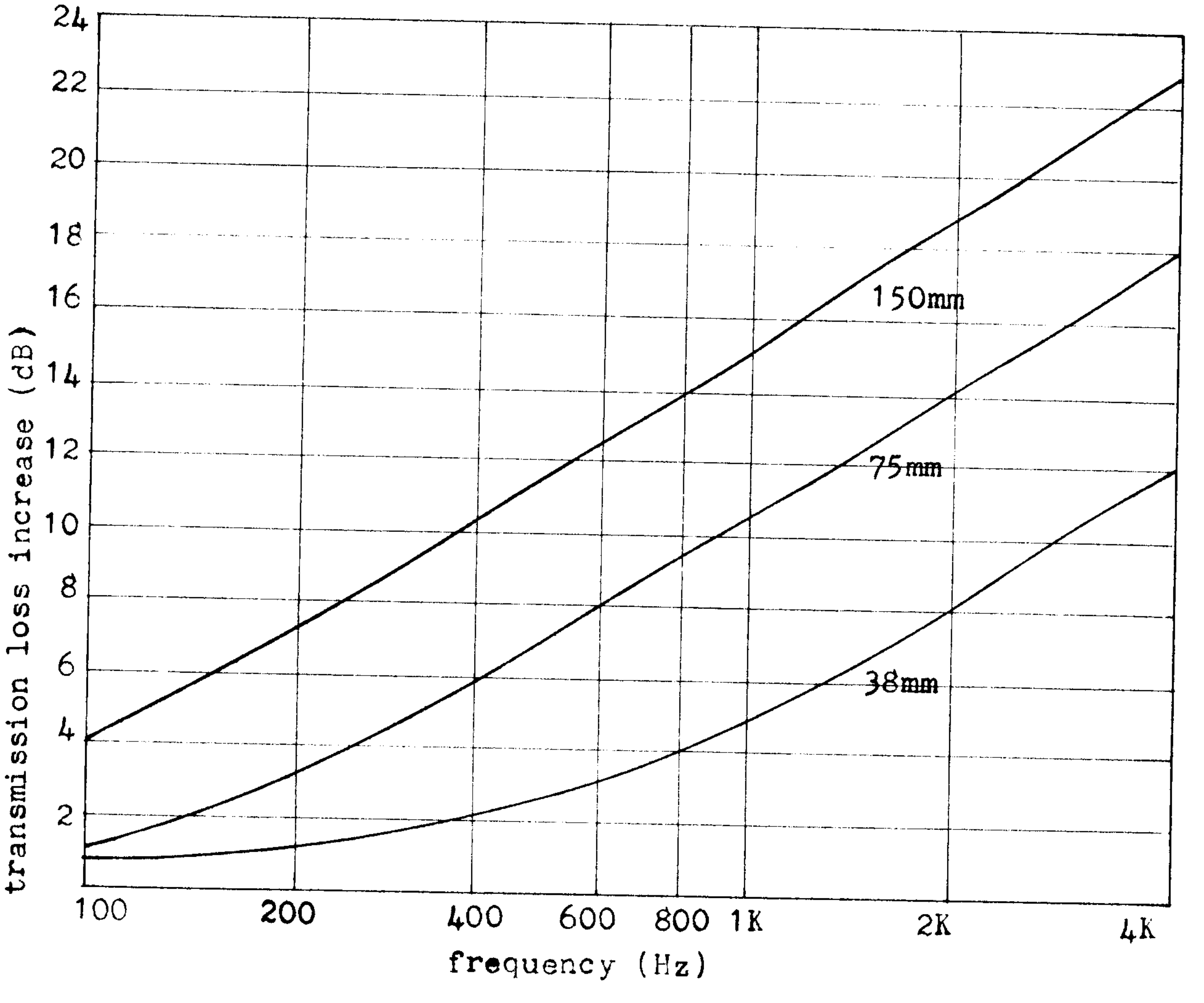


FIGURE 2 - INCREASE IN TRANSMISSION LOSS DUE TO AIRSPACE WIDTH IN DOUBLE PANEL

Similar principles apply to double glazing. Figure 3 shows the improvement in transmission loss as the air space between panes increases. The points to bear in mind concerning double glazing are:-

(1) Resilient mounting of at least one pane.

(2) Absorbent lining to reveals.

(3) As large an airgap as possible.

(4) Variation in glass thickness.

Having now determined how to specify a suitable panel, be it wall, floor or ceiling, to provide a degree of insulation, the next problem is to ensure that in the built form, the full potential is realised.

2.3 FLANKING TRANSMISSION

An important aspect of sound insulation often overlooked is that the total insulation of a composite construction is controlled by its weakest link. Figure 4 shows an approximate method of determining the overall T.L. of a panel containing a segment of lower insulation. The influence of airgaps or penetrations can also be seen clearly. For example, a penetration with an area 1 cm^2 in a wall (T.L. of 60 dB) of 100,000 cm^2 will cause a reduction of 10 dB in the total insulation afforded by the wall.

Doors often form "weak links" in composite walls because of lower weight than the wall, and poor edge sealing. Obviously doors should be selected so as to allow a minimum drop in overall wall performance and of course be well gasketed. Location of doors in adjoining rooms should be as remote as possible. In very critical locations, provision of a sound lock will provide much greater insulation than can ever be gained from a single door installation.

Commonly, the greatest problem of airborne flanking transmission involves continuous ceilings between rooms without septum walls being carried up to the floor or roof above. Frequently in commercial/office space mineral fibre tile ceilings are fixed and then demountable partitions placed as required. The resulting "short circuiting" via the ceiling space does not allow the full insulation of the partition to be realised. The solution lies in making the ceiling discontinuous and extending walls up to the slab above.

Ventilation ducting to spaces requiring sound isolation form another flanking transmission path. With light absorbent ceilings, ducting can cause flanking transmission by noise "breaking into" the ducting, and then being distributed to other spaces. Registers do not necessarily need to be present. The problem can be avoided by re-routing duct layouts, separate branch lines or by using silencers in the system. Similar problems can also occur when the above ceiling space is utilised for return air.

Plumbing stack and vent pipes are capable of transmitting sound vertically and horizontally for great distances. Lagging and cladding the piping will generally provide the method of reducing transmitted levels.

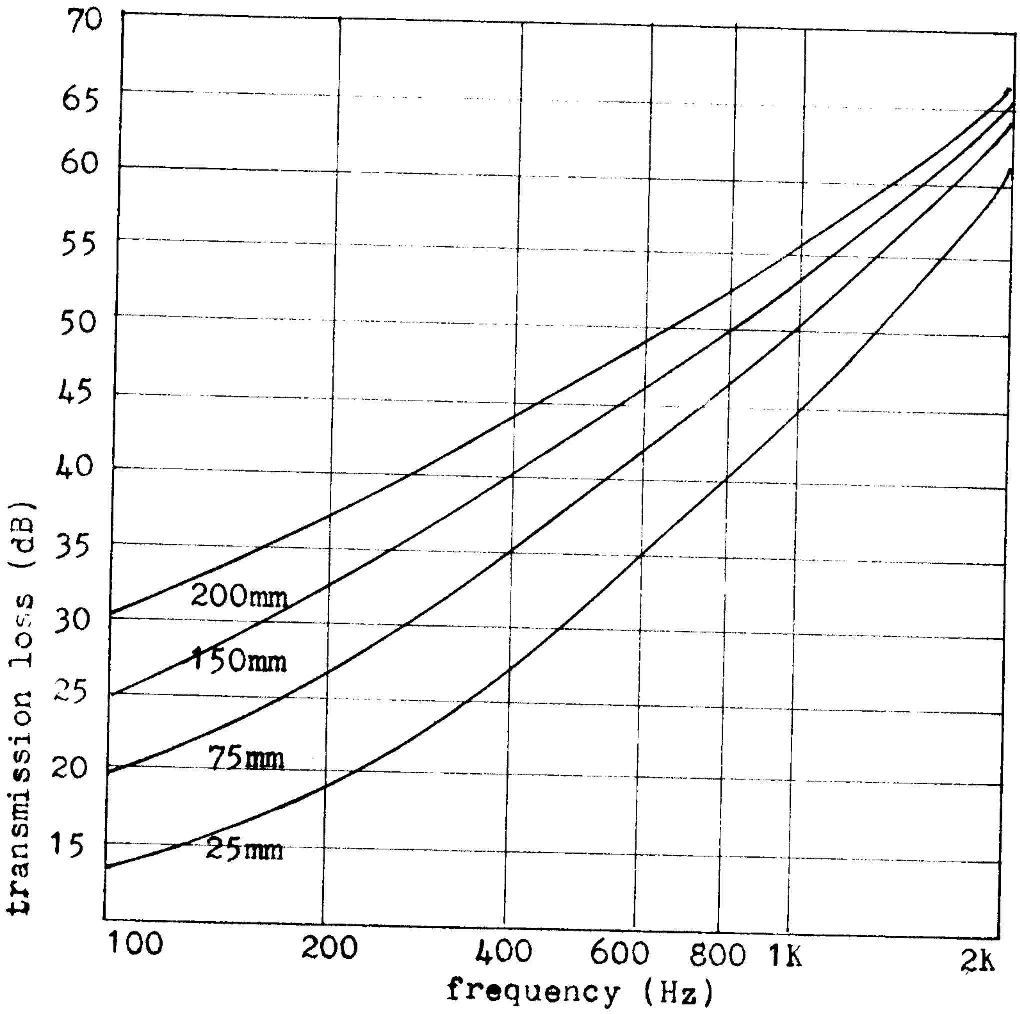


FIGURE 3 - TRANSMISSION LOSS VALUES OF TWO PANES OF 3 mm GLASS AT VARIOUS AIRSPACES.

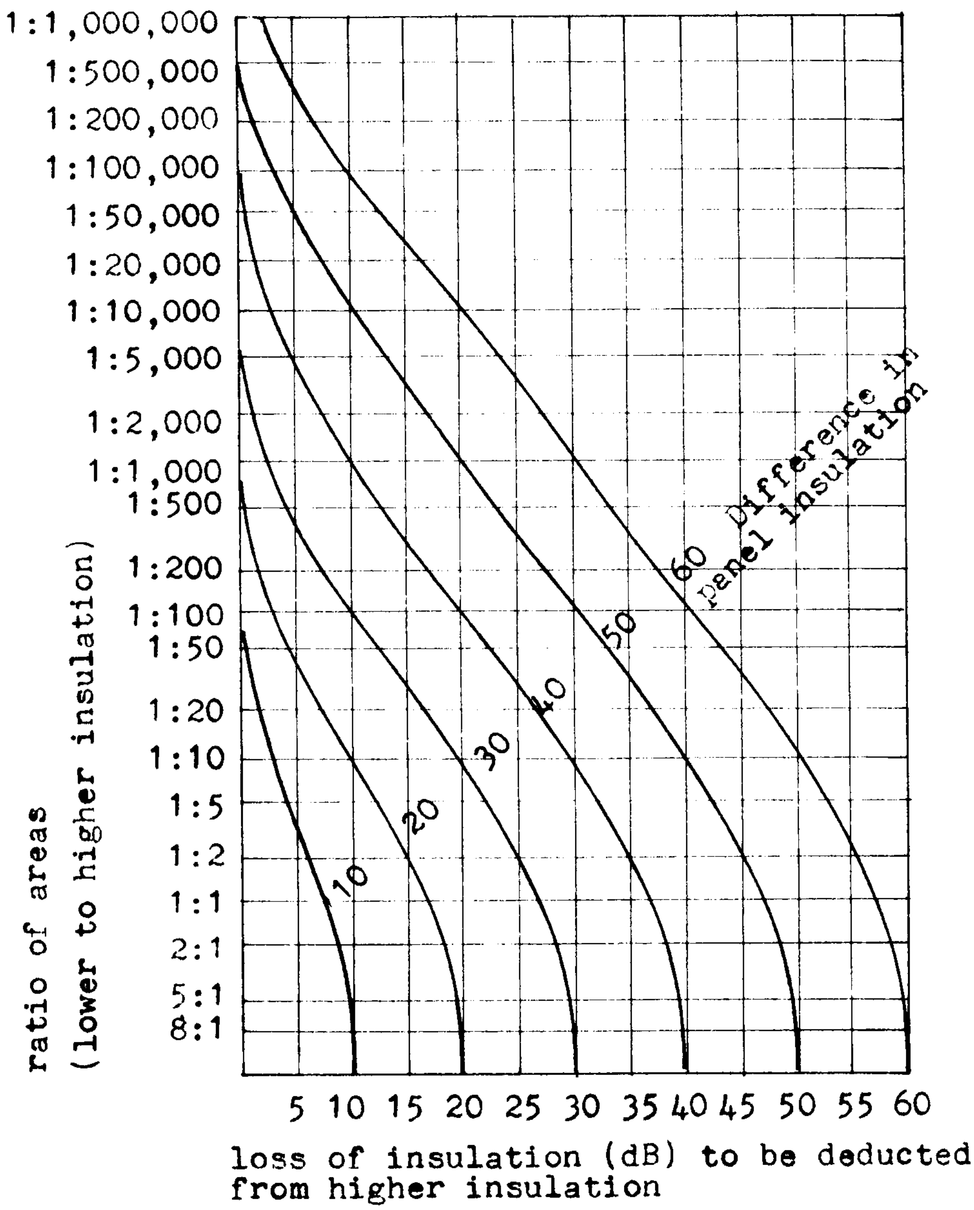


FIGURE 4 - INFLUENCE OF LOW INSULATION AREAS ON COMPOSITE PANELS

3.0 SOUND ABSORPTION

When a sound wave strikes a surface, its energy is partially reflected and partially absorbed. The ratio of the energy absorbed by the surface to the energy incident upon the surface defines the absorption coefficient and given the symbol α. Now α is dependent upon frequency. However, on occasions a Noise-Reduction coefficient (N.R.C.) may be given for a product. The N.R.C. is the average of absorption coefficients at the octaves centred on 250, 500, 1000 and 2000 Hz. The amount of absorption present in a room is calculated by multiplying the surface areas of each material by its absorption coefficient.

When a noise source is placed in a space, complex reflections occur from all room surfaces. The intensity of the reflected sound is determined by the amount of absorption present; however, the reductions that are obtained by this method are small. When considering noise insulation, the gains afforded by increasing sound absorption are no substitute for adequate sound insulation. Figure 5 shows the reduction in noise level within a space with progressive increases in absorption. It will be noted that a doubling of absorption from the original situation will only reduce reverberant levels by 3 dB. Of course reductions of this kind can be used successfully in conjunction with insulation.

Common building materials such as concrete, plaster, glass, masonry and hard flooring materials are sufficiently rigid and non-porous to be very poor absorbers.

Interior fittings such as curtains, furniture and carpets generally have reasonable coefficients of absorption, particularly at high frequencies. Figure 6 gives representative absorption coefficients for these common building materials.

3.1 POROUS ABSORBENTS

In order for the surface of a material to absorb sound energy it is necessary that:-

(1) the surface is relatively transparent to sound waves.

(2) the means are provided for the vibratory energy of the sound waves to be more or less completely transformed into heat energy by friction.

(3) an air space (particularly for low frequency) exists between the face of the material and the rigid backing surface behind it. See Figure 7.

The commonly used porous absorbers are "acoustic tiles" consisting in the main of mineral or vegetable fibres moulded into modules, varying in thickness between 9 mm and 19 mm. The surfaces are generally perforated or fissured. Figure 8 shows the average absorption coefficients of acoustic tiles. The major variation of efficiency is determined by the air space contained above the tiles. It will be noted that at low frequencies, tiles fixed hard to reflective surfaces (which is all too common a practice) provide very poor absorption.

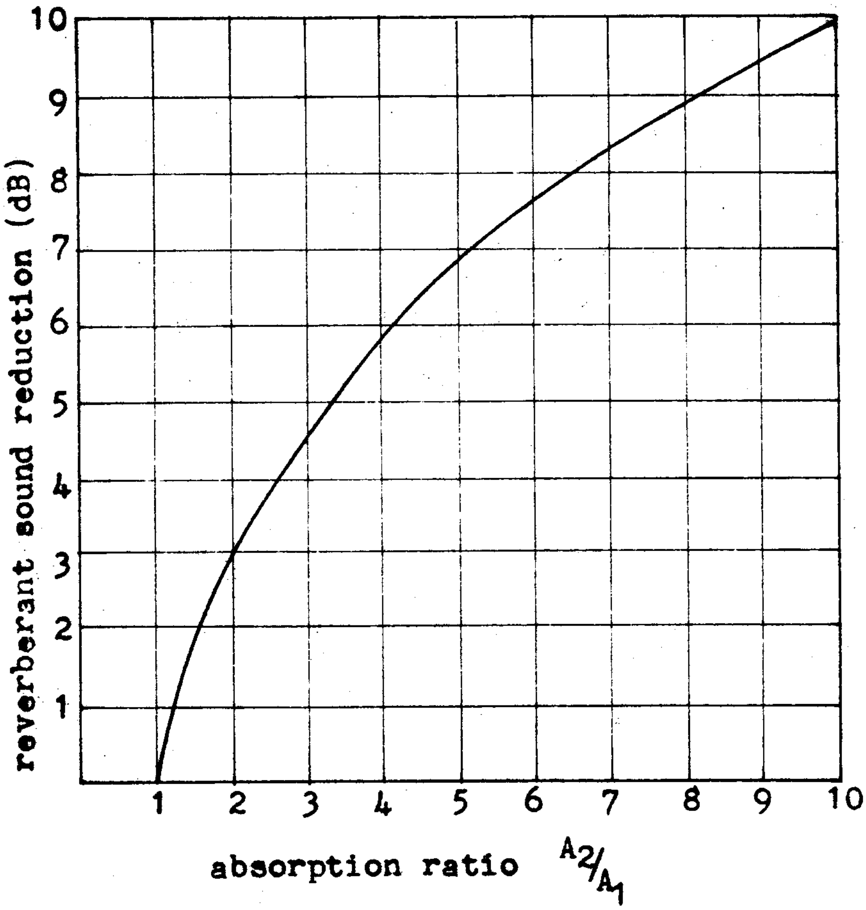
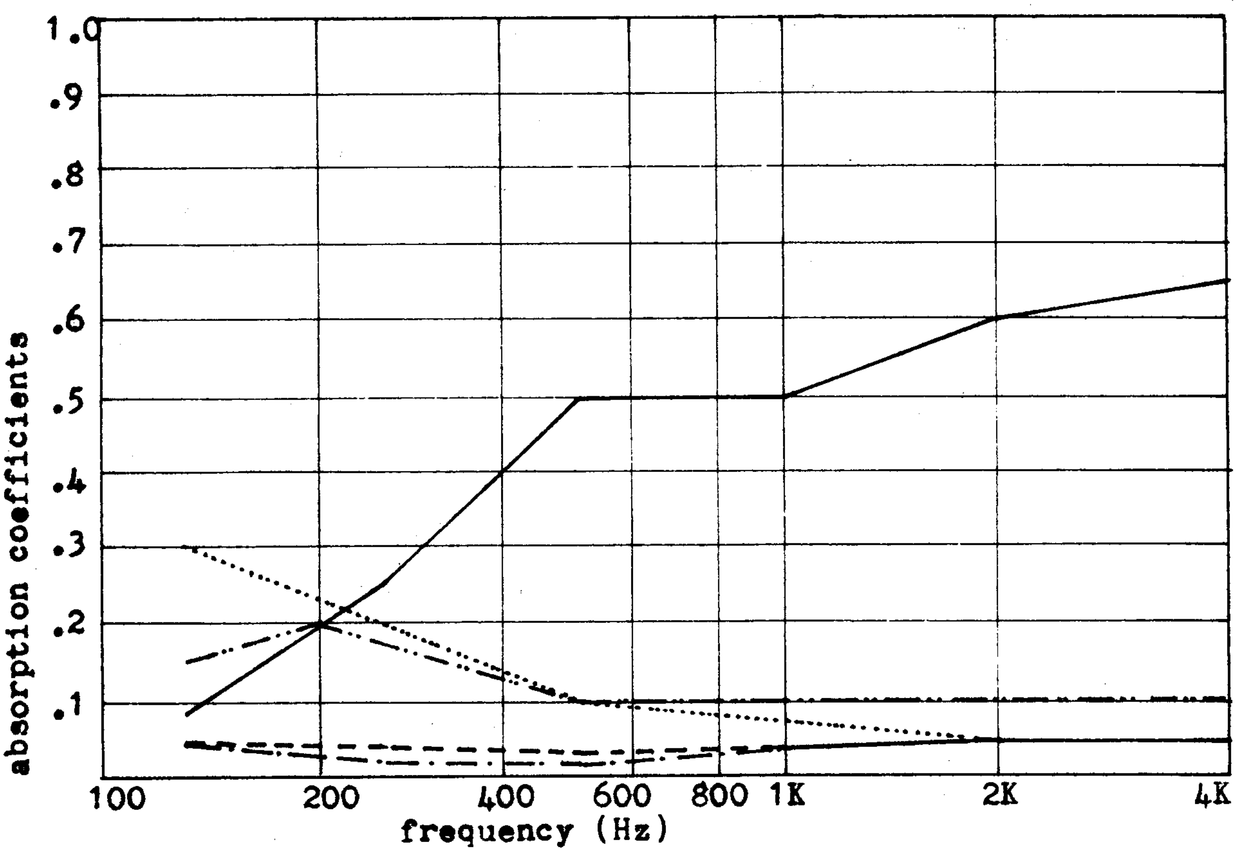


FIGURE 5 - REDUCTION OF REVERBERANT SOUND WITH INCREASING ABSORPTION

A_1 - original room absorption

A_2 - new room absorption



carpet with thick underfelt on concrete
4mm glass pane
T & G flooring
brickwork
concrete

FIGURE 6 - ABSORPTION COEFFICIENTS OF SOME COMMON BUILDING MATERIALS

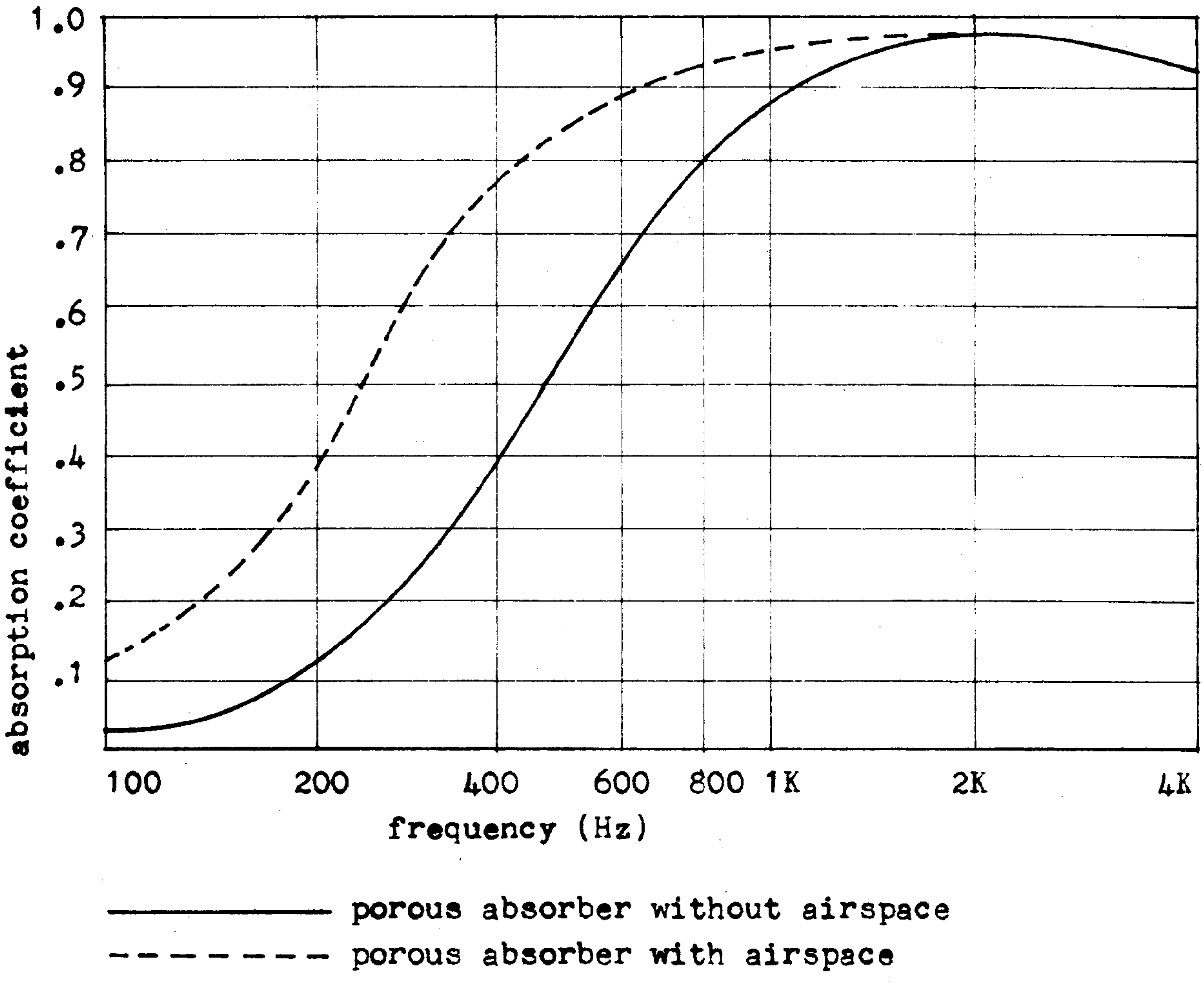


FIGURE 7 - EFFECT OF AIRSPACE BEHIND A POROUS ABSORBER

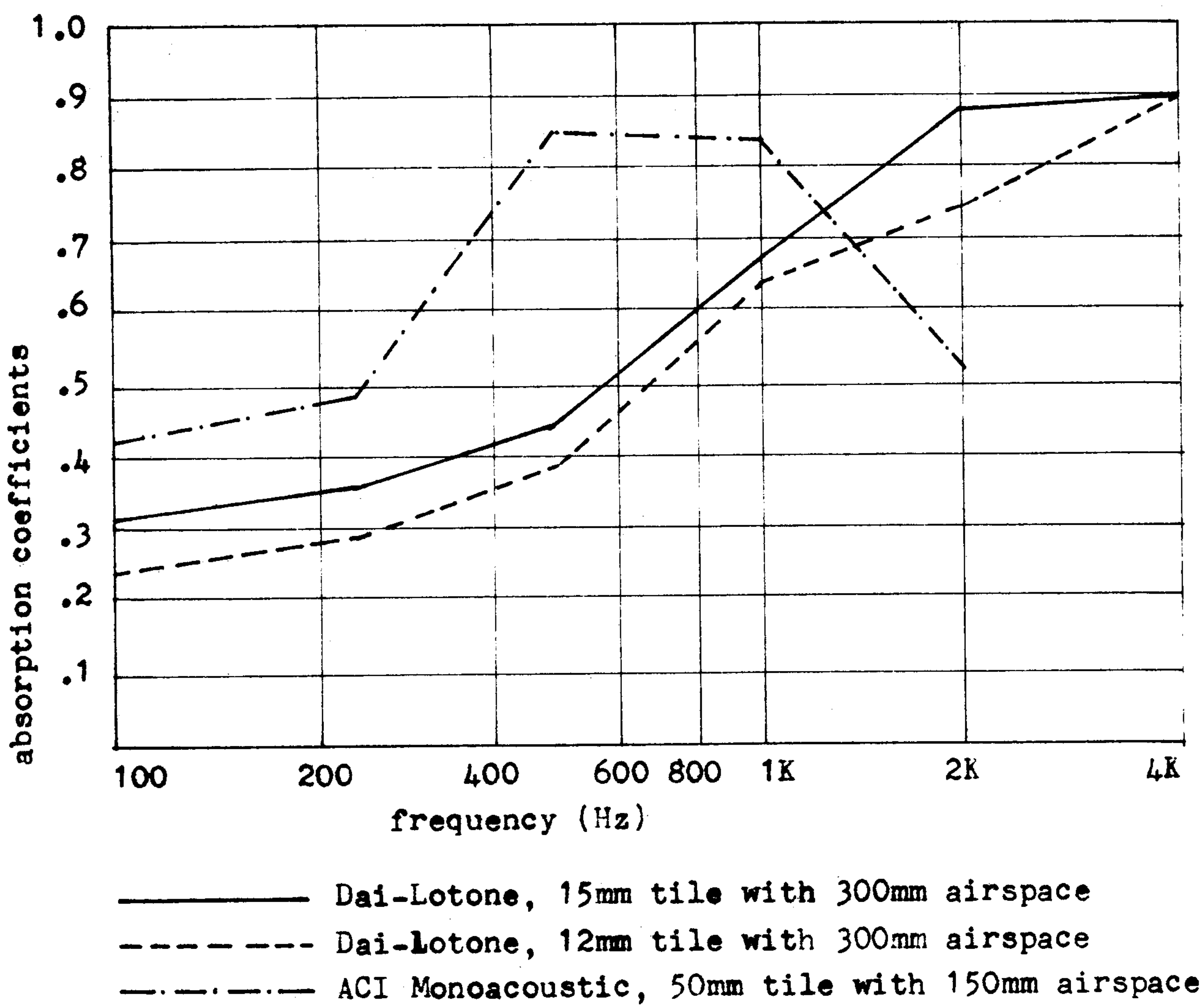


FIGURE 8 - ABSORPTION COEFFICIENTS OF SOME ACOUSTIC TILES

As mentioned above the absorption characteristics are conditional upon the porous character of the surface. Thus when it comes to painting, care should be exercised particularly with fissured tiles. Closing off the pores with paint will reduce coefficients substantially. When painting is necessary, thin water based paints with spray application are recommended.

3.2 PANEL ABSORBERS

As noted previously, low frequency is generally difficult to obtain with porous absorbers. Generally in office space and the like, this lack of low frequency absorption is not of great concern. However, in more critical spaces such as auditoria, the lack of low frequency absorption characteristic of porous absorbers can be balanced by the use of panel absorbers.

When a flexible impervious panel is set into motion by an impinging sound wave, part of the energy is removed through internal viscous damping due to panel flexure. Peak absorption occurs at the resonate frequency of the panel and generally falls away steeply each side. The resonate frequency is determined by the panel mass and the air space behind. Figure 9 shows how the resonant frequency drops as panel mass and air space are increased. The typically steep fall off in absorption can be decreased by damping the air space with a porous absorber.

3.3 CAVITY OR HELMHOLTZ RESONATORS

There are many forms of cavity resonators but all basically exist of an enclosed body of air which is connected by a narrow passage to the space containing the source sound. When a sound wave impinges on the neck aperture, the air is set into motion, which is carried through to the enclosed air body. Energy absorption occurs due to friction in and around the neck.

Single cavity resonators can be designed to provide absorption at any particular frequency. This can be of use when a reverberant condition exists at a single frequency. Using tuned resonators this frequency can be absorbed without increasing absorption throughout the rest of frequency range.

The more common usage of cavity resonators is found in perforated or slotted panels. With the addition in the air space behind the panel of a porous absorber the characteristic resonate frequency can be broadened. These are then generally termed multiple resonators.

4.0 CONCLUSIONS

The choice of materials to be employed in an acoustic design is largely determined by the problem at hand. Having once clarified that either sound insulation or sound absorption or perhaps both is required, the field is narrowed. However, once the acoustic requirements of the material are known, suitable materials can generally be found which comply with the other building parameters of cost, aesthetics and availability.

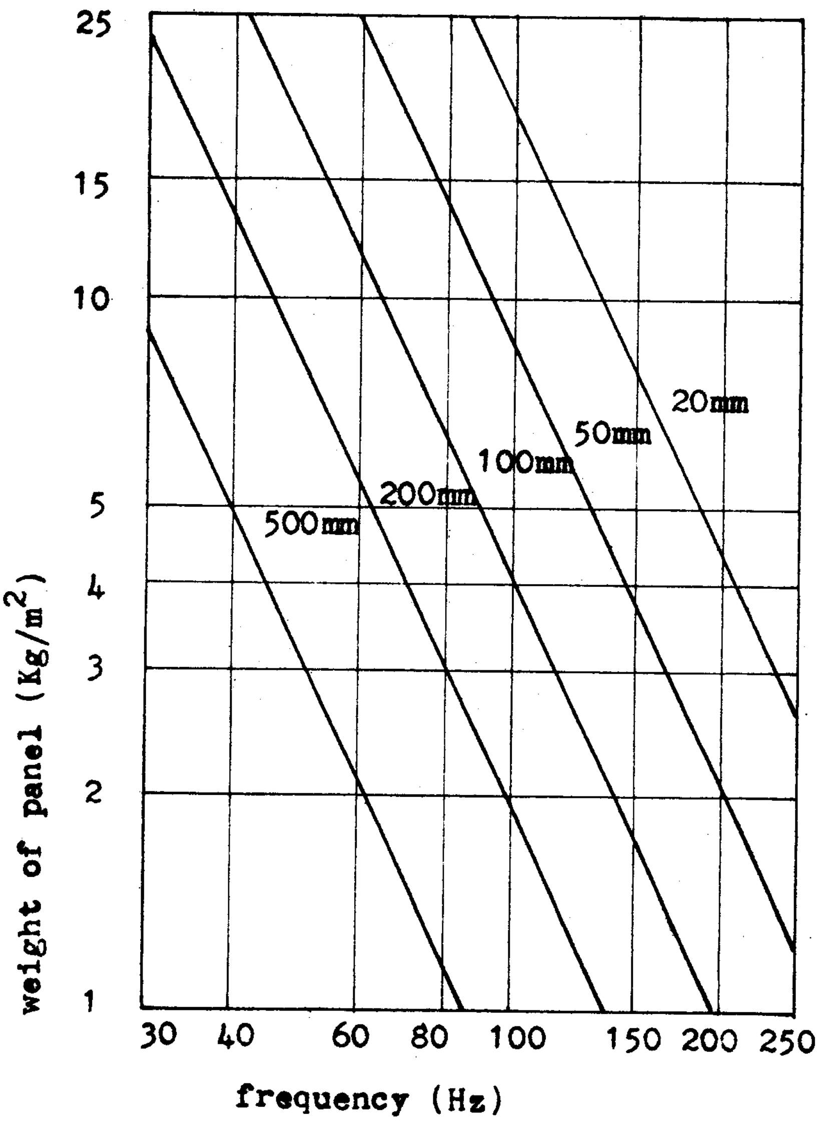


FIGURE 9 - RESONATE FREQUENCIES OF PANELS

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PAPER 7

- STRUCTURE-BORNE NOISE IN BUILDINGS -

By: R.B. King

1979 September 21 and 22

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1. INTRODUCTION

Structure-borne noise in buildings may originate from partitions excited by air-borne sound, or from impacts and other vibrations which are communicated directly to the building structure, or from a combination of both. Buildings obviously must be supported by load-bearing walls, columns, beams and structural floors which must all be joined together to form a structural framework of great strength and rigidity. Unfortunately, once vibrational energy has penetrated into a building structure, it is propagated long distances through common building materials with little attenuation (v. Table 1). Large areas of the walls and floors are often set into vibration, resulting in a high degree of radiated noise and associated nuisance.

Table 1

Attenuation of Compressional Waves in Solids

Material	dB/30 m.
Brick	0.5 - 4.0
Concrete	1.0 - 6.0
Steel	0.3 - 1.0
Wood	1.5 - 10.0

Compressional, or longitudinal, waves propagate through a building material with a velocity of propagation C_L given by

$$C_L = (E/\rho)^{\frac{1}{2}}$$

Where E = Young's modulus of the material

ρ = density of the material.

Common velocities of propagation and wave lengths of compressional waves are given in Table 2.

Table 2

Compressional Waves in Building Materials

Material	Velocity of Propagation	Wavelength at 1000 Hz
Air	344 m/s	0.34 metres
Brick	2,800 "	2.8 "
Concrete	3,400 "	3.4 "
Steel	5,050 "	5.05 "
Plywood	3,000 "	3.0 "

Shear, or transverse, acoustic waves excited in solids are known to have velocities of propagation approximately two-thirds of compressional, or longitudinal, waves in the same material.

Although both compressional and shear waves can and do exist in building structures and energy is readily converted from one type to another, particularly at discontinuities, corners and junctions, in many cases they do not give rise to components of velocity which are normal to the large surface areas found in buildings. However, they combine to form flexural, or bending, waves which also readily propagate through building structures. Since they give rise to components of vibration normal to the material surface, flexural waves can cause efficient radiation of airborne sound.

Flexural, or bending waves, are propagated in building materials having bending stiffness with a velocity C_B given by

$$C_B = (1.8\ C_L\ hf)^{\frac{1}{2}}\ \text{m/s}$$

Where C_L = compressional wave velocity of propagation in m/s.

h = thickness of building material in m.

f = frequency in Hz.

Thus the velocity of flexural, or bending, waves varies with frequency; i.e. - bending waves are dispersive.

Figure 1 shows the relation between bending wavelength and frequency for various thicknesses of concrete wall or floor and the corresponding value for air for comparison. Since bending waves are only propagated in walls and floors when the wavelength is greater than about six times the wall or floor thickness ($\lambda_B > 6h$), the upper limit of validity of the diagram is shown. Furthermore, it can be shown that at a given frequency, the power of flexurally vibrating panels to radiate airborne sound is greatly increased when the flexural wavelength λ_B in the wall or floor is greater than the corresponding wavelength in air. This lower limit of free radiation of sound is shown in Figure 1 as the wavelength of sound in air. Between these lower and upper limits, a building wall or floor element may be expected to couple readily to the air and to freely radiate airborne sound.

It can be seen from Figure 1 that it is normally the higher-pitched and more annoying, structure-borne noises that are transmitted readily over long distances throughout a building structure.

2. SOURCES OF STRUCTURE-BORNE NOISE AND METHODS OF CONTROL

The major sources of structure-borne noise in buildings can be categorised as follows:

i. Impact Noise
ii. Plumbing Noise
iii. Machinery Noise
iv. Low Frequency Vibration from External Sources

2.1 Impact Noise

Impact noise is caused by an object striking against or sliding on a wall or floor structure, such as that produced by walking, moving furniture, falling objects and slamming doors. In such cases, the wall or floor is set into vibration by direct impact and airborne sound is radiated both locally and at a distance.

i. Impact Noise Through Walls

The major causes of unwanted structure-borne sound transmission through party walls are:

(a) Kitchen cupboards mounted on the wall, where impacts are caused by placing dishes on shelves, etc. as well as the slamming of cupboard doors.

(b) Power-appliances mounted on the wall, such as knife sharpeners, can openers, etc.

(c) Power blenders and mixers operated on a cupboard top mounted directly on the wall.

(d) Dishwashers, garbage power disposal units, washing machines and driers in solid contact with the wall.

(e) Built-in wall units such as clothes closets and dressing tables where structure-borne noise is generated by the sliding of doors and drawers.

Most of these problems can be avoided by the following rules of thumb:

i. Where possible, plan to keep party walls free or clear of any appliances, cabinetry and household furniture.

ii. If unavoidable, then the party wall should be of isolated double-wall construction (no wall ties) and vibration-isolation mountings such as resilient gasketing and rubber blocks used for all appliances, built-in cabinets and closets.

ii. Impact Noise Through Floors

Impact noises usually constitute a serious nuisance problem because such noises generally are intermittent, of high intensity and impulsive in character. In most cases impact noise problems are associated with floor structures. The obvious solution is to prevent the impact blows giving rise to vibrations in the main body of the building structure by either:

i. providing resilient floor surface coverings which cushion the blow, such as soft carpet, rubber or cork tiles, etc.,

or

ii. having a discontinuous structure which prevents the vibrations excited at the source from being transmitted into the main structure and then propagated away to distant parts of the building.

Method (i) is effective in attenuating the high frequency components of impact noise in floors, but will often leave a most irritating thumping or booming noise in the occupied space beneath, particularly with floors of light frame construction.

Method (ii) does not exhibit this disadvantage. The basic types of construction techniques are now discussed.

(a) Cushion the Impact

The reaction of a structure to an impact blow at a single point may be simply expressed by the mechanical driving point impedance **Z**, the ratio of the alternating driving force to the resulting alternating velocity. For large plates of thickness h and excited transversely, it can be shown that -

$$Z = 2.3\ C_L\ \rho\ h^2 \quad \text{(N-sec/m)}$$

Wave Velocity C_L is in m/sec.

Material Density ρ is in kg/m^3.

Plate Thickness h is in metres.

The spectrum produced by an impact or blow can be estimated by considering an elastic plate of high mechanical resistance struck by a rigid mass m_o with a velocity u_o The resultant velocity amplitude u is given by

$$u = m_o\ u_o\ /\ Z.$$

For infinite plates of different materials

$$Z = A.h^n \quad \text{(N-sec/m)}.$$

Where h = thickness of plate in millimetres, and the constants A, n are given in Table 3 for common building materials.

Table 3

Driving Point Impedance of Infinite Plates

Material	n	A
Aluminium	2	31
Concrete	2	17
Plywood	2	4.7
Steel	2	93

The introduction of a surface resilience k by the use of carpet, rubber and cork tiles, etc., results in an impact isolation improvement ΔL, the difference of transmitted sound pressure levels with and without the resilient layer.

$$\Delta L = 20 \log \left({}^{v_1}/_{v_2}\right)$$

where v_1, v_2 are the surface velocities.

For the bare floor, the approximate value of v_1 is

$$v_1 = u = m_o\ u_o\ /\ Z$$

and for the treated floor

$$v_2 = \left({}^{m_o\ u_o}/_{Z}\right)\ \left({}^{f^1}/_{f}\right)^2.$$

Where

$$f^1 = \frac{1}{2\pi}\ \left({}^{k}/_{m_o}\right)^{\frac{1}{2}}.$$

Thus, $\Delta L = 40 \log \left({}^{f}/_{f^1}\right).$

This shows that the impact isolation improvement depends not only on the kind of floor covering but also on the striking mass and on the frequency of concern. It should be noted that no appreciable gain in airborne sound insulation is achieved by the use of such a resilient layer.

More sophisticated design techniques are available for preliminary design predictions of impact isolation improvement. Also the improvement ΔL has been measured and reported for a large variety of materials and configurations. By these means, effective control of impact isolation over sensitive occupied spaces can be maintained at the design stage.

Resilient finishes to a floor surface are not always provided as part of a building structure. Tenants cannot be relied upon to provide adequate floor coverings unless a carpet clause has been included in the lease contract for certain rooms. Therefore, in many cases alternative methods must be used.

(b) Float the Floor

Such constructions can be highly effective in reducing the transmission of impact noise. The resilient material supporting the isolated floating floor above the main structural floor may be in the form of rubber pads, wool blankets, springs, etc. Floating floors may be used over structural floors of masonry, wood or steel frame construction.

At a given frequency f, the impact noise improvement ΔL of such floating floors is approximately given by

$$\Delta L = 40 \log (f/f^1).$$

Where,

$$f^1 = \frac{1}{2\pi} \left(\frac{k_1}{m_1}\right)^{1/2} \text{ Hz},$$

m_1 is the surface density of the floating floor in kg/m^2,

and k_1 is the dynamic stiffness per unit area in N/m.

The stiffness k_1 depends on the combined stiffness of the resilient underlay itself and the layer of air entrained between the structural floor and the floating layer. When the resilient material is made of soft fibrous material and the lateral dimensions of the floating floor are large compared with the acoustic wavelength, then the stiffness of the entrapped air becomes predominant and

$$f^1 = 60/(m_1 d)^{1/2} \text{ Hz}.$$

Where m_1 is the surface density in kg/m^2,

and d is the thickness of the entrained air layer in metres.

It can be seen that the improvement ΔL is independent of the striking mass m_o only when the point impedance Z of the floating floor itself is very much greater than $2\pi f m_o$.

Such a resilient mass-spring system can be expected to exhibit a resonant frequency at which the impact isolation will be less than if the floating floor had been omitted. To avoid this problem, the resonant frequency f^1 should be chosen to be very low, preferably less than 20 Hz. This is achieved, for example, by having a high floating mass such as 50 mm concrete screed laid on a very resilient support such as 50 mm glass fibre quilting.

In practice the results obtained for floating floors do not agree entirely with the above simple analysis since such floors are never infinite in size and reflections occur from the free edges.

The following precautions should be taken to ensure the success of a floating floor wherein a resilient mat or pad is sandwiched between a structural floor and a floating floor:

i. The mass of the floating floor should be large compared with any loads it will support, in order to maintain a more uniform load distribution on the resilient underlay.

ii. The characteristics of the resilient mat or pad must be such as to resist breakdown or excessive deformation under long periods of loading.

iii. The joint between the floating floor assembly and the adjoining walls must be flexible and preferably airtight, so that the additional airborne sound insulation provided by the floating floor is not wasted.

iv. Any rigid coupling must be avoided between the floating floor and the structural support floor when installing pipe services, ductwork and electrical fixtures. It is preferable to avoid penetration of a floating floor by any such services.

(c) Suspend the Ceiling

Ceilings which are isolated from floor structures above by resilient channels, hangers, or separate ceiling joists, usually perform as efficient airborne noise insulators when tested in laboratory installations where flanking transmission is virtually eliminated. However, in actual buildings such vibration isolated ceilings are much less effective against impact noise unless the floor and ceiling composite structure is vibrationally decoupled from the adjoining load-bearing walls.

It is important to realise that the suspended ceilings normally used in practice provide very little impact sound insulation. Ceilings must be specially designed for this purpose.

Consequently, suspended ceilings are not recommended as a routine means of obtaining high impact noise isolation in new buildings.

(d) Changes of Area, Corners and Junctions

Once structure-borne sound has been excited in the main building structure, various proportions of the sound will be transmitted or reflected at the junctions of different structural elements. At the junction of two structural elements of different mechanical impedances Z_1 and Z_2, the complex reflection coefficient for compressional waves is given by -

$$\bar{r} = (Z_1 - Z_2)/(Z_1 + Z_2)$$

The decibel reduction in level of the transmitted structure-borne vibration is given by -

$$R(dB) = 10 \log \left(1/1-|\bar{r}|^2\right).$$

For an area section change of building element, R is quite small, an area ratio of 1 : 5 giving only 3 dB reduction for both compressional and flexural waves.

When two building elements, such as a wall and floor, are joined at right angles, a compressional wave in one results in a bending wave in the other. Flexural (bending) waves are propagated around such a corner, but the reduction is quite small, being only 3 dB for equal elements. Even when one element is double the weight of the other, the attenuation through the junction is only 6 dB. At a cross-junction of two equal building elements, the attenuation of flexural waves through the junction is 9 dB. However, the attenuation increases rapidly with differing thicknesses of the two building elements.

When structural elements are separated by a resilient layer of markedly different mechanical impedance, large reductions in transmitted energy are theoretically possible. For example, a 3 cm. thick section of cork inserted along the length of a 10 cm. thick concrete wall can give reductions of 10 dB at 400 Hz and 30 dB at 1600 Hz. However, the structural difficulties of inserting such layers normally prevent their widespread use even as vertical separating elements. When inserted horizontally in a load-bearing wall element, practical load bearing membranes give very little attenuation of structure-borne noise.

2.2 Plumbing Noise

In a normal multi-tenanted building, it is difficult to escape from the plumbing noise nuisance, which is often a source of embarrassment and irritation.

There are two basic plumbing systems, namely the water piping of both hot and cold water and the drainage system.

The causes and remedies of plumbing noise are one or a combination of the following (Table 4):

Table 4

Causes and Remedies of Plumbing Noise

Cause	Remedy
High velocity turbulent flow and cavitation around bends, connectors, valves and taps, causing rushing and whistling sounds.	Well-planned layout with use of pressure regulators, a minimum number of bends and maximum size pipes and valves to reduce water velocity. A flow velocity of 2 m/s or less in domestic systems is quite acceptable. Water pressure should be regulated to maximum of 50 psi in main supply lines and 35 psi in branch lines to individual apartments. Install low-noise cistern systems, using full-ported nozzles and aeration devices.
"Water hammer" pipe vibration caused, for example, by a dishwasher or clothes washer with a rapid-action electric solenoid valve.	Flexible hose connectors and air chambers at each outlet to act as shock-absorbing cushions.
"Snapping" or "creaking" of long runs of hot water supply pipe. Differences of 60°C can cause copper piping expansion of approximately 30 mm in 30 metres length.	Design for flexibility of piping at one end. Design supports so that piping can expand without binding.

(cont.)

Cause	Remedy
Running water noise from baths, basins and toilets.	Line all pipe clamps and supports with resilient material such as rubber, neoprene, wool or felt. Use similar resilient gaskets under bath tubs, toilets, showers, basins, etc. Locate piping runs away from sensitive spaces such as bedrooms, lounge rooms. Avoid long vertical drops into horizontal branches supplying apartments.
Garbage power disposal units, causing piping and sink vibration and amplification of radiated noise.	Flexible hose connector between unit and trap. Soft rubber isolation gasket between unit and sink.

2.3 Machinery Noise

(a) In multi-tenanted buildings, household appliances such as refrigerators, dishwashers, washing machines and clothes driers should be vibration-isolated from the floor by means of rubber mounts or pads. Otherwise structure-borne vibration will be transmitted into the floor which will amplify and radiate the noise at disturbing levels.

(b) Heating and air-conditioning installations in multi-storey buildings can be noisy and give rise to complaints from occupants. The major causes or sources of noise are:

i. Turbulent air flow in ducts and grilles.

ii. Drumming of duct walls.

iii. Mechanical noise from fans and motors.

The design for adequate noise and vibration control of a large installation is a specialist task requiring careful attention to detail at both the design and installation stages in such matters as:

i. Location of machinery: Where possible, plant rooms should be located in slab-on-grade or basement locations. Mechanical equipment should be mounted on concrete inertia blocks supported on vibration isolators. The floor slab under the isolators may need to be separated from the main slab by expansion joints. All pipes, ducts, etc. must be vibration isolated by flexible connectors from such machinery. In-line pulsation dampers may be necessary in compressor and hydraulic lines.

ii. Specification and selection of low-noise machinery and equipment.

iii. Vibration-isolation of machinery, piping and ducting.

iv. Careful duct design to minimise air velocities, also vortex generation at turning waves, grilles and duct junctions.

(c) Other Equipment : Complaints of structure-borne noise can occur by occupants of top-floor apartments due to uninformed roof-top installation of such machinery as:

i. Cooling towers

ii. Airconditioning plant

iii. Lift drive equipment

iv. Swimming pool equipment

v. Ventilation and exhaust systems

vi. Transformers

Special precautions should be taken to vibration-isolate such equipment in an effective manner.

2.4 Low Frequency Vibration From External Sources

Low frequency vibrations from railroad, subway and truck traffic may give rise to complaints by occupants of buildings erected near such sources.

The following guidelines may be of assistance in preliminary planning:

i. Road and freeway traffic (buses, trucks, cars) do not normally produce perceptible vibration levels at more than 50 m. from the road. At closer distances, some isolation of the building against ground-borne vibration may be necessary.

ii. Light rail traffic produces barely perceptible vibration levels at a distance of 5 m. from the track. It is therefore unlikely to be a cause of complaint of structure-borne noise in an adjacent building.

iii. High speed commuter heavy rail transport produces vibration levels that are only just perceptible at 50m. However, the vibration levels developed on the track bed and tunnel walls of an underground heavy rail system could be clearly perceptible, bordering on annoying, in a nearby or overhead building, particularly in city areas where the rail track and tunnel run close to lightly-damped concrete and steel building structures. Perceptible vibration levels may be produced in the building at very low infrasonic frequencies of approximately 5 to 10 Hz, together with unacceptable structure-borne noise levels at approximately 60 Hz.

Where such problems are likely to occur, specialist prediction, design and installation techniques are required to provide adequate vibration isolation of firstly, the rail track from the surrounding tunnel and secondly, if necessary, tbe building from the sub-soil.

The prediction of structure-borne vibration levels and the associated radiated noise levels requires estimates of:

i. Track and tunnel vibration levels.

ii. The attenuation of vibrational energy with distance from the tunnel.

iii. Transmission of energy into and throughout the building structure.

iv. Acoustic radiation characteristics of building structural members.

Some of the following techniques have been used with varying degrees of success to isolate buildings from externally induced low frequency vibration.

(i) Trenches

The effectiveness of trenches cut into the ground between the building and the source of ground-borne vibration is highly dependent on the nature and properties of the ground and the foundation bed on which the building is erected. If the building rests on a foundation bed of firm dry gravel and the ground above is hard packed clay or sand, a trench which is cut down to the gravel bed and filled with loose gravel may attenuate low frequency vibration before it reaches the building. Rock, clay, sand and chalk are good transmitters of vibration, whereas gravel is a poor transmitter.

(ii) Baseplates

In the past, buildings have been erected upon thick load-bearing baseplates of lead, asbestos, rubber and cork. The most systematic research and development in recent years would appear to have been with large rubber antivibration mountings. Such mountings have been employed to support whole buildings. Normal working pressures for various types of rubber range from 800 kg/m^2 to 70 tonnes/m^2, the deflection for a single layer being approximately 3mm., giving effective isolation against ground-borne vibration of 15 Hz and above. By interleaving layers of rubber with metal sheets, deflections can be increased and natural frequencies reduced even further for improved isolation in the infrasonic and audible ranges of frequency. In some cases, rubber-in-shear mounts have been used. Weathering and long-term permanent set no longer appear to be problems.

3. CONCLUSION

In practice, building structures are acoustically complex. The structure-borne sound transmitted from one space to another can be propagated with little natural attenuation both via the common partition (if any) and via the remainder of the supporting structure.

Every effort should be made to prevent, or at least reduce, the initial ingress of such vibrations into the main building structure. Where this is inadequate, the length of continuous structural transmission path should be limited by the introduction of joints, changes in materials and dimensions, and decoupling devices, as close to the source and as repeatedly as necessary.

In all but the simplest of cases, specialist advice should be sought to prevent disasters and to ensure the most cost-effective design.

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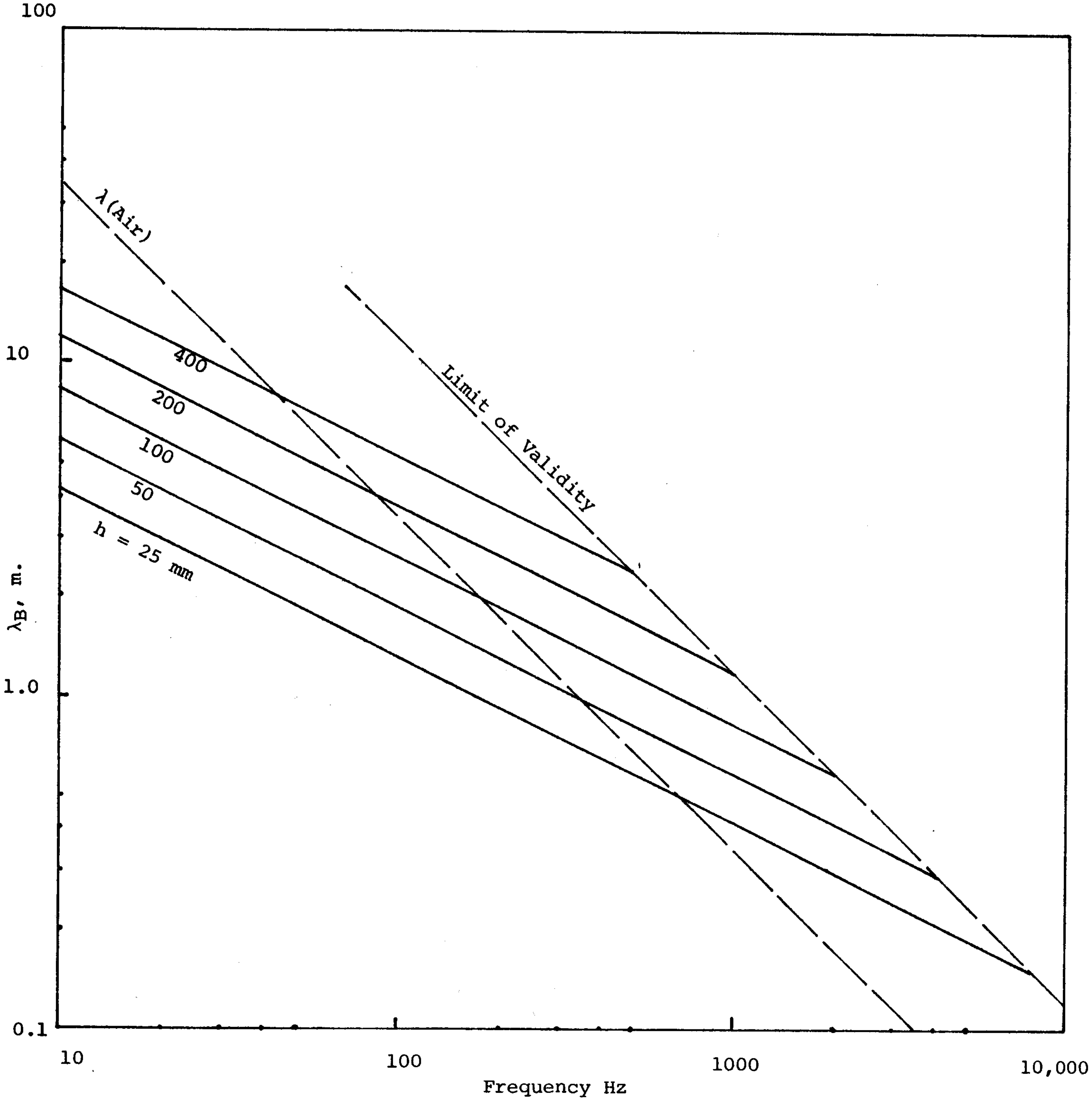

BENDING WAVELENGTH λ_B FOR CONCRETE WALLS

FIGURE 1

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BUILDING ACOUSTICS / DESIGN CRITERIA

Paper 8: SUMMARY OF ACHIEVEMENT OF DESIGN CRITERIA

Anita Lawrence, Graduate School of the Built Environment, University of New South Wales.

INTRODUCTION

The title of this summary is perhaps too ambitious, since it is evident from the previous papers that the criteria themselves are by no means settled, thus whether or not they have been achieved cannot yet be assessed.

Building acoustics has been the subject of many theoretical studies, and practical applications of the results of these studies as well as empirical solutions have been employed in buildings for at least three decades. However, it appears that it is only now that some of the 'correct' questions are being asked, with regard to human expectations; - that valid criteria and standards can begin to be formulated; - and that the complex systems that are called buildings can be analysed, albeit crudely, in order that acoustic performance may be predicted and measured.

As stated by Carolyn Mather, in the first paper, there are three areas in which efforts in noise abatement have been directed:

- elimination of health damage (particularly hearing)
- minimisation of interference with activities
- improvement of perceived quality of acoustic environments

It therefore seems appropriate to summarise achievements in each of these three areas.

ELIMINATION OF HEALTH DAMAGE

With respect to autonomous arousal it appears that no scales, indices or criteria yet exist, although it is known that quite low noise levels may affect autonomous body responses. More research is necessary in this area.

Noise-induced hearing loss is now well understood, at least for non-impulsive noise exposure, although there are political and economic factors which intervene when so-called 'safe' levels are determined. For example Australian States have endorsed an 8-hour exposure of 90 dB(A) (measured on 'slow' response at that) as the standard, whereas several studies have shown that much lower limits are necessary to protect a significant proportion of the population from noise-induced hearing handicap.(1). Even the 90 dB(A) standard is exceeded in many workplaces and it will be difficult to reduce the levels simply by engineering noise controls and by modifying buildings. However, the enforcement of recent legislation will ensure that serious efforts are made in this area.

Although not included by Carolyn Mather as a 'health effect'. continued interruption to normal sleep patterns by noise, even if not consciously perceived, is thought by some to have a deleterious long-term effect on health. Indeed, Paul Dubout suggests that 'a quiet place for sleeping' is one of the main requirements when setting indoor noise criteria. But, as he says, although there are a number of descriptors relating to loudness, noisiness, speech interference, etc. no specific descriptor is available for rating the potential of an acoustic environment for sleep interference.Thus such standards that are available, such as the indoor provisional criteria quoted by Dr.Mather of 35-50 dB(A) L_{eq}, together with a proviso that L_{max} should not be more than 10 dB(A) above these levels (for the different stages of sleep), may not be defined in terms of the most appropriate descriptor.

None of the authors have included 'annoyance' as a possible health effect, although an annoyed person certainly does not enjoy complete 'physical and mental well-being'. However, annoyance prediction is one of the very grey areas of acoustics and the most definite finding to date is that there is little correlation between any noise descriptor and individual annoyance reactions in 'real-world' situations. Nevertheless, the US Environmental Protection Agency has set some goals, in terms of L_{eq} (24 hr) and L_{dn}; both of which require the level, L_{eq}, not to exceed 45 dB(A) at night or 55 dB(A) during the day. These levels are somewhat higher than those suggested as maxima in AS 1055, Noise Assessment in Residential Areas. Both John Modra and Brian Harris have shown the difficulty of achieving these goals, at least near busy roads and airports. Railways, also, produce excessive levels during train passbys.

MINIMISATION OF INTERFERENCE WITH ACTIVITIES

Objective criteria are more readily available in this area, particularly with respect to interference with speech communication. Carolyn Mather has quoted maximum L_{eq} levels of 65 dB(A) for outdoors and 50 dB(A) for indoors for normal conversation at a distance of 1 metre; lower voice levels would require a further reduction of 5 to 10 dB.

Again, if these criteria are compared with John Modra's prediction of traffic noise levels at sites near major Melbourne thoroughfares, it is seen that they are exceeded at approximately 85% of the sites considered. (L_{eq} is usually 3 units below L_{10} for general urban traffic).

It is more difficult to relate L_{eq} criteria to aircraft flyover levels, since the number and duration of each flyover must be known as well as the maximum level. However, it would be safe to conclude that conversations are interrupted during each aircraft flyover at sites located a considerable distance along the approach and take-off flight paths. Brian Harris has given an interesting review of the considerable developments in aircraft noise suppression technology over the last two decades and he pointed out that if this had not taken place as a result of community concern, the situation would be much worse than it is now. However, he also warned that after the replacement of domestic medium and short range aircraft with 1970's technology machines, little further reduction in levels can be expected in the forseeable future. Since it is expected that the numbers of aircraft will increase, there is little hope of achieving outdoor (or even indoor) noise criteria in the vicinity of airports.

Although John Modra did not discuss the future possible reductions of individual vehicle noise levels, again, it is not likely that sufficient reductions can be achieved for conventional road vehicles to obtain compatibility with the speech interference criteria quoted.

It is possible to achieve satisfactory indoor noise levels by the correct selection of building components - using guidelines such as those provided by Robert Burton - Paul Dubout has pointed out that as yet there is no satisfactory method of rating building envelope performance with respect to the attenuation of transportation noises. In the United Kingdom, compensation is paid to those subjected to L_{10}(18hr) in excess of 68 dB(A), if the level is due to a new road or an improvement to an existing road. This is used to improve the attenuation of the building facade. There are proposals to introduce similar compensation in Victoria- but a degree of caution is necessary, in the light of the foregoing.

Even for one source spectrum, such as that from road traffic noise, the effectiveness of different components varies markedly according to whether the goal is the reduction of loudness (in dB(A)) or the improvement in speech communication (in SIL).(2)

There is the additional problem of the incompatibility of good envelope sound attenuation and natural ventilation (referring again to Robert Burton's paper in which the effect of very small openings on sound transmission loss is shown graphically). The conventional solution - that of installing mechanical ventilation or air-conditioning may itself produce new noise problems, as Bruce King warns, as well as impeding energy conservation.

Structure-borne noise in buildings was reviewed by Bruce King and it was shown that it can be controlled, although this control is difficult except at the design stage. Although some building regulations in Australia do include some measures to reduce structure borne noise (including plumbing noise) in multi-family buildings, their scope is limited and there are many older buildings in which the occupants certainly do not enjoy acoustic privacy with respect to their neighbours, one of the criteria mentioned by Paul Dubout. The knowledge is available to control structure-borne noise in buildings, although in practice other constraints, such as structural viability, may limit the attenuation that can be achieved economically.

The effectiveness of internal building components in attenuating airborne sound is usually ranked by the fitting of a grading curve. The shape of the curve used in Australia and the United States, as well as in some European countries, was originally based on the performance of a 230 mm brick wall, which was known to provide 'acceptable' privacy between neighbours in multi-family dwellings. The shape of the curve was later validated by Northwood, for a mix of 'typical household noises'. (These noises did not include high-powered hi-fi systems). Later work has shown that rating internal dividing elements against this curve is inappropriate in some circumstances,and Paul Dubout suggests that a small number of differently shaped curves should be available to suit different source spectra. However, he recommends that the STC curve (based on the 230 mm brick wall) should be retained - not only for continuity, but because of its fortuitiously close approximation to the A-weighted level difference either side of the partition for a pink noise source spectrum.

Robert Burton has shown how the sound transmission loss v. frequency characteristics of a building component can be modified by changing the surface density or damping - in addition, if high values of sound transmission loss are necessary it may be more economical to adopt double panel construction.

Thus it seems that in this field, provided that the source noise is known, and that the acceptable level in the receiving space is defined, it is possible to achieve the criterion by the suitable choice of building elements. (The importance of the background sound level in the receiving space must not be forgotten.)

IMPROVEMENT OF PERCEIVED QUALITY OF ACOUSTIC ENVIRONMENT

Peter Knowland drew attention to reverberation as an important factor in acoustic comfort, and yet this is rarely mentioned in criteria for noise control in buildings. Robert Burton gave examples of the types of material that may be used to control low, medium and high frequency reverberation, thus the tools are available, and the techniques are well-known (at least amongst acousticians).

Carolyn Mather agreed with John Large that to obtain overall improved quality of acoustic environments a different approach will be required - compared to that used for the protection of health and welfare of a community. Technical and economic constraints affect the quality that can be achieved at any time, but as these constraints change (for the better it is hoped) so should the goals. A third constraint is the political one - the decision of the community as transmitted through its elected government.

The goal, surely, must be the achievement of criteria such as those envisaged by the US EPA and AS 1055, in all inhabited spaces.

CONCLUSION

This last decade has seen a marked change in the availability of acoustic standards in Australia; - for assessing annoyance in residential areas; - for building siting and construction against aircraft noise intrusion; - for ambient sound levels in areas of occupancy in buildings;- for measuring reverberation times; - for measurement of transportation and constructional vehicles' noise; for hearing conservation and for acoustic instruments. In addition, various environmental, health and transport authorities have developed legislation covering various areas of noise and this has been enacted in many States.

Thus, as far as practical noise control is concerned, the last decade has been one of great progress. However, there are still too many unknowns - in deciding on correct descriptors of the noise environment - in the choice of rating systems for building components - in setting criteria, goals and legal standards - in achieving designed performance in practical building situations.

Transportation noise will continue to be the main bugbear preventing achievement of noise goals inside and outside buildings. Since source noise reduction of individual vehicles - cars, trucks, motor cycles, trains and aircraft - is extremely limited in the forseeable future, it is essential that land-use planning, building siting, building planning, design of building elements and the control of ventilation openings are all used to minimise the effects of external noise intrusion. For those worst affected, some form of compensatioln appears to be the only solution, so that they may achieve a reasonable standard of acoustical comfort at least within their own building.

Neighbour-noise, in multi-tenanted buildings, may be controlled readily with the techniques that are currently available, although in a free-market economy it is likely that these techniques will only be used effectively if building regulations require certain standards to be met. Much more research is required regarding the most appropriate noise descriptors and grading systems to be used for ranking the efficiency of building elements and noise reduction techniques.

The gulf between desirable goals for hearing conservation and for pleasant acoustic environments, and the actual acoustic environment present in a large proportion of workplaces and urban areas, is great. However, with the greater awareness in the community and the greater experience available in the acoustic fraternity (sorierty?) there is room for an optimistic hope for a guieter future.

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