NOISE ZONING

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NOISE ZONING

I N D E X

SESSION

INTERACTION OF MAN, NOISE AND ENVIRONMENT

by

R.G. Barden

Department of Mechanical Engineering
Monash University

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As we reflect on the interactions in our lives we find sound plays an important part in the many activities to do with our contact with others and the happenings in modern society. We sense and respond to sound as it appears in both the wanted and unwanted form. For the majority of people a world devoid of sound has really no meaningful dimension. There are, however, some who have no choice other than to live in a world of silence and of these a proportion, through lack of experience, are not able to comprehend what sound is really all about except perhaps in some abstract or indirect way. They are those who at the moment of birth have suffered the severe penalty of no hearing at all as an outcome of a natural malfunctioning to do with the embryonic process through which we all pass. Even at a later stage in our development a penalty may be inflicted by a natural or accidental process in addition to the exposure from the environmental conditions which the individual meets daily in the course of his living.

We see from these few remarks a linking together of three noteworthy considerations, the presence of man, environment and the presence of sound as a specific part of that environment, leading us to the discussion here. But it is because of man that such a discussion takes place. In his final Reith lecture "The future of man" P.B. Medawar (1) concluded by saying "that the bells which toll for mankind are - most of them anyway - like bells on Alpine cattle; they are attached to our own necks, and it must be our fault if they do not make a cheerful and harmonious sound". And in days gone-by the philosopher George Berkeley asked if a falling tree makes noise when no one is near to hear the sound. The dual nature of sound is therefore apparent - the physical interpretation due to the generation and dissipation of a form of wave energy and the human perception of the propagation of a disturbance, called sound, as this is felt by people.

In humans, the receptors sampling the environment are called exteroceptive receptors and are further classified according to the sort of stimuli to which they are sensitive. Those sensitive to an energy source some distance away are referred to as distance receptors. Furthermore because our existence often depends on the trend of the prevailing condition the division into a constant state or a changing state receptor is also made. The changing state receptors signal a change in the stimulus to give notice of a new happening which may be important. This is done by a rapid and immediate discharge of nerve impulses at the start and at the finish of the stimulus applied. The signals so created cause information to be transmitted to the central nervous system and the ear for instance might be expected to report all sounds within range. It is, however, more selective than this with some sorting and selection by the sense organs themselves followed by similar processes in the central nervous system for the interpretation of the incoming information by the brain. Sense organs are therefore banks of receptors situated between the brain and the environment. Often we seek out the stimulus to which we wish to respond. It is in this context that ears are not for hearing but for listening. The aim is to gain the more useful information from the functioning of the receptors and to generate nerve impulses as the effect of the environment is felt upon their outer surface. Evolution has seen that specific cells or modified nerve fibres respond to the particular sort of energy associated with the type of event that it selects to record for the purpose of passing information to the cerebral cortex of the brain. Within the brain other regions give aid to provide protection and indeed reflex action and the alerting of other senses may be taken as typical examples. Through audio-visual reflexes there is the natural tendency to turn in the direction of the sound to gain additional information to do with a specific happening within an environment.

The property of sensation and that of perception is of some importance as the complex signal web to do with our senses operates the human system of man. Sensation is the process of response by the sensory apparatus to a stimulus derived from a source. Perception is the process of becoming aware of the source originating the stimulus. By apperception there is recognition and identification of the source in accord with previous experience.

For each of us this built-in capacity is developed over an appreciable period of time and through learning allows one to listen. Without hearing, learning how to communicate needs a great deal of tuition. Perhaps the most important function of the ear is to hear the human voice and the speech contained in the human voice. For the conveying of information, speech is a most comprehensive pattern of sounds which leads to a closer contact and the likelihood of a more tolerable understanding of our fellow man.

However, to tolerate some humans and some happenings is a task bringing in many considerations. The behavioural sciences through such study fields as psychology, psychiatry, sociology and anthropology are gradually contributing to a better understanding of the interweaving factors which cause action and reaction between humans. Closely linked are our needs, desires and emotions (2). Reactions to emotions are not the same in everyone as is clearly demonstrated in the terms of behaviour. Such influences give effect to the quality of life as people in an environment respond. It has been remarked that "in a broad sense, man, as an organism lives and functions in an environment which can be described as the aggregate of all external influences affecting the life and development of the organism.

The environment consists of the air man breathes, the buildings in which he lives and works, the clothing he wears, the food and water he ingests and so on. Man, on the other hand, has been able to make profound changes in his environment, and this, in turn has introduced new factors which act on and affect, the life and development of man". Through a continuation of these remarks to do with the environment in relation to Otologic disease, Sataloff and Zapp (3) say: "environmental changes are perhaps most marked in the areas which may be called 'occupational' and these date roughly from the industrial revolution. They are occurring at a more rapid rate than at any previous time in history. The new products and services which have evolved spill over into the non-occupational environment, and the question arises as to what effect all these environmental changes may have on the incidence of new and old diseases".

New diseases might therefore be expected to arise from the neglect of some part of our general health. Health is now taken to mean a state of complete physical, mental and social well being and not merely an absence of disease and infirmity. In this statement attention is given to the physiological, psychological and sociological aspects of health. Unwanted sound and the annoyance caused by it impinges directly on the latter two and hearing loss from intense sound on the former. Basically the performance of a nation depends on the intelligence and the health of its people. Other things stem from these. The full potential in a nation can only be realised when people are able to use all their senses effectively. It is because of this that we should seek to avoid the further abuse of our environment as it too can contribute further to the already prevalent natural malfunctioning in each of us.

The effect of noise on behaviour and performance has received some attention. Broadbent (4) and Burns (5) have reviewed the situation to do with annoyance and the effect of noise on the way a task is performed. From experience general agreement would be expected about some noises being annoying to almost all people whereas of all the noises made only some are condemned. Individual differences are such that the response to a stimulus may range from neutrality (or indeed pleasant acceptance) to one of hostility. As would be expected many emotional associations do play an important part in this assessment. Because of the complexity of the interactions it is better to have a positive approach to see that some of the problems do not arise both in the work situation and in community life. There is some evidence that we are beginning to think in such terms to avoid some problems and this in turn will in a constructive way be most rewarding. In the seeking of value in our living, behaviour through the quality of the environment must surely be of some importance.

1.4

In the study of annoyance from noise the work for its measurement has been built upon studies to do with

(1) man's perception of the noisiness of the sound and its spectral and temporal aspects,

(2) man's social and political behaviour and the acoustical environment.

The physical nature of sound may be determined quantitatively through the spectral content in terms of frequency and intensity. From the consideration of intensity the unit, decibel, is defined in logarithmic form. By so doing, reference levels may be selected to give convenient numerical values for ease of handling in the field of practice. This partly arises because of the wide dynamic range encountered in the measurement of sound and partly because the hearing mechanism reacts to relative quantities rather than to absolute quantities. The product 10 log (ratio of intensity) expresses the value of the sound intensity in decibels. More widespread in its use is the sound pressure level in decibels with a reference sound pressure level of 0.0002 ubar. This is given by the product 20 log (ratio of S P L). As an indication of the variation in the intensity encountered a change of 10, 20 and 100 dB give intensity variations of 10, 100 and 10^{10} in the sound energy present.

In common use as a somewhat preferred measure is the unit dB A. This has arisen through the findings from subjective studies to do with the response of the ear to sound. It may be regarded as the human dB level for sounds of not too high intensity. The scale setting in a sound level meter is achieved by inserting a weighting network having appropriate attenuation values approaching the auditory response characteristic of the human ear with frequency. The unit dBA has been found convenient in assessing the noisiness of sound.

On the second issue of man's social and political behaviour enough has been said in the literature to show how difficult it is to bring forward findings in absolute terms. Firstly, of all the mass production systems the human one seems bent on producing models all of a different kind and because of this there is no single yardstick to say with certainty how a person is going to respond to an event. Secondly, the following factors show that location influences the problem of annoyance as well. Hawel (6) in giving these factors stresses that they are by no means exhaustive for an adequate study of annoyance.

PERSONALITY - the experience of the person and how he experiences the happenings in a given location influenced by:

The SITUATION - (day, night)

The present ACTIVITY of the person - (work, rest, play)

The specific QUALITY of the sound - (its nature and type)

The sound LEVEL dBA - (weighted loudness)

Each item mentioned has its own statistical interpretation and taken together they present a formidable problem for an overall assessment to be made in simple terms. The search is for some parameter, however imperfect, which might be used as a guide to judge whether or not a particular situation is likely to be annoying for most people. In cold scientific terms is there some objective parameter which might generally be used as a measure to allow this to be done?

Up to the present time there have been a number of suggestions in the field to do with machine noise and the community, examples are:

TRAFFIC NOISE INDEX

$$TNI = L_{90} + 4\,(L_{10} - L_{90}) - 30$$ and is usually 60 and above

The sound levels are taken as the value exceeded by the noise spectrum for a defined percentage of the time. It is often said that $L_{90\%}$ / 35 dBA at night and $L_{90\%}$ / 50 dBA by day.

In Sweden a survey showed that 20% of people were very disturbed at a mean energy level of 55 dBA outside dwellings based on a 24 hour period.

NOISE AND NUMBER INDEX

$$NNI = L_{PN\ max} + 15 \log N - 80$$ and is usually about 50.

Essentially this index was developed by the Wilson Committee on Noise in the United Kingdom for a number of events.

The perceived noise level $L_{PN\ max}$ was the average of the 2% time peaks. There have been many other suggestions and a recent one is worthy of a comment.

Dr. Robinson of the National Physical Laboratories has put forward the concept of Noise Pollution Level. It is made up of two parts, the first to take account of the general level (adaption level) and the second superimposes on this the effect of the fluctuating nature (the variability) of the sound. We may write

$NPL = L_{EQ}$ (Adaption Level) + 2.56 o (Fluctuating Effect)
where o is the standard deviation
and $L_{EQ} = L_{50} + 0.05\ o^2 \log_{10} e$.

Checks have shown that this expression agrees fairly well with estimates of annoyance obtained from other expressions in the traffic and aircraft noise fields. It is yet too early to say how effective this will be shown to be in the attempt to seek out a general measure of assessment for all situations. Much more work needs to be done.

The effect of noise on a person may range from demonstrated annoyance and speech interference to permanent hearing damage. Of the many reasons for seeking out the control of environmental noise, a number may be immediately listed in the search for better environments and less abuse of the individual. Specifically there is the consideration to be given to measures needed to avoid public nuisance. This must bring in how best to engineer the environment and its artefacts together with the need for regulations to protect and if necessary compensate the individual.

Also to do with environments there is the matter of effective communication between individuals and groupings through better intelligibility criteria as related to noise. Yet again there is often the need for a subtle balance required of an environment. The performing arts and other participating activities depend greatly on sound propagation and the control of the level of noise intrusion.

In the work day situation both work efficiency and safety have need of attention when noise is a component of the environment. However, of paramount concern is the problem of noise induced hearing loss both at work and in everyday living from the growing industrialisation of nations which paradoxically is created to serve man through a condition of generated increased stress. Little wonder then at some of the outburst which occurs in society as the individual responds to some of these happenings and questions some of the values in life today. With care and the will to act and through the guidance of responsible practitioners the value we should attach to our environment can be achieved.

Speech, directly and indirectly plays a decisive part in defining the requirements of many acoustical environments. The reception of speech may be masked by noise, other speech, music or limited through loss of hearing. This may happen when at the space point considered there is a conflict between the dynamic content of the wanted speech and the masking effect. The masking may encroach into the speech dynamic range or indeed submerge it completely. Intelligibility may be wholly disrupted or affected in part. Noise may be measured by assessing its speech interference level (SIL). Basically we may divide the core contribution to speech into three frequency bands contributing equally to speech intelligibility. These are 300 to 1200 Hz, 1200 to 2400 Hz and 2400 to 4800 Hz. There is, of course, some further contribution from the frequencies flanking the core width of the three bands.

It is normal for equipment used in practice to have four octaves spanning the range 300 to 4800 Hz. Because of this, where the noise level in the 300 - 600 Hz octave is not more than 10 dB above the octave which follows, the arithmetic mean of the levels in the three higher octaves may be used to determine the SIL. If the noise level in the 300 - 600 Hz octave is 10 dB or above then the mean of the levels in the four octaves should be taken.

In the United States there is the recent tendency (7) to move towards a preferred octave speech-interference level (PSIL). The octaves taken are those centred at 500, 1000 and 2000 Hz. It is claimed that the predictive property of such a measure reduces the error in the assessment of the degree of speech interference from diverse spectra noise. The PSIL seems to be a flat 7 dB lower than the noise level in dBA. For a normal voice and a raised communicating voice the distance between the speaker and listener for satisfactory face-to-face speech has been given.

Level dBA	55	65	75	85	95
PSIL dB	48	58	68	78	88
Normal Voice FT	13	5	2	1	0.5
Raised Voice FT	13	8	6	4	3

Even though methods are available whereby the acoustic requirements of a particular space or activity may be assessed and the desired result can be approached there continues to be in some cases a reluctance to avoid a stress situation. At airports, shipping and rail passenger terminals, places for holding of public meetings poor sound quality and low speech intelligibility persists. To the individual attending such places some of the information which should be heard is often most important.

The cause of poor communication may however not be wholly due to the physical environments. A language difficulty or a hearing loss may add with noise to limit the individual in the understanding of the information to be transmitted. This is a very special problem in Australia where so much reliance is being placed on a migrant work force in the development of this country. One should question very seriously the right of any group to inhibit further the difficult task of assimilation by inflicting an additional handicap on newcomers through the penalty of hearing loss. It is a special problem because both the hearing and learning of a language is concerned and this coupled with the trend of having a lot of migrants in high risk work situations creates goals which conflict. They conflict because to learn a language one must hear and furthermore to train and retrain a work force to maintain its effectiveness the hearing of an individual is important. And yet many who are in control give scant attention to quite unacceptable levels of noise and even hesitate to recognise the problem. Speech and the hearing of speech within environments is of prime importance not only for those of us already here but for those we wish to attract and hold for the future development of this nation. As a nation we might well ask what is the goal in allowing such wretched situations to exist.

Noise induced hearing loss is usually associated with occupational environments. Problems abound in modern industry and measures to protect the occupational health of people have seen much refinement and have been given a great deal of attention in recent times. Unfortunately not always can guidelines be given with certainty. Industry and commerce are business concerns and are subject to all sorts of risks. In the economic balance of such organisations action is possible if the degree of the risk is known. In the field of Noise Induced Hearing Loss (NIHL), the question of risk is raised.

In some industrial environments the worker is at risk because of likely hearing impairment. If control measures are taken too far then the industry is at risk because of the heavy cost of remedial measures and if attention is not given to these then there is the possibility of the risk of compensation. A compromise has to be found and this obviously depends on enlightened management willing to do their best in the circumstances and the workers themselves in making the most of protective systems for their benefit. The problems are:

1. What are the guidelines and how much agreement is there in the back-up studies supporting these?

. What is to be the basis for the estimation of risk?

If by the method of noise control the situation is not optimum then how best to introduce hearing conservation programmes with the co-operation of the workers?

Although highly complicated there are certain trends coming through. The requirement is to study a large group of people preferably exposed only to occupational noise and another control group assumed to be non-noise exposed. Furthermore we need to study these groups for a long time, a time expressed not in days but years. Usually this means case histories through surveys with all the doubts of recall and record. Some factors which come into the studies are:

SOCIAL - domestic and recreational, sporting, modern vibrant activity;

OCCUPATIONAL - type of activity in the work situation and the individual's medical history, if possible from birth;

RECALL - the interpretive capacity of the individual to give a balanced and an honest opinion.

If one accepts the basis on which the risk has been estimated then 80 dBA and below sustained for 8 work hours daily for 20 years shows the "susceptible" with soft ears to be affected. No one of course has a working life of only 20 years.

Technologically much more could be done to counter the problem of noise induced hearing loss. It is only of recent times that noise and vibration control have become equal partners at the technical design stage, the time to really consider noise, in the context of man, machine and environment. Post-design measures usually end up as ad-hoc measures to counter a nasty situation. This sort of palliative action tends to be costly. However, not always can engineering measures help and then personal protective measures must prevail.

I have attempted to say something about subjective aspects of acoustics which should I feel be of interest to those attending the conference. In part it is some of the influence felt by the individual when sound is a component of the environment. Sound often arises from our activities as we innovate and participate. It is, I feel, important for us not only to think deeply about the core activity in which we get immersed but also to think of the effects which are shed on the way. When unwanted these need serious consideration if we are to safeguard the conditions in which we live. Sound in its many forms will continue to contribute greatly to the life of man and in turn man through the control he has must learn how to dictate the true quality requirement for zones within his environment.

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Noise Zoning - A Logical Approach

by

J. A. Rose

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NOISE ZONING – A LOGICAL APPROACH

INTRODUCTION

In the last decade the general public has become aware that many of the benefits of living in an industrialised society are illusory. They now know that each advance in the speed or convenience of transport or in the application of power to reduce physical effort is usually accompanied by a reduction in the amenity of the environment.

Population density and industrialisation cause the accumulation of waste products which pollute the environment. Urban noise has been included because it is a major factor in reducing the pleasure of living in modern cities and towns.

Noise pollution is a growing problem in all developed areas of the world and communities are searching for a means of reducing its effects.

The ideal solution would call for elimination of excessive noise at the source but, until technology is sufficiently advanced to achieve this at reasonable cost or people are prepared to abandon the comforts and amenities which come from industrialisation, the goal must be to reconcile society to industry by proper planning.

Planning must take into account the trends in industrial growth, living conditions and transport needs with the aim of predicting the future environment and ensuring that any changes are beneficial.

Zoning, which is a method of delineating areas with particular requirements, is a logical step in planning to achieve the necessary reconciliation. When combined with a means for defining restrictions or specifying compatible land usages, it provides a rational solution to an otherwise intractible problem.

Other papers will deal with particular aspects of the problem but, to demonstrate the likely effectiveness of zoning, it is necessary to refer to the historical development of noise pollution, the extent of present knowledge regarding it, and future trends.

2 PROGRESSION OF THE PROBLEM

The growth of noise pollution is directly linked to the development of cities and industry.

Cities grew from the necessity for people to exchange goods of wider variety and in greater quantities than was possible in the village or town market. They were possible only in locations which had some natural advantage for transporting goods, such as a sheltered harbour or navigable river and in societies where it was possible to exploit the local natural resources of land and water with less than the full effort of the total population.

With the advent of industrialisation it was possible for less and less people to produce enough basic necessities for the overall society and the trend toward larger urban and smaller rural communities accelerated.

To enable these larger, more sophisticated societies to function, it was necessary to develop rapid and convenient transport systems for both people and goods. Not all of these developments were beneficial but at least they permitted people to communicate more readily and from this, together with available leisure, many cultural activities grew

Since industrialisation with its attendant urbanisation and transport needs has been proceeding for centuries it may be questioned why pollution is suddenly an urgent problem. The answer lies in a combination of factors:

First, pollution is a wasteful by-product of the use of natural resources which, in the case of fossil fuels, are not of limitless extent.

Second, the adaptation of people to the environment may have disguised warning signs which would indicate the possibility of subtle effects on them.

Though from the earliest days of the industrial revolution it was known that certain occupations were associated with deafness, extensive research on the critical aspects of harmful noise and its physiological effects has occurred only recently.

This research indicates that hearing damage of sufficient magnitude to cause communication difficulties is most unlikely to occur to residents in the neighbourhoods of industrial areas or near major airports. The Australian Parliamentary Select Committee on Aircraft Noise reported specifically on this subject:

Para. 6.2.1 "Effects on Health Persons":

> "Effects on Health Persons". The Committee concludes that at the exposure rates and noise levels commonly experienced by communities living beneath flight paths near major Australian airports any effects on the physical state of persons in good general health are negligible and it has not been given any medical evidence to the contrary."

It may be significant to repeat a statement given in the report of the International Civil Aviation Organisation (ICAO) meeting at Montreal in late 1969:

"In summary, long range epidemiological research on the potential effects of aircraft noise exposure is required to define the statistical significance of any effect of such exposure on physical or mental health. Such research should be performed with special emphasis on the question of whether there are long-term exposure effects at present unrecognised . . . "

This view would be endorsed by those who know the term "socio-acusis" which defines the difference in hearing levels between those living in advanced or primitive societies. It is assumed that the greater deterioration of hearing with age of those in developed countries is due to increased noise exposure.

Many statements have been made to the effect that background noise levels in major cities are rising at the rate of approximately one decibel per year. Though in Australia there has been no long-term programme to validate such an hypothesis, spot checks taken in central city and suburban areas over a period of years tend to support a growth rate of this order.

Is this progression inevitable if we are to retain the benefits of industrialisation and communication? Acousticians can assure the community that most of the benefits may be retained if we are prepared to accept some slight reduction in mechanical efficiency of machinery and in the development of real estate to suit short-term needs.

The first basic change in the growth of noise has been the evolution of communication systems which do not require the movement of anything larger than electrons. Although we all curse the telephone at times, there is no doubt that its use reduces the need for people to travel or to communicate by mail. Industrialised society with its high-speed transport could not function efficiently without the use of electronic communication systems as as these develop further, the need for business travel should dimish, though this may be offset by an increase in tourist travel or the transport of goods.

Another factor of growing significance is the application of automation to perform many of the more onerous or tedious tasks. Automation greatly changes the production/worker ratio and frees production plants from the necessity for location near large centres of population.

If further major improvements can be made in the distribution of goods and in communications systems we may see a reversal of the historic drift to the cities.

Already we have seen in Australia that the former natural requirements for the evolution of a town or city such as proximity to a sheltered port, water supplies, arable land and congenial climate can be ignored or created artificially if a valuable resource is available in sufficient quantity.

Planning should take account of these possibilities but at present it would be inadvisable to go beyond the existing "state of the art". The need for zoning to avoid problems of great magnitude can be gauged by reference to the growth diagrams for Australian cities, developed by the various planning authorities.

NOISE EXPOSURE

The response of people to sound has been investigated for many years and the methods of evaluating noise exposure are based on the characteristics found to be important.

Sufficient is known of the effects on hearing of long-term daily exposure to industrial noise to enable assessment of the risks involved and to indicate the most suitable corrective measures. Where doubt exists the corrections used are slanted toward conservation

While hearing conservation is most important in the fight against noise pollution, usually we are concerned with annoyance or loss of amenity to urban communities from industrial or transport noise.

The systems for dealing with community noise are not as well defined as for hearing conservation and have tended to develop around each type of noise separately This does not seem to be rational since all forms of noise, if they are perceptible, must contribute something toward overall experience.

Measurement systems range from the simple sound level meter to real-time analysers with their associated computers. Standard procedures have been devised using the "A" weighted response of the sound level meter to evaluate community noise.

The Commonwealth Acoustic Laboratories have for many years advocated this simple system combined with a correction procedure based on more complicated studies relating subjective response to particular types of noise.

Further advantages of using a common simple system are the ease of summing exposure from many different sources and the facility with which measurements may be performed by relatively unskilled personnel.

In our view the intricate operation is the correction of results and it is here that the greatest objectivity and expertise are needed to avoid errors which greatly exceed the probable measurement errors.

As results of further research become available, a continuing process of refinement should enable more accurate application of corrections so that separate individuals, after going through the steps of measurement and correction finish with the same result and that result also corresponds well with community response.

An overall system for dealing with community noise must include the following factors:

(a) Characteristics of all noise sources
(b) Noise control
(c) Subjective characteristics
(d) PLANNING
(e) Noise Reduction
(f) Motivation
(g) Community response

Steps (a), (b) and (c) determine Potential Noise Exposure (P.N.E.) and planning, which includes zoning, determines Noise Exposure (N.E.), which in turn can be modified by steps (e) and (f) before community response is assessed.

The form of community reaction to noise is not attempted here and it is doubtful if reactions found in one national group would be applicable to any other national community because of differing temperamental and sociological factors.

To avoid confusion, in this paper noise control is regarded as the specification of permissible noise levels while noise reduction involves the amelioration of noise exposure by architectural or engineering means.

The term PLANNING is shown in capitals as this includes ZONING, with which we are most concerned, but it also covers the specification of suitable constructions for various activities and zones.

The present systems which sum the total noise exposure over a complete day or for longer periods are somewhat illogical since they assume that people occupy the same premises over the complete twenty-four hours of each day of the year.

Of course, this applies in residential areas only to housewives and children below school age since the majority of workers and school children move into a different noise environment during the day.

It may be reasonable to consider those who are in one location most of the time since they are the main complainants but, if we are interested in the total effect of noise on the community, it would be more logical to relate permissible noise directly to all activities and the sensitivity of people to disturbance during particular aspects of daily life, i.e. a slight variation in noise could probably be permitted to correspond with the normal phases of sleep.

In 1957, Commonwealth Acoustic Laboratories (Ref. 1) suggested a term "Annoyance Index" (AI) to represent the summation of a series of noise events over a period and later (Ref. 2) suggested that one hour was a suitable period to adopt in Australia. This period was selected in the belief that people mainly complain about the noise experienced in a particular short period and that tolerance to noise varies significantly from hour to hour.

Hourly summations permit specification of noise exposure to suit natural variations and the method can be extended into daytime, night-time summations, etc. for comparison with other systems used throughout the world.

Though this method was developed for aircraft noise it is understood that both Western Germany and Switzerland are incorporating it into their new acoustical codes for community noise.

NOISE EXPOSURE PREDICTION

The most thorough attempt to predict future noise exposure is the Noise Exposure Forecast (N.E.F.) system developed to assist planning near airports in the U.S.A. and recommended by the Parliamentary Select Committee on Aircraft Noise for adoption in Australia. The Committee was very careful to restrict its use solely to the prediction of noise exposure and cautioned against its extension into definition of compatible land use or prediction of community reaction.

The system is based on dividing all common aircraft types into ten categories, allotting climb profiles according to category and planned flight distance, then deriving noise from sets of standardised curves. Landing noise contours are also available and the system includes methods for combining all operations and allowing for critical subjective factors such as time of day etc. Because of its complexity the system has been adapted for processing by computer.

Present weaknesses in the system, which could be easily overcome, are lack of allowance for ground-running of engines and the use of reverse thrust on landing.

These were probably excluded because, in effect, they are noise sources located on the ground and subjective response to such noise would differ from that of overflight. Present systems do not adequately explain the difference in subjective response for stationary, moving and airborne noise sources but motivational factors may be involved.

D.W. Robinson (Ref. 3) has suggested that subjects judge the "noisiness" of sounds in relation to their previous experience of similar noises and also to the situation in which they are listening.

In the well-known Wilson Report (Ref. 4) it was stated "a noise, originally annoying or disturbing, becomes tolerated and even unnoticed by most people when it has become sufficiently familiar", and in a previous paper (Ref. 5) the present author offered the lack of familiarity as a possible explanation for the adverse public reaction to the continually changing pattern of aircraft noise.

Though the N.E.F. system is based on the highly complicated unit, Effective Perceived Noise Decibel (EPNdB), with suitable corrections it could be expressed in simplified units such as "dBA". The simple measuring systems have been used for many years to rate the acceptability of industrial and transport noise systems.

If all methods of rating noise were expressed in the one unit it would be possible to derive a composite measure for noise exposure consisting of a number of events, each differing from the other and to allow for events which intermingle.

A plan (Fig. 1) is included which shows the noise exposure contours which could be derived if a common system of rating noise were adopted. It illustrates the levels of noise to be expected from the operation of an airport, railway, highway and industrial areas, together with general types of development which may be suitable for specific locations.

The noise contours are hypothetical but sufficiently close to reality to illustrate that:

(1) The area of noise exposure depends on the sideways spread of sound from vehicles, i.e., a change in directivity pattern may be as effective as an overall reduction of noise.

(2) When studying aircraft noise exposure it is necessary to consider the characteristics of aircraft and the paths they normally fly, i.e., the sound power, spectrum and directional characteristics of each aircraft type plus the aeronautical performance must be known to determine noise heard on the ground.

(3) Industrial noise is a problem for a small area in the immediate vicinity but does not affect a large proportion of the general population.

(4) Motor vehicle noise, because of the number of roads and the proximity of buildings to them must be the most widespread form of noise pollution.

(5) The area affected by noise near a major airport is probably much less than the total affected areas near a busy highway but airports are usually built fairly close to city centres on land suitable for residences, whereas road-side areas are less suitable for this type of development throughout the length of the highway.

CRITERIA FOR ZONES

Critical levels for zones must be expressed in units measured and corrected under standard conditions.

To apply criteria it is necessary to have reliable, accurate instruments and also personnel trained to carry out standard measurement techniques.

Before arriving at specific figures we must weigh the likely consequence of each proposal on the health, comfort or welfare of one section of the community against the economic burdens placed on others.

Criteria are therefore, to some extent, set by political decisions. This is not unreasonable since specialised groups, such as acousticians, may get out of step with general community requirements. However, it is the responsibility of specialist groups to keep the community well informed so that the most enlightened decisions can be made.

There is no simple way to compare the costs and benefits of the various alternative methods of alleviating noise pollution, but it is sometimes useful to show the effect of different options diagrammatically.

A diagram is included to illustrate the likely effectiveness and costs of steps (e) and (f) of the noise exposure system mentioned earlier.

The diagram is entered at the appropriate point on the noise exposure (N.E.) ordinate and a line is drawn parallel to the descending 45° lines until the limit of noise reduction to be applied is reached. A horizontal line is then drawn to the "Con" limit of the "Bias" graph. The "bias" section allows for the well known effect of community prejudice toward or against the source of noise. If the bias is "Con" a horizontal line is drawn from the entry point to the ordinate which gives an estimation of the proportion of the community who would be prepared to accept the noise in question. If the bias is "Pro" a line at 45° is drawn to the acceptance ordinate and if the bias is neutral, the centre-line becomes the start of the line at 45°.

At the bottom of the main graph are two smaller graphs, one showing the relative costs of engineering noise reduction and the other the costs of improving the public relationship (P.R.) of the source.

The point made is that the costs of engineering noise reduction are likely to increase greatly with each extra dB required, while the improved acceptance due to a good image is more likely to be linear in expenditure of effort or money with each dB gained.

The exponents x and y, together with the scales for Noise Exposure, Noise Reduction and Bias are all determined by the individual characteristics of each noise situation being studied and the graph is intended only to illustrate phenomena which are otherwise difficult to describe and balance one against the other.

Particular points being emphasised are:

1. Noise Reduction and public relationships are additive in obtaining higher acceptance of noise.

2. The relative costs per dB in each case may vary significantly.

3. The proportional acceptance scale derived from a standard distribution curve is likely to be linear in the middle and stretched at either end.

4. There will be some people indifferent to high noise exposure.

5. There will be a few people who object to even the lowest noise levels likely to occur in normal circumstances.

6. The costs of satifying this small group would be extremely high as a law of "diminishing returns" applies to most forms of noise reduction.

Examples shown on the graph are:

Line a: Fairly high noise exposure, noise reduction nil, poor, P.R., giving less than 20% acceptance.

Lines b,c,d: Fairly high noise exposure, moderate noise reduction, neutral bias giving approximately 50% acceptance.

Lines e,g,h: Fairly low noise exposure, moderate noise reduction, poor P.R., giving 80% acceptance.

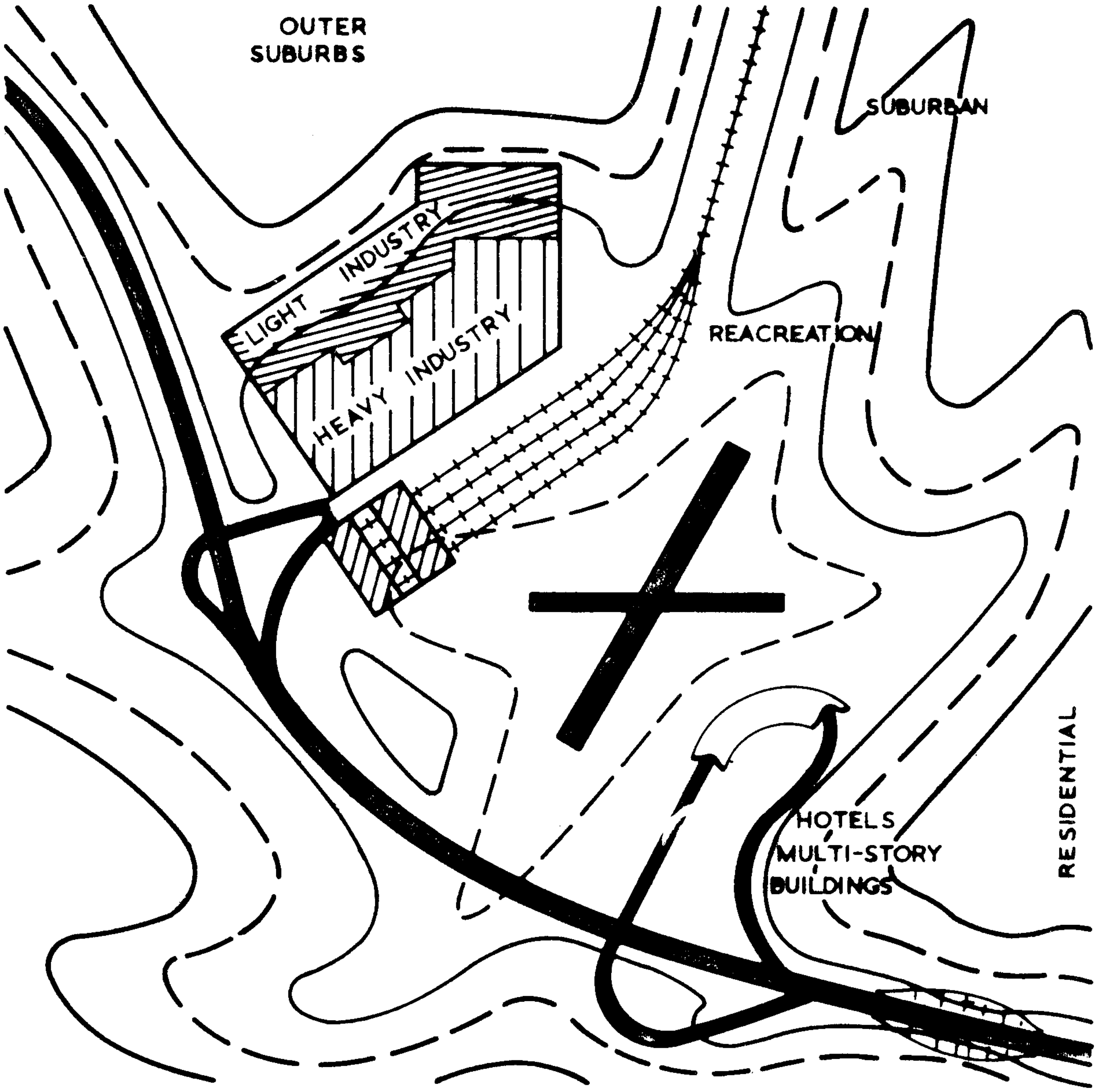
Lines e,g,i: As above but with good P.R. Giving 90% acceptance.

Lines e,j: Fairly low noise exposure, high noise reduction, poor P.R , giving 90% acceptance.

Line f: Cost of moderate noise reduction.

Line l: Cost of high noise reduction.

Though all socially conscious people would like to see noise pollution eliminated or drastically reduced, only practical solutions will win enough support for laws governing noise zoning and noise control to be enacted. Intemperate or idealistic proposals will do more harm than good and we must face the fact than economic consideration will determine the criteria which specify what level of noise exposure is or is not acceptable.



COMPOSITE NOISE EXPOSURE PLAN

FIG. 1

Community affluence may lead to more rapid exploitation of resources and therefore ptoential noise exposure, but it should also be used to lower critical levels of permissible noise.

It is noticeable that only communities which enjoy a high standard of development and education also have highly refined acoustical codes while, in less developed areas, the problems are more basic and the effects of noise are regarded as of minor importance

Surely Australia has attained a standard of living which demands more attention to the reduction of noise pollution

SPACING AND NUMBER OF ZONES

Two main factors determine the number and spacing of zones, the ease with which normal activities and land uses can be subdivided into noise categories and the degree of certainty with which noise exposure can be evaluated or predicted

It would be ludicrous to designate zones at either 1 dB or 20 dB spacings; the first would assume great predictive accuracy combined with a fine graduation in usage classification while the second would assume that our knowledge of future noise exposure and levels to suit particular activities is most inexact

Sufficient research data exists to indicate that transport noise could be predicted within a tolerance of ± 5 dB and this figure also represents a reasonable compromise for controlling industrial noise. Present measuring systems are within this range and changes in subjective response to noise are observed for variations below this limit.

However, when it comes to prediction of reaction to noise or definition of usages which are compatible with various levels, the position is not as clear At the ICAO meeting on aircraft noise, the Australian delegation undertook the task of comparing the numbers and classification of usages which were part of many national systems for controlling development around airports.

Most systems used three broad categories but some used five. When all systems were converted back to continuous listing of usages and compared one with another it became apparent that, despite international differences, there were many activities which could be collected together in three main groups while other activities were considered critical only in a minority of systems or were given vastly different ratings from system to system.

It was apparent that individual nations either reacted differently to aircraft noise or had not done enough research to correctly classify all activities

Because of this uncertainty, the meeting was unable to offer anything more than limited guidance on either compatible usages or zone spacings.

This field needs further research to establish which activities are compatible with exposure levels for all forms of noise and to suit each nation's particular temperament and economic circumstances. There is sufficient international agreement on important sectors for these to be applied without delay and the necessity for further research should not be used as an excuse to put off classifying suitable activities.

At this stage zoning in spacings of 10 dB are as narrow as present knowledge warrants but it should be remembered that refinement of present systems may permit 5 dB spacings at some time in the future

As the concepts involved in noise prediction are fairly new and few are experienced in the interpretation of noise exposure curves, planners should be reminded that noise conditions do not alter dramatically from one side of a noise contour to the other, and that factors such as existing usages must also be considered in any practical approach to noise zoning.

At London Heathrow Airport, when determining which areas were eligible for noise control subsidy, it was found necessary to alter the boundary lines from the strictly drawn noise contours to take account of local social and governmental features.

The recent outcry in Sydney concerning the suggested application of restrictions on development within zones defined by the N.E.F. system near Sydney Kingsford Smith Airport is merely an indication of the ignorance and fear such proposals meet among the general public and at local council level where parochial interests prevail.

COMPENSATION FOR THE EFFECTS OF ZONING

Zoning is most conveniently applied when Crown land is to be released for development. In all other cases zoning implies penalties or rewards due to the inhibitions placed on free development

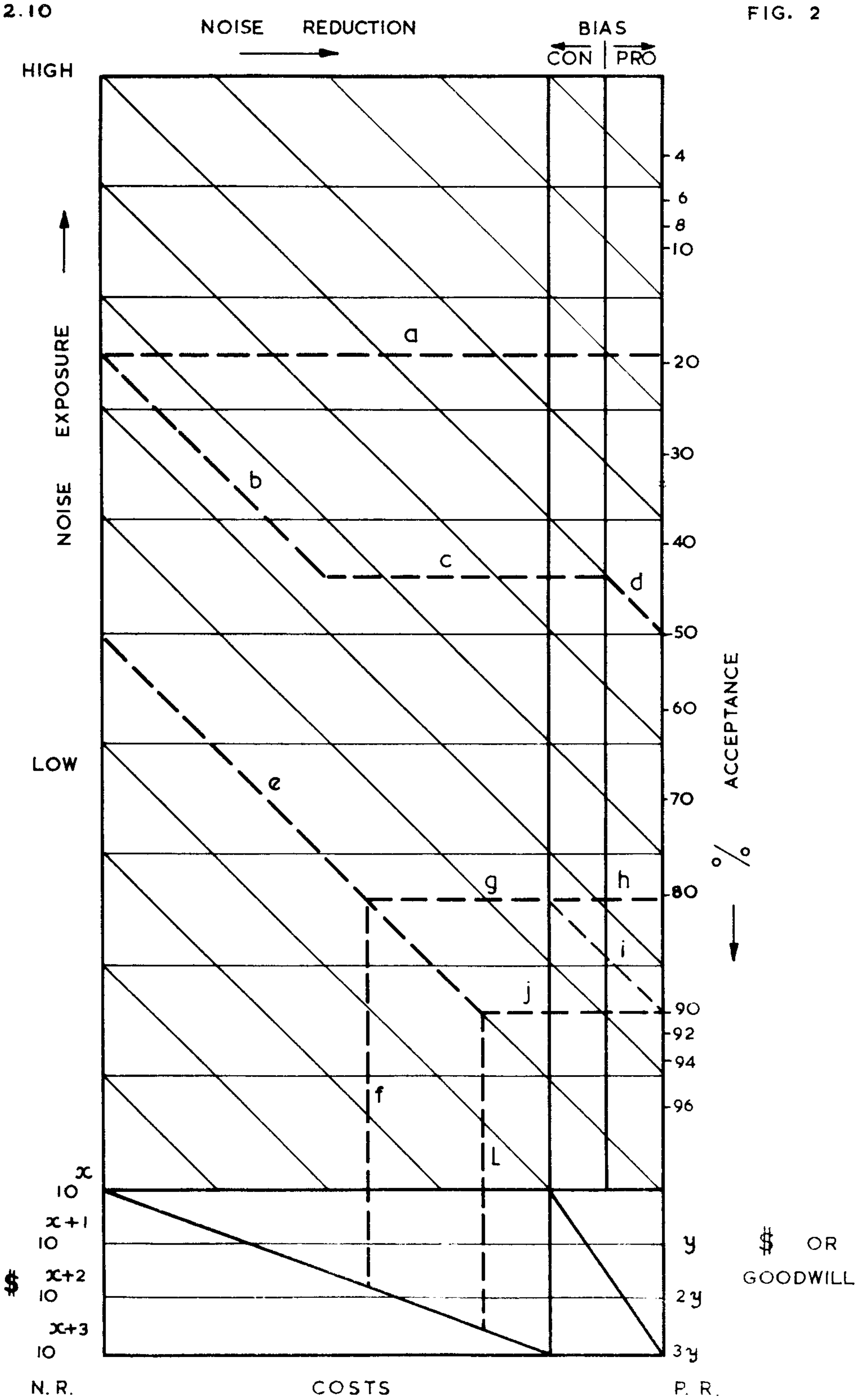
It would be fair to state that noise zoning is likely to lower the value of land in most cases and only in rare circumstances, such as a rezoning to "Industrial" in areas starved for industrial land, will the value be enhanced.

Just as it is reasonable to compensate those who have lost value by zoning, others who may profit by such alterations should be expected to contribute to a fund from which compensation is paid to those who would otherwise lose. Compensation should be determined by a tribunal which treats each case individually and decides on what form the recompense should take, i e a cash payment, subsidy toward noise treatment or resumption and payment of reasonable removal expenses

In certain cases it may be possible to retain the existing usage of land if noise reduction is applied but in residential areas this solution is rarely satisfactory. Two large programmes involving sound treatment of houses are those at London (Heathrow) Airport and Los Angeles International Airport. The first is a scheme which provides a subsidy of up to $200 on a $1 for $1 basis for minimal sound treatment and ventilation of three rooms. It has been estimated that only a small proportion (7% to 15%) of those who qualify for the subsidy have availed themselves of it. There are many speculative reasons for this poor response but, as yet, no valid explanation.

At Los Angeles, twenty houses of various constructions and ages were modified in three categories, minimal (costing approximately $3,200), medium ($4,800) and extensive ($12,600). Though many residents of the modified houses expressed satisfaction with the result, exterior noise became more noticeable and outdoor activities almost ceased. All of these houses were located in areas of very high noise exposure, but in areas of moderate exposure, minimal noise reduction may suffice for indoor activities with adaption to outdoor noise requiring less than the dramatic adjustment needed in the Los Angeles study.

FIG. 2



NOISE REDUCTION
BIAS
CON
PRO
HIGH
NOISE EXPOSURE
LOW
a
b
c
d
e
f
g
h
i
j
L
4
6
8
10
20
30
40
50
60
70
80
90
92
94
96
% ACCEPTANCE
$
10^x
10^x+1
10^x+2
10^x+3
y
2y
3y
$ OR GOODWILL
N.R.
COSTS
P.R.

Near industrial areas, the funds for compensation would be gained from the industries and the general community in proportion to the desirability of the particular industry Near transport sources such as airports, roads and railways, it is reasonable to expect the users to contribute their share of the funds required In many cases the facilities are owned by the community or used freely by a large proportion of them and compensation could come from general revenue Where the facilities may be owned by the community but used by a relatively small group, the burden of compensation should be borne by this minority to a great extent

In this regard the recommendation in the recent report of the Parliamentary Select Committee on Aircraft Noise that airport charges be related to the degree of noise exposure to occur with each aircraft flight is a first step which could be extended say for highways to cover the variation in noise exposure between different road users i e , noisy truck would pay more than quiet trucks or cars The aim of this variable charge should be to set the rates to that the increased cost of operating in a noisy way was slightly above the rate which applied if noise reduction devices were used

Most silencing devices add to both the capital and operating costs of transport systems and thorough studies of the economics of operation would be needed to set the charges fairly To the cry that this scheme would add an intolerable burden to transport costs, the answer must be that for too long there has been no incentive for the transport industries to minimise noise exposure and the more responsible and enlightened operators who are concerned with community welfare have been placed at an economic disadvantage to their less responsible competitors

Public authorities, which usually do not operate in a fully competitive situation should be the first to set an example, but could not be expected to assume an intolerable cost burden as most are in a critical financial situation already Acoustical manufacturers have a responsibility to ensure that correctly designed and durable silencers are available to suit each type of vehicles and that costs are moderate

Acousticians also should lend support to the standardising of noise measurement systems so that the testing of vehicle becomes routine for both licensing and monitoring of proper working order

ADMINISTRATION OF ZONING

Noise zoning must be administered only by those with sufficient expertise to handle the complex calculations and interpretation of results needed if all the interrelated factors are to be given due consideration

Within Australia, as in most countries we have adopted European administrative systems whereby control of buildings and zoning is mainly at the parochial level by local governmental councils It is probable that there are few councils here or overseas which have the equipment and expertise to administer noise zoning requirements It is understood that in Switzerland

and the Federal Republic of Western Germany, both countries with highly developed acoustical codes, this difficulty has led to the central government moving to assume control of the administration of noise zoning.

A further difficulty in the administration of noise zoning at local level arises because most noise sources traverse or abut more than one council area. In Australia it is common for a state or regional planning authority to assume control of proposals which affect the living and transport arrangements for large communities. This is probably the lowest level at which it would be possible to plan the acoustical environment for large airports, or road and rail systems.

CONCLUSION

At long last conservationists are being heard and serious attention is being paid to the problems brought about by excessive and wasteful use of our resources.

If we are to preserve sufficient of what is good in present urban life and avoid the censure of future generations we must revise our criteria for rating the advantages of new developments. At times we must stand in the way of progress until the ultimate benefit of a proposal has been determined.

The setting aside of zones devoted to particular activities is a method of compromising between the economic and aesthetic factors which determine the quality of living in urban communities. It further assumes that the right of individuals or small groups to develop property at will must be restrained for the benefit of the majority.

Zoning is the logical beginning of an overall scheme to alleviate the present and future problems of environmental noise pollution.

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ACOUSTICAL ASPECTS OF TOWN AND COUNTRY PLANNING

by

Professor F.W. Ledgar

Presented to the Australian Noise-Zoning Conference,
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Sponsored by the Australian Acoustical Society
(Victoria Division)

ACOUSTICAL ASPECTS OF TOWN AND COUNTRY PLANNING

When John Burns, as President of the Local Government Board, introduced the first town planning act in Parliament in Great Britain in 1909 he said:

> "What is our modest object? Comfort in the house; health in the home; dignity in our streets; space in our roads; and a lessening of the noises, the smoke, the smells, the advertisements, the nuisances that accompany a city that is without a plan ...."

The latest edition of the Melbourne Metropolitan Planning Scheme Ordinance lays it down that general industry and dangerous industry shall not be carried on within 100 feet of residential zones and that light industry shall be separated from residences by not less than 15 feet.

Light industry is defined as an industry "in which the building or works thereby occupied or employed, the processes carried on, the material used or stored, machinery employed, and the transportation of materials goods and commodities to and from the premises will not cause injury to or prejudicially affect the amenity of the locality by reason of the appearance of such buildings, works or materials or by reason of the emission of noise, vibration, smell, fumes, smoke, vapour, steam, soot, ash, dust, wastepaper, waste products, grit, oil or the presence of vermin or otherwise". I do not know if the sequence of offensive things has any significance but you will notice that noise comes first as it did in John Burn's statement of his "modest object".

Thus far has our art progressed in the twenty five years or so since planning legislation was introduced into Victoria and powers of control were granted to authorities concerned with town and regional planning.

These are the provisions which are intended to protect adjoining land owners from nuisance occasioned by industry. Planners appreciate that industry, of course, is not the only producer of noise nuisance. Dance halls, boy scouts halls and similar uses can generate considerable noise and may be controlled by authorities under by-laws or under planning permits. Various devices such as the requirement for the insulation of buildings invariably, in my experience, without specification of performance standards, distances from boundaries, and the control of hours of use have been applied on a somewhat arbitrary basis with varying degrees of success.

Having said these things you will appreciate why you do not have in your bound copy of proceedings a learned paper from me as you have from other speakers. My difficulty was that there seemed so little to say. This should not be taken as implying that planners are not concerned about problems of noise, but rather that their approach has been a somewhat broad and loose one relying on arbitrary distances from boundaries, separation of noisy and other offensive uses from other uses where practicable, by buffer zones, the prohibition of uses that are incompatible with their neighbours and the imposition of conditions requiring tree and shrub planting.

The effectiveness of tree screens to reduce noise is deep-rooted in planning mythology. They are effective against high frequency sounds whose wavelengths are not much larger than the leaves which are intended to impede them but tests show that a thousand foot belt of woodland thick enough to limit visibility to 70 feet will decrease noise in the 200-1000 cycles per second range by only about 20 decibels more than would the open distance alone.

There is also provision for control by-law. For example, the Victorian Local Government Act 1958 (s. 197 (1) (XXI) authorises the making of by-laws "prohibiting or minimising noises in any public highway". Disregarding some very interesting legal discussions that took place in the Victorian Supreme Court on the difference between noises and sounds, this is a step in the right direction in that the section of the act gives the responsible authority discretion to permit certain noises caused by amplifiers etc., the implication being that without such a permit all noises caused by such devices are prohibited.

Planners have long been calling attention to the volume of noise caused by traffic in city streets. Professor Myles Wright, writing in the Town Planning Review (Vol. 27, page 113) of conditions in London, asked whether our traffic engineers and by-law-making authorities have given enough constructive thought to the problem of noise. He expressed the view that there is perhaps no greater factor than noise contributing to the fatigue of modern urban living and pointed out that despite this capital cities still have their trams and tolerate the cacophony of hooting horns, squeaking brakes and squealing tyres. In some of the main thoroughfares of our cities the level of noise at ground, first and second floor levels is so great that windows cannot be opened when discussions are taking place. The classic case of this, in my experience, is the Town Planning Appeals Tribunal hearing room at the corner of Spring and Collins Streets in Melbourne. To reduce the noise of traffic in the room the windows have not only to be closed but also shuttered on the inside. This calls for air conditioning but, unfortunately, the noise of the machine used interferes with the microphones which relay the details of the proceedings to the tape recorder.

The resultant discomfort on some days has to be experienced to be believed. I have seen a witness faint.

Some thought is being given by road engineers to the problem of noise. It is reported that Soviet engineers in Moscow and Volograd are building experimental sections of roads in new city districts involving the construction of a three metre high earth bank with re-inforced concrete screens on top along each side of the road. The bank is to be planted with trees.

Some authorities overseas have exercised powers enabling them to prohibit the playing of portable radios in public places, parks and swimming pools. Selle, in Germany, is one example. An essay in Time magazine dated August 16, 1966 says

> "New York City has a strong new law requiring walls soundproof enough to reduce any airborne noise passing through by 45 decibels. In Geneva, Switzerland, it is an offense to slam a car door too loudly. France confiscates automobiles that repeat noise violations. The rubber-, plastic- or leather-guarded garbage can is commonplace in London, Paris and Berlin - an improvement that could hush Manhattan's most characteristic and deafening early morning sound. Bermuda has instituted the quiet motorbike. Outboard motors are losing their bark; truck mufflers that kill the roar are available.
>
> "In Coral Gables, Fla., a noise ordinance adopted by the city commission in June has set the allowable loudness for appliances so low that contractors are hesitant about installing any more air conditioners until the manufacturers have managed to reduce the noise ...."

South Perth has a by-law that provides that "no person shall cause or permit any noise to be made in a snack bar" and noise is defined as "any noise caused by a person or persons for advertisement purposes or in connection with addressing the public or by the use of motor-cycles, gramohphones, amplifiers, wireless appliances, bells or other instruments of appliances".

Airports and heliports have long been a matter for concern. I think it is unrealistic to expect any dramatic gains from the activity of aircraft designers. All that remains is a greater use of zoning of areas in the vicinity of landing positions. A good deal of work of a somewhat unco-ordinated nature has been done in relation to Tullamarine but not all the information is readily available but the stage has been reached when two new phrases "The noise shadow" and the "noise exposure guide" have moved into planning jargon. There was an interesting article in the Age on July 1st, 1970 on the effect of noise occasioned by Tullamarine Airport.

I know of few examples where measurements of noise have been introduced into statutory planning schemes. In zoning proposals for New York City put forward in the early sixties some provisions were included limiting the amount of noise which industry might lawfully make. The maximum permissible decibels are measured at the allotment boundary and they vary according to the cycle per second of the sound itself. Thus, in the light industrial zone, a noise level of 79 decibels is permissible if the noise does not exceed 75 cycles per second but the permissible decibel level drops to 39 if the cycles per second exceed 4800. There is a further provision that reduces the maximum permissible decibel levels by 6 decibels at all frequencies when the allotment boundary is also the boundary of a residential zone.

It does appear that knowledge of acceptable levels of noise is reaching or has reached a stage when it should be possible to formulate reasonable noise regulations but there is a reluctance to accept scientific data when produced. There is a strong subjective element. As Mr. Justice Sugarman of New South Wales said in a case between Pacific Mouldings Co. Pty. Ltd. and Bankstown Municipal Council "Such discomfort as may be experienced by individuals in residences as a result of noise is not, of course, a thing capable of scientific measurement but may well be dependent on subjective factors."

The New South Wales Land and Valuation Court in a case between Albert G. Sims Ltd. and Leichhart Municipal Council rejected a contention that a limitation on noise coming from industrial premises should be prescribed in terms of decibel readings. What the court was saying, in effect, was that, all people's ears are not alike.

In my experience I have often been faced by or been obliged to support complaints that certain uses would cause injury to amenity by reason of noise. Only once have I had to delve into the decibel. This was in a case where it was proposed to move an existing saw-mill from a town centre that was in process of redevelopment which affected the existing use. Noise level measurements were taken at and around the existing site and an attempt was made to gauge the effect of such noise on the environs of the new site. It did not seem a very scientific or particularly helpful exercise to me as the buildings on the old site were old and flimsy and the buildings on the new site were to be solid and well insulated. However, it was possible to say that if the old mill were removed to the new site the result would not be very pleasant.

In fact, the old mill on the new site would have been more offensive than it was on the old site because of the lower level of background noise on the new site.

That reminds me of another case in which I was involved. Application was made for a licensed restaurant on a site of about 1 acre adjoining residential development. The residents in the area objected to the proposal on the usual grounds - noise from loud music, drunken farewells, banging car doors, increased traffic, flashing headlights, lowered values etc. The applicants won their case but were somewhat apprehensive at the prospect of a flood of complaints from adjoining residents about the inevitable noise occasioned by loud music, drunken farewells, banging car doors etc. so they took advice from acoustic experts. The solution was simple. They installed a noisy fountain in the courtyard of the restaurant. It worked, but there was a period of concern during water restrictions. However, by this time local residents had become used to the noise caused by loud music, drunken farewells, etc., etc. There is a nice point to be made here. The sound of a splashing fountain in a courtyard of a building could be likened to the perfume that a woman applies after a bath. It enhances her basic charm. Our fountain, though, was not the equivalent of a perfume. It was a deodorant covering something unpleasant up.

My daughter studies with a transistor radio playing and achieves good results. This presumably is also an example of a deodorant noise which covers up the noise of stealthy feet outside her room or the banging door which disturbs her concentration.

Planners approach the subject of noise control with some hesitation. One of the reasons is that it is doubtful whether controls can be instituted that will satisfy all ears and to institute a control that did not, would be to deny or reduce the effectiveness of objection and civil action by the more sensitive. I have a whistle which when blown cannot be heard by my wife, is barely audible to me but makes my dog do a somersault. Second, a lot of people like noise, because noise and power are related. The quiet motor-mower sells less well than the noisy one because the noisy one gives the impression of being more powerful. The same applies to motor-boats, motor bikes, motor cars and music as far as a certain age group and level of intelligence is concerned and their numbers are legion.

I suspect that despite the scientific evidence you may be able to produce about the measurement of noise levels, we shall continue to leave recourse to complaint and injunction as the main means of control. By all means let there be noise abatement, let there be research and let there be community protest. I am in favour of the prohibition of all noise in some places so that it is possible with complete certainty to escape to peace and quiet.

The problem is an age-old one. Juvenal in Imperial Rome complained about the all night cacophony and observed that most sick people perish for want of sleep.

We seem to object more strongly to new noises - the jet plane, the whine of an electric planer or a circular saw and the shriek of a high powered drill. I'll guarantee that in the Middle Ages there were complaints about the clatter of an iron bound wheel on cobble-stones or the noise of the ringing hooves of the drayhorse. I suppose we can take comfort from the fact that we are very adaptable and can erect our own defences. When I am tempted to watch a television programme that involves commercials and I am too tired to leave the room, I close my eyes while they are on and press my fingers intermittently against my ears. This produces a most interesting and varied sound.

I would like to finish with a quotation from Schopenhauer. He said:

> "The amount of noise which anyone can bear undisturbed stands in inverse proportion to his mental capacity and may therefore be regarded as a pretty fair measure of it".

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NOISE-ZONING & LAND USAGE

by

Roger Wilkinson

Presented to the Australian Noise-Zoning
Conference, March 6th - 8th, 1971
Warburton, Victoria, sponsored
by the Australian Acoustical Society
(Victoria Division)

NOISE-ZONING AND LAND USAGE

by Roger Wilkinson
B.Mech.E.,B.E.E.,M.I.E. Aust., Member National Council of Acoustic Consultants, U.S.A., Partner, Carr & Wilkinson, Consulting Acoustical Engineers, Sydney.

ABSTRACT: This paper is mainly slanted at noise-zoning and land usage with respect to industrial noise affecting mixed residential and industrial areas, but also gives some coverage to traffic, aircraft, railway, subway, demolition, building and construction, entertainment and rural noise sources. Effective noise-zoning and land usage programmes can be achieved only with the maximum awareness and co-operation of all Governmental instrumentalities concerned, together with a realistic, practical and economical approach by the community in general and land owners and developers in particular.

PREAMBLE: TO BUY OR NOT TO BUY ......

Too many people buy their house or residential land during week-ends.

In doing so, they are almost oblivious of their week-day neighbours who may range from noisy industrial undertakings, construction or demolition sites, busy peak-hour roads and other transportation routes, 'frantic' entertainment noises to rural machinery noises, which may turn their future into an acoustical and mental disaster, rather than the 'Seventh Heaven' they envisaged.

Why is it that Town Planning Zoning classifications don't necessarily designate the Noise Zoning to be expected within those Zoning classifications?

The most common problems encountered by firms consulting in acoustical projects are associated with lack of information, foresight or consideration of acoustical problems connected with new premises, new neighbours or new processes. Problems encountered range from inter-unit noise propagation within multi-home-unit buildings, through similar problems (either activity or machinery noise) in commercial buildings, to mixed industrial and residential area problems.

A study of the noise characteristics of a site before purchase of the land and before the layout and design of a building could make it unnecessary to seek difficult and costly noise reduction solutions after a building or project is completed.

If the proposed site is near what appears to be high noise sources, such as highways, expressways, industrial districts, etc., some evaluation of both day-time and night-time outdoor noise levels is essential. For residential areas, if the average night-time background noise level is unusually high, or if there are frequent, but intermittent, unusually loud noises, a full acoustical appreciation should be performed or other sites sought.

Of course, noise level is only one of the many factors which need to be considered in site selection and building layout and design. Apartments close to public transportation, shopping facilities and business districts will be relatively high noise areas but the location may be more convenient than in quieter outlying areas. For instance, although the noise levels due to individual trains are quite high (of the order of 80 to 85 dBA at 100 ft.) there are few complaints concerning this source of noise. This may be because of the fact that the Railway is probably the oldest established noise source and people have generally grown up with the noise and moved to houses knowing that they will hear the trains. In the case of aircraft and road traffic, however, many previously-quiet areas may suddenly become affected by a new route and everywhere there is a steady increase in the use of these two forms of transport.

Experience shows that there is no 'general case' and that each situation must be considered on its own merits. However, lack of information, planning or appreciation of consequences in particular cases have lead to some very annoying, quite frustrating and expensive situations -- all of which could have been so easily avoided by consideration of the type of noise-zone of the location involved.

NORMALLY-ACCEPTABLE-LEVELS: TOWN PLANNING ZONE VRS. ACOUSTICAL ZONE

What noise levels are acceptable for various community types?

Whilst not completely comprehensive, British Standard (BS4142:1967) and the Draft I.S.O. Standard for Calculating Normally-Acceptable-Levels for "Industrial Noise Affecting Mixed Residential and Industrial Areas" both give very useful guidelines for prediction of various degrees of lack of acoustical amenity for such mixed areas. In fact, application of these techniques is extremely useful in predicting (or justifying) neighbour reaction to traffic, transport, demolition, building and construction, entertainment and rural noise sources.

In most cases, it is found that Australian residential communities are 5dBA or 5NRs less-tolerant to industrial noises than would be predicted by the B.S. or I.S.O. techniques. However, this observation is made mainly in the course of dealing with existing problems, in which a deal of antagonism and resentment already exists with respect to industrial noises, etc.. This perhaps suggests that for new industrial noise sources, designed to comply with the B.S. or I.S.O. proposals prior to being imposed on nearby residential areas, the calculated normally-acceptable-levels may be adequate for Australian residential communities, presuming such communities are not already aroused against industrial noise sources.

In applying both B.S. and I.S.O. techniques to calculations of Normally-Acceptable-Levels there is obvious requirement for control of land usage, with respect to the noise zoning to supplement the conventional Town Planning zoning classifications. Dissention often exists between the legal Town Planning classification of an area and its assessed acoustical classification. For instance, a Town Planning classified Light Industry may be a quite heavy industry in the acoustical sense. For example, panel beating and sheet metal works may be allowed within Town Planning "Light Industrial" Areas, whereas they might incur a Heavy Industry classification within the acoustical environment surrounding such areas. On the other hand, a Town Planning classified "Heavy Industry" may create very little noise in its vicinity and therefore may form a suitable buffer zone between noisier undertakings and nearby residential areas.

Town Planning projects and Building Approval deliberations should include consideration of the noise zone or noise climate into which the approved building will go -- especially if the existing factories or other potential noise-making concerns in the area are currently emanating little to no noise from their operations, access and egress. In particular, subscripts designating "noisy" or "quiet" conventional Town Planning zone classifications, could be of very significant assistance to town planners, municipal authorities, real estate agents and potential purchasers alike.

In making such considerations, many Town Planning and Local Council authorities fail to realise that noise propagation has little concern about a line drawn on a map to demark industrial/residential boundaries. In general, there is not much acoustical separation from one side of a street to the other -- but obviously there can be a change of Town Planning zoning from one side of the street to the other. In particular, antagonistic reaction can be expected from residences, etc. one to two streets removed from a noisy industrial premises, especially if the industrial zone (or particular offending factory) is not readily visible from these removed locations.

Whilst visual shielding of noise sources such as roadways, railways and industrial undertakings is known to have a beneficial psychological effect on reducing annoyance created by such sources, very few shielding devices (especially trees and other foliage) have a very beneficial acoustical effect in actually reducing noise levels by any significant or consistent amount. Whilst acoustical designers can and often do utilise topographical barriers and/or specially-designed barriers or enclosures to reduce the transmission of noise from a source to its surrounds, Town Planners are usually solely reliant on the attenuation provided by "depreciation of noise with distance" between the noise source and the critical areas concerned.

Figure 1 shows typical "depreciation of noise with distance" from various types of noise sources, with respect to a measurement made at say 10 ft. from a small or "point" noise source. As seen from Figure 1, sound depreciates, or attenuates, at differing rates, depending on the height of the source above ground, the type of surface between the source and the observer and whether the noise source is a "point source" (e.g. a noisy pump) or a "line source" (e.g. distant, busy roadway). As most noise is generated at ground level, it was thought that one advantage that tall buildings would offer was a reduced noise level on floors well above the street level. Tests on a large number of tall buildings have shown, however, that there is an appreciable reduction between ground level and the first two or three floors, but after that, there is very little additional reduction for further increase in height. The reason for this seems to be that whilst the higher portions of the building are further removed from the vehicles below, they have a much greater catchment area from which the noise comes. This is borne out by the fact that individual vehicle noises tend to diminish and that traffic noise becomes a more steady roar. Another factor which becomes important for the highest floors, is the effect of wind noise which, although it may tend to mask traffic noise, can also itself become very unpleasant. In the case of lower floors, the height and proximity of other buildings is important, as in the case of comparatively narrow roads with tallish buildings on each side, where a canyon effect can build up, giving very high noise levels on upper floors. Although the height of a building cannot be used

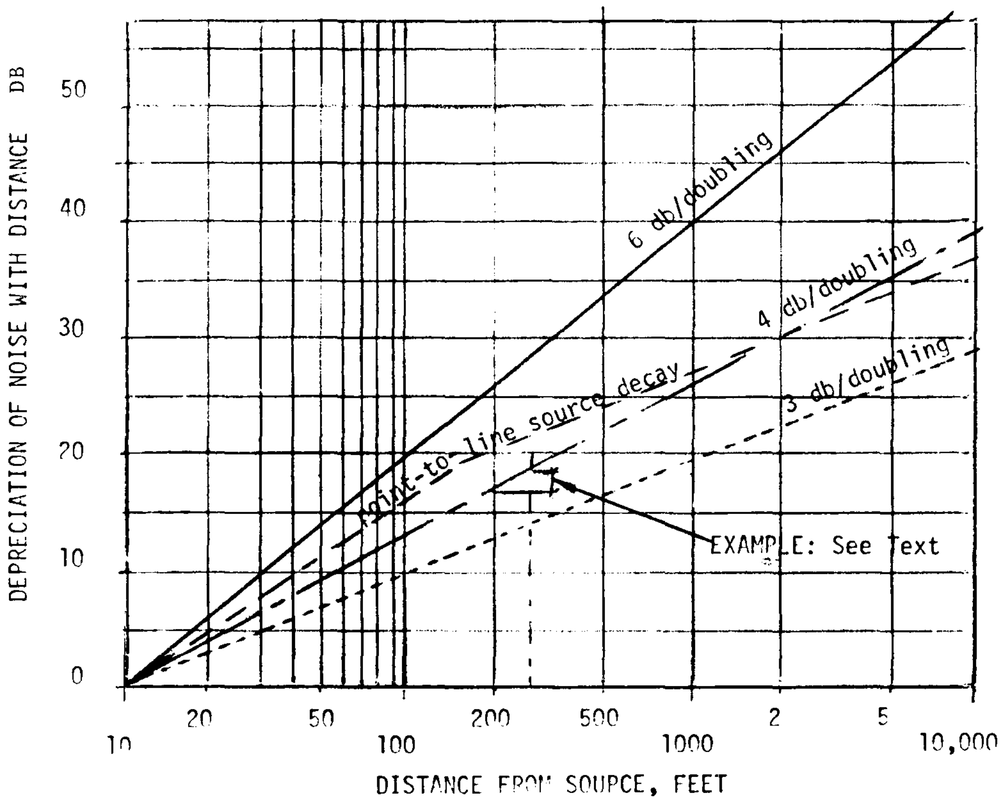

FIGURE 1: Depreciation of Noise with Distance, with respect to the sound level at 10 ft. distance from a point source.

NOTES RE FIGURE 1:

1. For large noise sources (e.g. a large opening to a factory, or many dispersed noise sources of comparable level) the reference point should be at least 1 x major dimension of the source from the source.

2. Typical noise sources decaying at 6 dB/doubling of distance would include high-flying aircraft or high level dischargers (e.g. refinery 'torches').

3. Typical noise sources decaying at 4 dB/doubling of distance would include a pump or a compressor mounted in the open and propagating noise over typical open level ground:

4. Typical noise sources decaying at 3 dB/doubling would include a pump or compressor as above but, propagating noise over very hard ground, concrete or open water.

5. The "point-to-line source decay" curve shown is typical of the decay of overall noise effect with increasing distance from a busy roadway.

satisfactorily as a protection against traffic noise, its design can be. One example is by the use of a podia, which effectively shield the floors immediately above them. Several successful designs involving the use of podia/barrier type shielding have been constructed.

The attenuations shown on Figure 1 are for usual-to-best noise propagation conditions such as those encountered on still-to-light-breeze nights. They therefore represent the information required to calculate the worst-conditions likely to be encountered, which is usually the design requirement for successful noise reduction programmes and/or Town Planning layouts.

After establishing the noise level created by a noise source (either by measurement or reference (1) or (2)) Figure 1 can be used to determine the distance required to provide the required attenuation between such a source and the level required in a critical acoustical area nearby. Or, alternatively, Figure 1 can be used to determine the maximum noise level output of an undertaking located at any distance from a critical acoustical area, the normally-acceptable-level of which has been calculated by either B.S. or I.S.O. techniques. As seen from Figure 1, if the offending noise source is say 200 ft. from (and within) an Industrial Zone boundary having residences on the other side of a road demarking this boundary, there is very little attenuation (1 to 2 dB) in the additional 60 ft. or so to the commencement of say the adjoining residential area. Further, there is only an additional 2, 3 or 4 dB reduction to houses one or two streets further removed from such a noise source.

Similarly, aircraft flying at say 1000 ft. above ground level will produce only approx. 6 dB lower noise levels at ground level, for similar operations, at double this altitude. In addition, the higher altitude affects a wider strip of land under the flight path, so there are pros and cons with respect to this altitude-variable in endeavouring to curtail the effects of aircraft flight paths.

It is therefore evident that planning authorities and practices should take into account the necessity of restricting both noise level outputs from various classes of operations and the distances or zoning or inter-zoning associated with adequate acoustical separation of these operations from more critical (especially residential) areas.

SPECIALLY NOISY UNDERTAKINGS

The Wilson Report (3) recommends that specially noisy processes should be registered as such and that it should be the duty of Inspectors, appointed by an appropriate governmental Minister, to ensure that people using these registered processes employ the best practical means to prevent and to counteract the effect of the noise. The Inspectors should become experts in industrial noise problems so that their views are respected and their help sought by factory owners and legal authorities.

If such recommendations are adopted, firm central control will eventually be exercised over registered processes. It is recognised that the compilation of such a registry and the training of an inspectorate can only be done gradually, but, when the control is in full force, the users of registered processes should be exempt from statutory nuisance proceedings, unless the Minister responsible for registering the process consents to the proceedings. It is envisaged that consent would be given where the Minister considered that the factory occupier was not employing the best practical means of preventing or counteracting the effect of the noise created.

Specially noisy processes are, in general, associated with heavy industries which, when set up, cannot easily be moved. It is therefore extremely desirable that when planning authorities are considering an application for siting of a factory in which a specially noisy process might be used, the authority should be required to consult the Minister responsible for the register of such processes before they grant the application.

ARE ESTABLISHED BUSINESSES EXEMPT?

Many local authorities consider that they have serious difficulty in abating noise nuisance from trade and industry if the occupier of the premises from which the noise is coming claims that he is using the best practical means of preventing it. The local authority cannot usually or readily confirm or deny this and therefore, hesitate to take proceedings. Perhaps, at the present, this defence must be available to trade and industries but, surely in the long run it is undesirable.

Owners and managers of noise-making industries are often outraged at the apparent injustice when well-established businesses are oppressed(and even served injunctions to cease operations) by encroaching residential areas. This unfortunately-frequent situation demonstrates a lack of awareness, liaison, practical town planning and sense of obligation of land developers and owners.

How can people, in all conscience, feel committed to an expensive noise reduction programme when, for instance, they build a multi-million dollar complex in a large sheep grazing area, almost out of sight of the nearest residences then, because local authorities allow residential sub-division right up to their boundary, they are expected to reduce their noise levels so that they comply with residential requirements, at their boundary.

Yet this is not untypical of many situations experienced in this, and other, countries.

However, on the other hand, the legal fraternity tend to view this situation as one in which industries have 'got away with' excessive noise creation at their boundaries for a number of years -- and now they should do something about it!

Again, this time within the commercial building field, it's about time letting agents and developers implemented a bit of noise-zoning and space usage within such buildings. Perhaps it's time they discontinued the practice of spending a lot of money on air conditioning plant isolation and plant room silencing, just because the Managing Director happens to require to occupy the upper floor of the building, immediately above which happens to be noisy reciprocating compressors, air handling plant, etc.

NOISE ZONE IMPLEMENTATION

How then can successful Noise Zoning and Land Usage be implemented and developed?

Unfortunately, in general, noise-zoning is almost non-existent in this country and future programmes start from well behind "scratch".

Giving due recognition to the fact that the noise factor is only one of many factors requiring Town Planning consideration and also recognising the economics of siting, communication, transportation and topographical factors, some compromise is essential. Such compromise should not allow flagrant disregard of rights of other people, but should combine the various expertise required for the successful implementation of noise zoning schemes.

For instance, various measures are adopted to adapt streets in existing towns to keep traffic moving. Restrictions on parking, waiting and unloading are the obvious ones and as palliatives they also help to reduce noise in encouraging free flow with fewer steps (assuming that the more obvious measure of diverting all through traffic by means of ring roads and by-pass roads has already taken place), but in any large urban environment virtually all traffic has some reason for being there and is not just passing through. Restrictions at particular junctions, such as the banning of right turns, has little overall effect on traffic noise -- traffic in one particular street may be reduced by such measures but at the expense of some other.

Most cities have grown up in a more or less haphazard manner and very few of the roads existing in our cities were designed to take the enormous volume of traffic which they do now. The direct result of this influx of vehicles is that alternative routes are constantly being sought to relieve the congestion. These alternative routes are frequently through residential streets which are even more unsuitable for carrying large volumes of heavy traffic than the so-called major roads which they relieve. Hence, they start by being the 'short-cuts' which the knowledgeable few take at peak hours when the main roads tend to become blocked. Sooner or later they become official alternative routes by which traffic is encouraged to go and this, whilst partly solving (or by-passing) deficiencies in main road systems, creates near-hellish acoustical (and other) conditions on and around the residential streets concerned.

With respect to roadways, railways, aircraft flight paths, etc.,Noise Zoning and Land Usage plans must take into account the transition of such noise sources from a "point source" in close proximity to these sources to a "line source" at more distant points. In particular, the 10% exceedance levels fall at approximately 5 dB per doubling of distance, whilst the 90% exceedance levels fall at only approximately 3 dB per doubling of distance from such a noise source. The overall effect being illustrated by the double-sloped line in Figure 1.

Hence, we may conclude that Planning authorities and/or developers are faced with two propositions. Firstly, they may create and implement rigid zoning requirements, including emanated noise level restrictions, or, secondly, they may exist within current Town Planning practices by requiring usually-more-stringent emanated noise level limitations to adjacent properties, leaving specifically designated buffer areas, wherever possible.

It appears that the second alternative offers the only practical approach to existing areas, although idealogical concepts of the first alternative should be firmly embedded in Town Planning revisions or modifications to as-yet-undeveloped areas.

Such concepts should consider that a very large area of any developed city is quite seriously affected by flight paths, motorways, railways, subways, and entertainment areas. It, therefore, seems logical to co-ordinate the location and time of usage of such areas to facilitate their acoustical integration and joint attenuation to residential and other non-noise backgrounds. Surely there is no sense in propagating the already-proved acoustical disasters associated with endeavours to integrate such facilities as airports, flight paths, noisy industrial operations, railways and major roads with residential areas! Where such noisy operations exist, plan the Town Planning around them! For instance, if a valuable mineral deposit is known, allow sufficient buffer area around it to enable quarrying and haulage operations to be noise-controlled within practical limits, but still comply with requirements in residential areas nearby.

Technical solutions are available to most noise annoyance problems, but the solutions become much more economical and practical when tackled in the Town Planning stage, so that buffer zones of Land Usage, having appropriate mediating noise level outputs, are interposed and/or increase the general ambient noise level and generalisation of audible noise sources propagated to residential areas or other critical locations.

Where re-siting is neither envisaged nor practical, potential or existing industrial noise offenders should comply with at least the requirements of B.S. or I.S.O. recommendations for the most critical neighbouring area. Recent legislation in the U.S.A. has brought strict control of industrial noises in all its aspects and there is much evidence of the requirement for similar legislation in Australia.

CONCLUSION

The special acoustical problems associated with supersonic aircraft, subsonic flight paths, motorways, containerised cargo and general wharfage areas, round-the-clock warehousing areas, railways, subways and quarrying activities are currently best handled by integration of these facilities so that one or more facilities overlap the others, in both the physical and acoustical sense, whilst buffer-zoning lighter industrial and/or entertainment areas and/or parklands, etc., between such noise sources and residential areas. Activities such as intermittent or out-of-zone industrial activities, demolition, building and construction activities should be subject to either legislative or Local Council control, within predetermined acoustical limits or recommendations such as B.S. or I.S.O. techniques.

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PUBLIC TRANSPORT NOISE

by

C.L. FOUVY

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PUBLIC TRANSPORT SYSTEM NOISE and NOISE ZONING

by C.L. Fouvy

SUMMARY

Public transport systems on land fall into two basic classes - those with rubber-tyred vehicles and those with steel-wheeled vehicles. Both have noise problems, although in the past, noise from steel-wheeled vehicles (passenger and goods trains, elevated, surface and underground rapid transit trains, and trams) has tended to predominate. Noise can be reduced at its source, or the path of the sound can be controlled by shielding or isolating the noise from nearby people. Measures designed to isolate noise can be regarded as Noise Zoning. Reduction of noise at its source can often be achieved, and is most economically and efficiently achieved at the design stage. When reduction at the source cannot be readily achieved, acoustic isolation of the noise source becomes necessary. Fifty years ago, no one expected steel wheels to run quietly on steel rails. However, much has been achieved in obtaining quiet operation, though some vehicles of older design are sometimes noisy. One of the main problems still to be fully solved is the quiet operation of trains in tunnels. The problems of rubber-tyred public transport vehicles are similar to the increasing noise problems posed by motorcars and trucks.

INTRODUCTION - THE DUAL NATURE OF NOISE PROBLEMS

1. Noise is defined as "sound which is undesired by the recipient" (ref. 3). It is undesired not only because of its general nuisance value, but also because it is a hindrance to efficient work and conversation, and can cause hearing damage. Land public transport systems - railways, tramways and bus systems - have all at one time or another evoked complaints about their noisiness. At present, however, any problems with this noise have been very much overshadowed by two others; aircraft noise, and motor vehicle noise, particularly that from fast vehicles moving in groups along expressways, freeways and motorways.

2. Because of the way in which noise is defined, a noise problem is always two-sided. There is the sound itself - its source and means of propagation, and there are the people who are within reach of the sound and, for some reason, find it annoying and undesirable. Problems with the sound itself are, though often difficult, generally clear-cut and capable of logical solution. The problems of people's reactions to noise show wide variety and are much more complex.

TACKLING A NOISE PROBLEM

General Considerations

3. There are two distinct steps in tackling a noise problem - firstly, establishing the fact of a noise, that a machine or activity is noisy; and secondly, dealing with the source of the noise by identifying it and then quietening it or isolating it. Any measure designed to isolate a noise (usually without significantly reducing it at its source) can be regarded as Noise Zoning - on either a large or a small scale. Thus, the isolation of noisy activities (such as aircraft engine testing) in unpopulated areas, the confining of a noisy machine inside a solid enclosure, or the wearing of ear muffs, are all forms of noise zoning.

4. Establishing the fact of a noise is not a clear-cut process. Any particular sound may at the same time be one man's noise and another man's music; or the same sound may to a particular person be welcome one day and annoying the next. There are no specific characteristics of a sound which can be used to positively distinguish noisy from non-noisy sounds. At best, any specific characteristics which we might identify - such as loudness - can be no more than probable indicators of noise, with a higher or lower degree of probability. Even sounds of extreme loudness, pitch, or frequency of occurrence, and which can cause hearing damage (e.g,

loud discotheque music) are not universally recognized as undesirable - as noise.

5. But in spite of this difficulty of positively identifying noise characteristics, there are certain characteristics of sounds such as loudness ("an observer's auditory impression of the strength of a sound", ref. 3), pitch, frequency of occurrence type (steady or impact) and unintelligibility, or some combination of these, which are regularly associated with sounds normally regarded as noise. Loudness has always been regarded as one of the more important of these characteristics because "although it is not the only subjective characteristic of a sound, it has been shown by experience that the average person's degree of tolerance, or aversion, to an unwanted sound is in general more closely related to the loudness of that sound than to any other factor easily susceptible of measurement" (ref. 4.).

6. This approach using average behaviour covers most situations, and leaves out only the exceptional cases like the "dripping tap", and just-audible electric transformer hum (100 Hz) types of problems. Since the early 1930's much work has been done in the field of audio-psychometrics to measure the average relationships between people's subjective assessments of, and reactions to sounds, and those physical characteristics of a sound which can be readily measured (see Appendix I).

Noise Criteria

7. A number of noise criteria have been developed as a result of the large amount of psycho-acoustic research which has been carried out. In practice, the simpler criteria are those which involve Sound Levels in decibels (dB, relative to the reference pressure of 0.00002 N/sq m) obtained by means of a Sound Level Meter. They are simple because measuring the sound level of any noise can normally be obtained by means of a single meter reading. This advantage of the single sound level reading outweighs the disadvantages that sound levels are not always closely related to loudness (refs. 4,8) and that the decibel scale for quoting sound levels is not easily understood by laymen. However, experience has shown that, as a rough guide to grasping the significance of the decibel scale of sound levels, a halving or doubling of the loudness of a sound corresponds to a change of about 10 dB.

8. One of the simplest noise criteria is given in TABLE I-1 (Appendix I) which gives the decibel ratings of some common sounds (but excluding aircraft noise) together with a subjective assessment of their relative loudness. Readings over 80 dBC (i.e, using the meter's "C-weighting" network) indicate sounds usually described as "very loud", while readings over 100 dBC

indicate sounds which are likely to be "deafening". TABLE 1 below shows a more recently developed Table of Noise Levels of some Typical Sounds (from ref. 17, p 3) which gives their Sound Levels in dBA (i.e, using the "A-weighting" network which gives reduced sensitivity to low-pitched sound) together with a measure of their loudness in Sones (on a loudness scale designed to give scale numbers proportional to the loudness, ref. 3, defn 3011) and the corresponding Loudness Levels in Phons (from ref. 5.). In this Table it can be seen that loudness levels in phons are significantly greater than sound levels in dBA, the numerical differences varying from 11 to 16. (This is discussed in more detail in Appendix II).

TABLE 1 - NOISE LEVELS OF SOME TYPICAL SOUNDS

NOISE SOURCE OR ENVIRONMENT	SOUND LEVEL (dBA)	RELATIVE LOUDNESS (Sone)	LOUDNESS LEVEL (Phon)	DIFFERENCE (Phon-dBA)
Room in a quiet London dwelling at midnight	32	-	-	-
Soft whisper at 5 ft	34	1.6	47	13
Men's clothing department of large store	53	7	68	15
Self service grocery store	60	10.6	74	14
Household dept. of large store	62	11.3	75	13
Busy restaurant or canteen	65	13	77	12
Typing pool (9 typewriters in use)	65	15	79	14
Vacuum cleaner in private residence (at 10ft)	69	17	81	12
Inside small saloon car at 30 mile/h	70	24	86	16
Inside small sports car				
at 30 mile/h	72	-	-	-
at 50 mile/h	75	-	-	-
Inside compartment of suburban electric train	76	26	87	11
Ringing alarm clock at 2 ft	80	34	91	11
Loudly reproduced music in large room	82	-	-	-
Printing press plant (medium size automatic)	86	56	98	12
Heavy diesel propelled vehicle about 25ft away	92	111	108	16

NOTE: These figures are given merely as a rough guide; they are for the most part single measurements, and might be expected to differ by several decibels if repeated in similar situations. Loudnesses in sones have been converted to loudness levels in phon by means of the standardized relation between them (ref.5).

9. Other noise criteria involving sound level measurements rather than a more complex analysis are the British motor vehicle noise level limits contained in parliamentary Regulations first prescribed on 15th March 1968. The noise limits prescribed under Regulation 23 are given in TABLE 2 below (from ref. 18, p 23)

TABLE 2 - MAXIMUM PERMITTED NOISE LEVELS (Regulation 23)

CLASS OR DESCRIPTION OF VEHICLE	MAXIMUM SOUND LEVEL (see note)
Motor cycle with a cylinder capacity not exceeding 50 cu cm	77 dBA
Motor cycle with a cylinder capacity exceeding 125 cu cm	86
Any other motor cycle	82
Goods vehicles with a maximum gross weight exceeding $3\frac{1}{2}$ ton -	89
Motor tractors; Locomotives; Land tractors; Works trucks; Engineering plant; and Passenger vehicles constructed to carry more than 12 passengers, exclusive of the driver	
Any other passenger vehicle (i.e, constructed to carry not more than 12 passengers, exclusive of the driver)	84
Goods vehicles with a maximum gross weight not exceeding $3\frac{1}{2}$ tons; and any other vehicles not classified above	85

NOTE: Sound levels (in dBA) are to be measured according to the method in BS 3425: 1966 (ref.7).

10. Noise criteria involving more complex types of measurements are the Maximum Permissible Speech Interference Levels (refs. 15A, p 63 and 15B, p 115) included in Appendix

I; the Noise Criterion (NC and NCA) curves (ref. 2, pp 518-21) or charts (ref. 15B, p 117); and the criteria for indoor noise levels (ref. 15A, pp 64-5) shown in TABLE 3 below.

TABLE 3 - CRITERIA FOR NOISE CONTROL

TYPE OF ROOM	MAXIMUM PERMISSIBLE SPEECH INTERFERENCE LEVEL (see note)
Small private office	45 dB (40)
Conference room for 20	35 (30)
Conference room for 50	30 (25)
Movie theatre	35 (30)
Theatre for drama (500 seats, no amplification)	30 (25)
Coliseum for Sports only (amplification)	55 (50)
Concert halls (no amplification)	25 (20)
Secretarial offices (typing)	60 (55)
Homes (bedroom)	30 (25)
Assembly Halls (no amplification)	30 (25)
School rooms	30 (25)

NOTE: Levels are as measured when the room is not in use. Each Speech Interference Level (SIL) is the average of the sound levels in the three octave bands with centre frequencies of 500, 1000 and 2000 Hz. These levels are numerically greater than levels based on the earlier 850, 1700 and 3400 Hz octave bands (ref. 15B, p 118) which are shown in brackets and were 5 dB lower.

11. The published noise criteria based on noise levels likely to cause permanent hearing loss show considerable variation. As yet there is no close agreement among research workers in this field. Several criteria for people exposed regularly to noise for 8 hours per day are quoted here. The higher of these risk levels have been set so that, on the average, persons will not suffer serious hearing losses if the levels for the exposure durations are less than those indicated, although some susceptible persons may suffer significant losses at these levels. The 8 hour/day levels are given as octave band levels (=96, 96, 88, 86, 85, 86 dB) for the seven octave bands at 125 to 8000 Hz (ref. 15A, p 68). The sound levels of

this noise are 99dBC, 97dBB and 93dBA (for C-, B- and A-weightings respectively). By contrast, a conservative damage risk criterion - a suggested preliminary test (ref. 15B, p 123) - is based on the sound level in dBB. "A reading above 100 dBB indicates that the noise is probably unsafe for everyday exposures, at least for some people, and noise reduction or ear protection is necessary. Readings below 80 dBB indicate that there is probably no danger from the noise even if it is a simple tone". A reading of 80 dBB is equivalent to about 74 to 77 dBA.

12. From the noise criteria given above and in Appendix I it can be concluded that, apart from the more critical cases involving interference to speech communication, noise problems occur when the sound level is above 80 to 85 dBA. In recent years, experience has shown (ref. 19) that the sound level at A-weighting (dBA) is amongst the most useful of the single-number noise ratings, and that it correlates well with other more complex measurements such as Loudness, Perceived Noisiness, Speech Interference Level and NC Level (see Appendix II).

Public Transport Vehicle Noise

13. The title allotted to this paper may suggest that public transport vehicles - trains, trams and buses - are inherently noisy. While in the past this has often been the case (with the exception of trolley buses), it is not universally so now. Much quietening of public transport operations has been achieved over the last forty years, although there are still some problems requiring solution.

14. With public transport vehicle noise there are two situations to be considered - inside and outside the vehicles. The magnitude of any problems with the noise outside or inside trains, trams and buses is indicated by the measured noise levels given in the following Tables and in Appendix III. Noise levels for cars and trucks have been added to the externally measured levels for comparison. TABLES 4 and 6 contain externally measured noise levels at 7.5 metre (about 25 ft) from the longitudinal centre-line of each type of vehicle. TABLES 5 and 7 contain typical noise levels measured inside passenger vehicles. The levels in TABLES 4 and 5 were measured in Melbourne, while those for the numbered noise spectra in TABLES 6 and 7 were obtained from various published sources (refs. 11, 12 and 18). (Noise spectrum numbers correspond with those in Appendix III.)

TABLE 4 - EXTERNAL SOUND LEVELS : MELBOURNE VEHICLES

VEHICLE TYPE	SOUND LEVELS AT 7.5 metre (dBA)			
	No.	MEAN	Max	Min
Suburban Electric Train at 30-35 mile/h				
(a) Blue	5	81*	83	78
(b) Red - accelerating	2	88*	(88)	(88)
- normal speed	4	83*	84	82
Tram at 20-25 mile/h	27	80*	88	70
Diesel Bus (City, Suburban)				
- accelerating	6	86	89	83
- 20-30 mile/h	8	83	85	79
Truck				
(a) Two-axle - accelerating	5	90	91	90
- at 20-30 mile/h	4	83	85	80
(b) Semi-trailer - accelerating	4	93	95	87
- at 20-30 mile/h	5	87	95	83
Car at 25-35 mile/h	21	73	84	65

* NOTE: Levels for the noise at rail joints, measured with the normal rms - indicating sound level meter were momentarily about 2dB above those shown. For a full evaluation of this noise, impact noise analysis is necessary.

TABLE 5 - INTERNAL SOUND LEVELS : MELBOURNE VEHICLES

VEHICLE TYPE	INTERNAL SOUND LEVELS (dBA)			
	No.	MEAN	Max	Min
Suburban Electric Train				
(a) Blue				
(i) motor coach - 30-35 mile/h	6	71	74	67
" " " (tunnel)*	1	74	(74)	(74)
(ii) trailer coach	6	70	73	66
(iii) noise at rail joints	3	76	80	72
(b) Red				
(i) motor coach - accel.	6	80	86	74
" " " (tunnel)*	1	84	(84)	(84)
" " - 30-35 mile/h	6	74	77	70
" " " (tunnel)*	1	81	(81)	(81)
(ii) trailer coach - accel.	6	74	80	72
" " - 30-35 mile/h	6	72	74	70
(iii) noise at rail joints	3	78	82	76
Tram at 20-25 mile/h	33	76	82	68
Diesel Bus (City, Suburban)				
(a) Front engine - accel.	5	84	86	82
- 20-30 mile/h	5	78	83	73
(b) Underfloor engine - accel.	8	82	86	78
- 20-30 mile/h	8	78	80	74

NOTE: * between Jolimont and West Richmond.

TABLE 6 - VEHICLE NOISE LEVELS (EXTERNAL) AT 7.5 METRE : VARIOUS SOURCES

VEHICLE TYPE (Spectrum No.)	SOUND LEVELS		SIL (dB) (Note 2)	CALC LOUDNESS		PERCEIVED NOISINESS
	dBC	dBA		Sone	Phon	(PNdB)
(1) Subway train (in open)		88	78	51	97	100
(2) Av. for diesel and steam trains		91	79	70	101	104
(3) Electric trains		74	65	21	84	86
(4) Old type tram (USA)		85	74	41	94	97
(5) PCC type (1947) tram		74	65	21	84	86
(6) Av. truck/bus (full throttle)		93	87	89	105	108
(7) " " " "		89	82	64	100	103
(8) Truck in suburban street		78	71	32	90	92
(9) Truck in city street		78	71	32	90	93
(10) Diesel truck, standard muffler		90	81	62	100	103
(11) Same truck, exptal. muffler		88	79	52	97	100
(12) Car in suburban street		68	60	16	80	80
(13) " " "		68	60	19	82	83
(14) Car (av.spectrum) - 50 mile/h		73	66	22	84	86
(15) Car (av.spectrum) - 35 mile/h		69	62	17	81	83
(16) Car (av.spectrum) - 30 mile/h		67	60	15	79	81
City bus (at start of acceleration)						
(a) Average condition	92	85				
(b) Engine enclosed	85	71				
(c) Engine enclosed + exptal.muffler	80	67				
(d) Engine enclosed + exptal.muffler + fan removed	77	66				
Same bus (after 6 sec.)						
(b) (As above)	65	57				
(c) (" ")	66	57				
(d) (" ")	66	60				

NOTES: (1) These results have been summarized from the numbered spectrum noise levels given in Appendix III. Unless stated, vehicles are at normal speeds.

(2) Values of SIL are based on octave bands centred at 850, 1700 and 3400 Hz.

(3) The sound levels for the city bus were calculated from several low-pass, band-pass, and high-pass sound level vs time graphs (ref.12, fig. 31.41).

TABLE 7 - VEHICLE NOISE LEVELS (INTERNAL) : VARIOUS SOURCES

VEHICLE TYPE (Spectrum No.)	SOUND LEVEL (dBA)	SIL (dB) (Note 2)	CAL. LOUDNESS Sone	CAL. LOUDNESS Phon	PERCEIVED NOISINESS (PNdB)
(17) Subway train	94	84	70	101	104
(18) " "	91	79	58	99	101
(19) Railway coach car at 0 mile/h	52	43	6	66	64
(20) Railway coach car at 30 mile/h	54	45	7	68	66
(21) Railway coach car at 50 mile/h	56	46	8	70	68
(22) Railway coach car at 60 mile/h	57	47	8.5	71	69
(23) Railway coach car at 70 mile/h	58	48	9	72	70
(24) Railway coach car at 90 mile/h	60	50	10	73	72
(25) Old type tram (USA)	86	73	47	95	98
(26) PCC type (1947) tram	78	63	27	88	90
(27) City bus (normal floor) 20 mile/h	74	63	21	84	85
(28) City bus (normal floor) 40 mile/h	78	71	29	88	91
(29) Same bus (exptal.floor) 20 mile/h	67	55	15	79	80
(30) Same bus (exptal.floor) 40 mile/h	70	64	24	86	88
(31) Inter-urban bus (normal engine mount)	62	46	13	77	76
(32) Inter-urban bus (engine partially isolated)	52	42	6	66	64
(33) Inter-urban bus (engine wholly isolated)	48	39	5	62	58

NOTES: (1) These results have been summarized from the numbered spectrum noise levels given in Appendix III. Unless stated, vehicles are at normal speeds.

(2) Values of SIL are based on octave bands centered at 850, 1700 and 3400 Hz.

15. Three additional Tables have been developed on the basis of results in Appendixes I and II in order to extend the usefulness of the measured sound levels for Melbourne vehicles given in TABLES 4 and 5. TABLES 8 and 9 repeat the general values of sound level in dBA (of TABLES 4 and 5 respectively) and give values of loudness level and speech interference level estimated by means of equations in TABLE II-3 (Appendix II). TABLE 10 combines the noise ratings of TABLE I-2, the maximum permissible speech interference levels of TABLES I-3A and I-3B, and equation (6) of TABLE II-3 to provide a series of ratings for noise inside public transport vehicles.

TABLE 8 - VEHICLE NOISE LEVELS (EXTERNAL) AT 7.5 METRE : MELBOURNE
Showing Estimated Values of SIL and Loudness

VEHICLE TYPE		SOUND LEVEL (dBA)	EST. SIL (dB) (Note 2)	ESTIMATED LOUDNESS	
				Phon	Sone (Note 3)
Train					
(a) Blue		78-83	68-73	89- 93	30-39
(b) Red	- accelerating	88	78	97	52
	- normal speed	82-84	72-74	92- 94	37-42
Tram	- normal speed	70-88	60-78	82- 97	18-52
Diesel Bus	- accelerating	83-89	73-79	93- 98	39-56
	- normal speed	79-85	69-75	90- 95	32-45
Truck					
(a) Two-axle	- accelerating	90-91	80-81	99-100	60-64
	- normal speed	80-85	70-75	91- 95	34-45
(b) Semi-trailer	- accelerating	87-95	77-85	97-104	52-84
	- normal speed	83-95	73-85	93-104	39-84
Car - normal speed		65-84	55-74	78- 94	14-42

NOTES: (1) Estimated values were obtained from sound levels (dBA) in TABLE 4 by means of equations (6) and (2) in TABLE II-3 (Appendix II).

(2) SIL are based on levels in octave bands centered at 850, 1700 and 3400 Hz.

(3) Loudness in sones were obtained from loudness levels by means of the relationship specified in BS 3045: 1958 (ref. 5).

TABLE 9 - VEHICLE NOISE LEVELS (INTERNAL) : MELBOURNE

Showing Estimated Values of SIL and Loudness

VEHICLE TYPE		SOUND LEVEL (dBA)	EST. SIL (dB) (Note 2)	ESTIMATED LOUDNESS	
				Phon	Sone (Note 3)
Train					
(a) Blue	- motor coach	67-74	57-64	79-85	15-23
	- trailer coach	66-73	56-63	78-84	14-21
(b) Red - motor	- accelerating	74-86	64-76	85-96	23-48
	- normal speed	70-77	60-67	82-88	18-28
- trailer	- accelerating	72-80	62-70	84-91	21-34
	- normal speed	70-74	60-64	82-85	18-23
Tram - normal speed		68-82	58-72	80-92	16-37
Bus					
(a) Front engine	- accelerating	82-86	72-76	92-96	37-48
	- normal speed	73-83	63-73	84-93	21-39
(b) Underfloor engine	- accelerating	78-86	68-76	89-96	30-48
	- normal speed	74-80	64-70	85-91	23-34

NOTES: (1) Estimated values were obtained from the sound levels (dBA) in TABLE 5 by means of equations (6) and (2) in TABLE II-3.

(2) SIL are based on levels in octave bands centered at 850, 1700 and 3400 Hz.

(3) Loudness in sones were obtained from loudness levels by means of the relationship specified in BS 3045: 1958 (ref. 5).

TABLE 10 - RATINGS FOR NOISE INSIDE PUBLIC TRANSPORT VEHICLES BASED ON SPEECH INTERFERENCE LEVEL (SIL)

NOISE RATING (Note 1)	DEGREE OF SPEECH COMMUNICATION POSSIBLE (Note 2)	SIL (dB) (Note 2)	ESTIMATED LEVELS EQUIVALENT TO SIL (Note 3)	
			dBA	Phon
Relatively Quiet	Normal conversation at 1 ft.	up to 64dB (69dB*)	up to 74	up to 85
Moderate	Normal conversation at 6 in.	65 to 70 (70 to 75*)	75 to 80	86 to 90
Noisy	Raised voice at 6 in.	71 to 76 (76 to 81*)	81 to 86	91 to 95
Very Noisy	Very loud voice at 6 in, or Shouting at 1 ft.	77 and over (82 and over*)	87 and over	96 and over

NOTES: (1) Noise ratings in this TABLE have been based on the degree of speech communication possible between two people.

(2) The degrees of speech communication possible and associated values of SIL correspond with the voice levels and distances between persons in TABLES I-3B and I-3A. Both types of SIL are quoted - those based on octave bands centered at 850, 1700 and 3400 Hz, and those in brackets and marked * on octave bands centered at 500, 1000 and 2000 Hz.

(3) Estimated levels were obtained by means of equations (2) and (6) in Appendix II. Limits for 95% confidence in the estimates are ± 4.8 for SIL/dBA, and ± 2.6 for dBA/Phon conversions.

16. The noise of Melbourne's public transport Vehicles, as typified by the noise levels in TABLES 4, 5, 8 and 9, can be assessed by comparison with the levels given in TABLES I-2 and 10. The criteria of TABLE I-2, although originally developed for classifying motor vehicle noise (ref. 17, p 200), can be extended

to other vehicle noise (heard externally), Sounds having sound levels of 82 dBA or less are likely to be regarded as "Quiet" (72 dBA or less) or "Moderate" (or Acceptable); above 82 dBA, sounds are likely to be regarded as "Noisy" or "Excessively Noisy" (93 dBA or more). From the measured sound levels in TABLE 4, the percentages of each type of vehicle likely to be regarded as "Quiet" or "Moderate" - with levels of 82 dBA or less were

cars	-	approximately	90%
trams	-	"	65%
trains, buses	-	"	50%
trucks	-	"	10%

17. When the levels in TABLE 4 are examined in more detail, the newer suburban trains are seen to be significantly quieter than the old "red" trains, trams are now quieter than several years ago (through the use of trolley shoes, composition brake shoes and quiet transmission gears), and the greatest noise from buses and trucks (particularly trucks) is when they are accelerating.

18. The noise heard inside trains, trams and buses can be similarly compared with the criteria of TABLE 10 (which are similar to those of TABLE I-2). On the basis of the figures in this Table, 80 dBA is the critical level. With noise heard inside vehicles, sounds with levels of 80 dBA or less are likely to be regarded as Relatively Quiet to Moderate, since normal conversation between two people is possible at distances of 6 in. or more. Above this level, internal vehicle sounds are likely to be regarded as Noisy or Very Noisy. Of the measured internal sound levels in TABLE 5 (and 9) but excluding those for noise at rail joints, all for the newer trains and for "Red" trailer coaches at normal speeds, and about 50 percent for "Red" motor coaches at normal speeds were 74 dBA or less (Relatively Quiet). Noise inside "Red" trains during acceleration was generally Moderate, being sometimes Noisy in motor coaches. Noise inside trams was normally Relatively Quiet to Moderate (10 percent of readings were 81 dBA or more - Noisy) while noise inside diesel buses was mainly Moderate at normal speeds and Moderate to Noisy during acceleration. Noise inside the newer type buses with underfloor engines was somewhat less than that inside older type buses with engines in front.

19. The noise from public transport vehicles, though sometimes loud, is not a continuous disturbance. The external noise levels in TABLES 4 and 6 are indications of maximum or near-maximum levels, rather than of levels which occur during the whole time a vehicle is moving. The greatest noise is

likely to be emitted by large vehicles fitted with diesel engines - diesel railway locomotives (Spectrum No. 2), or diesel trucks and buses during acceleration (TABLE 4 and Spectrum Nos. 6 and 10). A further disadvantage of road vehicles with diesel or petrol engines when compared with rail vehicles is that their noise increases more rapidly with increasing speed. Typical increases are 6 to 9 dB for a doubling of speed, compared with a corresponding 4 to 6 dB for rail vehicles (refs. 11, 12 and 18).

20. The vehicle noise levels from various published sources (mostly British and American), which are given in TABLES 6 and 7 are similar to those in TABLES 4 and 5. Because they are generally for individual vehicles of either older or more recent design, they provide limits which enclose the locally obtained levels. Their main purpose in this paper is to illustrate the effects of various noise-reducing designs and treatments.

Vehicle Noise Reduction

21. The principles involved in reducing noise are set out in detail in a number of published references such as the Handbook of Noise Control (ref. 12), Noise Reduction (ref. 2) or the G.R. Handbook of Noise Measurement (ref. 15). Three distinct stages in the process of quietening a noisy machine or activity can be identified - analysis to locate noise sources and paths by which the noise is transmitted (for which noise and vibration measuring instruments intelligently used are an invaluable aid), modification of the machine or activity (by either reducing the noise at its source or modifying the sound path between noise source and nearby people), and design of a quiet alternative. Experience has shown that the most economical way of incorporating noise-reducing features into machines and activities is to do it at the design stage rather than by late modification of existing equipment. The design of quiet alternatives is thus, because of its economy, an important aspect of reducing noise, and can be illustrated by reference to the noise spectra of TABLES 6 and 7 (where all spectra are numbered to correspond with the details in Appendix III).

22. The first two spectra for train noise measured externally (Spectrum Nos. 1 and 2) show the extent of the noise made by several types of railway vehicle. The subway train is of an earlier American electric design notorious for its noisiness. Diesel and steam locomotives are also well known for their noise. The main sources of noise have been found to include wheel and rail irregularities, exhaust, engine and transmission noise, rattling brake and other ancillary gear (e.g, air-compressors, couplings) and body noise excited by

vibration transmitted from moving parts. The spectrum for electric train noise (no. 3) shows that a reduction in loudness of at least 60 percent (from 51 or more to 21 sone) can be achieved by suitable design. In the electric train, engine and exhaust noise (and fumes) have been eliminated by a change to electric motors, transmission noise by the use of helical or hypoid instead of spur gears, rail irregularities by the use of long welded rails made of steel which resists the formation of surface corrugations, and wheel irregularities by means of electric braking or composition (instead of cast iron) brake shoes. Recent train designs such as the new NSW GR inter-urban trains show that even further noise reduction is possible through the use of pneumatic springing.

23. A similar noise reduction is shown in the two spectra for tram (or street car) noise (nos. 4 and 5). In the PCC (President's Conference Committee) design which included resilient wheels and other noise reducing features similar to those on the electric train described above, a loudness reduction of 50 percent was achieved when compared with trams of earlier American design. In addition, the noise levels for the newer Melbourne Suburban trains when compared with those for the older red trains (TABLE 4) show that noise due to spur gears during acceleration has been eliminated by the use of quiet gears (with a reduction of 7 dB) and that general running noise has been reduced by about 2 dB through the use of composition brake shoes. Tram noise has been similarly reduced so that their average noise at normal speeds is now less than that of buses and significantly less than that of trucks.

24. Noise levels in TABLE 6 (without spectrum number) show ways in which bus noise can be reduced - by isolating and enclosing the engine and by using specially designed mufflers.

25. The noise spectra in TABLE 7 show something of the way in which properly designed body insulation (body panel and floor) and engine mountings can reduce the noise inside public transport vehicles.

26. Some aspects of public transport noise such as the noise from railway shunting yards have already been subject to some degree of noise-zoning. Many such yards are situated in industrial areas and are therefore some distance away from residential areas. Other aspects include the problem of railway points and crossings, and the problem of the more powerful diesel or petrol engines required to improve the acceleration and speed characteristics of buses and trucks. The rail crossing problem is being tackled by the development of "resilient" crossings in which wheel flanges are carried across the rail gap on a resiliently supported groove base. These crossings effect a significant reduction in impact. The bus and truck problem requires continued research into resilient

engine mountings, engine isolation, and more efficient mufflers.

27. The problem of underground railway noise has been the subject of much research. The solution tried in the Metros of Paris and Montreal has found at least a partial but somewhat expensive solution to the noise problem through the use of rubber tyres (in addition to the steel wheels and rails which are necessary for safety in case of blowouts, and also at points and crossings). The noise reducing treatments used in Toronto (described in ref. 12) include tunnel walls treated internally with 2 in. thick glass wool and track supported resiliently on $\frac{1}{2}$ in. thick rubber pads. At present, no published results are readily available for comparison of train operations in the tunnels on these two systems. However, the principles of quiet operation of trains in tunnels are stringent and include the need for smooth wheels and rails, resiliently-supported rails (with supports - e.g, rubber rather than ballast for space economy - having a resilience at least as low as 100 ton/in. (ref. 14)), rails treated to reduce vibration, tunnels with acoustically treated walls to reduce reverberation to a minimum, and adequate carriage body insulation.

CONCLUSION

28. When the various sources of community noise are seen in perspective, existing noise problems arising from public transport operations are not as serious as those posed by aircraft, trucks and some industrial processes. Already, through careful design, much has been achieved to reduce the noise of trains, trams and buses. Further reduction of noise is both desirable and possible, particularly in the fields of diesel engine noise and the operation of trains in tunnels. Some noise-zoning (e.g, of railway marshalling and shunting yards) is already practised. However, the extension of noise-zoning without reduction of noise at its source, into passenger transport operations is undesirable since passenger vehicles perform a service in direct contact with the general public.

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APPENDIX I - RELATIONSHIPS BETWEEN PHYSICAL MEASUREMENTS AND SUBJECTIVE ASSESSMENTS OF SOUNDS

30. The various relationships between the measurable physical characteristics of a sound and a person's subjective assessment of it can be divided into three groups -

(1) those which require a simple single intensity measurement of the sound,

(2) those which require the resources of a well-equipped acoustical laboratory, and

(3) those which require some analysis (e.g, octave, one-third octave or narrow band) of the sound.

(1) Single Measurement

31. Among the earliest relationships were those which showed the relationships between subjective assessments of a noise and single sound intensity measurements obtained with a sound level meter. Typical of these is the following TABLE of Decibel Ratings of Common Sounds (ref. 20), in which sounds and their sound levels are listed with a subjective assessment of their relative loudness. All sound levels are in decibels (dB) relative to the reference pressure of 0.0002 dyn/sq cm or 0.00002N/sq m. Sound levels referred to as dBC are obtained with the "C-weighting" network which allows approximately equal meter sensitivity to sounds of various pitch. Use of the "B" and "A-weighting" networks (giving sound levels in dBB or dBA) progressively reduces by specified amounts (ref. 8) the sensitivity of the sound level meter to sounds of low pitch.

TABLE I-1 - DECIBEL RATINGS OF COMMON SOUNDS

SOUND	SOUND LEVEL (dBC)	SUBJECTIVE ASSESSMENT
Threshold of pain	120	
Thunder, artillery Nearby riveter Underground train Boiler factory	110 100	Deafening
Loud street noise Noisy factory Lorry unmuffled Police whistle	90 80	Very loud
Noisy office Average street noise Average wireless Average factory	70 60	Loud
Noisy home Average office Average conversation Quiet wireless	50 40	Moderate
Quiet home or private office Average auditorium Quiet conversation	30 20	Faint
Rustle of leaves Whisper Sound-proof room Threshold of audibility	10 0	Very faint

(This TABLE was derived from TABLE I in ref. 20)

32. Some more recently found relationships of this type are given in the "Wilson" Final Report on Noise (ref. 17) presented to the British Parliament in July 1963, which includes a TABLE of Noise Levels of Some Typical Sounds (see TABLE 1 in paragraph 8 of this paper), and gives the results of experiments carried out to obtain subjective ratings of motor vehicle and aircraft noise (see TABLE I-2 below). Other subjective assessments in which office noises rated as quiet, noisy, etc were correlated with various objective noise measurements, are given in ref. 19. The results were similar to those for the outdoor noises in TABLE I-2 except that "Quiet" corresponded to 43 dBA or less, "Moderately Noisy" to 43-57 dBA, "Noisy" to 57-70 dBA, etc.

TABLE I-2 - SUBJECTIVE RATINGS OF MOTOR VEHICLE AND AIRCRAFT NOISE (As heard out-of-doors)

SUBJECTIVE NOISE RATING	NOISE LEVEL LIMITS for	
	Motor vehicle Noise	Aircraft Noise
Quiet	up to 72 dBA	up to 76 dBA
Moderate (acceptable)	73 to 82	77 to 93
Noisy	83 to 92	94 to 107
Very or excessively Noisy	93 dBA or more	108 dBA or more

(This TABLE was derived from the graph at ref. 17, p. 200)

33. All these assessments, though simply expressed, suffer the disadvantage that decibel readings do not mean very much to the layman. That a change in sound level of 9 to 10 dBA corresponds to a halving or doubling of the loudness is not usually very much extra help, and further types of measurement have been attempted.

(2) Acoustical Laboratory Assessments

34. The main laboratory assessments of people's reactions to sounds and noises have been concerned with measuring Loudness, Noisiness (or Annoyance), Interference to speech, and Hearing Loss in relation to exposure duration.

(a) Loudness Measurement

35. Measurement of the loudness of a sound needs at present to be carried out under controlled laboratory conditions by comparing the sound under test with a standard sound (normally a 1000 Hz pure tone). The listeners taking part in these loudness comparisons are asked to make either "equal loudness" judgments, or judgments involving relationships such as "twice as loud" or "half as loud".

36. Two different loudness units have been developed for specifying the results of these measurements. The PHON is the unit of Loudness Level (ref. 3, definitions 3012, 3013) such that the loudness level of a sound is n phon, when it is judged (under the specified conditions) by a group of normal observers as being equally loud as a standard pure tone of 1000 Hz which has a sound pressure level of n dB (re 0.00002 N/sq m).

37. Several groups of relationships have been developed from measurements of this kind - equal-loudness contours for pure tones, equal-loudness contours for bands of noise, and a number of "engineering rules" for estimating the loudness of sounds from their measured sound levels. Following earlier determinations of Equal-loudness Contours for Pure Tones by Fletcher and Munson (1933) and Churcher and King (1937), the more recent determination by Robinson and Dodson (1956) has since been adopted as a British Standard (ref. 6) and also as an international standard (ISO/R226-1961). Several determinations have been made of equal-loudness contours for bands of noise - by Pollack in 1952 (ref. 15A, p 46), and several times since 1955 by S S Stevens. These contours find a useful application in calculating the loudness of noises (normally broad band) from an octave or one-third octave band frequency analysis. The most recent determination is "Procedure for Calculating Loudness : Mark VI" (refs. 16; 15A, pp 49-52; and 15B, pp 111-114) and has been used for calculating the loudness of the sounds quoted in this paper. A typical "engineering rule" developed from laboratory loudness measurements for estimating loudness levels from measured sound levels is, for "white noise",

$$\text{Loudness Level (in phon)} = \text{dBC} + 10$$

for values of sound level above 50 dBC (developed by S S Stevens in 1955). Similar rules for estimating the loudness levels of the noise of transport vehicles could be developed from measurements such as those given in Appendixes II and III.

38. The SONE (ref. 3, defn 3011) is a unit of Loudness such that a sound of loudness 2 sones would be judged (under controlled conditions) "twice as loud" as a sound of loudness 1 sone, or "half as loud" as a sound of loudness 4 sones. The sone scale of loudness has been standardized such that a sound having a loudness 1 sone has a loudness level of 40 phon. The

relation between the sone and phon scales is referred to as the "Loudness Function" and has been standardized (ref. 5).

(b) Measurement of Perceived Noisiness

39. Perceived Noisiness or Annoyance, a characteristic of noise treated as analogous to, but distinct from, loudness, has been the subject of recent investigations, particularly by K D Kryter who has developed a procedure for calculating the Perceived Noisiness of a sound from its octave, or one-third octave band levels (ref. 13) similar to Stevens' procedure for calculating the loudness of noises. The units for quoting perceived noisiness are the NOY and PNdB (analogous, respectively, to the sone and phon), and have also been used in this paper.

(c) Speech Interference Levels

40. The ability of background noise to interfere with, or mask speech communication between people has also been the subject of much research. As a result, Tables of Speech Interference Levels have been developed. They specify the approximate degree of speech communication between two people, which is possible with different levels of background noise. The Speech Interference Level (SIL) of background noise has been variously defined - earlier in terms of the sound levels in octave bands centered at 850, 1700 and 3400 Hz (ref. 15B, p 115), and more recently in terms of octave bands centered at the preferred frequencies (ref. 1) of 500, 1000 and 2000 Hz (ref. 15A, p 63). In either case, the speech interference level is defined as the average of the band levels in the three specified octave bands; with the addition that, if the level in the 425 Hz octave band exceeds that of the 850 Hz band by 10 dB, the SIL (old octave bands) is calculated as the average of the levels in the 425, 850, 1700 and 3400 Hz bands. The following Tables of maximum Speech Interference Levels show the SIL values which should not be exceeded for reliable conversation at the specified distances between people, and for several voice levels (Tables from refs. 15A, p 63; and 15B, p 115).

TABLE I-3A - MAXIMUM PERMISSIBLE SPEECH INTERFERENCE LEVELS

(Octave Bands centered at preferred frequencies of 500, 1000 and 2000 Hz)

DISTANCE BETWEEN PERSONS (ft)	MAXIMUM SIL (dB) WITH VOICE LEVEL			
	Normal	Raised	Very Loud	Shouting
0.5	(76)	(82)	(88)	(94)
1	70	76	82	88
2	64	70	76	82
3	60	66	72	78
4	58	64	70	76
5	56	62	68	74
6	54	60	66	72
12	48	54	60	66
24	42	48	54	60

NOTE: The values of SIL in brackets, for 0.5 ft, are not included at ref. 15A, p 63.

TABLE I-3B - MAXIMUM PERMISSIBLE SPEECH INTERFERENCE LEVELS

(Octave Bands centered at frequencies of 850, 1700 and 3400 Hz)

DISTANCE BETWEEN PERSONS (ft)	MAXIMUM SIL (dB) WITH VOICE LEVEL			
	Normal	Raised	Very Loud	Shouting
0.5	71	77	83	89
1	65	71	77	83
2	59	65	71	77
3	55	61	67	73
4	53	59	65	71
5	51	57	63	69
6	49	55	61	67
12	43	49	55	61
24	37	43	49	55

(d) Hearing Damage and Noise Exposure

41. Although much laboratory research has been done to establish relationships between human hearing loss and exposure to noise, the published results as yet shows no general agreement. TABLE I-4 below (from ref. 15A, p 68) show Damage Risk Levels (for noise in octave bands centered at preferred frequencies) which may be too high, particularly since "these Risk Levels have been set so that, on the average, persons will not suffer serious hearing losses if the levels for the exposure durations are less than those indicated. Some susceptible persons may suffer significant losses, however, so that it is wise to reduce the noise level or provide ear protection if the levels approach those shown in the Table".

TABLE I-4 - DAMAGE RISK NOISE LEVELS

EXPOSURE DURATION (hours/day)	DAMAGE RISK LEVELS (dB) Noise in Octave Bands Centered at						
	125 Hz	250	500	1000	2000	4000	8000
8	96	92	88	86	85	85	86
4	103	96	91	88	86	85	87
2	110	101	94	91	88	87	90
1	118	107	99	95	91	90	95
0.5	126	114	105	100	95	93	99
15 min	135	122	112	106	99	98	104
7 min	135	135	122	114	105	104	111
3 min	135	135	134	124	113	111	120
1.5 min or less	135	135	135	134	124	121	130

NOTE: The 8h/day levels correspond to a noise having sound levels of 99 dBC, 97 dBB and 93 dBA. For noises having spectra with sharp peaks or made up mainly of pure tones the damage risk levels are lower than those in this Table.

42. By contrast, a suggested preliminary test based on sound levels at B-weighting (in dBB) states that "a reading above 100 dBB indicates that the noise is probably unsafe for everyday exposures, at least for some people, and noise reduction or ear protection is necessary. Readings below 80 dBB indicate that there is probably no danger from the noise even if it is a simple tone" (ref. 15B, p 123). A sound level of 80 dBB is normally equivalent to about 74 to 77 dBA.

(3) Assessments based on Noise Analysis

43. Subjective assessments of noises which require analysis of the noise are important not only because they allow a more detailed subjective assessment, but also because analysis is a most efficient means of determining both the source of the noise and methods of reducing it. Such analyses are carried out with the aid of instruments such as frequency analyzers (octave, $\frac{1}{3}$-octave, or narrow band), and graphic and tape recorders in addition to a sound level meter.

44. These assessments include the calculation of Loudness, Perceived Noisiness, and Speech Interference Levels (already referred to above), the calculation of Noise and Number Indexes (ref. 17, p 207 ff) and Traffic Noise Indexes (ref. 18, p 3), and the use of Noise Criterion (NC and NCA) Curves (ref. 15B, p 117; ref. 19; and ref. 2, pp 518-23), and Residential Noise Criteria (ref. 15B, pp 119-22).

45. Because many common noises, such as traffic and aircraft noise, vary considerably with time, noise ratings such as the Noise and Number Index and Traffic Noise Index have been developed to include the effect of time. Thus, the Noise and Number Index at any location (developed initially to rate aircraft noise) includes the "average peak noise level" (in PNdB) together with the number of aircraft passing overhead per day. The London Traffic Noise Index incorporates the variability of noise level at any given location with time by means of two computed sound levels, L_{10} and L_{90}, where L_{10} (dBA) is a near-maximum level exceeded only for 10% of the sampling period, while L_{90} (dBA) is a near-minimum level which is exceeded for 90% of the sampling period. It was found that both these indexes correlated well with people's dissatisfaction with the noise conditions.

Summary

46. The work done in acoustical laboratories is an important part of the continuing research into ways of reducing noise, the inefficiency it causes, and damage to hearing. The many published results of this work are then available for solving other noise problems for which simpler noise measuring instruments only are available.

47. Single instrument readings, such as sound levels obtained with a sound level meter, have their main use in the preliminary stages of tackling a noise problem, and provide initial estimates of its magnitude. For more detailed investigation, additional analyzers and recorders are required. These more detailed measurements serve two purposes. The band levels obtained from frequency analysis of the noise, and the

variation of level with time and distance from the source, provide detailed information for locating the noise source (or sources) and reducing its effects, while use of the band levels in conjunction with laboratory-determined loudness, noisiness, speech interference or hearing loss criteria enables the subjective aspects of the noise problem to be more clearly determined.

APPENDIX II – SOUND LEVEL IN dBA AS A SINGLE-NUMBER NOISE RATING

48. The usefulness of any single-number noise measurement or rating - such as a sound level meter reading - is considerably increased when, for groups of common sounds, there is reasonable correlation between the single-number rating and other more complex ratings of the noise such as its loudness, speech interference level or perceived noisiness (ref. 15A, p 57; ref. 19). The published results from full noise analyses can then be used with the results of other tests on similar noises to estimate from sound level meter readings, the corresponding values of loudness, etc. Because groups of octave band spectra of the noise inside and outside trains, trams and buses were available, the relationships between the various sound levels (dBC, dBB and dBA), and the calculated values of SIL, Loudness Level and Perceived Noisiness of each sound were examined.

49. For the first analysis, the 33 numbered spectra (Appendix III) were taken as one group to check the average differences between sound level (dBC, dBB and dBA) and the corresponding loudness level, SIL and perceived noisiness. The spectra were then divided into three groups - rail vehicle noise (external) road vehicle noise (external) and noise from all vehicles (internal). Averages were then calculated of the differences between sound level in dBA, and loudness level, SIL and perceived noisiness. The spectra were finally taken as one group for an analysis of the correlation between loudness level, SIL and perceived noisiness (taken one at a time) and various combinations of sound level (dBC, dBB and dBA).

50. The results of the first analysis are shown in the Table of Mean Differences (TABLE II-1). In general, they show that differences between calculated loudness level, etc and sound level in dBA are less variable than differences between the calculated values and sound levels in dBB or dBC. This can be interpreted that sound level in dBA is a more reliable estimator of loudness level, etc than sound levels in dBB or dBC. The chief exception to this was that, of the differences between sound level and loudness level (in phon), the least variable was that between phon and dBB (with 95% confidence limits of $\pm$ 0.5). Although the difference between phon and dBA showed the greatest relative variability (with 95% confidence limits of $\pm$ 0.8), this was only

slightly greater than the variability of the differences between phon and dBB, and PNdB and dBA, and equal to that of the difference between SIL and dBA.

TABLE II-1 - TABLE OF MEAN DIFFERENCES FOR VEHICLE NOISE SPECTRA

DIFFERENCE BETWEEN		MEAN VALUE (± 95% Conf. Limits)
Sound levels in dBC and dBA,	dBC-dBA	9.1 ± 1.3
" " " dBB " dBA,	dBB-dBA	5.0 ± 0.7
Loudness level and dBC,	Phon-dBC	2.4 ± 0.7
" " " dBB,	Phon-dBB	6.4 ± 0.5
" " " dBA,	Phon-dBA	11.4 ± 0.8
SIL and dBC,	SIL-dBC	-18.9 ± 1.8
" " dBB,	SIL-dBB	-14.8 ± 1.2
" " dBA,	SIL-dBA	- 9.8 ± 0.8
Perc. noisiness and dBC,	PNdB-dBC	3.4 ± 1.2
" " " dBB,	PNdB-dBB	7.4 ± 0.7
" " " dBA,	PNdB-dBA	12.4 ± 0.6

51. The value of Phon-dBA (for transport vehicle noise) in this TABLE is of the same order as values obtained elsewhere. In TABLE 1 (above) the average difference is 11.4 for a wide variety of sounds. R.W. Young in his article on "Single-number Criteria for Room Noise" (ref. 19) obtained a similar value - the small difference between his 13 and the 11.4 above being mainly due to the difference between office and vehicle noise spectra. Young obtained the following mean differences for 17 office noises: dBB-dBA = 5.4, SIL-dBA = 9.8, PHON-dBA = 13.3 and PNdB-dBA = 12.9; and for 10 idealized spectra: dBC-dBA = 4.9, dBB-dBA = 3.2, SIL-dBA = 8.7, PHON-dBA = 13.0 and PNdB-dBA = 12.2.

52. The average differences, dBC-dBA and dBB-dBA, were inserted in TABLE II-1 to briefly characterize the spectra for transport vehicle noise included in the analysis. For the sound spectra studied, the sound levels in dBC and dBB were, on the average, 9 and 5 (respectively) greater than corresponding dBA levels.

53. When the 33 spectra were grouped, the differences for

the three groups showed a number of individual characteristics (TABLE II-2 below). In this TABLE, individual mean differences which differ noticeably (by about 1 dB or more) from the overall mean values have been underlined.

TABLE II-2 - TABLE OF MEAN DIFFERENCES FOR THREE GROUPS

NOISE SPECTRUM GROUP	DIFFERENCE	GROUP MEAN DIFFERENCE	OVERALL MEAN DIFF. (TABLE II-1)
Rail - External (5 spectra)	dBC-dBA	6.6 ± 2.5	(9.1 ± 1.3)
	Phon-dBA	9.5 ± 0.9	11.4 ± 0.8
	SIL-dBA	-10.4 ± 1.3	- 9.8 ± 0.8
	PNdB-dBA	12.0 ± 0.9	12.4 ± 0.6
Motor Vehicle - External (11 spectra)	dBC-dBA	7.3 ± 1.6	(9.1 ± 1.3)
	Phon-dBA	11.5 ± 1.2	11.4 ± 0.8
	SIL-dBA	- 7.6 ± 0.7	- 9.8 ± 0.8
	PNdB-dBA	13.7 ± 1.0	12.4 ± 0.6
All vehicles - Internal (17 spectra)	dBC-dBA	10.9 ± 2.1	(9.1 ± 1.3)
	Phon-dBA	12.2 ± 1.3	11.4 ± 0.8
	SIL-dBA	-10.5 ± 1.2	- 9.8 ± 0.8
	PNdB-dBA	12.4 ± 0.8	12.4 ± 0.6

54. The internally measured levels for all vehicles were grouped together because there was no simple logical way of classing the differences which, as indicated in TABLE II-2, showed considerable variation for a group of 17 spectra. Even when spectra for luxury vehicles (railway coach car, inter-urban bus) were separated from those for the city and suburban type vehicles (the most obvious sub-grouping exhibited by the differences), each sub-group of differences showed considerable variability.

55. In the third analysis, more general (but still simple) relationships between the calculated values and sound levels in dBA dBC were examined - of the form

$$N = a \cdot dBA + k \quad \ldots\ldots \quad (1)$$

$$\text{or, } N = a \cdot dBA + b \cdot dBC + k \quad \ldots\ldots \quad (2)$$

where N is a calculated loudness level, SIL or perceived noisiness, a and b are coefficients of estimation, and k is a constant. (In the earlier analyses, the average differences gave relationships similar to that in equation (1), but as the particular case of a = 1).

56. The correlation equations obtained as a result of this third analysis are given in TABLE II-3 below, and show dBA as a more reliable single-number rating than dBB or dBC. Equations containing both dBA and dBC simultaneously as independent variables have been given in their original and in an alternative form (with "A" numbers) to show the way in which these levels influence the dependent variables. Each equation is given with its Multiple Correlation Coefficient (R), its Coefficient of Determination (R^2), and the limits with which estimated values can be obtained with 95% confidence in the estimate. The coefficient of determination is a useful measure since it specifies the fraction of the variability in the data which has been included in the estimating equation developed from them. The results thus show dBA and dBC taken together as slightly more efficient estimators of loudness, etc than dBA alone.

TABLE II-3 - EQUATIONS SHOWING CORRELATION BETWEEN dBA and dBC, PHON, SIL and PNdB

EQUATION	CORRELATION COEFFICIENT (R)	COEFFICIENT OF DETERMINATION (R^2)	95% CONF. LIMITS FOR ESTIMATED VALUES
(1) dBB = 0.452 dBA + 0.564 dBC - 1.36	0.998	0.988	± 1.8
(1A) dBB = 1.016 dBA + 0.564 (dBC-dBA) - 1.36			
(2) PHON = 0.866 dBA + 21.30	0.994	0.988	± 2.6
(3) PHON = 0.950 dBB + 10.50	0.993	0.986	± 2.9
(4) PHON = 1.047 dBC - 1.32	0.984	0.969	± 4.4
(5) PHON = 0.598 dBA + 0.337 dBC + 13.28	0.996	0.994	± 2.0
(5A) (PHON-dBA) = 13.28 - 0.065 dBA + 0.337 (dBC-dBA)			
(6) SIL = 0.998 dBA - 9.38	0.986	0.972	± 4.8
(7) SIL = 1.075 dBB - 20.28	0.967	0.935	± 7.3
(8) SIL = 1.171 dBC - 32.59	0.948	0.899	± 9.1
(9) SIL = 1.213 dBA - 0.270 dBC - 2.94	0.987	0.975	± 4.8
(9A) (SIL-dBA) = 2.94 - 0.057 dBA - 0.270 (dBC-dBA)			
(10) PNdB = 1.008 dBA + 12.12	0.993	0.987	± 3.2
(11) PNdB = 1.103 dBB - 0.27	0.990	0.981	± 4.0
(12) PNdB = 1.212 dBC - 13.76	0.979	0.959	± 5.8
(13) PNdB = 0.777 dBA + 0.290 dBC + 5.22	0.995	0.990	± 2.9
(13A) (PNdB-dBA) = 5.22 + 0.067 dBA + 0.290 (dBC-dBA)			

The equations in this Table have been used in estimating, from measured sound levels in dBA, the values of loudness level and SIL in TABLES 8, 9 and 10 above. The equations with "A" numbers are equivalent alternative forms.

APPENDIX III - OCTAVE BAND SPECTRA FOR VEHICLE NOISE

57. As additional illustrative material for this paper, 33 numbered noise spectra were selected from the published books and articles indicated under Figures III-1 to III-7. The octave band spectra (given in terms of the older series of bands centered at 53, 106, 212, 425, 850, 1700, 3400 and 6800 Hz) are for noise measured both inside and outside some typical public transport vehicles and, for comparison, some motor trucks and cars. Because no spectra of bus noise were readily available, and because the authors of the British Road Research Laboratory report, "A Review of Road Traffic Noise" (ref. 18) grouped trucks and buses together as "heavy commercial vehicles" (ref. 18, Figure 1), these spectra have been included as typical of some aspects of bus operation.

58. In Figures III-1 to III-7 the various spectra have been grouped according to measuring position (outside or inside vehicle) and vehicle (train, tram, bus/truck or car). The calculated values of sound level, SIL, loudness and perceived noisiness of each noise have been summarized in TABLE III-1.

59. For ease of comparison, all sound levels measured externally have been converted to those estimated to occur at 7.5 metre (about 25 ft) from the longitudinal centre-line of each vehicle. This distance (7.5 m) has been standardized for many vehicle noise measurements (ref. 7). Three types of distance conversion factors were used. Values of conversion factor associated with a two-fold change in distance were 3 dB for trains (taken as line sources), 4 to 5 dB for trams, buses and trucks, and 6 dB for cars (taken as point sources).

TABLE III-1 - TRANSPORT VEHICLE NOISE SPECTRA

NO.	CALCULATED SOUND LEVELS			SIL (dB) (Note)	CALCULATED LOUDNESS		PERCEIVED NOISINESS	
	dBC	dBB	dBA		Sone	Phon	Noy	PNdB
1	93.4	91.9	88.4	78	51	96.8	63	99.8
2	101.2	97.0	91.2	79	70	101.2	86	104.3
3	80.9	78.0	74.3	65	21	84.2	24	86.1
4	90.2	88.7	84.7	74	41	93.7	51	96.7
5	80.2	78.0	74.2	65	21	84.2	24	85.9
6	100.8	96.1	93.3	87	89	104.7	113	108.2
7	93.1	91.4	89.0	82	64	100.0	80	103.2
8	87.6	82.6	77.8	71	32	89.8	37	92.0
9	87.5	80.6	77.6	71	32	90.2	40	93.3
10	98.0	94.6	89.9	81	62	99.7	79	103.1
11	92.9	91.1	88.4	79	52	97.0	65	100.3
12	75.5	71.5	68.2	60	16	80.3	16	79.5
13	79.4	74.1	68.2	60	19	82.2	20	82.8
14	79.2	76.4	73.3	66	22	84.5	24	85.9
15	75.2	72.4	69.3	62	17	80.8	20	83.3
16	73.2	70.4	67.3	60	15	79.1	17	81.1
17	97.6	96.7	93.9	84	70	101.4	87	104.4
18	94.9	93.4	90.8	79	58	98.6	69	101.2
19	65.0	58.5	52.2	43	6	66.1	5	64.1
20	66.8	60.5	53.9	45	7	67.7	6	65.9
21	69.5	62.5	55.5	46	8	69.6	7	67.9
22	70.7	63.9	57.2	47	8.5	70.9	8	69.4
23	71.7	64.9	58.1	48	9	71.7	8	70.4
24	73.4	66.4	59.6	50	10	72.8	9	72.3
25	94.6	90.8	86.1	73	47	95.4	57	98.4
26	87.2	83.4	77.5	63	27	87.5	31	89.6
27	79.6	77.1	74.5	63	21	83.3	23	85.4
28	84.7	81.6	78.5	71	29	88.4	35	91.3
29	76.5	74.3	67.3	55	15	79.4	16	79.8
30	83.7	79.9	70.2	64	24	85.6	27	87.5
31	79.8	72.6	61.7	46	13	76.9	12	76.3
32	64.8	58.8	52.0	42	6	65.9	5	63.5
33	61.0	54.8	48.0	39	5	62.3	4	58.5

NOTE: Because the originally quoted octave band levels were for bands centered at the earlier frequency series of 53, 106............. 6800 Hz, the Speech Interference Levels in this Table are the averages of the sound levels for octave bands centered at 850, 1700 and 3400 Hz.

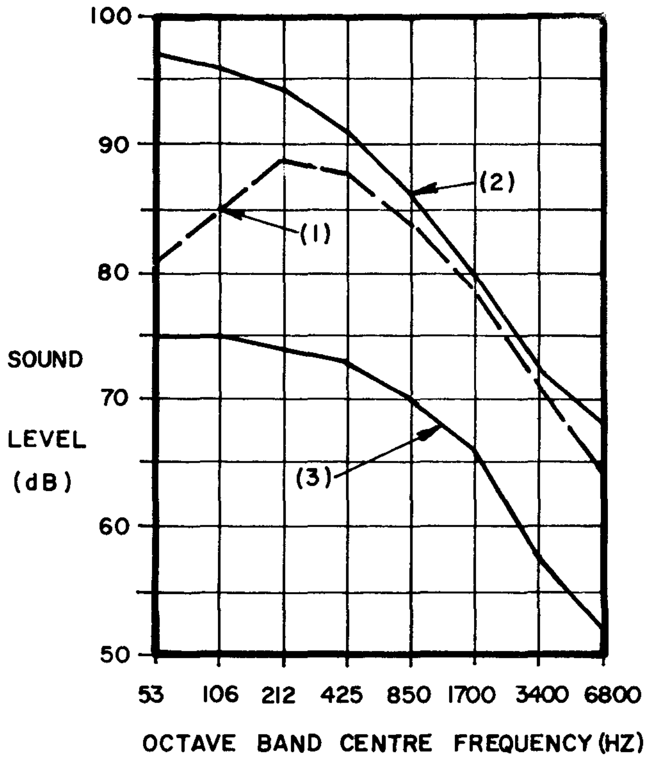

FIGURE III - I TRAIN NOISE (External) AT 7·5m

(1) SUBWAY TRAIN (in open)
(2) AV. SPECTRUM FOR DIESEL AND STEAM TRAINS
(3) ELECTRIC TRAIN

} REF 12, from FIG 32·13

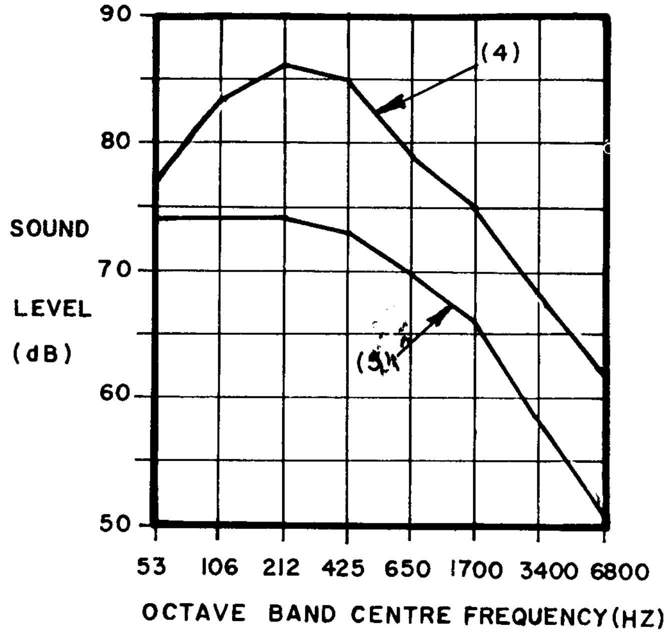

FIGURE III-2 TRAM NOISE (External) AT 7·5 m

(4) OLD TYPE TRAM (USA) } REF 12, FIG 32·13
(5) PCC TYPE TRAM (1947) }

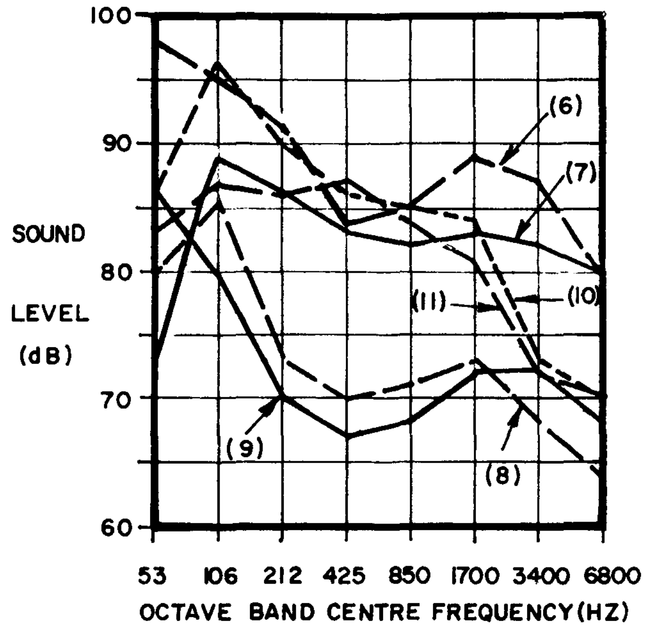

FIGURE III-3 TRUCK & BUS NOISE (External) AT 7·5m

(6) AV. TRUCK / BUS (8-litre engine–full throttle, BS 3425 test) } REF 18, FIG 1

(7) " " " (5·95 litre " – " " " " } REF 18, FIG 1

(8) TRUCK IN SUBURBAN STREET (Melbourne)

(9) TRUCK IN CITY STREET (Melbourne)

(10) DIESEL TRUCK, STD MUFFLER } Cruising, Level grade, engine at 1900 rev/min, REF 11, from FIG B-11, B-12.

(11) " " , EXPTAL " } Cruising, Level grade, engine at 1900 rev/min, REF 11, from FIG B-11, B-12.

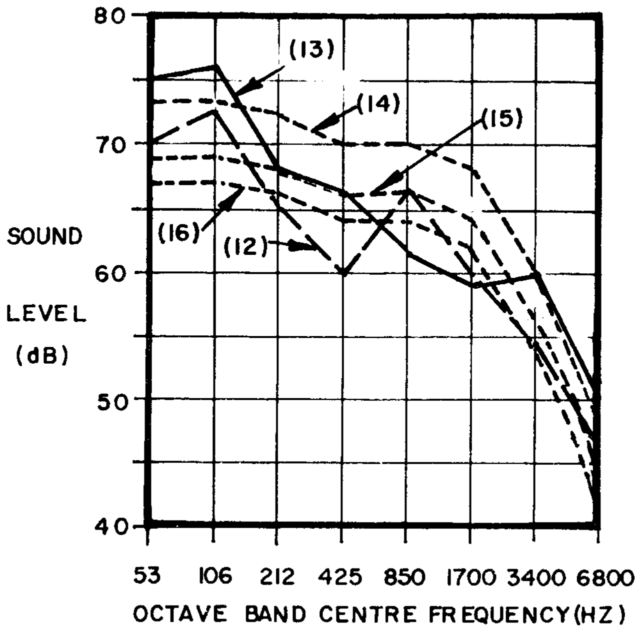

FIGURE III-4 CAR NOISE (External) AT 7·5 m

(12) CAR IN SUBURBAN STREET (Melbourne)

(13) " " " " (")

(14) CAR (AV. SPECTRUM), CRUISING AT 50 MILE/H, REF 11, FIG B-4

(15) " (" "), " " 35 " } REF 11, from FIG B-4, B-5.

(16) " (" "), " " 30 " }

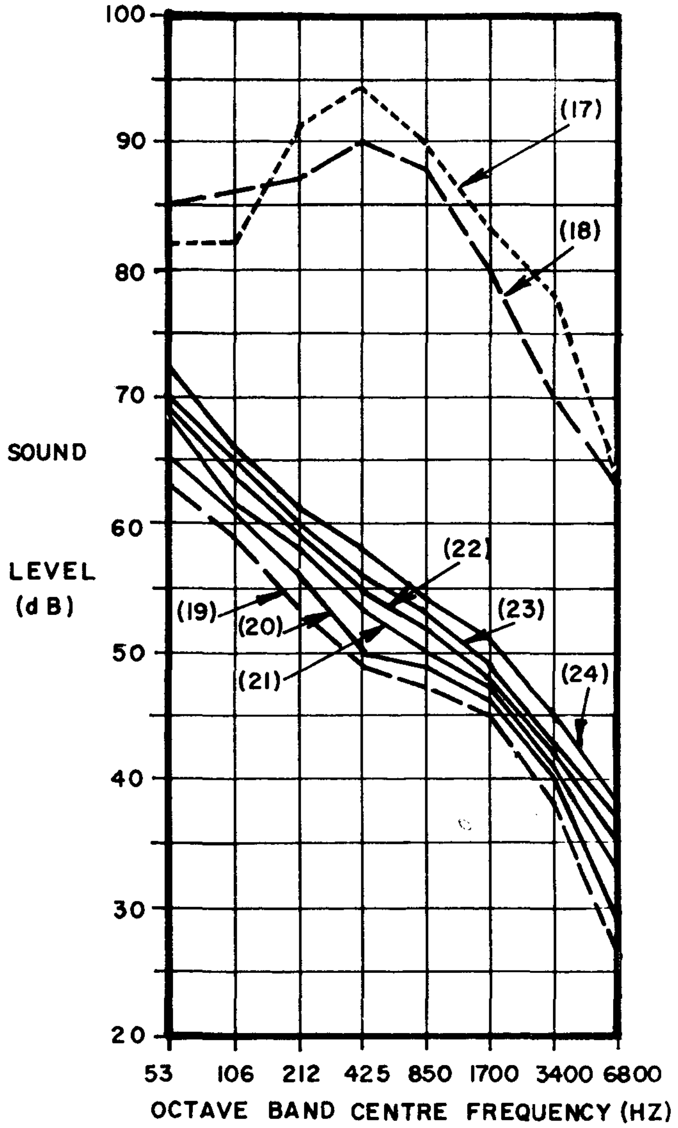

FIGURE III-5 TRAIN NOISE (Internal)

(17) INSIDE SUBWAY TRAIN, REF 12, FIG 32·17

(18) " " " , REF 12, FIG 32·18

(19) to (24) INSIDE RAILWAY COACH CAR AT 0,30,50, 60,70 AND 90 MILE/H, REF 12, FIG 32·1

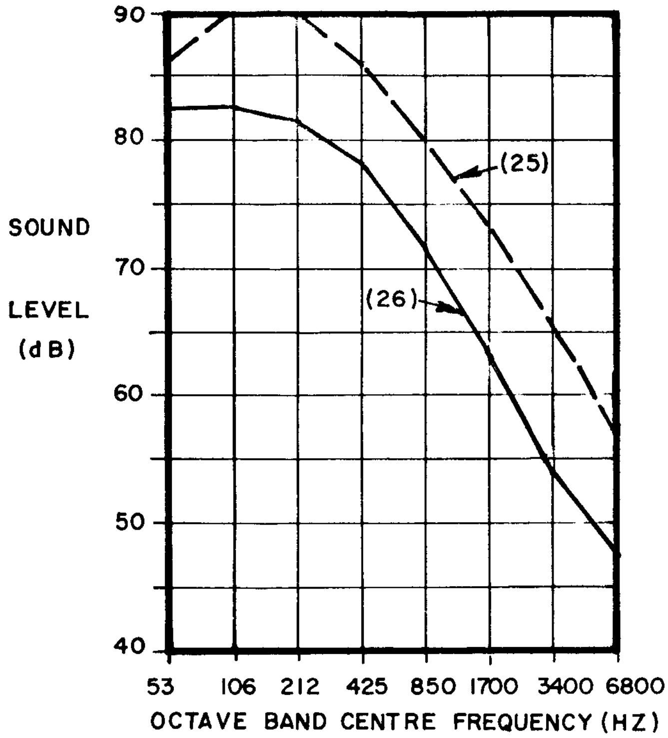

FIGURE III-6 TRAM NOISE (Internal)

(25) INSIDE OLD TYPE TRAM (USA)
(26) INSIDE PCC TYPE TRAM (1947)
} REF 12, FIG 32·18

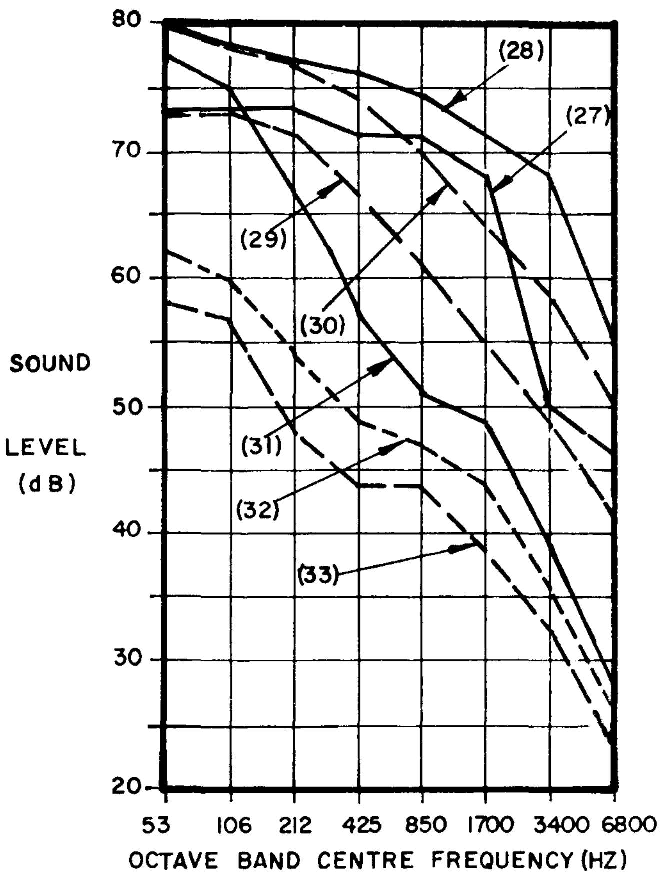

FIGURE III-7 BUS NOISE (Internal)

(27)	INSIDE CITY BUS (NORMAL FLOOR) AT 20 MILE/H	REF 12, FIG 32·11
(28)	" " " (" ") " 40 "	
(29)	" " " (EXPTAL FLOOR) " 20 "	
(30)	" " " (" ") " 40 "	
(31)	INSIDE INTERURBAN BUS (NORMAL ENGINE MOUNT)	REF 12 FIG 32·6
(32)	" " " (ENGINE PARTIALLY ISOLATED)	
(33)	" " " (ENGINE WHOLLY ISOLATED)	

HIGHWAY NOISE

by

J.F.M. Bryant
AUSTRALIAN ROAD RESEARCH BOARD

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INTRODUCTION

1. Noise from vehicles is becoming an important consideration in the planning, design and location of highways and in the use made of the adjacent land.

2. Vehicles powered by means of the internal combustion engine are inherently noisy (1) and the use of conventional rubber tyres also contributes (2), especially at high speed and on wet surfaces. As the density of vehicles per unit length of roadway increases the noise level at a fixed point relative to the road increases. The noise level also increases with speed of a vehicle. On major highways, the noise generated by motor-vehicles may be greatly in excess of that produced by the occasional vehicle travelling through the local street system.

3. Extensive highway construction has been embarked on, in recent years, in the major automobile - using countries and with it there have developed concepts of high-speed, multilane roads in both urban and rural areas. Since they are both expensive and durable, methods of locating and designing these facilities have been developed and refined in order to provide for expected growth of the population and the trips that automobile-users may be expected to make in future years.

4. Noise is a concomitant of urban life. Historically, the cottage industry may also have been a noisy industry; the Industrial Revolution and the age of steam were notable as much for the noises made by the engines and machines as for the goods that were produced. The rich and powerful were able to shut themselves away in solidly built homes or offices, the labourers and artisans were unimportant. In contrast, the modern western society has adopted a different style of housing and is subjected to different forms of sound from those of its predecessors. Whereas in the Public Health Act of Victoria, anachronistically, "steam whistles or like appliances" are described as "a nuisance or dangerous to health or offensive" which any person may take action to have abated, under the Act, it is much more difficult to define "objectionable noises at unreasonable times", which it is intended that Victoria's Local Government Act should control and regulate (3) and the private citizen is placed at a disadvantage. Nevertheless, the single, static, private noise source can be dealt with. Noise generated by the transportation utilities, on road or rail or in the air is ubiquitous and fills large volumes with sound energy at high density.

DIMENSIONS OF THE PROBLEM OF HIGHWAY NOISE

5. Classical analysis of noise problems is usually concentrated on four aspects of the system which may be described as follows:

(a) Identification and description of the noise source or sources.

(b) Description of the noise power generated by these sources in terms of wave-form or spectrum, time, directionality, etc.

(c) Characteristics of the propagation path.

(d) Response of those subjected to the noise energy.

If the response (d) is drastic or if the agent responsible for the source (a) is wise, remedies are put in hand based on the now well-established techniques of acoustical science and engineering.

6. An important aspect of noise sources in highway noise, and indeed of all transportation systems, is its non-stationary character. This fact has important implications for the other parts of the system described above, as will be discussed later. Another attribute of the highway scene is the multiplicity of sources, the number and strength of which vary with time. The distribution of sources in space and time means that the possible propagation path also has variable characteristics in addition to those affected by meteorological conditions.

7. The effects of noise on man have been a subject for investigation for many years and were surveyed by Kryter twenty years ago (4). Rosenblith and Stevens (5) were the first to provide a comprehensive method of determining the probable community response to imposed noise. More recently an attempt has been made to scale the particular attributes of traffic noise by means of a Traffic Noise Index (6). However, it seems adequate to rate noise in terms of the relative sound pressure level weighted electrically in accordance with a criterion first developed to correspond with the functional characteristics of the human ear (6). It appears that the relative strength of the subjective response to a noise is reliably indicated by the dB(A) level of the noise, the relationship commonly taking the form

$$R = C + BL(A)$$

where R is the "strength" of the response of a sufficiently large group of people. L(A) is the A-weighted noiselevel of the disturbing sound. C,B are coefficients the magnitude of which depend on the spectral characteristics of the noise and possibly the social characteristics of the respondents. It would seem that for a particular type of noise, e.g. highway traffic noise, a linear regression equation as indicated above is adequate for planning purposes and in recent discussions on this subject noise levels in dB(A) have been used exclusively. This paper will lopt the same approach.

RESEARCH INTO HIGHWAY NOISE

8. Without personal contact with the research being conducted in other countries, the knowledge available to an investigator in Australia is perforce restricted to published reports and investigations made by others whilst abroad. A review of overseas research made on this basis is therefore necessarily incomplete and may suffer from serious deficiencies. It will however serve to highlight the need for similar research in Australia and the directions that such research might profitably take.

9. A major advance in the examination of the problem of noise in Britain was made by the "Wilson Committee" (7) in 1963. This committee was set up in 1960 by the then Minister for Science "to examine the nature, sources and effects of the problem of noise and to advise what further measures can be taken to mitigate it". At that time the Noise Abatement Act of 1960 had already brought noise within the definition of the "statutary nuisance" to which the various Public Health Acts referred. Since publication of the Wilson report further control of noise has been attempted, particularly with regard to motor vehicles, and research into the causes, effects and control of noise greatly stimulated. After the British Road Federation conference on "Road and Environmental Planning and the Reduction of Noise" in March 1969, and with the support of the Road Research Laboratory, a Working Group on Research into Road Traffic Noise was set up and met in April, 1969 (2). The group has recently issued its first report (8) which contains over 150 references, about half of which are British sources. This review is a succinct description of the current status of traffic noise research in Britain and indicates the direction likely to be taken by noise control measures.

10. The road traffic noise report just mentioned also describes briefly the situation in other countries (Table 2, ref. 8). Of the twenty-one listed (including two states of the U.S.A.) Australia is not one!

11. In the U.S.A., apparently only two States, California and New York, make any attempt to control the noise emitted by road vehicles (8) but the Federal Government has considerable power, through the Federal-Aid, Highways, Act of 1956 (c.f. the Commonwealth Aid, Roads, Act), to influence the construction of roads forming part of the Interstate system and through the National Traffic and Motor Vehicle Safety Act and the Highway Safety Act, 1966. Certainly the latter deal principally with safety and their chief value with regard to noise would be in the modus operandi established for dealing with such problems on a national basis.

12. The Highway Research Board of the US National Research Council has undertaken research into the effect of highway noise on people and property near the highway either directly (9) or as part of the general disturbance caused by roads due to vibration, light, odours, outlook, etc.

IDENTIFICATION AND DESCRIPTION OF NOISE SOURCES

13. Noise made by motor vehicles is generated over large areas of land, particularly in cities, towns and villages where the population density is relatively high and a large proportion of the land is used for roads. However, the noise is most intense on busy highways. Although noise problems exist with respect to local surface streets they are not usually as serious as those associated with major highways or trunk roads. In this paper, attention will therefore be devoted chiefly to the latter.

14. The noise-generating propensities of vehicles have been described by Priede (10) who relates the vehicle elements to the noise generated externally as follows:

Source	External Noise Characteristics
Engine airborne noise and its transmission	Major source of high-frequency noise
Engine exhaust	Major source of low-frequency noise
Engine inlet	Next most important source of low-frequency noise
Fan noise	Can be significant in low and middle frequency ranges
Road-excited tyre noise	Significant source of noise

In experiments using a light car (1100cc), Harland (2) found that the rolling noise, with the engine off, was only 3-4 dB(A) below the normal noise made by the vehicle at either a steady speed or accelerating at 50 m.p.h. on a smooth, dry road. On a wet surface the rolling noise increased by 12 dB(A), making it the most important source of noise.

15. A comparison between different types of vehicles is difficult since different elements of the power system contribute sound energy in different parts of the audible spectrum. A detailed analysis has been made by Priede (10). However, the important middle frequencies are represented by the engine and the UK Working Group suggests the following relationships for different types of engines, as a function of engine speed.

Diesels : $dB(A) = 30 \log_{10} N + k$

2-stroke) & turbo-) charged) Diesels) : $dB(A) = 40 \log_{10} N + k$

Petrol : $dB(A) = 50 \log_{10} N + k$

where N is the engine speed and k is a variable parameter. Caution is needed in applying these results to Australian conditions as, unlike the U.K., no regulation of vehicle noise is at present imposed in this country. However, the higher rate of increase of the noise generated by 2-stroke Diesels is notable since this type of power-pack is popular in Australia. Thus, Johnson and Saunders (11) report a smaller variation in the effect of varying the proportion of heavy vehicles in the traffic stream than did Nickson (12).

16. The much-quoted London Noise Survey, reported by Stephenson and Vulkan (13) found that the mean levels in dB(A) for a variety of vehicles to be as follows.

Vehicle type	Mean Level dB(A)	Standard Deviation db(A)	Noise energy equivalent P.C.U.
Car, under 1100 cc	70	2.5)	
Car, 1100-1600 cc	71	2.6)	1
Car, over 1600 cc	72	2.9)	
Light commercial	73	2.4	1.5
Heavy commercial	81	3.3	10
Motor cycles	77	3.9	4

The noise equivalent in passenger car units for commercial vehicles is a useful concept since it corresponds with that used to evaluate the effect of such vehicles on the traffic capacity of roads.

THE TRAFFIC STREAM

17. Consider a single stream of traffic, having an average speed of v m.p.h. and an average flow rate of q vehicles p.h. Then, the mean density of the traffic is

$$k = \frac{q}{v} \text{ vehicles p.m.}$$

and the mean headway from vehicle to vehicle is

$$t = \frac{3600}{q} \text{ seconds}$$

The average spacing between vehicles is

$$d = tv = \frac{5280}{k} \text{ ft. p. vehicle}$$

The density of vehicle cannot exceed about 176 vehicles per mile since each vehicle requires about 30 ft. of road. Also, in general, drivers cannot under most circumstances drive with headways shorter than about 1.5 sec. The maximum speed at which drivers may travel is usually determined by a legal speed limit or the geometric design of the road. If it were possible, by suitable design of the vehicle or the road, e.g. automatic guidance and control, for the traffic to travel at the maximum speed say 60 mph while retaining the maximum density of 176 veh. p.m. the flow would be 10,560 veh. p.h. These parameters define an area on the capacity diagram (Fig. 1) within which theoretically permissible speed-flow relationships may occur. In the practical case, the speed-flow relationship is very different from the theoretical. Blunden estimates that the maximum practical capacity for unrestricted flow on multilane roads is about 1500 veh. p.h. at speeds between 35 and 40 m.p.h. (14). Buckley (15) reports observations of traffic on the 8-lane Hollywood Freeway indicating a flow per lane of 2130 veh. p.h. at a mean speed of 47 m.p.h. from which he calculates that the distribution of headways may best be described by a "semi-random" distribution function from which a "zone of emptiness" of 1.27 sec. is determined; i.e. no vehicle ever has a lesser headway than this.

18. The distribution of vehicles along the road, in terms of headways or spacings is important to the calculation of the total acoustic intensity of the noise at any point relative to the road. An examination of several high quality roads in New South Wales and South Australia (16) led to the conclusion that "the distribution of road traffic on any particular facility can be satisfactorily approximated by the Poisson distribution, provided the practical capacity of the facility being considered has not been exceeded". The use made of this distribution by Galloway, et al, (9) is therefore acceptable although more accurate calculations would be possible using the semi-random distribution due to Buckley (15). However, high precision in calculations of the combined effects of streams of vehicles is not warranted, especially with regard to multilane roads.

19. The presence of commercial vehicles, especially heavy trucks, has a serious effect on the speed-flow relationship of traffic on a road. It was found in an investigation of traffic

behaviour on a level, 2-lane, two-way rural highway near Melbourne (17) that the speed-flow relationship could be expressed, for two mixtures of vehicles as

$$q = 1.35\,v - 0.034v^2$$ for traffic with 30% trucks

and

$$q = 2.14\,v - 0.056v^2$$ per passenger cars

Neglecting the quadratic term, it can be seen that the effect of the trucks is to reduce the average speed of the traffic stream by 37%. Where overtaking is difficult due to a high density in the opposing lane, queues may develop behind slowly moving trucks. On multilane facilities greater opportunity exists for passing heavy trucks and the only effect of such vehicles is through their greater sound energy output and the length of time for which this remains above any particular value at a given point relative to the road.

THE URBAN ROAD NETWORK

20. Roads have been classified by Clark (18) as:

Arterial
Sub-arterial
Collector
Principal local
Secondary local
Lane

where arterials may be further divided into:

Freeways : divided, no access, grade separation.

Expressways : divided, partial access, little grade separation, or none.

A picture of a modern urban major road network may be built up by considering sub-arterial roads as being spaced at about one mile apart and arterials (usually freeways) at two to five mile intervals. The sub-arterials provide for through traffic movement between areas and across cities and allow speeds of 25 m.p.h. in peak hours (with parking and turning restrictions) and 35 m.p.h. or more in off-peak periods. Freeways are designed to permit speeds of from 35 to 50 m.p.h. (19)

21. It has been suggested (20) that freeways should be spaced at not less than 2-mile intervals and for a city like Melbourne the spacing might be as follows:

Population Density	Freeway Capacity		
	4-lane	6-lane	8-lane
6,000 per sq. mile (outer suburbs)	miles 2	miles 5	miles 7
10,000 per sq. mile (inner residential suburbs)	2	3	4

22. The provision of major arterial highways is expensive and a proportionally long life is expected of them. In this regard they are similar to railways and exert a similar influence on land settlement and development. However, their justification depends on extension of present trends in population and land use. The Melbourne Transportation study estimated that 3.7 M people would be living in the Melbourne Metropolitan area by 1985 and the Melbourne and Metropolitan Board of Works projects 5.0 M by 2000. However, patterns of development in Melbourne are changing and a lesser growth rate has been forecast (21).

23. Studies of future transportation needs have been made for several Australian cities. From the reports of these studies it is possible to estimate the amount of freeway and expressway mileage per square mile within the study areas forecast by the planners as being necessary to cope with future growth and present congestion. Comparison on this basis may also be made with urban areas in U.S.A. in which freeway networks have been developed.

City	Area (sq. miles)	Proposed Freeway and Expressway (miles)	Route Length per square mile
Adelaide	715	110	0.154
Brisbane	368	96	0.261
Hobart	78	28	0.365
Melbourne	1264	307	0.242
Boston	2518	568	0.226
Los Angeles	1949	528	0.271

Ganz (22) quotes Wilber Smith as suggesting that the freeway requirements for a city should be from 2.5 (for large, dense cities) to 3.5 (for less dense or outer urban areas) route miles per 10,000 automobiles. Assuming car ownership in Melbourne in 1985 to be 0.35 unit per person, this criterion would forecast a need for 300 to 400 route miles of freeway by that time. The proposed arterial network for Melbourne at least is therefore not excessive on this criterion. However, the estimated cost of the freeway network for the Melbourne Metropolitan area of $1,675 M (1968 values) may be much larger than the funds available within the planning period. Nevertheless a study should be commenced, here in Melbourne as elsewhere, of the extent to which noise from operation of the freeways and other main arterials will affect neighbouring land-users.

FREEWAY LOCATION AND DESIGN

24. Little attention has been given to problems of noise in relation to highway design and location in Australia; when mentioned it is usually in association with "aesthetic" factors. Flint (23) describes a rating scheme for the evaluation by a panel of the acceptability of proposals for transport facilities in terms of community values. Noise is not specifically mentioned but, he says, " a feature of the rating panel technique, which may be advantageous in some respects but could well be a shortcoming, is that it attempts to assign numerical values to factors which are essentially qualitative in character". This is not true of noise; in physical terms calculations may be made sufficiently accurately to enable quantitative estimates to be made of the noise exposure anywhere relative to the road. All that is now lacking is the set of criteria describing community reaction to noise and this may soon be achieved. Using the recommendations of the Wilson Committee (7) for maximum 10% levels of noise in dwellings Brown (24) was able to compare costs of barriers along the highway and treatment of neighbouring dwellings but reached the disappointing conclusion that "the cost of achieving high environmental standards is prohibitive ... and therefore it must be accepted that recommended standards of noise protection will not be achieved in the vicinity of urban motorways".

25. Since special protective measures against the propagation or penetration of noise add significantly to the cost of the highway, the alternative of locating the facility in the best situation must be fully explored. Barkan (25) suggests that arterial routes in urban areas are best located on wedges of unused land between ribbons of developed areas; through blighted areas, particularly those subject to redevelopment; along rail-roads and shore lines of bodies of water; adjacent to borders of parks and other sizeable tracts of city or institutional property.

26. Aesthetic considerations were raised at a conference

on "Freeways in the Urban Setting" in Hershey, Pennsylvania, 1962. The need for systematic design was emphasised: "the construction of efficient, effective and attractive freeways demands a total design concept. This means the integration of all aspects of design into a whole that is satisfying and effective and integrated with its surroundings". A study in San Francisco, 1960, developed an "index of freeway effect on community appearance". Eleven types of freeway structures were rated by means of penalty points (Table 1, of ref. 25). The penalty rating of these types of freeway correspond roughly with their propensities for creating a noise in the environment.

27. It may be noted that public opinion is often opposed to the use of parkland for freeway or other road development and may exert a powerful political influence. The legislature of Connecticut in 1965 gave local municipalities the power to veto the acquisition of park land for highways. The alternative of using a tunnel for the freeway is extremely costly, perhaps prohibitively so if artificial ventilation is required (26). Unfortunately, when it is proposed to use parkland to locate a freeway, the opportunity is rarely taken to redistribute such public space. In Melbourne at least, parkland is poorly distributed and much of it is excessively large, imposing diseconomies on public utilities and serving only a favoured few within easy reach. It is important, therefore, in the location and design of freeways, that planning should be extremely broad-based. Loder (27) states that "in the process of detailed freeway location, it is often very tempting to save property demolition by locating the freeway within public open spaces. This action should only be tolerated if equivalent areas are made available for the same purpose".

ROAD DESIGN FOR MINIMUM NOISE

28. The number of lanes on the facility, the nature of the pavement, the geometric design (grades, interruptions to steady flow, etc.), the composition of the traffic (cars, light and heavy trucks, motor cycles) and the load (the speed-flow relationship) are all factors determining the sound energy density at a point close to the road. The structural design of the road influences the propagation path of the sound waves at greater distances from the pavement. The propagation of sound is also influenced by meteorological conditions at sufficiently large distances.

29. The structural elements of the road construction that affect the propagation of sound are as follows:

(i) Width of road reserve, separators and median

(ii) Elevation or depression of the road relative to the point of observation

(iii) Interposition of barriers, including specially constructed screens, mounds, banks of cuttings, buildings, etc.

(iv) Density and area of vegetation

The relationship of the physical dimensions of these elements to the sound energy density or intensity may be determined by theoretical means or empirically. Much research in recent years has been directed towards the confirmation of theoretical concept, e.g. the affect of obstructions, or the development of ad hoc design methods.

30. Calculation of the sound intensity at a distance from a uniformly spaced, linear stream, of moving sound sources has been performed by Johnson and Saunders (11) and in Japan (29). When the observer's distance d is short compared with the spacing between vehicles, the sound pressure level naturally fluctuates with period s/v, where s is the spacing and v the speed of the stream, i.e. the sound pressure level at a time t after any one vehicle has passed the observer is given by

$$L = PWL - 8 - 20 \log d + 10 \log \left[\frac{\pi d}{s} \frac{\sinh(2\pi d/s)}{\cosh(2\pi d/s) - \cos(2 \; vt/s)} \right] \text{dB}$$

where PWL is the power level of a single source, measured in db relative to an appropriate standard (e.g. 10^{-13} watt).

At greater distances, i.e. for d/s $\frac{1}{4}$, the mean sound level is given approximately by

$$I = PWL - 3 - 10 \log (ds) \quad \text{dB}$$

and the fluctuation in the instantaneous level disappears. It will be apparent that the mean sound level varies inversely with both distance and vehicle spacing. Since the latter also varies inversely with the rate of flow, for a given mean speed of the traffic stream, the mean sound level will increase by 3 db for every doubling of the flow rate but decrease by 3 db for a doubling of the distance of the observer from the stream. These results were only partially confirmed by the simulation study conducted by Gallaway, et al. (9). It was found that the decrease in level with distances greater than 300 ft. was greater than 3 dB(A) per doubling of distance because air absorption became significant. Thus, the reduction over the interval 100-1000 ft. was estimated to be 15 dB(A) whereas the simple theory predicts only 10 dB(A). However, when the density is high, either on a single lane of traffic or the geometric single lane equivalent of a multilane road, the effect of vehicle spacing falls from 3 to 2 dB(A), due to the Poisson distribution adopted to describe the headways. A similar result is described by Jordan (28) although the effect is confounded by the diminishing speed of the traffic, so that above 1000 v.p.h. the sound level increases but slowly. In this situation the presence of trucks in the stream affects the level profoundly, not only because the truck power level is higher than that of passenger cars but also their speed may be low. This case was considered theoretically by a Japanese Committee (29).

31. The recommended width of right-of-way for urban freeways is from 250 to 300 ft (20). However a width of as little as 150 ft. may be adopted for economic reasons, especially if cost of construction is high. Within this right-of-way up to eight lanes may be constructed with a total capacity (two-way) of 12-16 thousand v.p.h. Divided arterial roads with separate service roads are usually contained within a 198 ft. right-of-way. Under these conditions, residential buildings may be within 200 ft. of heavy traffic. Except when the road can be constructed in waste land, etc. the cost of acquiring added width of right-of-way may be high, although much less than that of tunnelling.

32. Variation in road elevation affects profoundly the sound intensity in the neighbourhood of the road. The road may be raised on a structure or on a bank or it may pass through a cutting of variable depth or be depressed below datum level over long lengths. An extensive field investigation was undertaken in U.S.A. by the Franklin Institute (30) during which a comparison of theoretical and measured sound level reductions for a variety of configurations was made. The theoretical reduction was simply that due to distance attenuation, i.e.

$$Lp = Lx - 20 \log \frac{v}{r_x}$$

where Lp = SPL at distance r from the source

Lx = SPL at distance r_x from the source and r, r_x are measured perpendicularly from the point of observation to the centre line of the outside lane. The levels in dB(A) were read simultaneously of trucks travelling in the outside land of the road, the reference point (r) being a constant 10 ft. from the centre line of this lane while the variable distance (r_x) did not exceed 600 ft.

33. The results of observations made of sound attenuation over a distance from the highway indicate that depressed highways or roads in cuttings show the greatest potential for sound level reduction provided that the observation point is well out of the line of sound. Similarly, when the highway is elevated or on fill, an excess reduction in sound level is obtained for points out of the line of sight; but in this case only a narrow zone close to the highway is benefited. The reader is referred to the report (30) for further details. It should be added that similar investigations should be pursued in Australia and special instrumentation devised for the purpose.

34. Since diffraction over a barrier causes a diminution in sound intensity (31), the use of barriers has been advocated as a sound control measure on highways. The cost of a barrier 10 ft high on both sides of a highway is estimated by Brown (24) to be £50,000 stg per mile; a somewhat lower cost could perhaps be achieved with cheaper materials, e.g. lightweight concrete, since the actual transmission loss of the barrier need not be great. The most serious objection to barriers is with regard to the geometric design of the highway. Problems arise concerning safety and visual appearance both for the road-user and in the neighbourhood of the highway. Dennington (32) suggests that "to screen a fixed point a known distance from the road will require a certain length of screen in order to cover the passage of noisy vehicles, this being their purpose, having accepted that the background noise due to other traffic cannot be so eliminated. At least three times the distance of the point from the road may be surmised as being a necessary screen length, in order to allow for the vagaries of wind, and still screen the heavy vehicle. With such a rule, the priority that restrained curves and sightlines may have on the position of screens and the effects of varying cross-section, it is to be questioned whether many effective lengths of screens would be feasible if it was desired to give equal treatment to the majority of nearby residents". The sight-distance problem is greatly accentuated at interchanges and screens could not be tolerated where merging of traffic streams occurs.

35. Embankments also may serve as barriers and have some advantages over screens. If an excess of spoil is available near the site, it is economical to place it in mounds suitably designed and located to screen sensitive areas. Such earthworks may be landscaped to improve the aesthetic environment of the highway and the batters constructed to provide optimum safety for vehicles leaving the road accidentally.

36. The use of vegetation for sound reduction is ineffective, large areas of dense and high shrubs or trees being needed to obtain even a few dB of attenuation. However, the aesthetic and safety aspects of vegetal covering of medians, outer separators and off-pavement areas of the road reserve are important and do much to make the facility acceptable to the neighbourhood as well as refreshing the road user. Barkan (25) suggests that "visual aspects of freeway location and design should be considered from the points of view of both the user and of the people in the areas through which it passes". Since aesthetic improvement of highways is given much lip-service but little attention in practice in this country, perhaps even the slight benefit obtained with vegetation as a noise control measure should receive greater emphasis.

37. It has been mentioned that a wet pavement generates

a higher noise level than does a dry surface. However, the dry pavement itself may cause more or less noise according to the roughness and nature of the material. Harland (2) points out that road surfaces are designed primarily for safety and that, whereas with a dry surface the harshness of the micro-surface determines skidding resistance, under wet conditions and high speed the macro-texture or roughness is the important factor in maintaining maximum contact areas between the tyre and the road. Galloway, et al. (9) found a difference of 5 dBA between a rough asphaltic or concrete pavement and a smooth, nearly new concrete pavement, the difference being independent of speed. Spectral analysis indicated that the major contribution to the difference in levels was at frequencies above 1 KHz. William (33) reached the conclusion after examining these data that "a high-quality road surface is therefore beneficial both in terms of safety and noise" and that "the maintenance of road surfaces in good order is a question of cost and the advantages of regular attention to their conditions should be stressed whenever there are prospects of reductions in national finances for roads".

38. Although not normally considered to be part of the road design, elements of bridges or joints in segmented pavements may be a source of noise. It has been reported to the author that bridge railing of poor acoustic design may be a source of noise in high winds. Expansion joints in bridges may also be a source of impulsive noise when struck by vehicles. Designs for bridge rails may readily be tested in a wind tunnel and noise from finger-plates eliminated by proper design. Expansion joints in pavements when correctly constructed and filled are not a source of impact. However, since the various Traffic Acts in Australia do no more than prohibit "excessive" or "undue" noise from vehicles due to bad loading, the noisy truck rattling over every joint and bump in the pavement is by no means uncommon.

SYSTEM DESIGN

39. Little attention has been given to the effects of wind and temperature gradient in the lower atmosphere with regard to the propagation of acoustic waves. The author has considered the effect of these variables (31) but in the absence of adequate meteorological data proper estimates of their effect are difficult to make. The Japanese committee on traffic noise (29) notes that wind and temperature variation may have pronounced effect on long distance propagation and quote the following example:

> " according to results of measuring in detail, over several months at London airport, attenuation considered to be due only to the effect of wind (at a speed of 4.5 m/sec. and at 1000 Hz) was found to be almost nil down wind 1000 metres from source. The attenuation existing was roughly the same as the attenuation due to distance; including air absorption. Also, at a low frequency of 50 Hz, the

attenuation was several dB less than the attenuation due to distance. However, upwind at 1000 metres and 1000 Hz, the amount of attenuation was about 17 dB greater than down-wind ".

Since Australia, on the whole, enjoys a temperate climate, natural ventilation is commonly used, especially in summer. The use of double-glazing for windows and high-loss structures may therefore be quite limited as a means of reducing the annoyance caused by traffic noise.

40. It is generally conceded both by acoustic engineers generally and by those studying traffic noise in particular, that prevention is better than cure and noise should be mitigated at the source. This means stronger measures must be taken to suppress the noise of vehicle power-units particularly those of heavy trucks, buses and motor bicycles (although the annual gross mileage of the last-mentioned is rapidly falling in Australia). There is only a limited margin in which to reduce the power-unit noise of passenger cars before tyre noise becomes equally important, especially at high speed. Steps have been taken in some countries (8) to limit noise but a serious attempt to reduce levels below those now existing has not been made. Unless steps are taken in Australia to peg or reduce the noise generated by heavy vehicles and vehicles with inadequate exhaust muffling it seems rather pointless to design highways to high standards of noise suppression.

41. The location of highways is influenced chiefly by cost. A method of costing the disamenity of highway noise is therefore needed to remove decisions from the political arena, as Loder advocates (27). A householder situated near a freeway interchange may accept an increase in noise in return for rapid access to the facility. However access must be limited for traffic reasons and, as the capacity of the road is approached, selected exits and entrances may be closed. The disamenity suffered by the house-holder is severe if he suffers both an increase in environmental noise and an extended travel time for most of his journeys.

42. Freeways are essentially high capacity traffic arteries. To provide the bare traffic capacity of one lane of freeway requires two to five lanes of urban surface streets with at-grade crossings, on which travel time would be at least doubled and the service inferior (26). The widening of sub-arterial roads is not only often not feasible but may be destructive of amenities. The traffic hazard for vehicles and pedestrians on surface streets may be ten times that of freeways. There is, therefore, increasing need for the rapid construction of freeways. As the chief concern of the highway designer is to obtain maximum capacity per dollar and the facility may not

reach capacity for some years there is a strong inducement to save money by neglecting the requirements imposed by adequate noise control.

43. As Neutze has pointed out (34)

> " Planners (who could be called 'environmentalists') might be described as those who are expert in anticipating the effect of changes in land use and other physical changes, through its likely physical effects, on the whole environment. Planners not only know the effects of alternative actions but they can also, presumably because of their training,apply various tests to assess the relative desirability of the alternatives ".

Since the tests, at least with regard to the control of noise are rapidly becoming more accurate, the highway planner has additional tools at his disposal to ensure that the roads for which he is responsible are not only technically adequate but socially acceptable as well. The overlay system devised by McHarg (35) may be used also to investigate the incidence of traffic noise on communities adjoining the highway. It is desirable to use acoustic energy densities in such investigations since such absolute quantities may be added or subtracted directly without the need for logarithmic addition curves. On the basic plan of sections of the route several overlays may be prepared on transparent material showing the desirable densities according to community noise criteria, the densities occurring not more than 10% or not less than 90% of the time, night-time densities according to the season, the effect of prevailing wind or atmospheric temperature gradient and the "shadows" cast by the banks of cuttings, mounds, screens or barriers, etc. Density contours should also be prepared showing the effect of increasing traffic as the facility reaches capacity and the effect of greater percentages of trucks in the traffic stream.

A POLICY FOR THE CONTROL OF HIGHWAY NOISE

The highway, especially the urban arterial freeway is an instrument for the distribution of noise energy over wide areas of cities as a concomitant of its function for vehicle users. The geometric and pavement design of the road is determined by the characteristics of the vehicles and their drivers. Conversely, the properties of the road are reflected back in the design of the vehicles and behaviour of the drivers. In analogous fashion, from an acoustic point of view, structural design of the highway must take account of the noise power generated by the vehicles on it and the susceptabilities of the people who work or dwell near it.

Of vital importance to the formulation of a policy for highway noise control are the control at an economically effective level of the noise generated by vehicles and an acceptable balance of improved transport facilities and disamenity through increased noise and possible loss of aesthetic enjoyment in the neighbourhood. Research has indicated that with present design methods there are limits beyond which vehicle noise cannot be economically reduced. On the other hand, it has also been shown that protection of the community from the adverse effects of noise by means of enclosed or screened highways or special construction of dwellings may also be expensive. Solutions to problems raised by a large extension of the urban freeway system can only be found by participation of the highway planners in joint consultations with vehicle designers and town planners concerned with the quality of urban living. Indeed, the highway authority should play the leading role in this interchange by investigating the effect on the community of every facility that is built.

With major extensions and reconstruction of the road systems of our cities becoming more urgent, consideration of the social effects of the construction of freeways and interchanges should not be delayed. It is apparent that the basic data and techniques are now sufficiently well developed to enable planning of the acoustic environment to be performed to meet any desired standard of comfort provided that the two conditions of exercising the necessary degree of control and meeting the inevitable cost are met.

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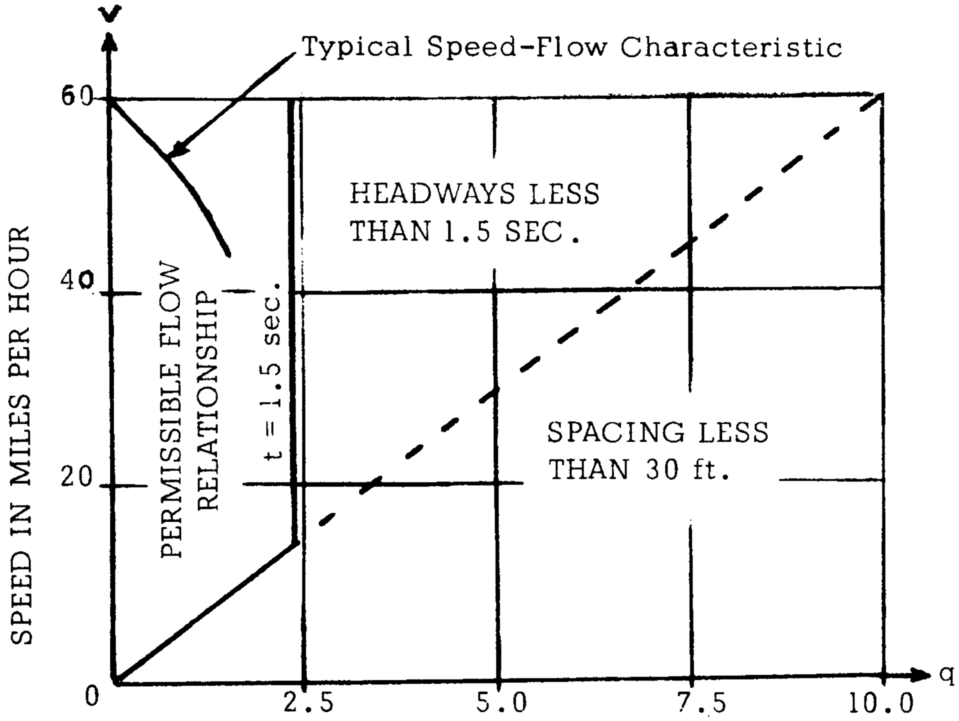
FIGURE 1



FLOW IN ,000 VEHICLES PER HOUR

CAPACITY OF A ONE-LANE ROAD

"TRAFFIC NOISE CRITERIA IN AUSTRALIA"

LOUIS A. CHALLIS, B.E., M.I.E., (AUST)

Consulting Acoustical Engineer

Principal of

LOUIS A. CHALLIS & ASSOCIATES
158 Queen Street, Woollahra. 2025.

Presented to the Australian Noise-Zoning Conference, March 6th-8th, 1971
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SUMMARY

This report discusses the generation of vehicle noise from the theoretical aspect and presents some of the unrestricted results of series of investigations into vehicle noise generation and measurements conducted on behalf of the Standards Association of Australia by Working Group AK2/1.

1. INTRODUCTION.

Few people in Australia live so far from urban development that they cannot hear the sounds of cars or trucks at some time of the day or night. For many, the sound of moving traffic forms a continuous background noise on which other sounds are superimposed.

Our responses to traffic noise are influenced by a multiplicity of factors and, consequently, are extremely complex. In general terms these may be classified as being either expressions of annoyance, difficulty in communicating, degradation in task performance, interference with sleep or rest, and the ever present minor effects on our relationships and feelings of well being.

Whilst studies of traffic and vehicle noise currently constitute a significant portion of all the applied acoustic research being conducted overseas, what little work is being done in Australia is in most cases neither publicised nor properly disseminated.

The Standards Association of Australia have set up a Working Group to study vehicle noise, its measurement and examine the requirements of setting acceptable criteria for the various classifications of vehicles.

This paper presents a background to the problem of traffic noise together with the results of a series of investigations conducted to determine the adequacy of the draft Australian Standard for the method of measurement of a vehicle noise.

2. CHARACTERISTICS OF VEHICLE NOISE.

The primary factors which affect the level of noise produced by a given car are determined by vehicle speed, acceleration, payload, road surface and last but not least the actual condition of the vehicle.

2.1 Speed.

Waters (1) has shown that an approximately linear relationship exists between the vehicle sound level in, dB(A), and the logarithm of the road speed V, for constant speed on a level ro Thus:

$$\text{Sound level in dB(A)} = 30 \log_{10} V + K \quad \ldots (1)$$

Where V is the vehicle speed in K m/h and K is an undefined constant.

Similar results have been obtained by Rathe (2) and by Priede for vehicle noise.

Galloway, Welden, Clark et al (2) have derived a useful relationship more suitable for computer analysis where the sound level is specified in an empirically derived equation as being:

$$\text{Sound Level in dB(A)} = 16 - 10 \log_{10} \left(\frac{d}{50}\right)^2 + 30 \log_{10} \mathcal{V}$$

$$= 50 - 20 \log_{10} d + 30 \log_{10} \mathcal{V}$$

where $\mathcal{V}$ = speed in m.p.h.

& d = distance, in ft. to the vehicle.

2.2 Acceleration.

All vehicles produce more noise whilst accelerating than when travelling at constant speed. Whilst some reasonably documented tests have been performed, those readily available as octave band data are restricted to tests performed with equipment using the old octave band centre frequencies. These results compared the increase of noise between constant speed and acceleration.

The spread of these results show that whilst the mean increase, is of the order of 8 decibels in each of the mid frequency octave bands, it can vary between 3 decibels and 15 decibels in the extreme cases (See Figures 1 and 2).

2.3 Payload.

Very little research has been done on the effect of payload on the noise produced by vehicles. Whilst it is clear that passenger cars are affected significantly and can produce up to 10 decibels more noise, the same cannot be said for all trucks. (6).

In general, however, a heavy payload causes trucks to use lower gears and results in a longer exposure to the truck noise than would otherwise be the case.

2.4 Road Surface Noise.

The problem of road surface noise can be considered as being linked with the problem of tyre noise and the problems of providing safe road conditions.

In general, it can be stated that a smooth road and smooth tyres will result in the lowest noise generation.

Unfortunately, from the noise generation outlook in designing road surfaces, the primary consideration must be good adhesion and resistance to skidding.

Unfortunately, such surfaces are noisier than smooth surfaces.

Typically road surface noise can be specified for a vehicle coasting as being:-

$$\text{Sound level dB(A)} = 0.2V + K$$

where V is the Vehicle speed in Km/h and K is a constant dependent on road surface conditions.

Wet road surfaces produce broad band noise at frequencies above 1kHz. (See Figure 3). Typical increases are 10 decibels higher on smooth asphalt and at least 8 decibels higher on rougher concrete. There is no significant spectral difference between wet concrete and wet asphalt.

3. THE MEASUREMENT OF VEHICLE NOISE.

3.1 Much of the literature on Vehicle noise is based on measurements taken in accordance with the I.S.O. R362 -1964 (E) test procedure. This procedure requires the vehicle, driven in a specified gear at a closely defined speed, to be accelerated under full throttle. Whilst the procedure is designed to assess the maximum sound level emitted on the road, it does not necessarily provide all the information required for either a full evaluation of a vehicle nor in a manner which is compatible with our available urban or suburban facilities.

3.2 The measurement of Vehicle noise presents a number of practical difficulties in Australia. As the aim of such measurements is to regulate the noise of individual vehicles, then it is essential that the existing international standards (namely I.S.O./R 362 - 1964 (E)) and the derivatives of this standard be fully compatible with the new Australian Standard.

Working Group AK2/1 of the Standards Association of Australia considered that a simplified test was just as necessary as a comprehensive mobile test and attempted to develop such a test (7).

The purpose of such a test would be to meet the requirements of on-the-spot examinations at roadside check points, police stations, and vehicle registration offices and to serve as the test when prompt examination is required. In addition, the simplified test would be capable of being performed at a greater number of locations whose specified acoustical requirements would be less rigorous than those of the comprehensive test.

3.3 In October, 1970 the Working Group held a Field Day at Warwick Farm in order to determine the following:

(a) The adequacy of the comprehensive test.
(b) The adequacy of the simplified test.
(c) The correlation between the comprehensive and simplified tests.

In addition, it was hoped that the results of these tests on 28 new vehicles would constitute a basis for setting realistic criteria of acceptability for new cars in the 70's.

3.4 The measurements conducted at Warwick Farm were in accordance with the I.S.O. test but incorporated a number of additional tests including:

(a) Noise recorded on an Impulse Precision Sound Level Meter.

(b) Measurements recorded on a 'D' Scale weighted Sound Level Meter.

(c) Measurements conducted at points other than those specified by I.S.O. R362 with both precision and non precision Sound Level Meters.

(d) Measurements of stationary vehicle noise.

(e) Measurements of the Vehicle Noise using a real time spectrum analyser.

(f) Measurements inside the cabins of some trucks to compare internal and external noise.

3.5 The results of the Field Day were particularly interesting and several of the more interesting results are presented. It was found:

(1) That the majority of cars (in terms of total percentage sales) are considerably quieter than any of the international criteria.

(2) That trucks with exhaust pipes venting above microphone height can produce higher noise levels at positions beyond the standard position of 7.5 metres from the centre of the track.

(3) That the driver performing the tests requires a degree of skill which can only be derived with practice.

(4) That artificial attempts by the driver to reduce the maximum noise level generally result in a series of inconsistent results.

(5) That the stationary test, as proposed did not offer either an adequate degree of correlation with the mobile test, nor provide a safe test for the individual vehicles.

(6) That most trucks exceeding the European criteria for noise annoyance, also exceed hearing conservation limits when the vehicle windows are open.

CONCLUSION.

Legislation provides only one means of the many available to reduce the problem of vehicle noise.

Its primary purpose is to control the Noise from the "Mad Fringe" who insist on modifying their cars to produce more noise than is usual, as well as those people who deliberately or flagrantly allow their vehicles to deteriorate in such a way as to become more noisy.

Whilst it may often appear that legislation is aimed at forcing manufacturers to produce less noisy cars, this is not the case. Rather, in fact, setting the criteria of acceptability due notice is taken of the upper 10 percentile group of the noisiest vehicles.

The release of the draft Australian Standard for the method of measurement of noise emitted by Vehicles will only constitute the first step in what it is hoped will be a concerted effort to reduce the growing problems of noise from motor vehicles in Australia.

With approximately 4,877,000 registered vehicles in Australia now and with the total numbers doubling approximately every fourteen (14) years, our problem is compounding at a rate at which technology will be hard pressed to match.

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COUNTRY	U.K.	W.GERMANY	ITALY	SWITZER-LAND	FRANCE	HOLLAND BELGIUM	CZECH.	DENMARK	S.A.E.
Method of Test	BS 3425	I.S.O.	I.S.O.	I.S.O.	I.S.O.	I.S.O.	I.S.O.	I.S.O.	J-986a J-952b
Heavy Truck (200 h.p. +)	89	89-92	93	-	90	88-92	88-89	92	88
Truck (200 h.p. -)	89	85-92	93	-	90	83	85-89	89-92	86-88
Wheel Tractors	89	89-92	94	-	90	88-92	85-89	89-92	88
Crawler Tractors	89	89-92	90	-	90	88-92	85-89	89-92	88
Bus	89	89-92	93	-	90	88-92	85-89	89-92	86-88
Car	85	80-84	90	78	83	78	84	84	86

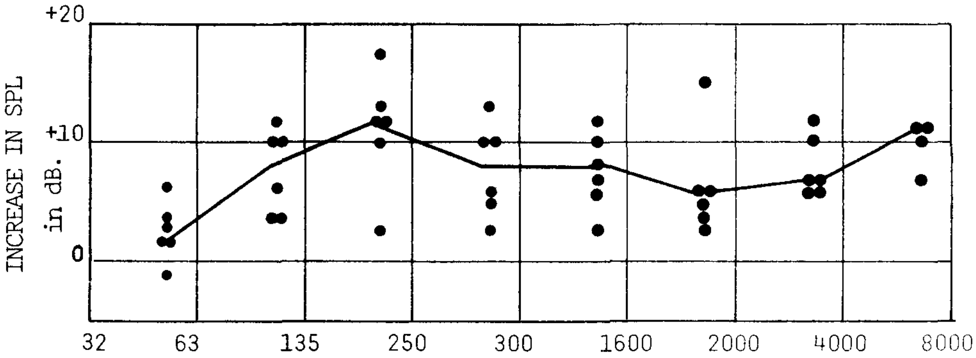

FIG. 1 Increase in Octave Band Noise Levels for cars accelerating cf. cruising.

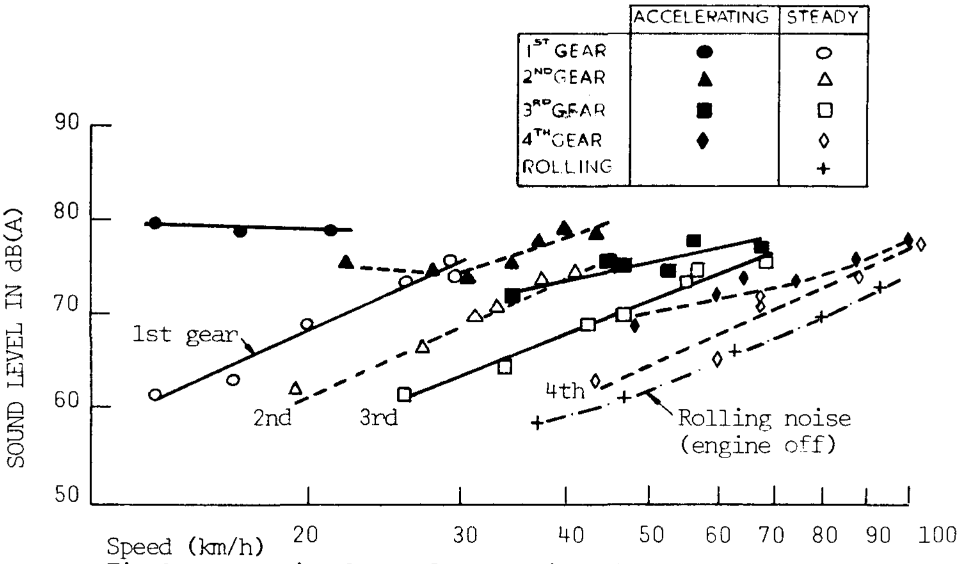

Fig.2 Noise level from Morris 1100 on smooth dry road under various operating conditions.

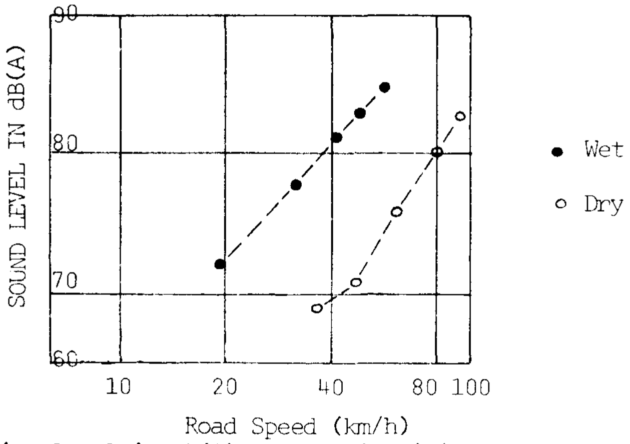

Fig.3 Noise level in dB(A) for Morris Mini 1100 on Wet & Dry operating conditions.

AIRCRAFT NOISE AND LAND ZONING AROUND AIRPORTS

by

Mr. J.H. Harper, A.F.C., B.Eng.Sc., A.M.T.C.,
F.R.Ac.S., M.I.E. Aust.,
First Assistant Director-General (Operations),
Department of Civil Aviation

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AIRCRAFT NOISE AND LAND ZONING AROUND AIRPORTS

The Problem of Aircraft Noise

Noise has sometimes been described as an unwanted sound and I must concede that, insofar as aircraft noise is concerned, this is very much the case today.

To go back a little way, aircraft noise was not a problem in the days preceding World War II when most of the busy airports of today, such as Melbourne and Sydney for example, were surrounded by vast areas of open paddocks, market gardens and the like.

After the war, the aircraft noise problem began to assume some significance as, during the late 1940s and early 1950s the airline fleets were enlarged and the aircraft entering service also increased in size, weight and power and, in consequence, became noisier.

I suppose we could say with reasonable accuracy that aircraft noise in Australia first started to become a significant problem, particularly at Sydney, with the introduction of the Lockheed Constellation aircraft in the late 1940s. These aircraft remained in service until the Super Constellations replaced them in 1954. The turbo-propellor Viscount aircraft was also introduced onto the Australian domestic scene in 1954 and a further "new" sound was introduced. Although there were some complaints about the noise created by the Viscount, they were nothing compared with what was yet to come with the turbo-jets.

Thus, previous noise problems paled in significance with the introduction of the first turbo-jet aircraft into Australia, on this occasion by our national flag carrier, Qantas, in 1959. This was indeed a new noise, as was readily noticed by the residents living in close proximity to Sydney (Kingsford-Smith) Airport.

The early "pure" jets gave way to first and second generations of bypass engines during the 1960s, until today, with the new turbo-fan engines available, we have for the first time a generation of engines designed with both noise and performance as prime definitive parameters. The Boeing 747 (Jumbo Jet), despite its vast weight, is significantly quieter than the smaller Boeing 707s and DC.8s, for example, although the turbo-fans which power the aircraft do not as yet have the same amount of inbuilt silencing that is being developed for other new engines such as the Rolls Royce RB 211 for the Lockheed

8.2

Tristar.

Forms of Aircraft Noise

Jet aircraft engines therefore create the major element of noise at our major airports today, with the pure turbo-jet engine rating as the noisiest. The principal sources of noise at the engine are the jet exhaust and the compressor.

Jet exhaust noise is generated by turbulent fluctuations in the mixing zone between the high-velocity jet gas stream and the surrounding air. The noise level is primarily dependent on the jet velocity, increasing very nearly in proportion to the eighth power of that velocity. Jet exhaust noise is broadband in nature (i.e. it has energy distributed throughout the frequency spectrum without any marked discrete tones) and, as it is generated entirely outside the engine, presents a difficult suppression problem.

The compressor noise is generated within the engine and propagates forward out of the inlet. This noise contains high-pitched discrete tones as well as broadband noise. The discrete frequency noise originates from the periodic "chopping" of the compressor blades through the wakes of the guide vanes and stator vanes (similar to the principle of noise generation in a siren). The broadband noise is produced by the flow of turbulent air through the compressor.

Other sources of noise are the turbine and the engine casing. The turbine generates noise in a similar fashion to the compressor, but at a lower power level. The noise radiated from the casing is dependent upon the levels of internal noise associated with the above-mentioned processes and also upon the geometry and stiffness of the casing. Externally, this noise is also of a lower level than that of the intake and exhaust noise.

There are no longer any large turbo-jets operating on the civil register in Australia. The most common jet engine is the turbo-fan engine such as used in the Boeing 707, 727 and Douglas DC.9 aircraft. The turbo-fan engine was primarily developed to provide greater thrust and lower specific fuel consumption than the turbo-jet engine. In these engines a large fan section at the forward end of the engine provides the major proportion of the engine thrust. The gas generator (compressor - combustion section - turbine assembly) acts more as a prime mover for the fan than as a means of providing engine thrust, although it still provides portion of this. Turbo-fan engines generate noise in much the same fashion as turbo-jet engines. However, in turbo-fan engines the jet exhaust velocity is lower and consequently the exhaust noise is lower. The fan noise, which is generated within the engine in much the same way as compressor noise and propagates forward out of the inlet and rear-ward out of the fan discharge ducts, tends to predominate. Overall, for the same thrust, a turbo-fan engine is generally quieter than a turbo-jet engine.

A turbo-prop engine (e.g. as installed in Fokker F.27 and Lockheed 188 aircraft) can be considered roughly as an extension of the turbo-fan principle, with the fan section being replaced by a propeller. In this type of engine the gas generator is used to drive the propeller through a reduction gearbox, only a small amount of thrust being produced by the exhaust. Compressor and propeller noise predominate in such engines, which have a characteristic high pitch whine. This can be objectionable, especially at close quarters.

Piston engined aircraft (e.g. Douglas DC3, DC4/Carvair and most light aircraft) are less noisy than jet aircraft. The main noise sources in this case are propeller noise and exhaust noise. The exhaust noise is generally fairly well muffled, but the propeller noise can be quite annoying. However, the only time such aircraft are likely to represent a major annoyance is during the night time (e.g. freighter operations) or during ground testing of engines in aircraft - which is often prolonged.

The noise from helicopters, some of which can be annoying, is generally fairly low. Apart from the engine exhaust, the main noise source is the rotor noise (hence the nick-name "chopper").

The only other form of aircraft noise worth mentioning is the "sonic boom", an effect of the shock waves produced in supersonic flight. There are indications that this could be a problem in the future along the flight path of supersonic transport aircraft, but solutions have not been fully explored or developed at this time. As a matter of interest, the Department of Civil Aviation is funding a research project at Sydney University which is aimed at the study of configurations to minimise the strength of "booms".

The noise produced by vertical lift turbo-jet engines beneath the ascending or descending VTOL (vertical take-off and landing) or STOL (short take-off and landing) aircraft, which are likely to come into quite wide use in the future, is likely to be concentrated in a relatively confined circular zone. The noise level beneath large diameter, horizontally mounted fans may prove comparable with conventional helicopter rotors. However, they may also generate objectionable high pitched sound in the horizontal plane, thus extending the possibility of noise nuisance over a greater surface area.

Regulations to Limit Noise Nuisance at Source - Noise Certification

The possibility of developing certification standards to control the permissible noise output of aircraft of new design was first publicly mooted at the London Noise Conference, 1966, and further explored in "Tripartite" technical discussions between USA, Britain and France during 1967 and 1968.

Since that time aircraft manufacturing countries, including Britain and the USA, have passed domestic legislation enabling their aviation authorities to prescribe noise certification standards. The USA was first in the field in the publication of such standards, an FAA Notice of Proposed Rule Making dated January 1969, being followed on 18 November 1969 (just prior to the ICAO Special Meeting on Aircraft Noise) by the issuance of Federal Aviation Regulation No. 36.

The requirements of FAR 36 are mainly applicable to subsonic transport category aircraft of future design. The certification noise limits are specified in the form of maximum noise levels (expressed in Effective Perceived Noise Decibels - EPNdB) that may not be exceeded under closely defined test conditions at three standard measuring points - one under the landing approach path, one under the take-off climb path, and another to the side of the runway centre line. The noise limits chosen are such that aircraft that comply with the standards will be noticeably less noisy than the current types of turbo jet aircraft. The Federal Aviation Administration has also given notice that these requirements will be kept under close review and will be made progressively more stringent as, and when, it is found to be "economically reasonable and technologically practicable" to take such action.

The new requirements will apply in full to the Lockheed 1011 and DC-10 "Trijets" and to all other future subsonic transport category aircraft manufactured in, or imported into, the USA. Since it was already well advanced in production before any proposed noise standards were announced, some minor relaxations of the standards are being allowed for the initial version of the Boeing 747 "Jumbo Jet". However, after a date yet to be ratified all future production Boeing 747s will have to meet the standards in full. At the same time it should be noted that, even in its current version, the Boeing 747 is already significantly quieter than turbo-jet aeroplanes of earlier design, e.g. Boeing 707s and DC-8s, as mentioned earlier.

At the ICAO Special Meeting on Aircraft Noise, agreement was reached on the details of proposed international noise certification requirements that will be consistent with, and very close to, the requirements prescribed in FAR 36. It was recommended, in addition, that these requirements be given the status of Standards, obligatory on all contracting States, by publication as part of a separate new Annex to the Convention on Civil Aviation (Chicago Convention).

Recognising that certification standards for new design can only be fully effective in the long term and that most of the noise in the vicinity of the world's airports will continue to be generated by existing (non-noise certificated) aircraft for the next ten to fifteen years, the meeting also discussed the possibility of modifying ("retro-fitting") existing aircraft to obtain reductions in noise output. It soon became apparent that such action would involve technical, economic and regulatory problems of great magnitude and that there was not yet sufficient reliable data available to enable soundly-based decisions to be made. The Meeting accordingly recommended that ICAO establish an appropriate body to investigate the matter of possible "retrofit" requirements as a matter of the utmost urgency. It was also recommended that this same body should proceed with the development of noise certification requirements for other classifications of aircraft not covered by the initial recommendations, commencing with noise standards for supersonic transports (SSTs). Similar work is also proceeding independently in the USA.

Since Australia is not a manufacturer of large civil jet aircraft, we would not expect to become involved in any major noise certification projects in the foreseeable future. We shall, however, need to take local regulatory action to put the ICAO requirements into effect after the new Annex has been issued and becomes effective. This is not expected to occur before August 1971. We are already represented on the body established by ICAO to undertake further development of noise certification requirements, as discussed in the preceding paragraph.

The "Quiet" Engine Program

Much development work is being done in an endeavour to cut down the propagation of noise through the engine inlet. Splitters, air inlet bullets and concentric rings are among the features being tried out. Care is necessary in designing these devices to ensure that engine airflow is not limited to the extent of introducing problems of surging or loss of performance. It is also necessary to provide adequate anti-icing protection of inlet splitters and similar devices.

Another development being studied is the oblique inlet. Physically, this looks like a protruding lower lip and its aim is to act as a shield against engine inlet noise being propagated in a downward direction. This work is closely associated with general considerations of optimum duct/nacelle/aircraft configurations. Other points being considered in this connection include longer ducts and shielded intakes. The positioning of engines on aircraft is also being considered in great detail. Some manufacturers are proposing to make more use of the possible shielding effect of the aircraft wing, e.g. by placing the engines above the wing.

Sound absorptive lining is now being extensively used in the design of fan ducts, engine side panels and exhaust ducting. Care must be taken to ensure that such linings are not susceptible to absorbing flammable fluids, such as hydraulic oil, etc., creating attendant fire hazards. They also represent a significant weight penalty.

There is an increasing tendency for turbo-fan engines to be designed with larger by-pass ratios. This involves a progressive increase in fan diameter and reduction in rotational speed. The jet exhaust velocities are consequently lower, resulting in a reduction in the associated noise.

Inlet guide vanes have been dispensed with on most new large turbo-fan engines to eliminate discrete high-pitched tones at the blade passing frequency, the loudest and most annoying noise from early fan engines.

Intensive efforts were applied to the design of airborne jet exhaust noise suppressors during the development of the first commercial turbo-jet powered transport. Such suppressors were found to be most effective at very high jet velocities and a typical example is used on some Douglas DC8 aircraft. It has been stated that this installation cost $4 million to develop. Because of the lower jet velocities of turbo-fan engines, substantial jet exhaust noise suppression does not appear to be feasible by the application of designs similar to those developed for pure turbo-jets. However, research is continuing on the development of devices that can promote rapid mixing of the exhaust with the surrounding air without causing prohibitive losses in aircraft performance. It is believed that the Rolls Royce/Bristol Olympus engine for the supersonic Anglo/French Concorde will incorporate a retractable inflight silencer incorporating this principle. Apparently, the proposal is to use this silencer for take-off, when exhaust noise is most critical, and to retract it during cruise flight.

The new Rolls Royce three-shaft engines, so far the only ones of their kind, are likely to have a special facility for slowing down rotation of the fan section during landing approach. This would lower the fan noise while still retaining the necessary capability for rapid power response in an emergency.

Incorporation of advanced noise suppression features in the "new generation" turbo-fan engines developed for aircraft such as the Boeing 747, Lockheed 1011 and Douglas DC-10 have already had a marked effect. Although these new engines will produce approximately three times the take-off thrust of present day turbo-fan engines used in Boeing 727, 707 and Douglas DC-9 aircraft, their noise levels will be significantly lower.

In 1968 the National Aeronautics and Space Administration (NASA) of the USA initiated a "quiet engine" design program valued at $50 million. Pratt and Whitney and General Electric are the major participants and under the terms of the program are each required to produce two demonstrator engines with noise levels 15-20 dB below present day engines in the 20,000 lb. thrust category. Engines of comparable thrust capacity are currently being used in Douglas DC-8 and Boeing 707 type aircraft. It is hoped that new noise suppression proposals will arise from this program, which is expected to be completed by 1972.

Expected Noise of Future Supersonic Transport Aircraft

In view of the early stage of development of supersonic transports, reliable quantitative information on noise levels is not yet available. However, initial information on the Concorde suggests that the noise levels beneath the approach path will be some 5 PNdB less than current jets, beneath the take-off path will be comparable, and on the side-line will be some 5-10 PNdB greater than those of current subsonic commercial jet aircraft. It is believed that these estimates include the effect of a retractable in-flight silencer, which is reported to reduce engine noise during take-off by approximately 5 PNdB. Noise certification requirements for the supersonic transports have not been developed yet, but these are expected to be developed in the near future. It is not possible to predict how the Concorde will stand in relation to any such standards.

No information is available on likely noise levels of the proposed US supersonic transport, but it is apparent that the problems to be solved will be at least as severe as those associated with the Anglo-French Concorde.

In view of the high proposed operating altitude for supersonic transports, engine noise during en-route flying is unlikely to be of concern. However, there are indications that the "sonic boom", an effect of the shock waves produced in supersonic flight, could be a problem in the future along the flight paths of supersonic transport aircraft. Solutions to this problem have not been fully explored or developed at this time.

Aircraft Noise Abatement Procedures

At all Air Traffic Control-staffed airports, my Department employs aircraft noise abatement procedures on a 24-hour basis.

These procedures are, particularly in the case of the capital city airports, quite complicated and primarily are designed with a view to reducing the amount of noise exposure experienced by residents around the airports to an absolute minimum and, having done this, spread the remaining noise inconvenience as equitably as possible.

In addition to specifying noise preferential runways to be used and flight paths to be adopted by arriving and departing aircraft, departing aircraft also carry out a procedure after take-off which is designed to get the aircraft as high as possible as soon as possible - simply stated, this procedure involves maintaining specified airspeeds at take-off power until a certain height or distance is reached, following which normal climb procedures may be followed.

The above procedures, of course, are only employed when operational considerations permit. For example, poor visibility, low cloud or extreme wind conditions may well preclude the use of the optimum runway for noise alleviation.

Ground Running of Aircraft Engines

Current restrictions at Australian capital city primary airports limit the noise nuisance caused by engine ground running.

Barriers, such as walls or earth banks, have been tried overseas. They have been found to be partially effective for piston engined and turbo-prop aircraft in attenuating the high frequency propeller noise, and for jet aircraft in attenuating the high frequency compressor and turbine whine. However, they are likely to have little effect in reducing low frequency jet exhaust noise, which is much harder to attenuate. This type of barrier has been shown to have a use for small aircraft such as military jet fighters where the aircraft can be almost completely enclosed with ease. In such cases the engines are generally set lower to the ground and operate at lower powers than current commercial jet aircraft and hence present a less difficult attenuation problem. Since the amount of noise attenuation is a function of the barrier height, relatively small earth banks or walls can be used by comparison with those that would be necessary for an installation for a large commercial jet aircraft.

The amount of noise attenuation of a physical barrier is also a function of the distance of the noise source from the barri and the distance of the noise receiver from the barrier. Best attenuation is achieved when the noise source is close to the barrier and the receiver is far from the barrier or vice versa. Because of the above, physical barriers can be particularly useful for shielding a well-defined localised area but are not so useful where a widely dispersed area is to be shielded. At the same time it is suspected that such barriers may have a psychological value independent of the degree of silencing actually obtained. TAA have almost completed the construction of an earth bank at their new maintenance base at Melbourne (Tullamarine) Airport, which will provide an opportunity for local evaluation of these matters.

Another form of noise barrier is the so-called "hush-house". This works on the principle of enclosure of the noise source in a special hangar or similar structure. Lufthansa, the West German flag carrier, is believed to be using one of these "hush-houses" in the form of a large sound-proofed hangar in which entire aircraft are placed for in-airframe engine ground running. Another form of "hush-house" is being evaluated at Los Angeles International Airport. In this case the aircraft is almost completely surrounded by a circular enclosure. This installation is reported to have cost $148,000. Since in these types of installations it is necessary to have one side open for the escape of exhaust gases and for aircraft access, care must be taken to ensure that the structure does not become a "megaphone" amplifying noise in one direction. This problem is understood to have been experienced with the Lufthansa and Los Angeles installations. It is also understood that initial experience with the Los Angeles facility has revealed that engine exhaust recirculation can cause engine surging and tail plane buffeting and that modification may be necessary.

The typical engine test cell consists of a heavily sound-proofed building, in which the engine is run prior to installation in an aircraft, attached to an equally heavily sound-proofed control room. Baffled openings are provided for inlet air and exhaust gases. In some cases the exhaust gases are directed through a vertical stack to assist in noise suppression. Provided engine test cells are properly designed they will mostly eliminate any external noise nuisance problems. These cells are used before and after overhaul and for performance checks on engines out of the airframe. A typical example of a modern test cell design is TAA's new cell at Tullamarine.

For engines installed in aircraft movable and fixed exhaust noise suppressors are available. It is reported from overseas experience that movable suppressors are only marginally effective, besides being somewhat difficult to handle. The main problem is that, if a unit is light enough to be movable, it is likely to have limited silencing ability and poor durability. Those overseas operators who elect to use suppressors are tending to use fixed types, since these are much more effective. They are also more expensive than the movable types. Incidentally, it should be noted that exhaust noise suppressors are of little effect with turbo-prop engines where the majority of the noise is generated by the propeller and compressor, and would probably only be partially useful for turbo-fan engines with high by-pass ratios where the majority of the noise will be generated by the fan and compressor. They will be most effective with pure turbo-jet engines or with turbo-fan engines having relatively low by-pass ratios. Such is the experience at London Airport where fixed noise suppressors in use by BEA are reported to provide a 20-22 dB reduction in noise level. The costs of the BEA installation are not known, but it is reported that BOAC has spent £480,000 on fitting noise suppressors of comparable type and incurs a sum of £450,000 annually in additional maintenance costs.

Intake noise screens, both in the form of a wire mesh type screen attached to the engine intake and a box type shield around the engine intake, have been tried on both turbo-fan and turbo-jet engines, but their effect is apparently fairly localised and they can produce attendant problems of engine surging. They are not feasible for turbo-prop engines because of the presence of a rotating propeller in front of the engine.

During recent years aircraft and engine manufacturers, under pressure from aircraft operators, have been giving considerable attention to the incorporation of design features that will reduce the need for ground running of installed engines - e.g. provision of more sophisticated instrumentation and detection equipment to facilitate rapid and accurate "trouble shooting"; provision of auxiliary power units, enabling hydraulic and electrical systems, etc., to be checked out without the need to run one of the main engines. The benefit of this work has already become apparent in the current generation of turbo-jet aircraft, and additional improvements are due to be incorporated in future aircraft types.

Noise Monitoring

For some time the Department has been investigating the use of both fixed and mobile aircraft noise monitoring systems. The House of Representatives Select Committee on Aircraft Noise has now recommended that the monitoring of aircraft noise be introduced in Australia but not yet on a widespread basis. It is probable that the first monitoring systems will be installed at Sydney.

At this stage it is apparent that for at least a year after the initial installation of monitoring equipment, it will be used to gather representative data for the further study of aircraft noise problems and to establish the purposes for which the monitoring system will be used in the future.

Noise Exposure Forecasting

In the preceding parts of this paper I have endeavoured to give an outline of the forms of aircraft noise and the community problems created by aircraft noise as well as an account of the quite strenuous efforts of the aviation industry to reduce the effects of aircraft noise through various abatement procedures and, in the longer term, through improved design of aircraft engines and engine installations.

However, despite the reduction of the aircraft noise problem being achieved through the vigorous endeavours of the aviation industry - endeavours which I feel might well be emulated with respect to other sources of noise in our community - there will be, in the foreseeable future, residual aircraft noise disturbance in some areas adjacent to busy airports. The seriousness of such disturbance varies with the purposes for which the community uses these areas and also with the type and density of traffic over the areas. Of course, the density of air traffic is related to the community's needs for air transportation and the frequent suggestion made that traffic should be restrained or restricted in order to reduce noise is hardly satisfactory to the community as a whole, even though it appeals to some sections.

For some time it has been apparent that there is a need to determine quantitatively the noise exposure to which people are subjected in particular locations near an airport. A great deal of work has been done in overseas countries to establish methods for determining aircraft noise exposure and the human response to various levels of exposure. One such method, called the Noise Exposure Forecast (NEF) method, was developed in the United States and, here in Australia, the Department of Civil Aviation has adopted this particular method. It is used to provide predictions of noise exposure in NEF units derived through the summation of the perceived noise level created by each flight to or from an airport. Thus, the forecasts are based upon the characteristic noise output of each type of aircraft using, or expected to be using, a particular airport, and such factors as:-

(i) the magnitude and duration of aircraft noise as determined by type, weight and flight profile,

(ii) the distribution of the noise energy over the spectrum of audible frequencies,

(iii) the forecast frequency of aircraft movements on various flight paths, and

(iv) the distribution of aircraft movements by day and night.

Extensive social studies conducted in the United States have provided a correlation between the levels of noise exposure in NEF units and the average human response. It is possible that under our living and working conditions, human response may be different somewhat from that in the USA. In due course, experience in the use of the NEF method and perhaps some local social studies will indicate the validity of the method in Australia as it is now applied.

I should mention that the House of Representatives Select Committee on Aircraft Noise was very interested in Noise Exposure Forecasts and one of the recommendations made was:-

> " The Noise Exposure Forecast system of the United Federal Aviation Agency be adopted by Australia but used as a guide to noise exposure only. Cautious restraint is necessary when town planning authorities apply the accompanying land use categories to Australian conditions. "

The NEF method is currently used to make plans of airport localities showing contours of noise exposure. In this way, the more critical areas of noise exposure are defined. In the use of these charts, it is important however to keep in mind the note of caution expressed by the Select Committee. Not only is the similarity of human response in Australia and the USA to be determined, but it must be appreciated that the Noise Exposure Forecasts involve forward predictions of aircraft movements at each airport by route, by aircraft type and by day or night. There is obviously a substantial element of judgment in the arduous work of those making these predictions. Nevertheless, it is a sincere attempt to define the extent of the aircraft noise problem near each airport at a given time in the future. It provides a means for examining the effectiveness of noise abatement measures and also for considering the planning and regulation of land use near airports.

Land Use Zoning

As the main impact of aircraft noise is felt in areas adjacent to airports, it would obviously be a completely effective solution to the aircraft noise problem if the use of these areas is controlled so as to be compatible with the respective level of noise exposure. I am referring to the residual levels of noise exposure after the aviation industry has adopted all reasonable measures for noise abatement such as those now in train. In practice, however, this ideal is difficult to achieve, either because of the existing urban development close to airports or because with the establishment of a new airport there is an immediate tendency for urban development around it. This does not mean to say that the zoning of land areas around either new or existing airports is not a worth-while endeavour despite all the practical difficulties.

Some important measures at Tullamarine were recently announced. An interesting example of what is now being attempted overseas is the next airport to be built for Montreal. It will occupy some 10,000 acres - Tullamarine is about 5,500 acres - and a reservation of a further 55,000 acres of land around the air-port has been made so that its use can be planned and controlled.

The Noise Exposure Forecast method I have outlined offers a basis for planning or re-planning the use of land near airports. Normally, three zones of noise exposure, defined in NEF units, are used as follows:-

Zone A - in which the NEF is less than 30 units

Zone B - in which the NEF is between 30 and 40 units

Zone C - in which the NEF is greater than 40 units

If the boundaries of these zones are plotted on airport locality charts they appear as contours of given noise exposure, e.g. NEF 30 and NEF 40. Zone A does not have any outer limit in the American system and experience gained recently in Australia confirms the difficulty in giving any precision to the location of NEF contours lower than 30.

Appendix A is the land use compatibility table published in the United States for the three NEF zones. It covers a number of major land use categories having different sensitivities to noise and may be used as a guide for the planning of other land usage. The table emanates from American studies using wide-spread sampling of individual and community responses to aircraft noise. It is appropriate, therefore, to repeat the Select Committee's injunction of cautious restraint when town planning authorities apply the land use compatibility table to Australian conditions. It might be appropriate, for instance, for planning authorities in considering the rezoning of rural areas to other uses to apply at least a 5 NEF unit buffer.

The importance of recognising the limitations of the system is again emphasised. Even in areas outside those in which reactions are expected, individuals can be expected to make complaints as personal reaction can vary over a wide range. Also, persons who would normally tolerate the level of noise to which they are exposed can easily be mobilised by small pressure groups into complaining or into exhibiting other reactions, to a greater degree than the forecast indicates. Apart from this variability of human reaction, there are other factors which could cause the forecasts of NEF values to be inaccurate to some extent.

I have pointed out that the Noise Exposure Forecast is not a precise or perfect technique, but until such time as Australian or additional overseas experience suggests the desirability of modification, this system is offered as the best available practical guide for use in land zoning or other actions which it is felt are necessary as a result of aircraft noise.

The application of the system to a particular airport environment is depicted in appropriate NEFs prepared by the Department of Civil Aviation. After the Department of Civil Aviation has provided the Noise Exposure Forecast, it is for the planning authorities to apply that forecast in a manner that is considered appropriate. As the Minister for Civil Aviation has emphasised on a number of occasions, in other than Federal Territories only the State and Local Government Authorities have the required planning (or land use zoning) powers. The Department therefore makes these Noise Exposure Forecasts available to the State Planning Authorities and to Local Governments, supplementing the release of this information by detailed explanation through the Airport Noise Abatement Committees. This distribution is intended to pay proper regard to the normal lines of Government communication.

The most difficult situation in planning land use is that of the existing airport with urban development up to its boundaries. Sydney is a case in point where land use control offers very little in the short term but this is not to say that in the longer term the planning and control of re-development of close-in areas could not steadily achieve a substantial reduction in the overall problem of noise disturbance from aircraft. Whilst the open spaces near Tullamarine may never be provided near Sydney airport, at least selected industry could take the place of residences in some areas.

In conclusion, may I say that I hope this paper will have served to give you a general understanding of the aircraft noise problem as well as of the efforts of the aviation industry to become a better neighbour to the communities it serves, and, at the same time, I hope I have left with you some thoughts as to the measures which those responsible for urban planning and zoning might take so that the best possible balance can be achieved between the community demands for an efficient air transport system on the one hand and freedom from noise disturbance on the other.

APPENDIX "A"

LAND USE COMPATIBILITY TABLE

Noise Exposure Forecasts necessarily involve many assumptions. Expected aircraft movement rates will be influenced by unforeseeable changes in the size of aircraft in the future which, along with navigation and air traffic control system improvements, may achieve handling capacities at variance with those anticipated. It is assumed that there will be close co-operation between State and Local Government, Health, Planning and Building regulatory authorities on the one hand, and the Commonwealth aviation authorities on the other, since land use near airports has a very significant influence on terminal traffic patterns which, in turn, are an important influence on traffic handling capacities.

U.S. Land Use Compatibility Table is published as a guide.

ZONE (NEF Range)	A (Less than 30 NEF)	B (30-40 NEF)	C (Above 40 NEF)
LAND USE COMPATIBILITY Residential	Yes	Note (2)	No
Hotel, Motel, Offices, Public Bldgs.	Yes	Yes Note (3)	No
Schools, Hospitals Churches, Indoor Theatres, Auditoriums	Yes Note (3)	No	No
Commercial, Industrial	Yes	Yes	Note (3)
Outdoor Amphitheatres, Theatres	Yes Notes 1 & 3	No	No
Outdoor Recreational (Non-Spectator)	Yes	Yes	Yes

NOTES: (1) A detailed noise analysis should be undertaken by qualified personnel for all indoor or outdoor music auditoriums and all outdoor theatres.

(2) Case history experience indicates that individuals in private residences may complain, perhaps vigorously. Concerted group action is possible. New single-dwelling construction, Note (3) applies.

(3) An analysis of building noise reduction requirements should be made and needed noise control features should be included in the design.

REALISTIC COMMUNITY NOISE CRITERIA

ANITA LAWRENCE
SCHOOL OF ARCHITECTURE
UNIVERSITY OF NEW SOUTH WALES

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REALISTIC COMMUNITY NOISE CRITERIA

SUMMARY

In setting limits for community noise it is essential that a balance is obtained between the need to reduce excessive noise and the costs incurred in noise reduction. The greatest problem foreseen is that of reducing transportation noise to levels acceptable in residential areas.

INTRODUCTION

If noise in a community is to be controlled it is necessary to establish objective criteria with which particular noises may be compared. The principle guiding the selection of these criteria is that people are entitled to work, sleep and enjoy their recreation without experiencing annoyance from excessive noise.

In a community containing multitudinous noise sources of greater and lesser magnitude any control which will lead to a significant reduction in overall noise levels is essentially a long-term project. Indeed, the problems involved are so complex, and the costs involved so major that it might be asked - why bother, when the majority of people do not voice dissatisfaction with their noise climate? This point is well illustrated by the houses and flats still being built along major highways and apparently occupied with little delay. People still move into suburbs adversely affected by low-flying aircraft, and there is apparently no reduction of property values in these areas.

However, there is an obvious parallel between noise and air pollution. A few years ago there was little general interest in the cumulative effect of discharging large quantities of carbon monoxide and other waste products into the atmosphere. Now many communities have expressed a general alarm at the situation and governments are legislating to control and reduce air (and water) pollution levels. Noise too is an insidious destroyer of the urban environment. As in the case of air pollution, most noise is simply a by-product of some activity or process, and as a society becomes more technologically sophisticated, the number and extent of noise sources increases. This has resulted in a continual increase in the noise exposure of every person living in such a society.

One of the greatest difficulties to be overcome in determining realistic community noise criteria is that in many cases the immediate cost of reducing noise is considerable - requiring for example the redesign of machinery or the construction of a much more substantial building (including the installation of mechanical services) than would otherwise be required to satisfy the other environmental and functional criteria. On the other hand it has proved difficult to establish that noise actually costs the community a significant amount - either in monetary terms or in terms of health and efficiency. There is some evidence however that presbycusis may in fact be noise-induced, and that some industrial accidents have noise as a contributing factor.

Subjectively, many people now feel that noise is having a deleterious effect on their lives, and that this effect is steadily increasing in the absence of any controls. Noise reduction will undoubtedly contribute to the quality of the environment, and it is perhaps fortunate that our community, in common with those in many of the developed countries, has at last come to the point of realising that this quality must be protected, and, in several important respects, restored to former higher standards.

In view of the difficulty in establishing that actual monetary savings would result from noise reduction in a community, the cost to the community (either directly through subsidies, or indirectly through pricing) must be balanced against the subjective desirability of living in an improved environment. It is obviously necessary to take care in the choosing of criteria which are to be used for noise assessment. If the acceptable levels are set too low, the cost will be excessive, and other problems (such as privacy) may arise. Alternatively, if the acceptable levels are set too high, the effect may be only that existing levels are maintained and no overall reduction is achieved. The fact that not all community noise sources can be reduced quickly should not prevent action being commenced immediately. For the first few years there may well be some discrepancies, but this situation always occurs with the introduction of new standards in a society.

The method of applying community noise criteria must also be considered. In most countries, these criteria form the basis of legislation administered by local authorities, thus the methods of measurement and assessment of noise should be direct and readily applicable to common local situations. It is obviously important that any objective method of measurement and assessment of noise should have a high degree of correlation with subjective assessment and with community reactions.

A DEFINITION OF "QUIET"

Anyone who has experienced extreme quiet, e.g. in an anechoic room or an underground cave, when the only sound heard is that of physiological noise, realises that very quiet conditions are not necessary or even desirable in normal living. Perhaps the quietest conditions that are pleasant are those in a rural area, where the only noises heard are from "natural" sources - wind, birds, animals, etc. Other noises that are pleasant, even though fairly loud, are those of the sea and surf.

If it is assumed that rural noise levels should be acceptable to the majority of people it is necessary to determine what actual levels exist in such areas. At times even rural noises (for example from birds, insects and animals) are unacceptably high for some human activities. There is certainly variation from time to time and according to season. Little has been reported of measurements in rural areas. In a paper by Ostergaard and Donley (1) levels obtained in a rural area of France at night are quoted. These levels correspond to about NR 25-30 (or about 30 to 35 dBA). In another set of measurements by Ostergaard and Donley made on spring nights in a very low density New Jersey suburban community, not penetrated by major highways, the lowest 5% of readings were of a similar level. Thus it would appear that average natural noise levels are of the order of 30 dBA.

It is unlikely that any urban community could ever reduce all of its noise sources to such levels - in fact even hard-soled shoes would have to be banned for outdoor use on paved areas! Many urbanised people may in fact be disturbed by continual quietness. Another problem that arises is that an extremely low background noise level exposes any deficiencies in sound insulation inside buildings, and many noises that would not usually be heard inside or outside may become obvious and annoying.

CRITERIA DERIVED FROM CONSIDERATIONS OF MASKING

Since rural quiet appears impracticable in an urban community, particularly in daytime, some other criterion must be used to determine acceptable levels. A useful concept is that of masking. It is well known that the presence of one sound will mask another, i.e. make the second sound (which is audible when presented alone) inaudible. Many of man's activities produce a considerable noise level, e.g. speaking, moving about, using tools and appliances (even so-called quiet ones), and this noise will tend to mask noise coming from other sources. The most critical period is when sleeping, when the activity noise level is at its lowest.

For this reason it is common to set different criteria for day and night (which of course does not take into account those people who work night shifts).

Whether or not one noise will be masked by another depends on several factors, the understanding of which relies upon a knowledge of the physiology and psychology of hearing. Fletcher (2) and Bekesy (3) report many subjective experiments to determine the masking of one sound by another - particularly when the sounds are pure tones. This work was later extended by Zwicker (4) in his investigations into the loudness of complex sounds. The extent of masking depends on both the frequency and the intensity of masker and maskee. Generally low frequency sounds have a greater masking effect on high frequency sounds than vice versa. The masking is greatest when the two sounds have similar spectra.

To apply the concept of masking to community noise criteria it is necessary to determine noise levels which are commonly produced in the course of various human activities. At one end of the scale is heavy industry (where in fact, the noise levels are frequently those which constitute a danger to hearing) and at the other end is the "activity" of sleeping, where the levels are very low. Intermediate activities, for example in commercial buildings, range from noisy data processing offices in which conversation is difficult if not impossible, to quiet private offices. In the domestic field, there is again a range of activity noise levels from the use of appliances, such as washing machines, vacuum cleaners, hobby tools, to those in studies and bedrooms.

Masking criteria may be used to specify general background, or ambient noise levels which are suitable for different purposes. However, most noise problems arise from noises which are clearly attributable to specific noise sources. These may arise in several circumstances. 1, the specific noise source may be much louder than the general background noise in the area. This presupposes that the specific noise source does not operate continuously, so that the noise it produces can be compared with the ambient level when it is silent. 2, the specific noise may have a rythmic character, such as hammering; again, this intermittency allows frequent comparison with the lower, ambient noise level. 3, the specific noise may have a clearly recognisable pitch, attributable to pure tone components. In this case the masking of the sound is dependent on the ambient energy available in the "critical bandwidth" centred on that pure tone frequency, (Rice & Walker, (5). This also applies to noise which has prominent narrow band noise components. Another characteristic of a noise which may make it more easily noticeable and thus more annoying is a fluctuation in the amplitude of the sound, or of some of its components. Rice

& Walker (5) have also investigated this aspect but have not reached any firm conclusions; indeed, amplitude modulation may not be detected by conventional measuring equipment and may at times only be discerned from a spectrographic record.

THE EFFECT OF NOISE DURATION

Community noise levels rarely remain constant for any length of time and this is particularly true when the noise comes from traffic. It is necessary to equate the annoyance of an intermittent or fluctuating noise source with one which operates continuously. From the physical viewpoint, the idea of equivalent energy is worth considering. That is, the total sound energy received over a given period should not exceed a given value (which is usually quoted as an average value). This type of summation appears reasonable for continuously varying levels, such as those due to road traffic on a fairly busy road.

For particular sources which occur intermittently, e.g. blow-off valves, machines used for only short durations each day, it is usual to apply correction factors to the measured noise level, the correction depending on the percentage on-time or on the number of occurrences of specified duration within a certain period. Some criticism has been levelled at this approach, because an occasional loud noise is often more noticeable and may not be as acceptable as a continuous noise of equivalent energy. In particular, occasional loud noises at night are extremely disturbing, and an allowance for intermittency at night may not be appropriate.

THE EFFECT OF LAND-USE

Following considerations of masking the idea of setting different criteria for different types of land-usage appears appropriate. In other words, in an area devoted to heavy industry, inside the buildings of which loud noises are continuously operating, it is not necessary to limit community noise to low levels - provided that if outdoor rest areas are provided these can be shielded from excessive noise. On the other end of the scale, residential areas, where many people desire quiet surroundings, and particularly at night, when people wish to sleep, the levels should be set much lower. Commercial areas lie somewhere between.

One difficulty that arises in most developed countries is that there is no clear differentiation in land use zoning in the older cities, thus heavy industry and domestic buildings may occupy adjoining sites. The compromise reached is usually one that permits higher levels for residential sites in commercial or industrial areas. Thus, a person living in such an area is virtually deemed to be less sensitive to noise than another living in a purely residential location. This is perhaps not so illogical as it at first appears, because there is in fact a very wide range in noise sensitivity of different people. The difficulty is that economic factors such as cost of housing and accessibility of employment may to some extent prohibit the free movement of noise-sensitive people from noisy areas. However, at present attainable community noise levels appear to rise as the economic level of the inhabitants is reduced (apart from those who take refuge in remote outer suburbs).

SUGGESTED CRITERIA FOR COMMUNITY NOISE

For several years the International Standards Organisation has been considering a draft standard for "Noise Assessment with Respect to Annoyance" (6). This has also formed the basis for deliberations of the Standards Association of Australia Committee AK/5 which is preparing draft standards on the same topic.

In the Australian version it is proposed to set the basic criterion for community noise, measured within the boundaries of residential areas, as 40 dBA. This is applicable to continuously operating noises in rural residential areas in daytime, and also includes hospital zones and areas for recreation. Levels during the evening, defined as 6 p.m. to 10 p.m. are set at 35dBA, and at 30 dBA from 10 p.m. to 7 a.m. in the same areas. The basic level is varied for other residential areas, ranging from 45 dBA for suburban residential areas to 65 dBA for residential sites situated in areas which are predominantly industrial (daytime criteria).

Corrections are applied for variations in noise level. An equivalent energy basis is used for continuously varying noise such as arises from road traffic, and specific factors are used for intermittent operation of noise sources. For example, a correction factor of -8 dBA is applied to the measured noise level of a source which operates once only for 5 minutes during an 8 hour period during the day. Other corrections are also proposed for impulsive sounds (+5 dBA), for recognisable tone components (+5dBA) and for amplitude modulation or beating (+5dBA).

Finally the corrected measured noise level is compared with the appropriate noise zone criterion and the strength of community protest is assessed. If the rated noise level is within 5 dBA of the criterion little reaction is expected. As the excess increases the community reaction is expected to strengthen so that with an excess of 20-25dBA strong community action is predicted. It has been further suggested that with excesses of noise over criteria of more than 25 dBA a person may attempt to alleviate the situation by his own personal actions. An illustration of how the method of assessment may be applied is given by Lawrence (7).

COMPARISON OF SUGGESTED CRITERIA WITH EXISTING COMMUNITY NOISE LEVELS

Although some industrial and commercial undertakings do at present emit higher noise levels than those suggested, noise levels emanating from buildings can be fairly readily controlled. Techniques used include noise reduction at the source, and planning and constructional measures. The great difficulty at present is to maintain desirable community noise levels in the presence of road, rail, waterway and air traffic. Each individual vehicle itself is usually well above acceptable noise criteria,although its passage past a particular site occupies a very short percentage of a 24 hour period. When, in the case of road traffic, many hundreds of individual vehicles pass a given site in a day, the overall effect is a continuously excessive noise level. This appears to make a mockery of noise limits, with which industry and commercial buildings may be required to conform. For example, a typical car passing a residential site may produce over 80 dBA at the kerbside for about 3 seconds. Using a typical correction factor for duration (over 8 hours, daytime only) the equivalent noise level would be about 45 dBA or 5 units above the rural daytime criterion of 40 dBA. Ten cars passing during the same 8-hour period would have an equivalent noise level of about 53 dBA, 8 units above the suburban residential criterion of 45 dBA. By the time 100 cars occur over an 8-hour period no reduction to the measured level of about 80 dBA is applicable.

The reduction of level with distance between the kerbside and the site boundary would in most cases be insignificant. It is true that there would be a reduction of a few dBA at the building alignment for many domestic buildings, and a further reduction inside the building, but the residents would not have the quiet enjoyment of the whole of the site.

Many major highways of course have much higher traffic flows than those considered above - of the order of 1,000's of vehicles per hour in peak hours. Measurements made near the kerbside of 6-lane highways have shown average levels to exceed 74 dBA (3,000 v/hr) with the 98% maxima levels at about 83 dBA for the same flow rate. (Lawrence, Hegvold and Green, (7)). Aircraft constitute a similar problem and obviously residential community noise criteria cannot be met within close proximity to landing and take-off paths as well as in the vicinity of airports.

LOGIC OF SUGGESTED CRITERIA

Industrialists may well feel that they would be unjustly penalised by proposed noise limits, as it has been shown that present forms of transportation exceed these considerably. However, if noise is ever to be reduced in the community it is necessary to apply criteria without delay. Practically, noise sources which are enclosed within a building are much more amenable to control by available techniques than are transportation noise sources.

In the case of transportation noise, control at the source is again the ideal approach, and some progress has been made. Aircraft are already subject to noise control requirements in many overseas countries, albeit that the criteria set constitute only a maintenance of existing excessive levels. Motor vehicle noise is controlled in some areas overseas, and it is hoped that in Australia too this will be the subject of codes limiting the maximum emitted noise levels of individual vehicles under specified conditions. Unfortunately it seems unlikely that there will be a dramatic fall in transportation noise for some years, since many vehicles at present in use have many years of economic life, and, even if modified, are unlikely to comply with community noise criteria. New vehicles could be required to meet very strict limits, but those already in effect overseas set limits of about 85 to 90 dBA - which will only reduce the noise of very large commercial vehicles, or of cars without mufflers, etc.

One way in which logic can be satisfied is to limit the number of vehicles in different situations. Obviously, movement in residential areas should be limited to strictly local traffic, and residential buildings should not be permitted along main highways, railways, or near airports (including approach and take-off paths).

CONCLUSIONS

It is obvious that not all the answers are yet available with regard to people's reactions to noise. However, it is equally obvious that there is a rapidly increasing awareness in the community that a continued increase in ambient noise is deleterious to the quality of the environment. Not only should this increase be halted, but reductions in the existing noise levels are necessary in many urban locations - particularly when these are used for residential purposes and when they are in proximity to airports and highways.

Noise in the community arises from a multitude of individual sources, and in a free society it is difficult to exert sufficient control to produce an immediate significant reduction in noise levels. On the other hand, there are significant economic pressures to retain the status quo of laissez faire.

With each year that passes without effective control of noise the problem intensifies, and although it has been admitted that a dramatic reduction cannot be immediately expected from the proposals for community noise limits, the effect will be cumulative over a number of years.

Many overseas countries have already legislated for community noise control - and most of these have based their criteria on the proposed ISO document. In the words of van Os and van Steenbrugge (9), commenting on their experiences using the Netherlands Annoyance Act "Naturally the final criterion for the acceptability of the situation is not the rating system but the opinion of the neighbourhood. We have in no single case come across a divergence between the result of the rating system and the opinion of neighbours. This leads to the unavoidable conclusion that the system crude as it may be functions very well".

The swift adoption in Australia of the proposed "Noise Assessment with Respect to Annoyance in Residential Areas" code will surely lead to an improvement in the noise environment in our urban communities.

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NOISE, LAW AND ORDER

by

NOEL C. HAWTHORN, F.R.S.H., F.A.I.H.S.

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NOISE, LAW AND ORDER

This paper is intended to cover the existing law relating to control of noise, particularly here in Victoria, giving an outline of the shortcomings and difficulties in its enforcement.

It is also intended to cover the role of the Health Surveyor (Inspector) to whose lot generally falls the investigation of complaints and the finding of a solution, if possible, to the particular problem.

A summary of various complaints received, and incidents, will also be covered, together with a look at future legislation, which incidentally may well be law by the time this paper is presented.

Also, a brief look at the situation in other States, and what Local Authorities are looking for in control measures of noise pollution.

DEFECTS OF AUSTRALIAN LEGISLATION

The main defects are of course lack of uniformity or virtually no existing law, except in a very general sense. Industries with plant in more than one State may have to comply with widely different legislation, or as pointed out above, virtually no control at all.

This diversity of legislation, or lack of it, applies even within a particular State, such as Victoria.

TYPES OF LEGISLATIVE CONTROL

Basically, there are two types of legislative schemes. Both types have appeared from time to time overseas and here in Australia. They can be broadly termed the punitive and the preventative schemes.

(a) Punitive Legislation

This usually is the first type of legislation to appear in any control scheme, and it is the most primitive method of control. It prescribes fines for breaches of set standards or is so general that it is difficult to successfully take a case against the offender. It mainly deals with a limited type of source of emission, mainly industry, and relies on local responsibility for enforcement.

The basic flaw in its construction is that it does not attempt to prevent noise, at its source, only to punish it where and when it is discovered.

(b) Preventative Legislation

on the other hand, could and should be more effective.

Basically, its characteristics are as follows:

A central enforcement and appeal agency, in conjunction with Local Authorities, which allows the appointment of trained technical officers of noise control; scheduled premises which require permits to operate at all; and submission of plans for the repair, alteration or construction of new plant to the agency for approval and periodic inspection of plant by central and local officers. Apart from the list of scheduled premises, all private, i.e. non-industrial or commercial sources of noise pollution, should come within the regulatory powers of the enforcement agency. A flexible structure allows regulations to follow close on the heels of technical advances in measurement and control devices.

Prevention of noise at its source is of primary importance, but, although most Acts have some characteristics of preventative legislation schemes, none are complete and perfect.

Apart from choosing which type of scheme is the most efficient attack on noise emission, the legislators should also investigate what role the common law should play in any control scheme.

THE ROLE OF THE COMMON LAW

It has been suggested that in fact the common law - that law derived from previously decided cases and not founded upon statute, has much to offer as an effective weapon against noise in our community. At the very least it may provide a valuable source of remedies and compensation - in fact it has done so over the years. A number of people have found action at Common Law a successful remedy to their complaint (see Case Law).

(a) Types of Actions

There are four causes of action which are relevant. They are actions for damages due to the negligence of the defendant; damages due to the escape of a dangerous thing from the defendant's property; and the actions for private and public nuisance. A brief description of these actions may help to clarify the role of the common law in this field.

To succeed in an action for damages arising out of the negligent emission of a noise pollutant, the plaintiff must first show that the defendant ought to have foreseen that the plaintiff could be affected by any such emission, etc. For instance, a factory operator would be expected to realise that his employees and neighbours in the immediate vicinity will probably be affected by his activities. The plaintiff must then show that the defendant has in fact acted negligently and, because of this negligence, the plaintiff has suffered damage to his person or his property.

In an action for damages caused by the escape of a dangerous thing, the plaintiff must show that the defendant has brought onto his land something which is not naturally there and which is likely to be dangerous if it escapes. If it has escaped and injured the plaintiff or his property, then he may recover damages whether or not this event was foreseeable by the defendant.

The action of private nuisance is available to a land-holder whose enjoyment of land is diminished by the use to which the defendant puts his own premises. The plaintiff must show that the defendant has measurably spoiled his use and quiet enjoyment of his property and that this has occurred more than once. The court may balance the conflicting interests of the parties in reaching its decision. If it is socially undesirable that the defendant be forced to pay vast sums of compensation, or to close down his operations entirely, then the plaintiff will fail. If the balance of interests is weighed in favour of the plaintiff, and he can show that the nuisance is very likely to recur, then he may be granted an injunction to prevent the defendant from continuing the offensive operations under pain of contempt of court.

In certain circumstances, the Attorney-General may bring an action on behalf of the public at large. This type of nuisance must have affected a wide area and more people than a neighbouring land-holder. In such a case, a private individual who has sustained injuries may sue, although he is not a land-holder and has no proprietary interest which has been damaged. Apart from this situation, however, nuisance is limited to the land-holder himself and does not even extend to members of his family or household.

(b) Assessment of the Common Law Remedies

The significant characteristic of these remedies is that they are designed to compensate rather than prevent. The injunction as a remedy is only a limited exception to this proposition.

The arguments in favour of legislation in addition to the common law are overwhelmingly strong. These actions are obviously inadequate to maintain even the present standard. They have developed in circumstances which were alien to the present day urban environment and were never remotely contemplated as being an effective noise control measure. They cannot take effect until the damage has been done. Practically speaking, relatively few people in the community are clearly aware of their rights, and even fewer ever attempt to enforce them. This apathy is probably due to a large extent to the well-known expense and delay involved in court actions, and an innate Australian prejudice against litigation. These facts are magnified in their application by the social reality that in large and long-established cities like Melbourne and Sydney, part only of the community is severely affected by industrial noise. This part is likely to be poorer, less well-educated, and consequently even more suspicious of the law and its supposed traps than any other definable part of the urban community. Some of this disinclination to rely on the law to set right their grievances is justified.

For these reasons the common law alone may afford insufficient protection to the community, although it is considered that more use could be made of Common Law.

It would be short-sighted to ignore the common law when framing a legislative scheme to combat noise. The remedies referred to have some advantages over existing Australian legislation. They are developed methods of compensation in a field where the statutory provisions have been limited to prescribing and enforcing emission standards. <u>They are not limited to industrial or commercial sources, but are available against any offender.</u> A streamlined procedural system could make these common law actions an effective additional weapon against noise. An intensive campaign to educate the public as to their rights and the threat posed by all sources of emission, is necessary. Balance between the statutory scheme and the common law should be achieved for an efficient approach. It should be a defence at common law to show that prescribed standards have not been exceeded, and on the other hand, the help and facilities of local officers should be at the disposal of prospective litigants who need measurements of the noise emitted, and other evidence. The policy of the legislature should be to incorporate the common law with the general framework of the statutory scheme. A scheme which ignores the existence of the common law will be less efficient than one which does not.

Report from Adelaide, 9th October, 1970 -

"Age" - "A couple in the Adelaide seaside suburb of Marino are trying legally to stop 84 Sea Scouts and Cubs from making a noise.

Mr. and Mrs. K. Metanomski have taken out a S.A. Supreme

Court writ against the Australian Boy Scouts Association (South Australian branch).

The writ does not call for the association to cease using the scout hall next to the Metanomskis' house, but merely to stop causing a nuisance by noise and vibration.

The Marion Sea Scouts are afraid the writ will mean they will have to find another hall."

(c) Other Factors

While factors of law and government are essential in framing legislation, there are other areas of study which are necessarily involved in producing an efficient scheme to combat noise. Economics, sociology, architecture, acoustics and town and regional planning are the most obvious of these.

Allied to these economic and technical factors is the psychologically important need for increased public awareness. Noise pollution is a relatively insidious invasion of rights. It does not always have the startling flamboyance of other causes of public outcry, such as air and water pollution or transport inadequacies.

VICTORIAN LAW

The main Acts which deal with noise control are:-

Health Act, Local Government Act, Town and Country Planning Act and Motor Car Act.

(1) Health Act

The control of noise comes under the Nuisance Sections of the Act -

"Any condition whatever which is a nuisance or dangerous to health or offensive".

At first, this would appear to give an effective answer, but in practice, it is not an easy matter to prove; in any case the penalty is so low at a maximum of $40.00 that it is not worth the trouble and expense in taking an involved case.

There is also power under the Act to make regulations covering "the prevention of the use of steam whistles or like appliances at factories or other premises so as to be a nuisance", and further, "the prevention and abatement of nuisances (whether specified in this Act or not)".

The Commission of Public Health have been asked on many occasions to implement this power, but have failed to do so. It is a great pity that suitable regulations laying down acceptable standards have not eventuated under these provisions. This power could cover common law nuisances and give effective control.

(2) Local Government Act.

The control of noise under this Act comes under two provisions:-

(a) Section 197 - power to make By-laws.
(b) 15th Schedule, control.

(a) By-Laws

A Council can make By-Laws covering -

1. Regulation or controlling premises to prevent objectionable noises at unreasonable times.

2. Use of loud speakers, noisy brakes, etc., and to minimize noises in a public place.

3. Use of loud speakers by shopkeepers to attract people passing by.

4. Suppressing nuisances.

(b) 15th Schedule

Provides control of noises in a public library, museum, etc., loud talking and other unnecessary noises, etc.

It is obvious that there is limited control, and at first glance it may appear that the By-Law controlling or regulating premises with a view to preventing objectionable noises and unreasonable times, is all that one requires.

However, each case has to be taken on its merits. What is, in fact, an objectionable noise and an unreasonable hour is for the Court to decide.

(3) Town and Country Planning Act

This Act provides in a general sense some control in that in the issuing of permits, consideration is given to the amenity of the locality by laying down conditions including the emission of noise, which should not prejudicially affect the area.

(4) Motor Car Act

Section 83. "Where any motor car on any highway emits, except from some accidental or temporary cause, any offensive noise as to be an annoyance or danger to the public, the owner ... shall be guilty of an offence."

There are inherent difficulties in enforcement of this section. However, despite these, it is considered that, unfortunately, action is not taken as often as it could be.

TYPE OF COMPLAINT RECEIVED BY LOCAL HEALTH SURVEYOR

Barking dogs, howling cats, screeching cockatoos, pigeons cooing, crowing roosters, hammering late at night, blaring wireless, working on steel-hulled boat, musicians, drummers amplified, buzz saws and woodworking hobbies. Dairies - milk cans early in the morning. Whistles, loud speakers in factories calling to 'phone, etc. Escape of steam, dredge buckets, motor mowers, shunting in railway yards, bulk loading and unloading of flour by air compression. Blasting at quarries, refrigerator motors on outside walls, slamming car doors after a wild party. Public halls, church bells and carillon, domestic arguments.

ROLE OF HEALTH SURVEYOR

Generally, he is the first to whom complaints are made, at a local level, and is usually expected to perform miracles, particularly with arguments between neighbours. However, he is trained to inspect and investigate, to gather all relevant information or evidence for Court action, and most importantly, to evaluate the situation.

He, therefore, knows his limitations and readily refers to various experts, if necessary. Briefly, his role could be summed up as the eyes, ears and the right arm of Local Authorities.

In England, the control of noise and enforcement of standards comes under the Public Health Inspector.

A similar situation applies here in Australia, except of course, as already pointed out, that our legislation is woefully lacking and out of date.

FUTURE LEGISLATION

All States are looking at this matter, and here in Victoria a new Act, entitled the Environment Protection Act, will most likely be law by the time this paper is presented.

This proposed Act provides as follows:-

"Part VIII - Control of Noise.

46. The emission of noise shall at all times be in accordance with State environment protection policy specifying acceptable conditions for emitting noise and shall comply with any standards or limitations prescribed therefor under this Act.

47. No person shall emit or cause or suffer to be emitted noise greater in volume, intensity, or quality than the levels prescribed for tolerable noise without first obtaining a licence under this Act.

48. (1) Any person who emits or causes or suffers to be emitted objectionable noise within the meaning of the regulations shall be guilty of an offence.

(2) Any person who without a licence or contrary to any condition, limitation, or restriction to which a licence under this Act is subject emits or causes or suffers to be emitted noise that is greater in volume, intensity, or quality than the standard fixed by the regulations for the emission of noise which is tolerable noise in the circumstances shall be guilty of an offence.

(3) Any person who is guilty of any offence against any of the provisions of this section shall be liable to a penalty of not more than $5,000 and in the case of a continuing offence to a daily penalty of not more than $2,000 for each day the offence continues after conviction or after service by the Authority or a protection agency on the defendant of notice of contravention of the provisions of this section (whichever is the earlier)."

These provisions are far reaching, and it is understood that Western Australia has recently passed a similar Act with practically the same provisions regarding noise control.

South Australia has a special committee dealing with this matter and it is anticipated that similar legislation will be enacted there.

It may be of interest to note that the State Electricity Commission of Victoria has set up internally a special committee to deal with all aspects of noise throughout all their departments and activities.

" A number of authors have, from time to time, described noise as the unseen enemy. Noise is, unfortunately, the symphony of the machine age and likely to be a permanent part of our life. But it should be controlled and conducted as an orchestra and not run wild. It is sad to have to say that the public in general are not conscious of noise. Sections affected by it are very conscious of the problem but the majority, whom noise does not affect, do not recognise it as the problem it is.

Social noise is often unthinking noise. One which causes some irritation is church bells. One could not imagine that 30 or 40 years ago church bells would cause nuisance but now there are complaints because we are no longer a church-going society. Homes are now noisier through radios, record players, spin dryers which shatter wash day silence, motor mowers and now the man who tests his outboard motor in the rain water tub. Try a metal oil drum, filled with rain water with a 12 h.p. outboard motor lashed on to it, and you certainly have some noise."

Finally, Local Authorities are looking for acceptable standards of noise emission to be laid down, such standards to be readily and easily enforced. But above all, acceptance by everyone that excessive noise is not necessarily part and parcel of our modern environment, nor an adjunct to progress.

NOISE AND THE LAW

by

B.S. O'Keefe

BARRISTER, SYDNEY.

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NOISE AND THE LAW

Definition of terms:

1. Noise:

Mere sound itself is not sufficient. Noise has been judicially defined as "volume amounting to loudness" (Leslie v City of Essendon (1952 V.L.R. 222 at 231-232). Such a definition is, however, not sufficient for our present purposes because the extent of the loudness must be defined. For our purposes the extent of the loudness must be such that it results in "personal inconvenience and interference with one's enjoyment, one's quiet ... something that discomposes or injuriously affects the senses or the nerves" (St. Helen's Smelting Co. v Tipping (1865) 11 H.L.C. 642). It must materially interfere with "the ordinary physical comfort of human existence not merely according to elegant or dainty modes of living but according to plain and sober and simple notions obtaining amongst English people". (Vanderpitte v Mayfair Hotel Co. (1931) C.H. 138).

2. Nuisance:

The word "nuisance" itself is capable of multiple meanings both colloquially and legally.

Colloquially:

Nuisance may amount to nothing more than a mere annoyance to an individual and then only because of the peculiar and particular sensibilities of that particular individual.

Legally:

Sometimes "nuisance" is used to describe an activity or condition which is harmful or annoying. For example, a rubbish heap is a nuisance. At other times "nuisance" may be used to connote a legal liability. At other times the term is applied to the resultant harm flowing from an activity or condition. From the legal viewpoint this usage is to be preferred because "nuisance" is concerned primarily with results and effects rather than with conduct in the abstract sense.

In law "nuisance" may be classified as either:

(a) public, or

(b) private.

Public Nuisance:

A public or common nuisance is a criminal offence which covers a whole host of interferences with the rights of the public at large and it has been defined as "an act not warranted by law or an omission to discharge a legal duty which act or omission obstructs or causes inconvenience or damage to the public in the exercise of rights common to all her Majesty's subjects". (Stevens Digest of Criminal Law Article 235). Examples of public nuisance include the keeping of a common gaming house or a disorderly house or a brothel; selling impure foods; obstructing the highway or making it dangerous for traffic.

Public and private nuisance are not two species of the same genus. A public nuisance comes within the law relating private rights and liabilities (in this case the law of torts) when and only when it can be shown by some person that some particular or special damage has resulted to him beyond that suffered by the rest of the community. In 1535 Fitzherbert J. expressed the need for some special damage as "greater hurt or inconvenience than everyman had (Year Book 27 Henry VIII S. 27). Where this requirement is fulfilled the law of public nuisance affords a private right of action although no rights or privileges in respect of land of the aggrieved person have been invaded.

As to the remedies for public nuisance see later.

Private Nuisance:

The law of private nuisance is concerned with the protection of the rights which flow from some interest in land by giving a remedy in respect of interference with an occupier's interest in the use of his land. The interest protected includes not only the right to the actual use of the soil or land as such for any purpose but also the right to the pleasure, comfort and enjoyment that a person might normally be expected to derive from the occupancy of land.

The philosophy of the law of nuisance is to be seen in the well known maxim: sic utere tuo ut alienum non laedas. This branch of the law is concerned with maintaining a balance on the one hand between the right of an occupier to do what he likes with his own land and the right of his neighbour not to be interfered with in the enjoyment of his land on the other. (Sedleigh-Denfield v O'Callaghan (1940) A.C. 880 at 903). As a result it is concerned commonly with conflicts of interests between neighbouring land occupiers and the objects of this branch of the law is to adjust the respective rights and privileges of these neighbours.

Private nuisance may be said to have been committed when one person is responsible for an act or omission indirectly causing physical injury to land or substantially interfering with the use or enjoyment of land or an interest in land where in the light of all the surrounding circumstances this injury or interference can be said to be unreasonable.

Interest in land:

Only persons in actual possession of land are able to sue in nuisance for some interference with its present use and enjoyment. Possession of land in this sense includes not only the actual owners of the land but tenants in possession and even persons who are wrongfully in occupation of land. This rule operates with curious results at times. (See Malone v Laskey (1907) 2 K.B. 141) where a cistern, because of vibrations emanating from adjoining premises, fell and injured the wife of the occupier of neighbouring premises and it was held that she could not recover because she had neither a proprietary nor a possessory interest in the premises.

Physical Injury:

Sufficient invation of the interest of a land holder is established if he proves that his property or the activities conducted on it have suffered some sensible material injury which is not merely trifling in its nature and that diminution in the value of the property results.

It is a material injury to this sense if science can show some delaterious physical change in the property or in its proper enjoyment. (Gaunt v Fynney (1872) 8 Ch. 8 at 12) and sensible in this sense means no more than able to be perceived, e.g. shrubs die, windows break.

Substantial interference with enjoyment:

Where interference with enjoyment of land is relied upon as founding the action then it must be shown that it is substantial. No injury to health need be proved and it has been held (Andrea v Selfridge & Co. Ltd. (1938) Ch. 1) that the loss of even one night's sleep through excessive noise is not trivial. In this sense it is clear that an interference with enjoyment may be substantial though only temporary in duration.

Unreasonable:

"Unreasonableness" in the use of property is determined primarily by the character and extent of the harm in fact caused rather than that it was forseeable. A man may be liable for nuisance regardless of whether he could have reasonably anticipated the harmful consequences of the activities being pursued by him.

A balance has to be maintained between the right of the occupier of one parcel of land and the right of his neighbour.

Abnormal sensitivity and contract:

No action will lie for a nuisance in respect of damage which even though substantial is due solely to the fact that the Plaintiff is abnormally sensitive or uses his land for some purpose which requires exceptional freedom from any disturbing influences. Every person is entitled to do on his land anything that does not interfere with another person in the ordinary enjoyment of life or the ordinary modes of using property. Extraordinary and special requirements are not protected by the law of nuisance. If a man is peculiarly sensitive to noise either in his person or in his business so that he is prevented from working or sleeping by noises which would not injuriously affect other and ordinary persons, he indeed suffers substantial damage but his damage is not actionable as nuisance. Thus it has been said that a man cannot increase the liability of his neighbour by applying his own property to special uses whether for business or pleasure (Eastern & South African Telegraph Co. v Capetown Tramways (1902) A.C. 381) - c.f. Hollywood Silver Fox Farm v Emmett (infra).

Conduct of the defendant:

The law in judging what constitutes a nuisance takes into consideration the main object of the defendant's activity. In Hollywood Silver Fox Farm v Emmett ((1936) 2 K.B. 468) the Court held that the firing of guns out of spite against the plaintiff with the object of interfering with the breeding of silver foxes by him was actionable.

Thus it has been said that conduct has no socially valuable purpose when it is motivated by spite and when determining whether or not the balance is to be found in favour of one party or the other in the course of adjusting the rights of adjoining land holders, it is relevant to determine whether or not the act complained of was socially worthwhile or not. Hence the question af whether or not the conduct complained of is malicious, is relevant. As a general rule it can be said the more socially worthwhile the activity is the less likely it is to be held unreasonable for whilst it is probably not absolutely necessary that the country have motor cycle speedway tracks or race courses the need for power stations, factories and smelting works is obvious - but see later as to a restriction on this approach.

Defences:

1. Legislative authority.

2. (Prescription (but quaere - not for noise).

3. Agreement of neighbours.

Ineffectual defences:

1. Coming to the nuisance. It is now settled that it is no defence that the Plaintiff came to the nuisance. It was once thought that a person could not complain of a nuisance if with full knowledge of its existence he chose to become the owner or occupier of the land effected by it (noisy factory for example) but this has now, however, been held not to be the law.

2. Public benefit. It is no defence that the nuisance complained of although harmful to an individual plaintiff is beneficial to the public as a whole. Once a nuisance is established no consideration of public utility can be allowed to deprive an individual of the legal rights without compensation (Shelfer v City of London Electric Lighting Co. (1895) 1 Ch. at 316) and so it is clear that it is no defence that the nuisance results inevitably from some activity beneficial in a community sense.

3. Suitable place. It is no defence that the place from which the nuisance emanates is one which is suitable for the purpose of carrying out the activity or operation which gives rise to the complaint or that there is no other place available in which a diminished nuisance would result. If a place cannot be found where a particular activity will not cause a nuisance then it cannot be carried on at all except with the agreement of the adjoining proprietors or under some legislative protection which may be conferred by a scheme of town planning which sets aside particular areas for particular and perhaps noxious activities. So in deciding whether an interference is unreasonable, not only the usefulness of the act but also the locality in which the activity is being carried on must be considered. To operate a factory in a zoned residential area may well be unreasonable whereas the same activity might be lawful in a zoned industrial area. For example the noise of horses or machinery in a residential area may well be unreasonable whereas the crying of babies would probably not be (compare Ball v Ray (1873) 8 Ch. at 467 with Moy v Stoop (1909) 25 T.L.R. 262.

In deciding whether an action lies because of industrial interference the Courts have often taken account of the fact that the act complained of took place within a residential area. In Sturges v Bridgeman (1879 (11 C.H.D. 852) it was held material to the success in a nuisance action by a Physician who complained that his professional work was interfered with by industrial machinery that the locality in which the physician's rooms were situated was one in which many medical men practised.

4. Care and skill:

Nuisance is not a branch of the law of negligence and it is not necessary to prove negligence in the course of establishing a right arising out of an alleged nuisance. It is no defence that all possible care and skill have been used to prevent the operations complained of from amounting to a nuisance although the exercise of reasonable care to prevent annoyance may be relevant in determining whether a nuisance arising in the course of the ordinary user of land is actionable. i.e. on an objective test.

5. Contributory acts of others:

It is no defence that the act of the defendant would not amount to nuisance unless some other person acting independently of him did the same thing at the same time (example: many factories emitting smoke).

Examples of noises held to be nuisances:

Chapel Bells - Soltan v De Held (1951) 21 L.J. Ch. 153

Trade Machinery - Crump v Lambert (1867) L.R. 3 E 9 409

Dancing above other premises - Jenkins v Jackson (1888) 40 Ch. D.71

Whistling for cabs late at night - Bellamy v Wells (1890) 60 L.J. Ch. 156

Playing musical instruments and singing - Christie v Darcy (1893) 1 Ch. 312

Crowing of cocks - Ruthring v Ferguson (1929) S.S.R. (Q) 323

Refrigerating machinery in butchers shop - Randwick M.C. v Henderson 10 L.G.R. 18

Building work - Andrea v Selfridge (1938) Ch. 1

Central heating motor - Metropolitan Properties v Jones (1939) 2 A.E.R. 202

Lift doors banging - Newman v Real Estate Debenture Corp. (1940) 1 A.E.R. 131

Quarrying - Farley & Lewers ats Hornsby 78 W.N. (N.S.W.) 936

Remedies for nuisance:

1. Criminal prosecution (in the case of public nuisance only)

2. Abatement

3. Injunction

4. Action for damages.

1. Criminal prosecution: This is instituted by the Attorney-General.

2. Abatement: The right of abating a nuisance by self help is of ancient origin. Abatement, like most other forms of extrajudicial redress, has fallen out of favour with the increasing claim to legal control through the Courts. In many respects abatement resembles the right of forcibly resisting trespass either to person or to lands. The right of abatement is not confined to cases where the condition complained of can be removed from the land of the party complaining, but also justifies entry upon the land of another and the use of reasonable force in order to accomplish the desired object. However, care must be taken not to inflict unnecessary damage and where there are two ways of abating a nuisance the less detrimental must be adopted unless it would injure an innocent third party or the public and it seems that there is no privilege of entry and abatement unless a mandatory injunction could have been obtained, because otherwise a man might be able to gain a remedy by self help which would be denied to him if he had recourse to ordinary judicial remedies. Thus when the damage involved in terminating a nuisance is wholly disproportionate to the threatened harm the right of abatement may not be able to be exercised.

Abatement is only open to those who may complain of the offending condition as a nuisance. In the case of private nuisance that means the occupier and perhaps anyone acting on his behalf and by his authority. If the nuisance is a public one a private individual cannot abate it unless it does him some particular injury. A traveller on the highway is permitted to remove an obstruction but must not interfere with it beyond what is necessary to exercise his right of passage and he cannot justify his act if by avoiding the obstruction he may have passed on with reasonable convenience. This privilege is a means of redress alternative to damage so that once the nuisance has been abated the abator is precluded from pursuing his action for damages. This is a strong deterrent to its exercise since it involves loss of the right to compensation for any injury that one has suffered. (Laggan Navigation Co. v Lambeg Bleaching Co. (1927) A.C. 226).

3. Injunction: Equitable relief by injunction can be traced back to at least 1584. In general the Court is guided by the same principles in dealing with claims relating to nuisance as are ordinarily applied to the granting or refusing of injunctions. Hence, it must appear that damages would not afford an adequate remedy but this requirement is easily satisfied particularly where there is likely to be a repetition of the wrong. Where however the nuisance is not a continuing one, or the defendant does not claim a right to persist in his conduct,the grant of an injunction is conditional on proof of substantial injury. If it is only temporary or minor the plaintiff will be relegated to his remedy in damages. However, the equitable remedy extends even to a situation where although damage has not been actually suffered there is a strong probability that the apprehended nuisance will in fact arise or that the eminent damage if it materialises will be irreparable.

4. Damages: If the wrongful act is complete damages must be awarded once and for all and no further claim can be advanced with respect to further loss subsequently accruing from the same act. However, in the case of a continuing nuisance a new cause of action arises from day to day. Worse still on personal relations.

Contractual rights and obligations:

Persons whose sensibilities or activities require particular or special freedom from noise may obtain rights by contractual arrangements or by convenants in leases of the premises in which they may be or in which they may conduct their noise sensitive activities or they may place covenants relating to the use of particular parcels of land on such land before alienation.

The role of curial intervention in noise nuisance:

In most cases of nuisance, the decisive factor in determining whether or not the interference complained of is actionable is the gravity of the harm accruing to the complainant. Such harm is to be measured partly by the character and partly by the duration of the harm or injury involved. It has been said (Gaunt v Fynney supra) that "a nuisance by noise is emphatically a question of degree. If my neighbour builds a house against a party, next to my own, and I hear through the wall more than is agreeable to me of the sounds from his nursery or his music room, it does not follow (even if I am nervously sensitive or in infirm health) that I can bring an action or obtain an injunction. Such things, to offend against the law, must be done in a manner which, beyond fair controversy, ought to be regarded as acceptive and unreasonable" (at 12 per Lord Selborne L.C.) No one can claim the laws assistance to cut a swath of silence around him and object to his neighbours making sounds whether domestic, social or industrial. The essence of the law's role is to rationalise competing claims. In so doing the Courts have, in fact, embarked upon what is akin to judicial zoning, even though not aided to any real extent in this regard by the legislature. In the course of such judicial zoning the Courts have given more weight to the demands of a stable society and have declined to recognise what is claimed by some to be the greater good which springs from "progress". However, the really delicate problems of judicial zoning and adjustment of competing claims arise in localities which are in a state of transformation. In areas where the industrial or residential character of the area is well established, the Courts approach the task on the basis that it is relatively easy to determine the appropriate standard of silence or other comfort to which an occupier of land is entitled. Thus the noises that one expects to put up with in Woolloomooloo are distinctly different from those which one would expect at Point Piper or Vaucluse or Mosman, whilst the degree of silence and delicacy of environment that one is entitled to expect at Fitzroy differs significantly from that which one might expect at Toorak or at Ferntree Gully.

Although the Courts have embarked on the task of rationalising competing claims to use land it is significant that in New South Wales until recent times technical evidence as to the sound pressure levels emanating from a particular noise source was seldom used. The tendency to use such evidence is growing, because it is difficult to determine without the assistance of such evidence whether or not the subjective reaction of the person complaining (be he a plaintiff or a witness in public nuisance proceedings) is that of a person of abnormal sensibility. Thus what one witness will describe as an "intolerable noise", a "booming noise", an "incessant clatter" may to another person (even assuming such person not to be suffering from presbycusis or some other hearing defect) be not objectionable at all. Unless and until the Courts can be assisted by evidence of reasonably widely accepted standards which can be clearly expressed and are able to be understood by the reasonably intelligent layman (in the sound engineering sense) uncertainty of result in litigation and hence inadequacy and uncertainty of control of noise must persist.

Within the Common Law there must be a two-way traffic if noise problems are to be controlled effectively. The law must be prepared to adapt and to accept, in given cases, criteria that are more definite than "volume amounting to loudness".

Legislative control of noise:

No sophisticated legislative control of noise has, to date, been undertaken in Australia. The controls implemented in New South Wales and Victoria to date are few in number and limited in scope.

1. New South Wales

Section 289 of the Local Government Act, 1919 (as amended) provides that a local Council shall have power:

(c) - to control and regulate the use of premises so as to prevent objectionable noises thereon or noises thereon at reasonable hours;

(d) - to control and regulate noises on or near any public place and in particular to control noises from the exhaust gas of internal combustion engines other than the engines of motor vehicles.

The decision of Richardson J. in Williams v Storey (1957) (2 L.G.R.A. 266) assimilates the first part of s. 289(c) to the law of nuisance.

Clause 13 of Ordinance 39 under the Local Government Act, 1919 (as amended) gives a local Council power to control the noise emitted by internal combustion engines and power to prohibit their use between the hours of 9.00 p.m. and 6.00 a.m.

Ordinance 36 gives power to a particular Council to control the noises emanating from a coal handling depot.

2. Victoria:

The Local Government Act, 1928 Section 197(1)(xxix) enables Councils to control noise in public places and Section 197(1)(x) enables Councils to make by-laws "for suppressing nuisances".

The Health Act, Motor Car Act and Town and Country Planning Legislation also touch on the subject.

No in-depth studies appear to have been undertaken by legislatures in Australia in respect of noise problems, other than in relation to aircraft noise and this study appears to an outsider, at least, to have been characterised by a determined effort on the part of aircraft operators to extend hours of operation rather than to attempt to seek technical solutions to the problems of noise created by the industry.

Before effective legislative action can be taken, proper and adequate information in clear form must be available from those who have expertise in noise control and elimination as to levels which are acceptable within given environments. I would not however advocate that statutory provisions should derogate from the Common Law rather should it supplement and aid it. The Common Law, for all its imperfections, has an amazing way of adapting to changing circumstances. It is true that lawyers are conservative and that the law mirrors the conservatism of those who practise and apply it. However, it would appear that the ability of the Common Law to change and to adapt to the needs of a changing society and environment is greater than the ability or willingness of a legislature to bring about change. In all States of Australia the number of statutes which have been on the statute books since the turn of the century and which remain substantially unrevised is staggering. Now our society is beginning to recognise more and more the right of the individual to live in an environment that is decent. It is true that this growing realisation has been brought about largely at the cost of segregation of the environment in which we live. However, lawyers and the law recognise the cry for help of the society and I have no doubt that whether or not legislative action is taken to control noise levels as part of environmental control the law will recognise that individuals are entitled to live in an environment which is free from the irritating debilitating and even injurious effects of noise. To be effective and relevant, however, the law needs assistance from those who, like yourselves, are skilled in this particular branch of science.

NOISE ZONING IN INDUSTRY

by

R.B. RANDALL, B.Tech., M.I.E., Aust.

Presented to the Australian Noise-
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NOISE ZONING IN INDUSTRY

1. INTRODUCTION

Although the title of my talk is 'Noise Zoning in Industry', I feel it is worth expanding the scope a little to at least touch on the zoning of land around an industrial undertaking such as a large chemical complex. Although I expect that this will be discussed in other papers such as those on Town Planning and Land Usage, I would like to give an example of the way in which poor planning and lack of proper zoning has given rise to higher costs of noise reduction than would otherwise have been necessary.

I am also using the term 'Noise Zoning' fairly broadly to cover not only classification of fixed layouts, but also the modification of plant layouts at the design stage; in short, all the things which can be done to minimize or even eliminate the need for noise reduction of individual items of equipment. This modification of layout for acoustic reasons can be done at several levels; firstly in the arrangement of various plants on a site, then in the layout of each plant, and finally in the detailed layout of localised areas within the plant.

2. ZONING PROBLEMS AROUND ICIANZ BOTANY SITE

The background to the problems at ICIANZ Botany Site is very well summarized in a paper entitled 'Pollution Control in a Chemical Complex' by R.W.G. Hessey, which was delivered at the ANZAAS Congress in Adelaide in August, 1969, and from which I quote,

> "A feature of the location is its proximity to a recently constructed high rise residential area. For many years after production commenced in 1942 there were few residences close to the boundary and the surrounding area was thinly populated, being zoned as 'industrial' by the County Planning Authority. As late as 1962 when the site was already well developed as a chemical complex, land immediately adjacent was re-classified as residential and there are now houses within 60 ft. of the boundary and multi-storey appartment buildings within 500 ft. As was mentioned by the President of the Clean Air Society of Australia and New Zealand in his closing address to the 1969 Clean Air Conference, this is regarded by many as a classic example of poor urban planning."

This has contributed in no small measure to the necessity of exercising very stringent noise control measures within the plants in order to reduce noise at the site boundary to acceptable levels. The cost of these noise measures since 1965 has been approximately $1/4 million dollars, which certainly could have been reduced considerably if a buffer zone of say light industry had been provided around the site. And of course non-productive costs such as those involved in noise control, although very necessary in the present circumstances, eventually must manifest themselves as a cost to the community as a whole, as well as reducing our competitiveness in the international market. Even though we now attempt to incorporate noise control measures into new plants and extensions at the design stage, the initial poor planning will continue to make necessary the expenditure of many thousands of dollars for the whole life of the site.

This is not intended as a criticism of the people who made the planning decisions, since as little as ten years ago, very few people took noise into account in long-term planning. It is hoped, however, that it will help to avoid repetition of the same mistakes.

3. NOISE ZONING OVER THE WHOLE SITE

The site was originally laid out before noise problems were generally accepted as a design factor and so to a certain extent the situation has been aggravated by the proximity of certain Factories to sensitive residential boundaries. Since noise problems were first encountered, however, in the early 1960's, quite a deal has been done to rectify this situation, primarily through the setting up of an acoustic design section, and the employment of noise consultants.

The stage has now been reached where it has been written into the Project Design Manual that acoustics should be taken into account at all stages in the siting, layout and design of proposed new plants. The following examples are indicative of what can be done at this initial stage.

Many modern chemical plants are designed with much of their equipment out in the open, and so generally it is desirable to have this type of plant as far as possible from the residential boundaries (and also possibly from main office blocks on the site). On the other hand, relatively low noise producers such as warehouses and office blocks can utilise land close to the boundaries. They can often also be used to shield equipment installed in the open which would otherwise require housing purely for acoustic reasons.

The subject of shielding is one which it is worth pursuing further at this stage, because of its importance in this whole question of Noise Zoning. Although the attenuation which can be achieved by shielding is only of the order of 10 to 15 dB in general, this is quite often a significant reduction in residential noise problems. Fig. 1 (from Ref.1) shows the theoretical attenuation by shielding in terms of 'effective barrier height' and 'angle into shadow', which are defined in the figure. However, in using this graph, account must be taken of two factors. Firstly, since no ground reflection has been allowed for, it is probably wise to reduce the figures by 3 dB, at least where the ground between the noise source and the barrier is paved or otherwise hard. A further factor which is sometimes forgotten, is the possibility of leakage around the ends of a barrier. A way of taking this into account is to determine separately the sound levels resulting at a given location from each of the three paths, i.e. over the top and around each end, and then add the three by decibel addition. Fig. 2 shows a typical example, where the overall attenuation is less by 3 dB than that determined from the path over the top of the barrier only. Thus the overall attenuation provided by a barrier in practice is likely to be less by about 6 dB than that obtained at first glance from Fig. 1.

Another point worth keeping in mind is that a barrier of a given height has maximum effect when close to either the source or receiver. Since the receiver, in the case of a residential area is very widespread, this normally means that the shielding must be as close as possible to the source.

4. NOISE ZONING WITHIN A PARTICULAR SITE

When a plant has been sited, it is still possible to achieve optimum layout of the various sections, so that for example noisy equipment is shielded or placed as far as possible from the nearest residential boundary. Even with fixed internal layouts, as can be the case with standard designs, the plant as a whole can very likely be rotated. This is not to say that acoustical considerations should dominate the siting and layout of a new plant, as long as their importance as an economic factor is recognised and assessed.

5. CLASSIFICATION OF ON-PLANT AREAS

Coming now to the classification of on-plant areas with respect to noise, the emphasis shifts from residential noise to local noise as the major problem. The situation is complicated by the fact that noise limits now vary over quite a range, being possibly governed by considerations of hearing conservation, or ability to converse, in addition to annoyance.

The problem of hearing conservation introduces the further complication that the allowable limit depends not only on the noise level but also on the time for which individual operators are exposed to it, and this of course can vary with the mode of operation of the plant. Fig. 3 (from Ref. 2) shows the way in which allowable limits vary with the duration and number of exposures to which an individual is subjected. Some people recommend the use of other criteria, such as dBA levels, but the principle is still the same.

One area in which we have encountered this sort of problem is in the specification of allowable noise levels in the Company's Noise Standards. For noise levels below a certain figure, which we take from Ref. 2 as NRN 85, there is no problem in that it is safe for continuous exposure. At the other end of the scale it is possible to mark off certain areas where the noise level is too high even for short term exposure. In between is a grey area, where some discretion must be exercised.

For example, even if a given area requires operator attendance only for say 1/2 hour per day, it does not follow that this area can be zoned to have the allowance for 1/2 hour exposure per day. The same operators may have to service several such areas in the working day. Furthermore, not only plant operators, but also maintenance personnel have to be taken into account. In particular, a greaser for example, is likely to spend his whole day moving from machine to machine which otherwise may not require process operator attendance. Also, minor maintenance may be carried out in situ on one machine while others adjacent are still operating.

Because of the difficulty of incorporating these variables into a general rule, our approach has been to leave the specification of limits for intermediate cases to be considered and decided by the Company in each individual case. Table 1 shows the allowable limits written into the ICIANZ Standard for Turnkey Contracts. The various area classifications are defined as follows:-

(1) Restricted Area

An area with no access for any operation (including plant upsets). Plant Superintendent access possible for inspection only.

(2) Limited Access Area

An area in which access is required for a maximum period of 20 mins. per shift, provided that an individual operator or maintenance fitter will not aggregate more than three Limited Access Area exposures per shift.

(3) On-plant General Areas

Areas in which operating or maintenance personnel are occupied more than two hours per shift, e.g. regular operating areas, areas in which non-routine maintenance is carried out.

(4) On-plant Special Areas

Areas intermediate between classifications (2) and (3) may be classified 'On-plant Special', with an intermediate limit, dependent on the total exposure to which any individual may be subjected. All such areas are to be separately considered and agreed by the Company.

TABLE 1

	Area Classification	Maximum Noise Rating Number
(a)	Restricted Areas	110
(b)	Limited Access Areas	100
(c)	On-plant Special Areas	85 - 100
(d)	On-plant General Areas	85
(e)	Some speech communication required, e.g. workshops, operator cubicles, on-plant amenities	70
(f)	Speech communication essential, e.g. control rooms, canteens, off-plant amenities	60
(g)	Plant offices, laboratories	55

6. PROVISION OF LOW NOISE AREAS

In some cases, for example with compressor rooms, it can be an economic proposition to provide low noise areas for operators to spend the major part of their time, rather than reduce the overall noise level in a large building. By this means, the noise level to which the operator is subjected for the major part of the day can be reduced from say NRN 95 to NRN 80, even with standard partitions and door fittings. Ventilation should preferably be from outside. Even though experienced operators often get to be able to check machine condition largely from its sound, the author can see no reason why they should not become just as adept at interpreting the sound at reduced levels, as long as they are not reduced too far. In any case, the operator would then be able to do regular tours of inspection with no danger to his hearing, from the shorter exposure times.

In very noisy environments, or where a low noise level is to be obtained, e.g. a foreman's office, specially designed acoustic enclosures will be required. Fig. 4 shows such an enclosure, available commercially, which has its own ventilation system incorporated. These have been used with success in power stations and paper mills. One advantage is their portability; they can be moved around with a forklift truck, or even be mounted on wheels.

7. SUMMARY

To summarise, three major aspects of noise zoning in industry have been discussed. The first is the way in which the need for noise control measures can be minimised by paying attention to optimum layout, and application of the principles of shielding. Secondly, problems involved in the classification of on-plant areas, particularly with respect to hearing damage criteria, have been discussed, and finally the provision of low-noise zones as a haven in an otherwise noisy environment has been advocated as an often applicable solution to problems of operator exposure.

It is emphasised that the principles of noise zoning should always be applied at the earliest possible stage in planning, in order to reduce the non-profit earning costs of other noise control measures at a later stage.

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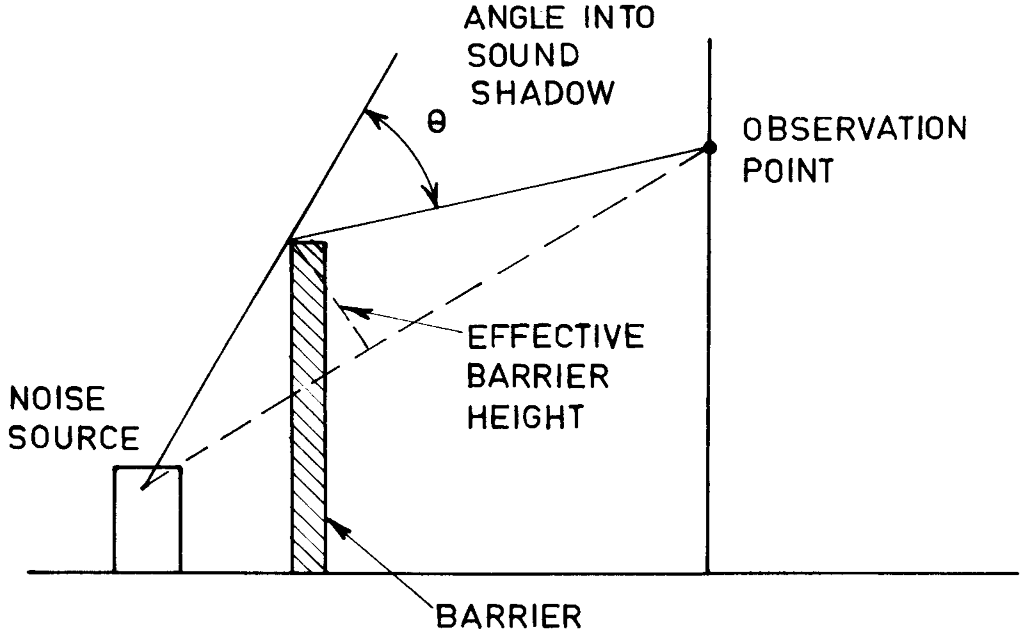
1. C.M. Harris (Ed.) 'Handbook of Noise Control', McGraw-Hill, N.Y., 1957.

2. I.S.O. 'Draft Secretariat Proposal for Noise Rating with Respect to Conservation of Hearing, Speech Communication and Annoyance'. Document 43 (Secretariat - 194) 314.



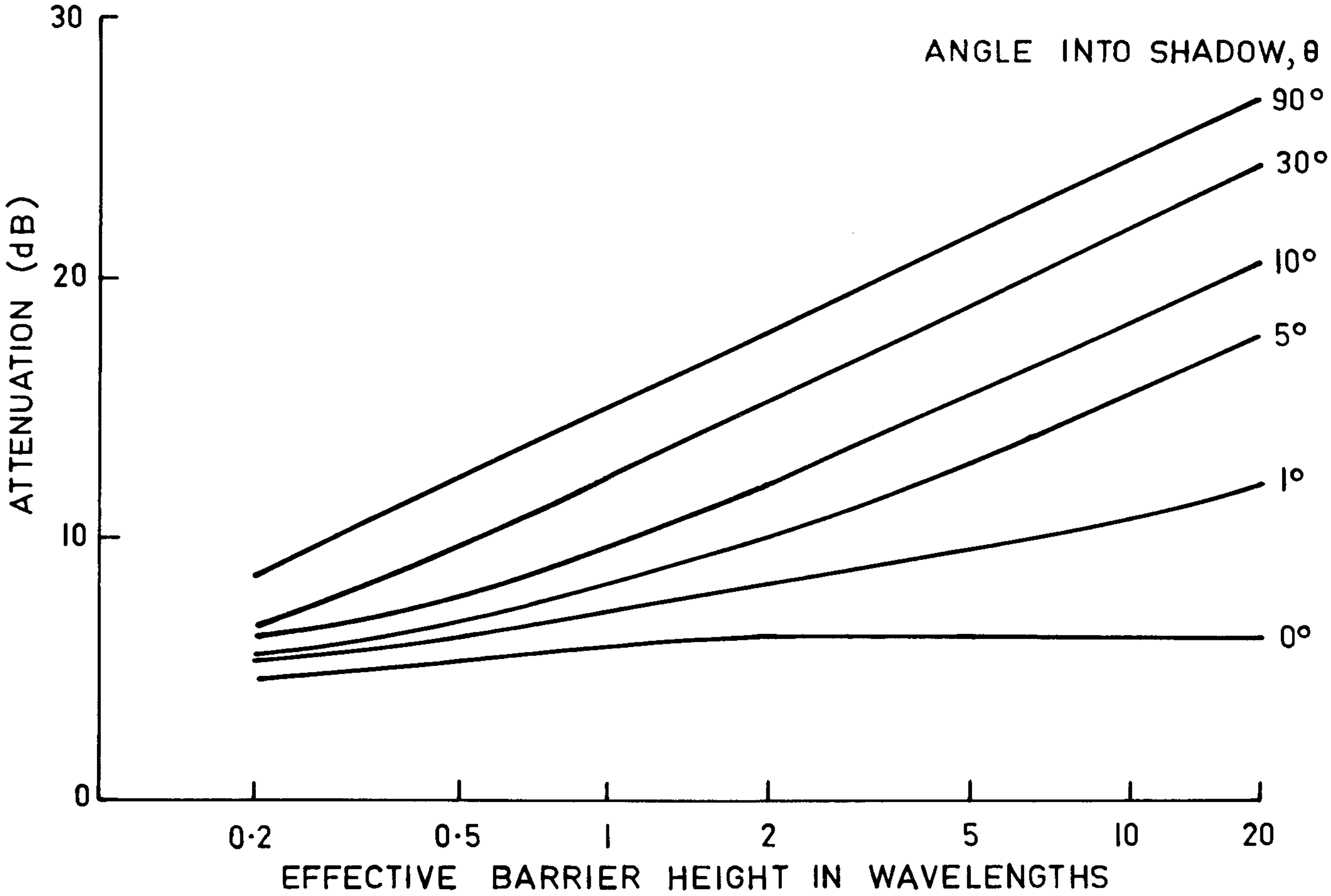


FIG. 1. SHIELDING PROVIDED BY BARRIERS

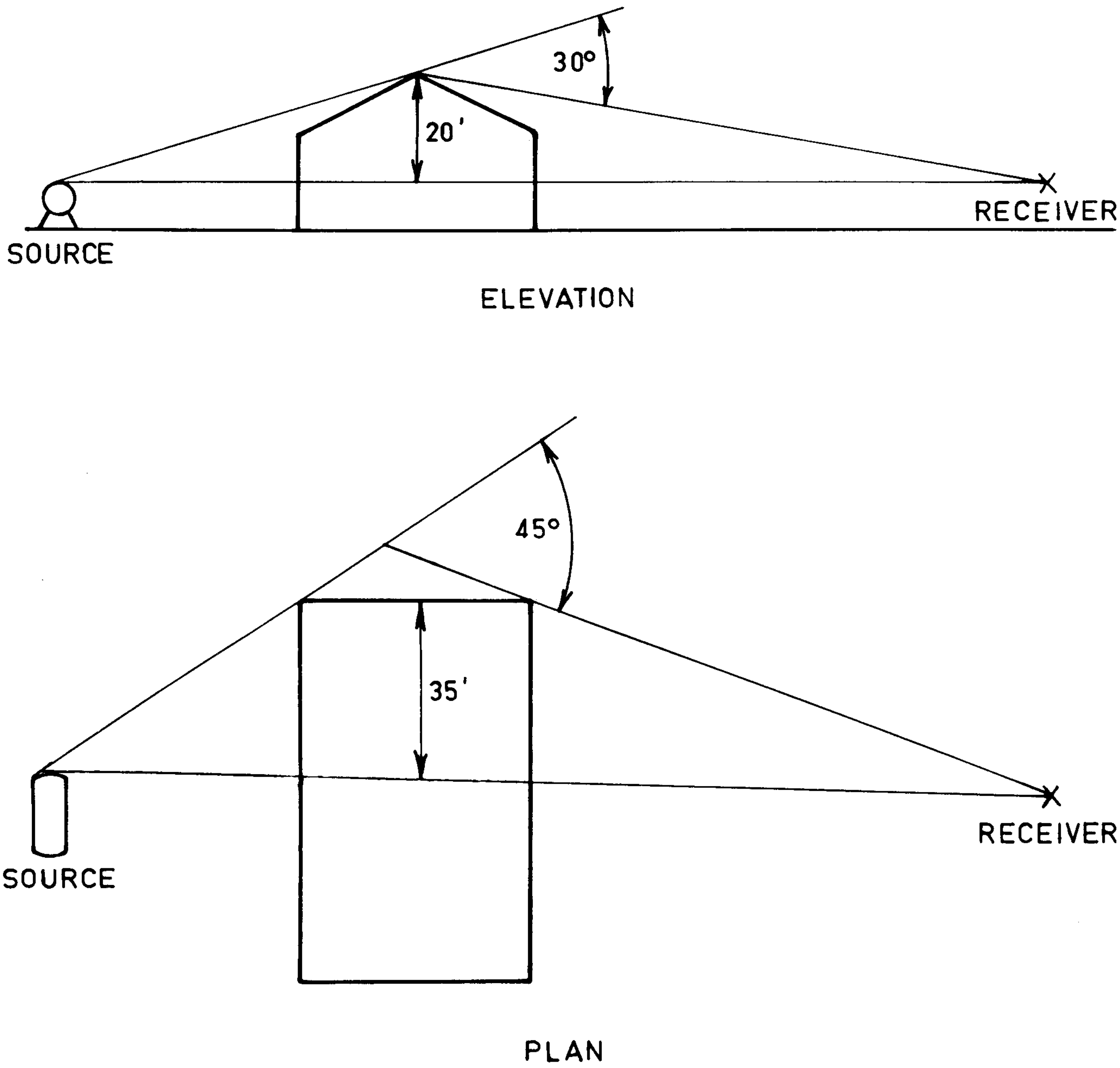


FIG. 2 SOUND LEAKAGE AROUND A BUILDING RESULTING IN 3dB OVERALL REDUCTION IN ATTENUATION

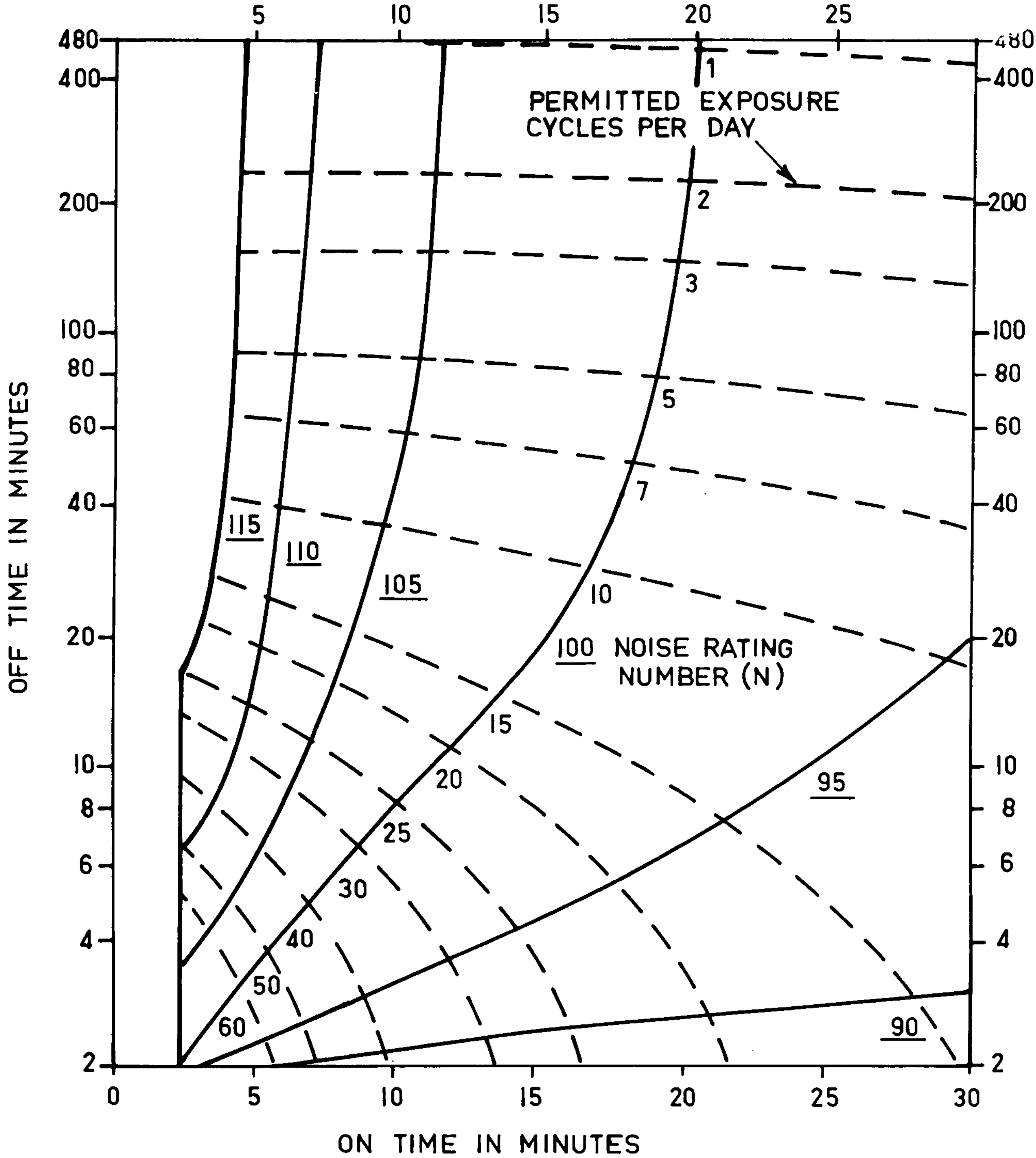


FIG. 3. NOISE RATING NUMBERS FOR INTERMITTANT NOISE EXPOSURE

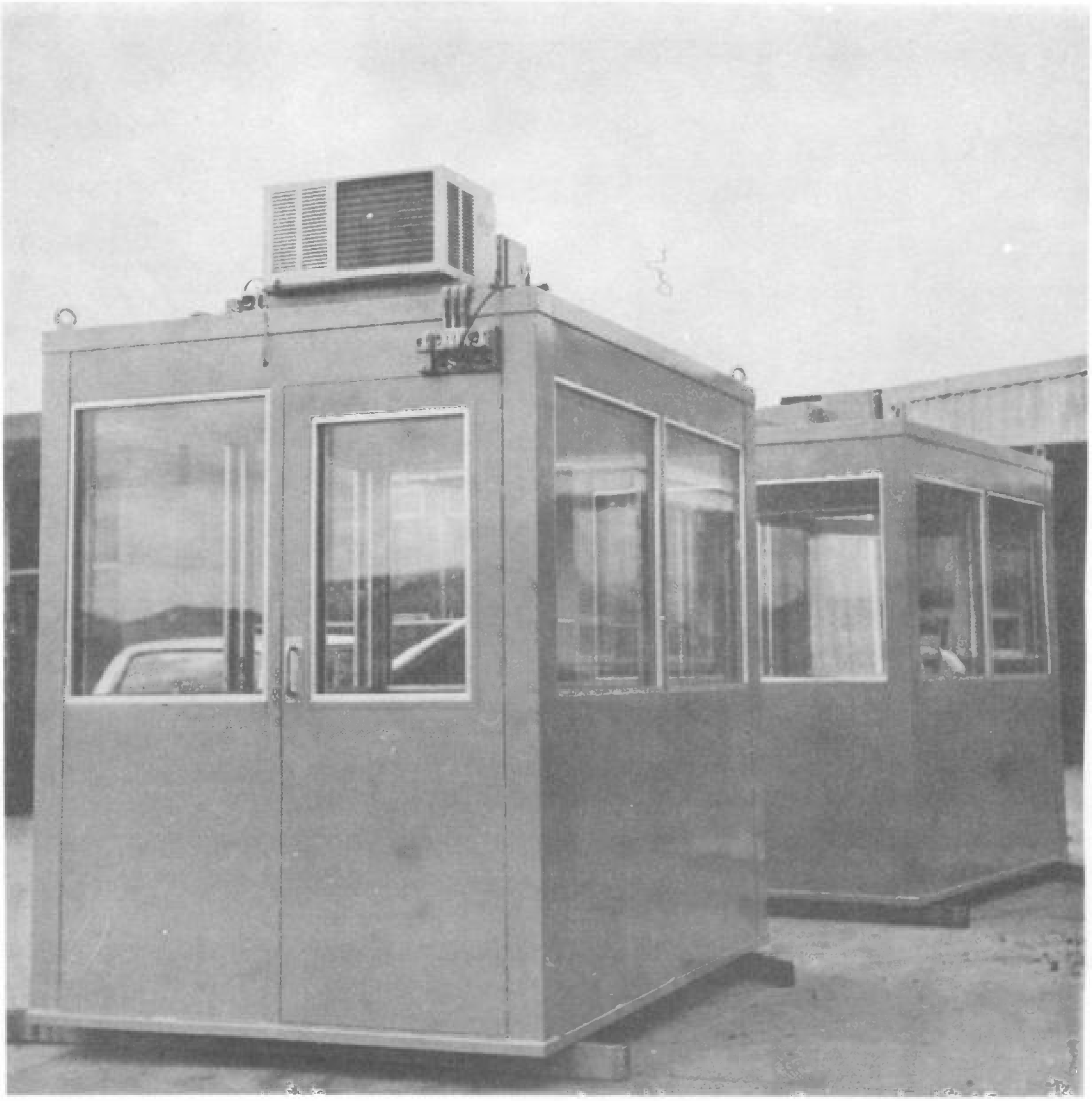


FIG. 4 PORTABLE SOUNDPROOF CUBICLE

NOISE ZONING IN THE INTERNAL ENVIRONMENT

by

PETER R. KNOWLAND

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NOISE ZONING IN THE INTERNAL ENVIRONMENT

Introduction

In any building project, consideration should be given to the acoustic zoning of the internal environment. These considerations will assist in achieving a better quality of living within the means of relatively normal building construction.

A building is a complex enclosure which is required to retain a multitude of related activities, functions and services. Some activities may produce noise, whilst others may require the absence of noise. The operation of most services produces noise and some an unnecessarily high level of noise.

There are two approaches that may be adopted after the noisy and quiet activities have been identified. The first is to simply plan ahead and if a quiet and noisy area coincide, then provide immense acoustic barriers between these areas. The other way is to grade each area acoustically so that areas of extreme noise level are not juxtaposed. The latter technique is of immediate interest and forms the basis of this paper.

Grading of noise activities within a building has a number of practical advantages. The main determinant is a practical restriction on the sound insulation achievable between adjacent areas. In a building of substantial structure, the limit of sound isolation between areas is of the order of Sound Transmission Class (S.T.C.) 50-55. Light structures drop this to the order of S.T.C. 45-50 and demountable partitions in typical commercial buildings at S.T.C. 40.

These considerations are important, it is not infrequent to find mechanical plant with sound pressure levels of 90-95 decibels at 1000 Hz contained within a building. It seems ludicrous to place a conference room, with a requirement of a sound pressure level of 25 decibels at 1000 Hz, adjacent to this plant. This situation would necessitate the intervening barrier to provide a sound insulation of 70 decibels, a condition difficult to achieve even with isolated construction.

Grading of areas has been carried out in a number of important projects; principally the National Library in Canberra and the Commonwealth-State Law Courts in Sydney.

The technique in its simplest form is to classify each area in the building with an I.S.O. noise rating number. The noise rating numbers are then compared. Extremes of noise rating numbers, say 35 decibels or more, are critically examined and if necessary, recommendations made for rearrangement of areas.

Apart from the technique discussed above, it is necessary to recognize potential problem areas. Some of these will be discussed in the subsequent section of this paper.

Commercial Buildings

Particularly in high rise buildings, zoning has to be carried out in two directions; in the vertical direction away from traffic noise or top level plant rooms, and horizontally away from the service core.

The vertical direction presents the usual problem situation. By some law of nature, executives flock to the top of a building, which usually means directly below the main plant room. A board room and a plant room represent the opposite ends of the noise scale in a building. The answer to this syndrome lies in the use of mid level plant rooms. I realise there are acoustic arguments against mid level plant rooms, the main one being that you affect people on the level above and below the plant room, whilst with a high level one you only affect the people below. However, it is not difficult to provide a cafeteria or an open office space on the levels next to the mid level plant room.

Zoning in the horizontal direction is of importance, yet is often neglected. The service core carries high velocity airconditioning ducting, lifts and hydraulic services.

High velocity ducting can make noise at the take off points, therefore it is wise to interpose a lobby or even toilet between the high velocity duct rise and the office space.

A table is included below which outlines both potentially noisy areas and areas requiring quietness. Where ever possible, these areas should be well separated.

Noisy	Quiet
Mechanical ventilation plant rooms	Board Rooms
Lift motor rooms	Executive offices
Airconditioning High velocity take off points	Theatrettes
Computer rooms	Staff lecture rooms
Accounting machine rooms	Libraries
Toilets	
Typing pools	

Home Units and Flats

This form of building has its over unique problems which, due to absence of steady background noise, tend to be more critical than a commercial building. In my opinion, zoning plays a most important part in these multi level domestic buildings.

The common mistake that is seen is the juxtapositioning of bedrooms of one unit to the bathroom of another. It is very important to group bathrooms and kitchens together and to locate these well away from the bedrooms of adjacent units.

Similarly, the main living area or lounge room presents a unique problem. It is an area that has a requirement in some cases, for very low noise levels and yet other times is the source of very high noise levels. This situation depends on whether the area is required for the purposes of reading or whether the occupant has high fidelity playback equipment which is played at concert hall level. The relationship of the lounge room to other rooms of the adjacent area should be given strong consideration, the best compromise in layout is to place lounge rooms next to each other.

Toilets have always been a strong problem. The best solution is to use a common toilet block at the centre of four dwelling units. Cisterns should be located at the very centre of the toilet block.

The main bedrooms should be positioned at the corners of this overall square plan.

It seems that the present method of construction based on the price that the home owner is prepared to pay will dictate the need for zoning in home units.

The population generally are not affluent enough to pay for the methods of construction which will give freedom from noise and freedom to make noise in a multi level dwelling.

Isolated construction of walls and ceilings, and isolation of plumbing whilst well established in acoustic practice can cause a substantial increase in overall costs. Naturally a developer will pass these costs onto the potential home unit owner resulting in an increase of the order of 50% in the total cost of the dwelling.

At this point in time, the home unit owner requires reasonable acoustic conditions and is prepared to put up with certain restrictions. Viz no operation of sink waste disposal units or washing machines after 10.00 p.m. Providing that intelligent zoning of the internal area is carried out and moderately heavy construction is employed, the quality of living can be reasonably satisfactory.

Session 14

ACOUSTIC DESIGN, CONSTRUCTION AND MATERIALS

W.A. Davern

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(Victoria Division)

ACOUSTIC DESIGN, CONSTRUCTION AND MATERIALS

SUMMARY

The prevention of sound travelling from one place to another depends for its success on the use of the principles of noise control. An understanding of these principles requires some knowledge of the mechanism by which sound is propagated. This paper discusses both of these considering also suitable materials to be used in the different aspects of noise control.

INTRODUCTION

In any plan for dividing an area into zones with the idea that the boundaries of such zones will among other things command certain noise level standards, the principles of noise control play a very important part. In this paper, the general characteristics of sound and its control will be outlined. It should be mentioned at the outset that these principles apply whether we are dealing with the overall plan e.g. for a city or simply the necessary noise zoning that must be observed on a site e.g. where the telephone switchboard operator would not be able to carry out her function if she were placed next to the weaving machine in a textile plant.

NATURE OF SOUND

All sound, wanted or unwanted, consists of some combination of simple longitudinal waves produced by a vibrating body. They travel through a medium - solid, liquid or gas - at a definite speed appropriate to the medium and if their frequency and intensity are within certain ranges they produce the sensation of hearing.

The acoustical engineer talks about sound pressures but the ear which is essentially a sensitive pressure measuring device does not respond linearly to pressure. The loudness of sound corresponds approximately to the logarithm of the pressure of the sound and the ear can cope with a very large range of intensities e.g. 2×10^{-4} microbar at the threshold of hearing to 200 microbar when pain begins to be sensed. Because of these factors, a logarithmic unit called the decibel, dB, is used for the sound pressure level (S.P.L.) of a sound. The sound pressure is related to the threshold of hearing:-

$$S.P.L. = 20 \log_{10} \frac{p}{p_o} \text{ dB}$$

where p = sound pressure (pressure units)

p_o = sound pressure at threshold of hearing (pressure units)

Figure 1 shows sound pressure and S.P.L. for some common sounds.

PHYSICAL PROPERTIES OF SOUND WAVES

Sound originating from a vibrating body at a point in a free homogeneous and undisturbed medium away from all reflecting and refracting surfaces is propagated radially in all directions and the wave front is said to be spherical. Energy is lost in propagation due to divergence in all directions and the sound pressure level of these spherical waves decreases inversely with distance from the source at the rate of 6 dB for each doubling of the distance from the source. This figure may be greatly modified by wind, temperature, and reflecting and diffracting objects in the path of the sound.

The distance a sound travels in one complete vibration is called the wavelength and is related to the frequency of vibration.

Velocity of sound = frequency x wavelength

Thus a frequency of 20 hertz, a low frequency sound, has a corresponding wavelength in air of $66\frac{1}{2}$ feet and 15,000 hertz, a high frequency sound has a wavelength of approximately 1 inch. Thus high frequency sounds have very small wavelengths and low frequency sounds very large wavelengths.

Sound waves are reflected off objects provided the wavelength is small compared with the dimensions of the object. If the wavelength is large compared with the dimensions of the object there will be hardly any obstruction offered to the propagation of sound and if the wavelength is comparable the sound will be diffracted around it. Sounds at high frequencies, small wavelengths, tend to be directional and low frequencies practically non directional.

Again, an important aspect of sound propagation is the transmission through cracks or holes. If the wavelength is large compared with the size of the opening the sound waves will be diffracted around the edge of the opening, if the wavelength is small sound will pass through without much hindrance. In other words, sound of any wavelength will pass through without much hindrance. Thus we see, sound of any wavelength will pass through even tiny cracks and can be the cause of problems in noise control.

SOUND TRANSMISSION

The transmission of sound can take place in two ways.

1. A vibrating body the sound source can act directly on the surrounding air and the sound then passes from one place to another through the air. This sound wave travelling through the air consists of rapid pressure fluctuations. When they meet a wall they force it to vibrate and the vibrating wall in turn acts on the surrounding air in the same way as a loud-speaker and the sound thus passes through the wall. The technique of airborne sound insulation is to provide a barrier which will not move easily i.e. a heavy barrier (Figure 2). Such a barrier is more effective for high frequencies than low. Also a rigid wall will vibrate less readily than a non rigid one. The main properties of a material which are efficient in the control of air-borne sound are mass and rigidity.

2. A vibrating body, if rigidly attached to a structure will cause the structure to vibrate and anything attached to the structure in turn will vibrate. Each of these vibrating objects will be acting as a source of sound i.e. a loud-speaker. The original vibrating object must be isolated in such a way that the vibration will not travel along the ground or through the structure of the building providing new sources of air-borne sound. This can be achieved by using flexible mountings, anti-vibration pads, and discontinuities in structures. (Figure 3).

SOUND ABSORPTION

If a sound is produced in a room which is lined with hard impervious materials it will bounce off these surfaces and the sound level in the room will increase. If these surfaces are lined with porous materials into which sound can penetrate with a resultant dissipation of sound energy the amount of reflected sound will be reduced. The sound level in the room will then not increase as much as with the hard surface linings. A sound absorbent lining reduces the build up of sound due to reflections, it does not affect the direct sound. (Figure 4). Worthwhile reductions up to 10 dB can be achieved by the addition of such materials.

Again, a duct lined with a sound absorbing system can reduce the level of a noise produced at one end due to the reduction of the multiple reflections that take place as the sound travels down the duct. Each time a reflection takes place some sound energy is dissipated in the absorbing material. Thus, by using adequate treatment in a duct, a sound produced at one end can be attenuated sufficiently by the time it reaches the other end. This allows necessary air to enter or leave an environment without increasing the noise level at the "quiet" end of the duct.

MATERIALS FOR SOUND CONTROL

We have seen that a material for the prevention of transmission of air-borne sound is one which is non-porous, heavy and rigid, while a sound absorbing material which is required for the reduction of reflected sound within an enclosure is a porous material through which the sound can pass. Its ability to absorb sound depends largely on how much energy can be dissipated in the passage of sound in through the material and back again. The basic properties of these two types of materials are opposed to each other and, in fact, for most noise problems both types of materials must be used in combination. Figure 5 gives values of transmission loss for some typical building materials and Figure 6 typical sound absorbing materials with their coefficients. The amount of absorption added to a room is the product of this co-efficient and the area covered by such absorbers.

Doors and windows are usually limiting factors to the prevention of sound from travelling from one place to another.

As regards windows, an open window will give a sound reduction of 5 - 10 dB depending on the proportion of open window and a closed but openable window with ordinary glass will give a net reduction of 20 dB. If the window is sealed, this value may rise to 25 dB. A sealed double window with $\frac{1}{4}$ inch plate glass with an 8 inch air space between the glasses and absorbent-lined reveals will attain 42 dB sound reduction.

An ordinary single, solid cored, door with only small edge gaps can achieve 25 dB reduction. To achieve higher insulation a refrigerator type door of heavier construction and with proper sealing gaskets would be required. Two doors separated by an air space or lobby will enable higher reductions of sound to be achieved e.g. in the vicinity of 45 dB if large air spaces, several feet long, are used. Such a door system installed in a wall giving a sound transmission of 45 dB alone would virtually not change this value. If however any type of door with large gaps round the edges was installed the 45 dB might be reduced to about 27 dB sound transmission.

The isolation of structure-borne sound caused by vibrating machinery can be accomplished by the use of flexible mountings, anti vibration pads, floating floors, etc. In small mountings, the materials used include rubber, metal springs, air tubes, cork, felt, glass fibre blankets. For large equipment, metal springs and rubber isolators are generally used.

For impact sound, e.g. footsteps, adequately resilient floor coverings (e.g. carpeting, rubber tiles, cork tiles) are used. For heavier impacts, the structure-borne type sound isolators mentioned above must be used.

NOISE REDUCTION

We are now in a position to examine the problem of "acoustically" separating two areas one of these areas containing a source of high level noise.

NOISE REDUCTION AT THE SOURCE

Let us assume that all has been done in the design of the object which is producing the unwanted sound to reduce the noise generated to a minimum for this is the most efficient way of overcoming any noise problem.

The first step then would be to completely enclose the source of noise in its own enclosure or a separate room or both. If it requires an air supply e.g. an internal combustion engine, then protected openings e.g. lined ducts or muffler systems must be employed to allow free passage of air without free passage of sound. The enclosure itself should be treated internally with sound absorbent material to prevent the increase in sound level when the source is enclosed.

Partial enclosures can serve a useful purpose giving worthwhile reductions where a complete enclosure is not feasible e.g. a press stamping products from sheet metal. Such enclosures internally lined with sound absorbers reduce the spread of sound.

The noise producer with its ducts, conduits pipes should be isolated structurally from the ground and building. Figure 7 illustrates an example of noise control which takes care of a number of noise problems.

NOISE REDUCTION IN THE TRANSMISSION PATH

If the transmission of sound inevitably takes place in the open then increased distance from such sources is the only recourse. For compact sources e.g. a jet airliner the noise will decrease by 6 dB for every doubling of distance. For an extended source e.g. a stream of traffic on a roadway the decrease will be only 3 dB per doubling of distance. (A change of 3 dB is just noticeable to the ear). Inside a large building the decrease with distance may be even less due to internal reflections but even here noisy areas and quiet areas should be separated as far as possible from each other.

NOISE REDUCTION AT THE RECEIVER

Workers in a noisy industry may have to resort to earmuffs or earplugs to protect them from noise where they necessarily have to work close to noisy plant. Again, a person living in a house on a busy road may have to close his windows or resort to greater effort e.g. install double glazed fixed windows and use forced ventilation or room air conditioning, to shut himself off from traffic noise in order to enjoy a good night's rest.

DESIGN FOR ACOUSTIC ZONING

We have looked at the principles of noise control and the properties of materials which can be used to achieve this control. It is now necessary to examine possible ways of meeting whatever sound levels may be laid down for particular areas. In fact, this is really dependent on the individual noise producers in this area. If the individual meets the criteria the area noise will be at a satisfactory level.

For outside noise e.g. aircraft, especially at take-off or landing or the traffic noise on freeways, we must rely heavily on the attenuation of sound with distance. Hence, the call for proper isolation of aerodromes to create a comfortable acoustic environment and the correct planning of freeways so that at least some protection in the form of cuttings and screens are employed where they necessarily must run through densely populated areas.

Again, the site planning of buildings with respect to general traffic noise should be examined e.g. the external wall of a building alongside a roadway might have no openable windows so that sound must travel over or around a building before it can enter through a vent or window; or a breakaway from the more usual design of a suburban house might have the bedrooms at the rear of the house. The window in a building is a weak spot where sound can more readily enter.

It is fairly common practice for industrial buildings housing noisy plant to be clad with corrugated materials. This provides a rigid lining and would provide a useful extra barrier in confining internal noises within the building if the large gaps formed where wall and roof structures meet could be effectively sealed. Again, no attempt seems to be made to prevent the exit of sound in the ventilating systems of such buildings. Indeed, the exhaust fans, where provided, frequently produce more noise themselves than what is emanating from inside the building. In order to enclose a noisy environment, it is necessary to seal the noise in by sealing the building and allowing air, people and machinery to enter and leave through openings that effectively reduce the amount of sound energy that can leave the building; for this is the only way by which the noise levels in an area can be controlled.

It is quite often found in industrial plant that where equipment is vibrating some care has been taken to try to isolate a machine on its mountings from the structural floor but rigid attachments to the machine e.g. conduits, ducts, fuel lines, etc., are clamped firmly to structural walls and ceilings effectively inducing vibrations into large areas which then act as sources of sound. Where vibration isolation is required, all attachments must be isolated.

Sound absorption can play a useful part in reducing the noise level in large plant. Figure 8 gives an idea of the effect of different amounts of absorption as experienced at different distances from the source of sound. Sound absorbent shields hung over noisy machines in a high ceilinged plant can provide some reduction in overall noise.

CONCLUSION

The noise level produced in a given area and, hence, on its perimeter will depend on the levels of noise sources within that area and how they are controlled. To reduce a noise effectively the source should be enclosed with materials of adequate sound reduction properties and all necessary openings should be protected to prevent the exit of sound.

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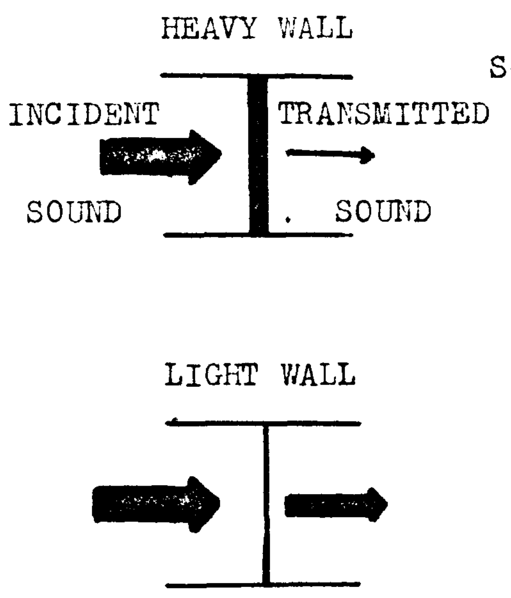
PRESSURE AND DECIBEL RATING OF SOME COMMON SOUNDS

Sound pressure p: Nm^{-2}	Sound pressure p: μbar	S.P.L. (dB)	Comment	
2×10^{-5}	2×10^{-4}	0	Threshold of hearing	
		10	Soundproof room	
2×10^{-4}	2×10^{-3}	20	Ticking of a watch	Very Quiet
		30	Quiet garden	Very Quiet
2×10^{-3}	2×10^{-2}	40	Average living room	Quiet
		50	Ordinary conversation at 1 metre	Quiet
2×10^{-2}	2×10^{-1}	60	Car at 10 metres	Noisy
		70	Very busy traffic	Noisy
2×10^{-1}	2	80	Tube train, Loud radio music	Noisy
		90	Noisy factory, Heavy lorry at 5 metres	Very Noisy
2	20	100	Steel riveter at 5 metres	Very Noisy
		110	Thunder, artillery	Very Noisy
20	200	120	Threshold of feeling	INTOLERABLE
		130	Aeroplane propeller at 5 metres	INTOLERABLE
200	2000	140	Threshold of pain	INTOLERABLE
		150	White noise causing immediate deafness	INTOLERABLE
		200	Atlas rocket launch (100 m away)	

Note: Each factor of 10 increase in sound pressure results in an increase of 20 dB in S.P.L.
A $\sqrt{10}$ fold increase in sound pressure corresponds to an increase of 10 dB in S.P.L.

Figure 1.

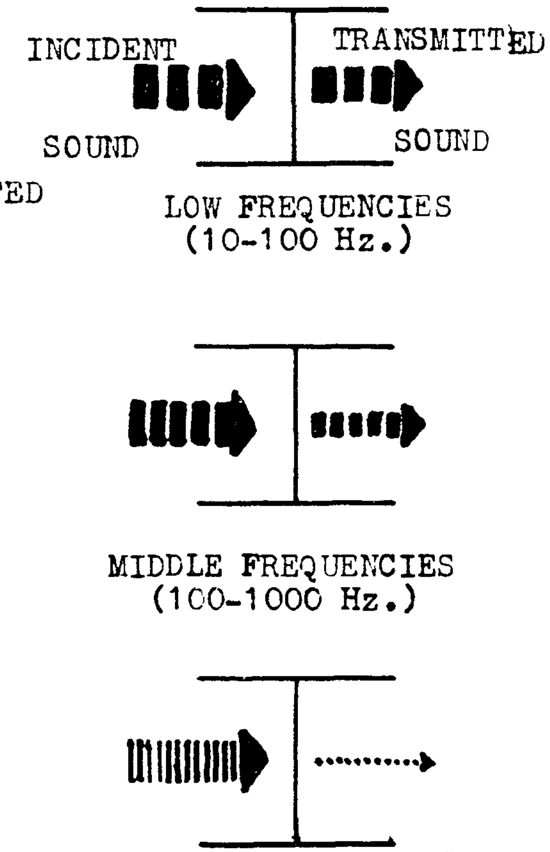
EFFECT OF WEIGHT OF WALL



A heavy wall is more effective than a light wall.

Figure 2.

EFFECT OF FREQUENCY OF SOUND.



HIGH FREQUENCIES (1000-10,000 Hz.)

Any wall is more effective at high frequencies than at low frequenci

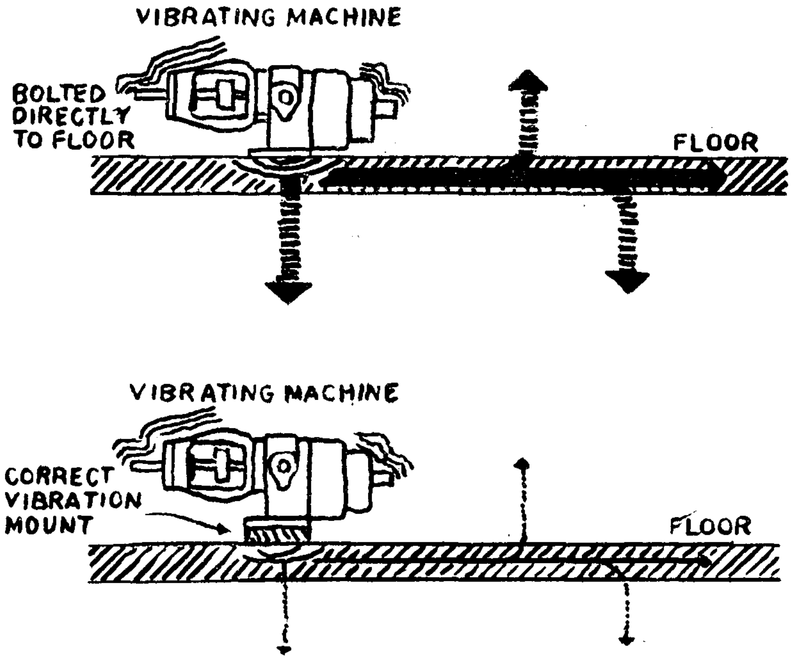
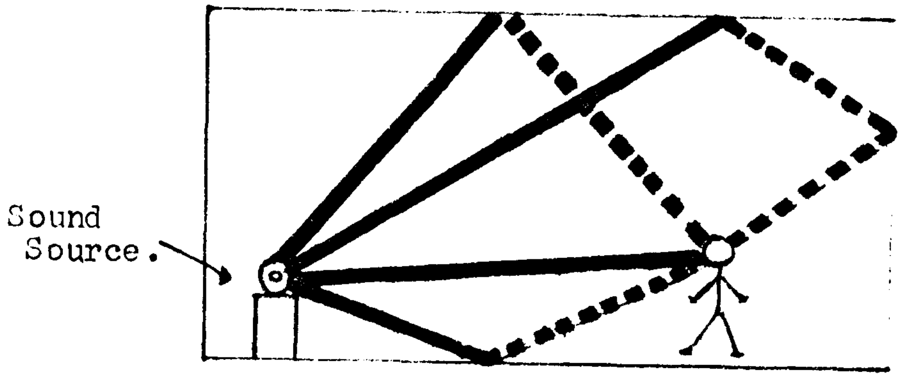


Figure 3. Vibration isolation.

Room with no absorbent treatment.



Room with sound absorbent treatment.

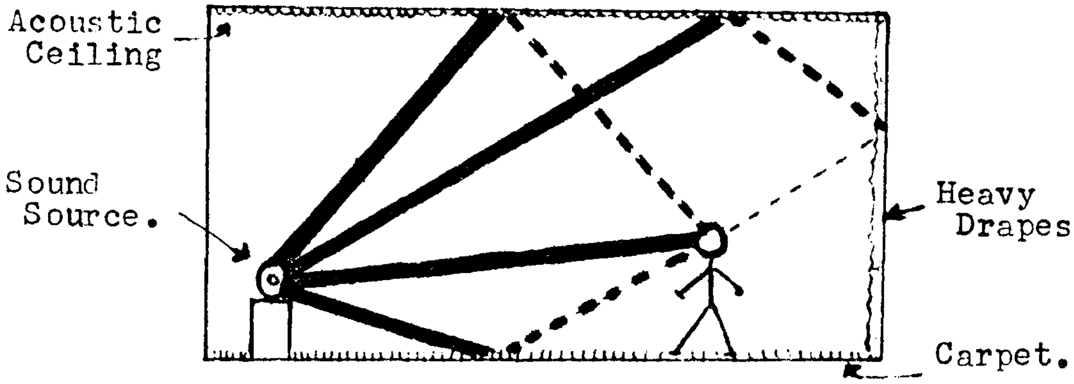


Figure 4.

Approximate insulation (dB).	Weight (lb/ft^2)	Construction.
55	190	18-in. solid brick plastered.
		15-in. dense concrete plastered.
50	90	9-in. solid brick plastered.
		7-in. dense concrete plastered.
	64	Two leaves 4-in. clinker block with 2-in. cavity, wire ties, plastered.
	38	Two leaves 2-in. clinker block with 6-in, cavity, wire ties, plastered.
45	50	$4\frac{1}{2}$-in. brick plastered.
		4-in. dense concrete plastered.
		8-in. hollow dense concrete block plastered.
40	30	3-in. clinker block plastered both sides.
	25	2-in. dense concrete.
	20	Two leaves, 2-in. wood-wool slab with 2-in. cavity, wire ties, plastered both sides.
35	50	$4\frac{1}{2}$-in. brick unplastered.
	20	2-in. solid gypsum plaster reinforced.
	10	2-in. compressed straw slab, plastered, both sides of timber frame.
30	6	$\frac{3}{8}$-in. plasterboard with skim coat plaster both sides of timber frame.
25	$2\frac{1}{2}$	$\frac{3}{8}$-in. plasterboard.
		$\frac{1}{4}$-in. asbestos cement sheet.
		$\frac{7}{8}$-in. tongue and groove boarding.
20	Less than 1	$\frac{1}{4}$-in. plywood.
		$\frac{1}{8}$-in. hardboard.
	$1\frac{1}{2}$	$\frac{1}{2}$-in. fibre insulation board both sides of timber frame.

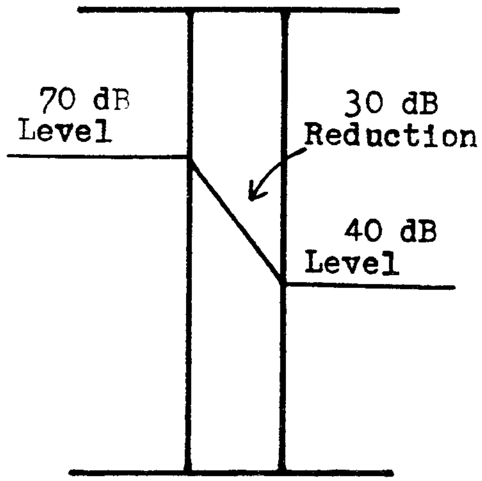
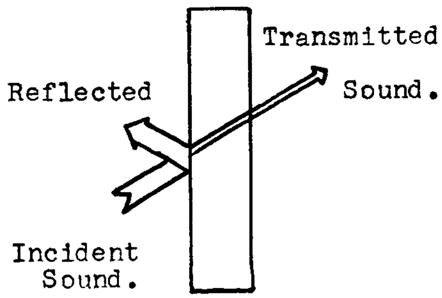


Figure 5.

Material.	Statistical Absorption Coefficient.			
	250	500	1000	2000 Hz.
$\frac{3}{4}$-in. sprayed limpet asbestos on backing.	0.15	0.29	0.77	0.88
$\frac{3}{4}$-in. sprayed vermiculite plaster on backing.	0.13	0.19	0.33	0.45
$\frac{1}{2}$-in. semi-perforated fibreboard on backing.	0.14	0.31	0.49	0.75
$\frac{3}{4}$-in. fissured rockwool on backing.	0.17	0.53	0.79	0.74
Perforated plaster tile with $\frac{5}{8}$-in. rockwool on backing.	0.35	0.55	0.76	0.42
Perforated metal tile with $1\frac{1}{8}$-in. fibre glass on backing.	0.26	0.50	0.83	0.88
As above on 2-in. air cavity.	0.62	0.87	0.94	0.87
Wool carpet on double underfelt.	0.11	0.25	0.55	0.84
As above but with 0.008-in. between carpet and underfelt.	0.13	0.32	0.70	0.78
1-in. polyurethane ether (flexible) foam on backing.	0.15	0.24	0.59	0.88



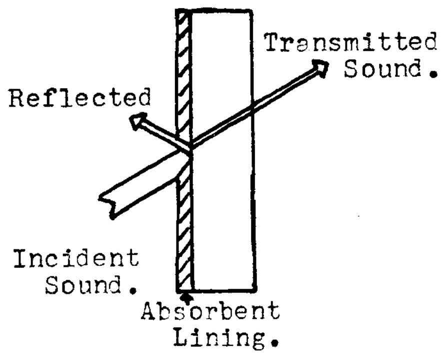


Figure 6.

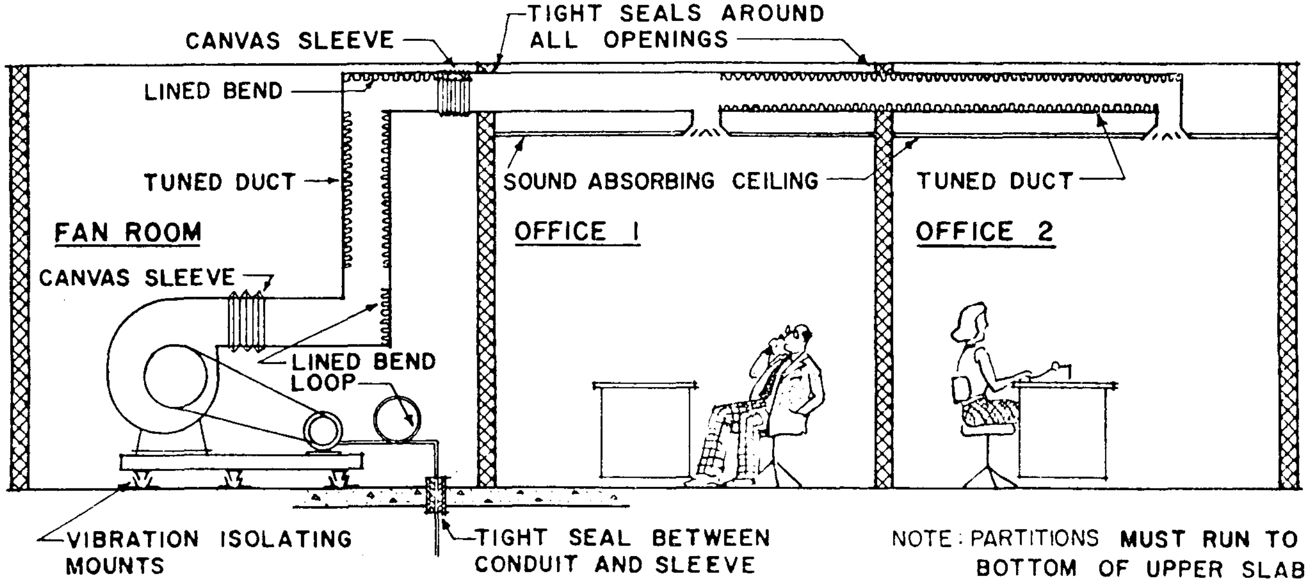


Figure 7.

An example of noise control in which many problems are encountered e.g. vibration, transmission of machinery noise from one space to another, transmission of noise along air passages, acoustic leaks, and violation of privacy.

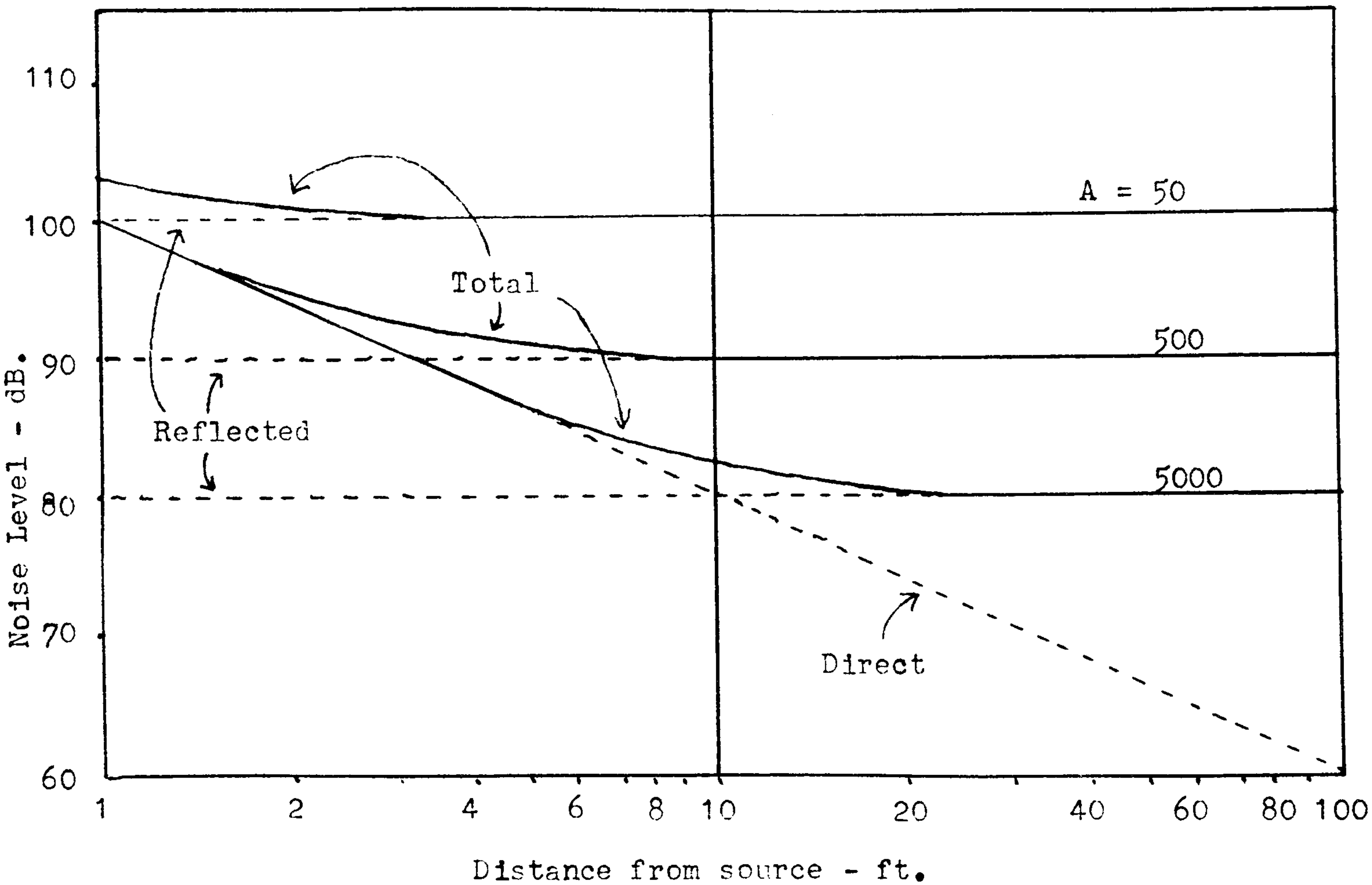


Figure 8. Relation of level of direct, reflected and total noise in regularly shaped room to absorption A and distance from single source.

ECONOMICS OF NOISE ZONING

by

H. VIVIAN TAYLOR, M.B.E., F.R.A.I.A.,
Architect & Acoustic Consultant
Melbourne & Sydney

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Warburton, Victoria.

Sponsored by the Australian Acoustic Society,
(Victorian Division)

ECONOMICS OF NOISE ZONING

SUMMARY

Provided acoustical aspects receive due and proper consideration in a Scheme of Zoning for land usage, it is shown that substantial savings are made in the staggering cost of reducing environmental noise to acceptable limits.

The economic study is based on examination of data derived from case histories where noisy undertakings have, or could have substantially affected the acoustic amenity of the neighbourhood.

INTRODUCTION

It has been shown on previous papers at this conference that differing noise sources over many years, indeed centuries, have been subject of complaint.

Those which appear to affect us most today arise from Transportation, Traffic, Industrial Undertakings, Mechanisation of office work, Mechanical Plant, and the like; also should be mentioned Entertainment.

To some of these sounds we become accustomed in due course and appear to accept. At any rate an awareness of them leads us to take steps to suppress or confine them, or relegate them to an area where they cease to be a nuisance.

More recently however the intense noises caused by aircraft operation and the difficulties of controlling these over large populated areas has highlighted the problem, and led to international examination and attempted regulation. So it is in this field that perhaps Noise Zoning has assumed prominent importance.

One of the early such attempts is instanced in the Chicago Zoning Ordinance (1) which came into effect in 1957. This delineated and classified Residential, Business, Commercial, and Manufacturing districts, each into various subdivisions, and stipulated the permitted maximum noise levels, expressed in decibels in octave bands as measured at the points of interest at the boundaries.

Applied to Australian conditions and in particular experimentally applied at the Auburn Municipality in New South Wales, the noise limits imposed were found to be realistic, satisfactory and capable of enforcement in law.

Moreover they gave the municipal authority some yard stick in the investigations of complaint, to the point as to when the council should take appropriate action, and when to ignore unjustifiable complaints.

AIRCRAFT NOISE

Regulations to control permissible maximum noise output from aircraft, based on International Recommendations and Agreement are envisaged for local application. (2), (3), (4).

The data derived from these, as also from noise monitoring around airports, will be helpful in establishing noise exposed areas and intelligent land usage. Apart from noise exposure forecasts (N.E.F.) upon which noise contours will be based, it is essential that the Town Planner, the Architect, and the Acoustical Engineer have available accurate basic information on Sound Pressure levels, expressed in octave bands or one-third octave bands, of the noise emitted from the various types of aircraft at various heights and distances under various conditions of operation and flight profile. The complicated permutations from which Noise Exposure Forecasts are derived do not arrive at a simple single figure design objective value.

Overlays of contours expressing maximum permissible loudness of aircraft operation will become an essential tool for the designer and the land zoner. The information is vital if any engineering assessment is to be made or the necessary design to control internal environment of a building in that area.

Moreover from the economic point of view, it becomes important to relegate the noisiest of industries to these noise exposed areas. How many of us, and how often have we had the case of the industrial undertaking, originally on a large open area of land, subsequently hemmed in on the perimeter of the works by dwellings with little or no sound insulation, and any one resident capable of obtaining an injunction at law which could have the effect of closing down the industry.

Contrast this with the cost of making an Airport environment suitable for residential development, where dwellings have pre-existed or have "grown" around an airport. The present state of town and country planning provides a depressing picture of our ability to achieve control.

Dr. Elfyn Richards of Loughborough University of Technology and a former member of the Wilson Committee on Problems of Noise quotes staggering costs of loss of amenity to the residential neighbourhood at Heathrow as £66 million per annum or one fifth of the annual value of the airport. (5). Moreover the sum is said to be increasing annually to a total of £3 million per unit N.N.I. (measured in noise and number indices).

Figures can perhaps be made to prove anything. But surely it is apposite that the value of first class land for industrial development close to an airport would not be less than its value for residential development.

To this must be added the substantial savings in constructional costs avoided by not having to contain a very noisy process within a heavily sound-insulated building. Site selection, therefore, becomes a paramount economic consideration.

ZONING OF LAND USAGE

In the Australian scene, as elsewhere, authorities controlling zoning in established urban areas have been hamstrung by pre-existing conditions, and much is to be desired, particularly where residential areas border on industry.

Further, industrial undertakings which are classified under "Noxious Industry", "Heavy Industry" and "Light Industry" can produce noises which do not necessarily accord with the classifications.

Regulation of noise emitted from such premises to permissible limits, as measured on the nearest residential or commercial boundary, should be the criterion of town planning or municipal acceptance.

Appropriate Standards and International Standards Organisation Recommendations (6). (7). (8) provide the bases for suitable criteria and codes for noise assessment and control. Simple dBA measurements as recommended in the Wilson Report on the Problem of Noise, and the more exact octave band analyses plotted against standard noise rating curves give engineering data for necessary sound control.

Experience gathered from case histories over many years where environments surrounding some similar major industrial undertakings in various Australian States has provided a fund of data on neighbourhood relationship to, and community acceptance of, industrial noise.

This study is all the more interesting when projected towards a type of production which has continued uninterruptedly over several decades, where in some cases improvements in equipment and techniques of sound reduction have occurred, and in others such as drop hammer forging, where noisewise at least no differences have been observed.

In some cases the additional traffic on perimeter roads has provided a measure of sound masking, permitting day time operation of an industrial undertaking without local objection, but as this traffic thins out at night time, the factory noise again becomes obvious, so reliance cannot be placed on continuous traffic masking, particularly as attempts are being made to reduce vehicular noise.

INDUSTRIAL NOISE

Undoubtedly one of the big problems here stems from bad zoning which vitally affects the economic issue. In town and country planning we find too often the industrial area with an unbuffered perimeter of single storey dwellings, on the opposite side of a street, or even abutting on rear or side boundaries. Such a condition should never be tolerated. It is totally unfair to industry and the home occupant. Several cases are examined.

In a Sydney suburb, a factory site area of $53\frac{1}{2}$ acres is bounded on two sides by main roadways, on the opposite sides of which are 30 residences fronting the works and a total of 172 dwellings in a zone exposed to factory noise comprising a total of approximately 270 acres. On the two other sides adjoining the factory site the neighbourhood is protected by the buffer zones consisting of recreation area (golf course) and an employee car parking area of some $16\frac{1}{2}$ acres.

The factory buildings are well constructed with the conventional masonry based walls, glazed above 7'0" level and with corrugated fibro-cement saw toothed roofs.

Noise from the works was one time cause of complaint extending in the residential area of 270 acres on two sides of the industrial undertaking; but the other two sides were completely protected.

This is a case where, in the absence of less sensitive noise zoned areas adjoining, the noise from the works had to be shielded from the residential area by two storeyed masonry buildings intervening on one side, and the other side by soundproof masonry walls. The cost of this, of the order of $350,000 could have been obviated by a scheme of noise zoning, permitting conventional construction.

This works out at a cost of approximately $2,000 per dwelling in the noise affected area. In a completely planned industrial scheme, housing properly designed and oriented with respect to the noise, could have been carried out with very little, if any, excess over conventional costs, using two storeyed or multi-storeyed constructions with main lighting and access facing away from the noise source.

Another single storey factory of 130,000 square feet had to be sited on an area of 20½ acres, zoned industrial but with perimeter housing. Sound sources from similar works were identified and measured, and it was possible to save $100,000 in cost of factory building by careful placement on site, avoiding masonry construction, and still providing completely acceptable acoustic conditions for the residential neighbourhood.

Examination of costs of housing large, noisy industries bordering a residential area, would seem to indicate some 30% to 35% increase over normal conventional constructions of brick outer walls and lightweight roofing.

INTERNAL ZONING

A brief note might be made of the economic advantages stemming from intelligent internal noise zoning in industrial and commercial buildings. This needs little elaborating; today, in commercial buildings we have such noise sources as "on site power" with enormous diesel driven electric generators, often located on upper floors, radiating as much sound power as an aircraft jet engine. The cost of containing this sound and vibration within a reasonable internal area is considerable.

TOWN & COUNTRY PLANNING

The theme of this paper is that much can be achieved by intelligent lay-out, zoning and planning for acoustic amenity, and there must be the greatest co-operation at all levels between governmental, municipal and other authorities, with Architects, Engineers, Town Planners and Acousticians. The economic effect of such planning would be immeasurable.

Noise zoning by the appropriate authorities should provide plans with contours of permissible noisiness, measured at appropriate points of interest, and designers and developers should work within the limits of noise radiation imposed.

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5. Dr. Elfyn Richards "The Cost of Airport Noise", New Scientist, 24th September 1970.

6. British Standard 4142 : 1967 "Method of Rating Industrial Noise Affecting Mixed Residential and Industrial Areas".

7. International Standards Organisation TC43 Secretarial 452 Doc. 529E Draft Recommendation "Noise Assessment with respect to Community Response".

8. Standards Association of Australia Doc. 1707 "Code for Noise Assessment in Residential Areas" in course of preparation, about to be issued as a document for public comment.

PURPOSE OF MEETING:

To bring together those interested in the design, construction and operation of buildings, plants, equipment and industrial undertakings, who are concerned with the suppression of unwanted noise; also Town and Country Planning authorities, Municipal Officers and others engaged in the administration and policing of regulations including traffic and aircraft authorities.

OBJECT:

The consideration and participation in discussion of up to date information on the many ramifications of noise abatement, and in particular, how noise can be controlled economically and effectively by appropriate noise zoning. The success of such an overall improvement in acoustic environment depends on the most complete co-operation at all levels of those concerned with planning, building, acoustic material supply and the formulating and administration of standards, codes of practice and ordinances.

LOCATION:

Warburton Chalet, Main Street, Warburton, Telephone 66-2544. The Chalet has 140 bedrooms, all with Hot and Cold water, 53 with bathroom ensuite, facilities for children, recreation and swimming and parking of motor cars.

WARBURTON:

- a timber-milling and tourist town with a population of over 1,600, situated 49 miles west of Melbourne on the Upper Yarra River in the foothills of the Great Dividing Range. It was founded in 1864 after the discovery of gold in the area. From Warburton, spectacular mountain scenery is within easy reach, Mount Donna Buang, Upper Yarra Dam, etc.

NOTE: Accommodation at the Warburton Chalet will be allocated strictly in order of receipt of applications.

NOTE:

CONFERENCE SECRETARY

G.R. HARDING,
C/o NONOYS PTY. LTD.,
480 CLAYTON ROAD,
CLAYTON. VICTORIA, 3169

PROGRAMME:

FRIDAY, 5th MARCH, 1971

Registration - social gathering

SATURDAY, 6th MARCH, 1971

9.00 a.m.	Registration
10.00 a.m.	Opening address - Mr. R.D.L. Fraser, Chairman, Town & Country Planning Board, Victoria.
SESSION 1 11.00 a.m.	Noise and the Environment - Prof. R.G. Barden, Monash University
SESSION 2 11.35 a.m.	Noise Zoning: A logical approach - Mr. J. Rose, Commonwealth Acoustic Laboratories
SESSION 3 12.10 p.m.	Acoustical Aspects of Town and Rural Planning - Prof. F.W. Ledger, University of Melbourne
SESSION 4 2.00 p.m.	Noise-Zoning and Land Usage - Mr. R. Wilkinson, Wilkinson & Carr, Sydney
SESSION 5 2.35 p.m.	Public Transport Noise - Mr. C.L. Fouvy, Melbourne & Metropolitan Tramways Board
SESSION 6 3.45 p.m.	Highway Noise - Mr. J. Bryant, Australian Road Research Board
SESSION 7 4.20 p.m.	Traffic Noise - Mr. L. Challis, Consulting Acoustic Engineer, Sydney
	Dinner and Entertaining

SUNDAY, 7th MARCH, 1971

SESSION 8 9.00 a.m.	Aircraft Noise - Mr. J. Harper, A.F.C. - D.C.A.
SESSION 9 9.45 a.m.	Realistic Community Noise Criteria - Miss Anita Lawrence, University of N.S.W.
SESSION 10 11.00 a.m.	Ordinances, Standards & Codes - Mr. N.C. Hawthorn, Chief Health Surveyor, City of Williamstown
SESSION 11 11.45 a.m.	
2.00 p.m.	Social Activity - Site Visit
6.45 p.m.	Sherry Party, Conference Dinner

MONDAY, 8th MARCH, 1971

SESSION 12 9.00 a.m.	Noise-Zoning in Industry - Mr. R. Randall, I.C.I.
SESSION 13 9.45 a.m.	Noise-Zoning in Internal Environment - Mr. P. Knowland, Consulting Acoustical Engineer, Sydney
SESSION 14 11.00 a.m.	Acoustic Design Construction & Materials - Mr. W. Davern, C.S.I.R.O.
SESSION 15 11.45 a.m.	Economics of Noise-Zoning - Mr. H. Vivian Taylor, Architect and Acoustic Consultant
2.00 p.m.	Panel Summary - Close of Conference

AUSTRALIAN NOISE ZONING CONFERENCE

MARCH 6-8th, 1971 - WARBURTON VICTORIA

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