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NOISE REDUCTION
OF FLOORS WALLS AND CEILINGS

INDEX

GLOSSARY OF TERMS

PAPER

CO-ORDINATOR OF TECHNICAL PAPERS AND DESIGN –
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GLOSSARY OF TERMS

Airborne Sound Insulation Index (Ia): A single figure which indicates airborne Sound Transmission Loss over the range 100 to 3150 Hz and is the value of the reference curve at 500 Hz when it has been shifted to match the measured characteristics within prescribed limits.

Attenuation: Weakening or reduction.

Co-Incidence Effect: Certain combinations of angle of incidence of sound waves, frequency of sound and wavelength of flexural vibrations in a panel will result in a co-incidence effect with resulting sound transmission loss (See Paper B).

Characteristic Acoustic Impedance of a Medium: is the ratio of the effective sound pressure at a given point to the effective particle velocity at that point in a free plane progressive sound wave. It is equal to the product of the density and the speed of sound in the medium (See Paper B).

Damping: Any influence which extracts energy from a vibrating system.

Decibel A Scale (dBA): A measurement of Sound Pressure through a weighted filter network which corresponds to the subjective response of the human ear.

Diffuse Sound Field: A diffuse sound field is one in which the sound pressure level is uniform throughout.

Energy Density: At a point in a sound field is the sound energy contained in a given infinitesimal part of the medium divider by the volume of that part of the medium.

Field Transmission Loss: The effective transmission loss of a component measured in its working situation. (The laboratory test figure will be influenced by flanking transmission.)

Flanking Transmission: The transmission of sound via paths (structural or airborne) other than directly through the component under test (See Paper B).

Noise Criterion (N.C.): For use in speech interference work: N.C. curves are of the audio spectra whose loudness level does not exceed the Speech Interference Level (S.I.L.) by more than 22.

Noise Rating (N.R.): A family of curves used to rate the acceptability of background noise.

Noise Reduction Coefficient: of a material is the average, to the nearest 0.05, of the absorption coefficients at 250, 500, 1000 and 2000 Hz.

Room Constant (R): A method of comparing the effective absorption of different spaces (See Paper D).

Sound Absorption Coefficient: of a surface exposed to a sound field is the ratio of the sound energy absorbed by the surface to the sound energy incident upon the surface. It is a function of both angle of incidence and frequency.

Sound Power (W): is the total sound energy radiated by the source per unit of time. (Ref. 10^{-12} watts).

Sound Pressure Level (S.P.L.): In decibels, is 20 times the log to the base 10 of the ratio of the pressure of the sound to the reference pressure.

(Ref. 2 x 10^{-5} Newtons/m^2.

Sound Transmission Class (S.T.C.): A single number rating which indicates sound transmission characteristics of a partition over the frequency range 125 to 4000 Hz. Specific STC Contours have been developed by which the S.T.C. of a partition can be established.

Sound Transmission Loss (S.T.L. or T.L.): Is equal to the number of decibels by which sound incident on a partition is reduced in transmission through it.

Speech Interference Level (S.I.L.): is the average of the sound pressure levels in 3 octave bands with centre frequencies of 1000, 2000 and 4000 Hz.

PAPER A.

RATING SYSTEMS FOR THE SOUND INSULATION OF BUILDING ELEMENTS.

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RATING SYSTEMS FOR THE SOUND INSULATION OF BUILDING ELEMENTS

SUMMARY.

In order to be able to compare the effectiveness of different elements with regard to their ability to control sound transmission in buildings, it is necessary to have some scientifically based rating systems. This paper attempts to answer some of the questions raised by the statement 'a sound insulating construction is required to reduce the sound transmitted to an acceptable level.'

INTRODUCTION.

The sound insulating properties of a material or system are important when it is required to reduce the transmission of sound. The first question which arises is, what is an "acceptable noise level" inside a room. Secondly, what is the nature of the sound that has to be reduced, and finally, what are the mechanisms of sound attenuation and how may performance best be specified? These problems will now be discussed.

WHAT IS AN ACCEPTABLE SOUND LEVEL?

An acceptable sound level may be described as one which does not interfere with the conduct of the normal activities in the room concerned. It is well known that the presence of one sound inhibits the perception of another - for example the age-old definition of quiet is that "one can hear a pin drop." The sound of the pin is always present, but only heard in the absence of other, louder sounds. Thus an acceptable level is one that is not noticeable when the normal noises associated with the activities of the room are present. Since activity noises range from very low levels - e.g. when reading or writing, to very high levels, e.g. when operating a lathe, it is obvious that a noise that would be most annoying in a library would be quite imperceptible in a factory.

The frequency of the sound is also important. The human ear is not equally sensitive to sounds of different frequencies; it is most sensitive at about 3,000 Hz and becomes less sensitive as the limits of the audio frequency range are reached (about 20 - 20,000 Hz). Thus a sound having most of its energy in the octaves centred on 1,000, 2,000 and 4,000 Hz would seem much louder than one with the same amount of energy centred on frequencies below 250 Hz.

Methods of specifying acceptable background noise levels in rooms take into account this varying sensitivity. Three systems are commonly employed - the decibel A-scale (dBA), the Noise Criterion (NC) and the Noise Rating (NR). The decibel A-scale is measured with a sound level meter incorporating a weighting network which matches the response of the ear to different frequencies. A single number that rates sounds with regard to their subjective loudness is obtained, but no information is available with regard to spectral composition. The Noise Criterion was developed by Beranek (1) and is related to the ability of people to converse easily at different distances apart. The Noise Rating was developed by the International Standards Organisation, ISO (2) and is an attempt to describe acceptable background noise for a wide variety of circumstances. It consists of a family of curves with which the measured noise spectrum is compared. The lowest curve not exceeded by the noise at any point is its Noise Rating. A typical Noise Rating curve, that of NR 30 is shown on Fig. 1.

WHAT IS THE NATURE OF THE SOUND THAT IS TO BE REDUCED?

This is a difficult question. With Regard to sound originating outside a building it has been estimated that at over 80% of urban sites, road traffic noise is the major source. (3) Measurements made locally and overseas have determined the levels that may be expected, (see Fig. 1). (4) For sites adjacent to airports and airport approaches the loudest noise sources are low-flying aircraft - although these are generally intermittent.

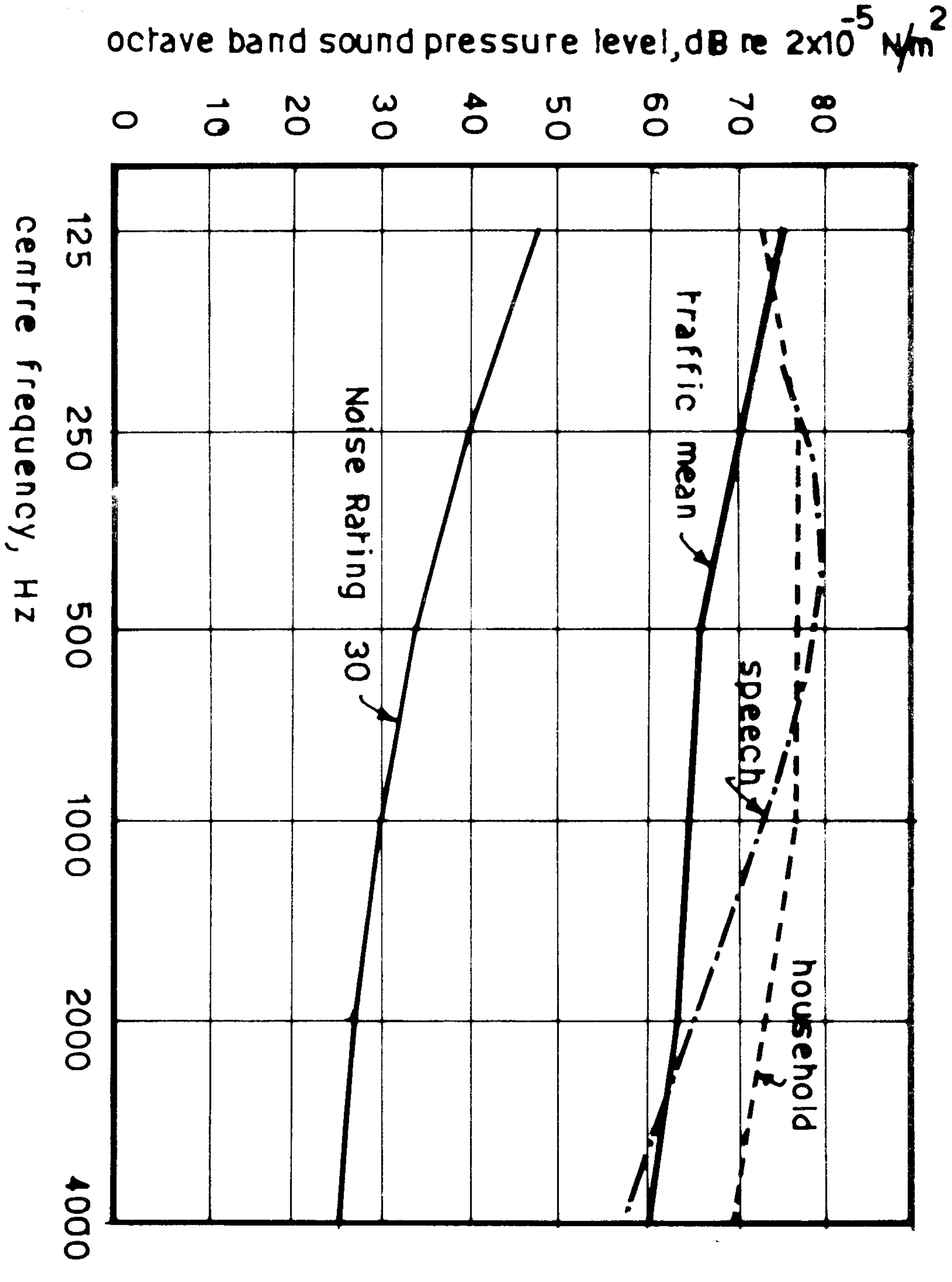

Fig. 1.

Typical spectrum levels of standard household noise conversational speech and road traffic, compared with an acceptable background noise of Noise Rating 30.

It is more difficult to decide the spectrum levels of noise originating inside buildings. Both airborne and impact noise sources must be considered. Most research into noise sources in buildings has been with reference to residential buildings and offices. In multi-storey residential buildings, social surveys have shown that the most disturbing noises are radio and tv, conversation, and impact noises such as footsteps, moving furniture and banging or hammering. Other prevalent noise sources are powered appliances - vacuum cleaners, polishers, washing machines, air conditioners, etc., and plumbing. Although there is naturally a great variation in the spectrum levels from different sources, many airborne domestic noises, including radio and tv have spectrum levels that may be characterised by the curve labelled "household" in Fig. 1. (from Northwood, (5)).

In offices the chief source of annoyance is usually the transmission of intelligible speech. Intelligibility depends on the speech levels transmitted relative to the masking (or background) noise level in the listening room. Speech levels in the source room depend on the type of conversation and the size of the room. The most important frequencies for intelligibility are from 1,000 to 4,000 Hz. Fig. 1 also shows typical speech levels in an office about 10 ft square (6). Other noise sources in offices are data processing machines - many generate a high noise level with a nearly flat spectrum.

SPECIFICATION OF SOUND ATTENUATION.

The mechanism of sound attenuation will be dealt with in other papers, it need only be stated here that in most cases the attenuation provided by a material or constructional system is strongly frequency dependent, generally being lower in the low frequencies, and increasing with frequency. Earlier attempts to characterise the overall performance by averaging over the frequency range from

100 to 3200 Hz proved unsatisfactory in practice - particularly with lightweight forms of construction.

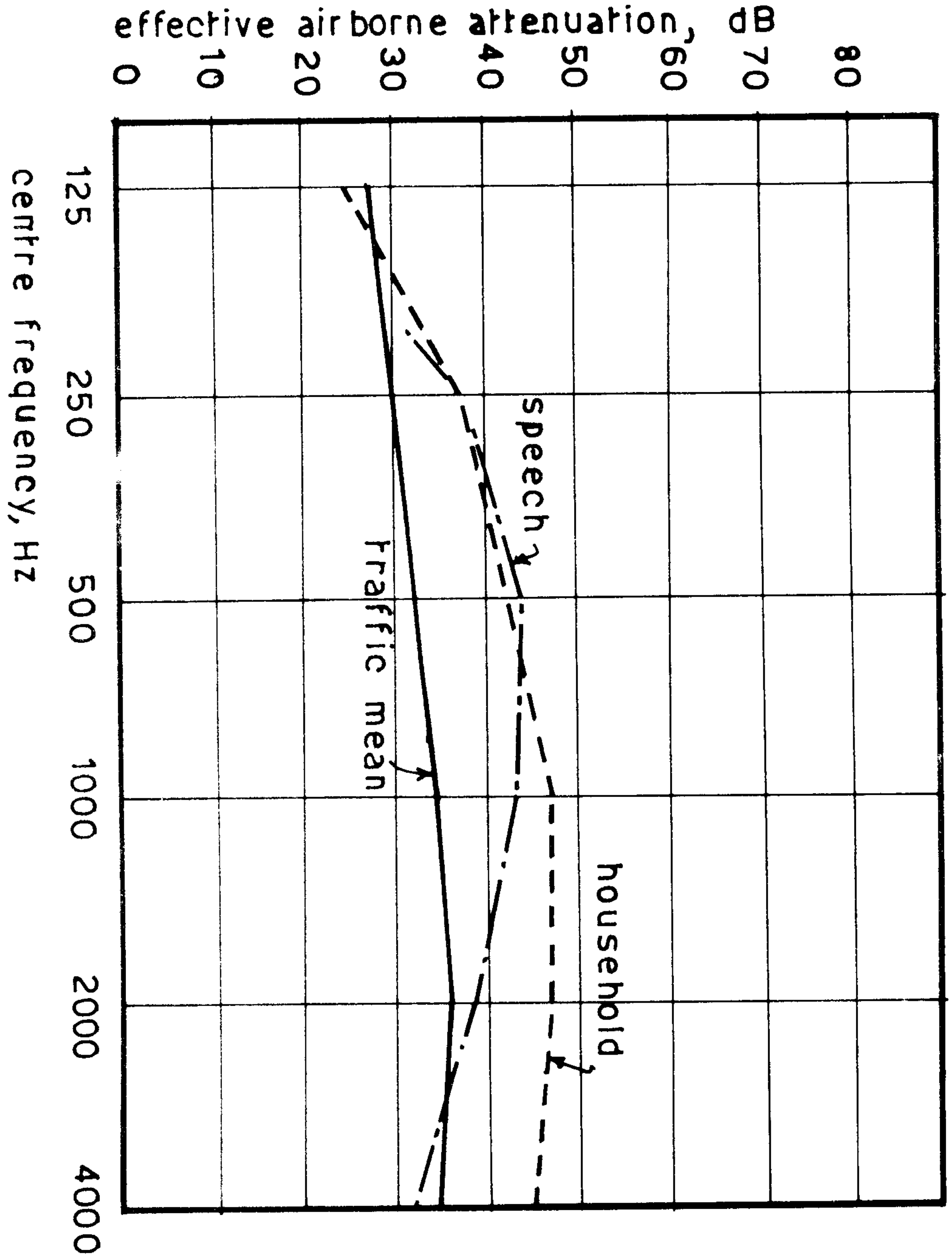

Fig. 2.

Attenuation required to reduce the airborne noise levels of Fig. 1. to the acceptable level of NR 30.

Ideally, the sound insulation of a building element would be individually specified over the frequency range to suit its particular use, by comparing the source levels with the acceptable noise levels in the room. For example, Fig. 2. shows the airborne sound attenuation required if the acceptable noise level in the receiving room is NR 30, for the cases of traffic noise (mean levels, 10 ft. from kerbside used) and standard household noise. In the case of speech, the attenuation required to reduce the peak speech levels to NR 30 is shown.

It will be noticed that these three attenuation curves have differing shapes, that required for traffic being much flatter than those for speech and household noise. (If it is required to reduce the maximum traffic noise levels to NR 30 the attenuation curve should be shifted up by about 10 dB at all frequencies. Again, if protection is required from raised speech, additional attenuation may be necessary.)

Unfortunately, in many cases, the detailed spectrum of the intruding noise is not known, and in addition in the description of impact noise it is found that the resulting noise transmission is a function of both source and the element itself. For these reasons, several attempts have been made to determine standard attenuation requirements for different purposes - termed "grading curves". A description of some of the more important curves will follow.

AIRBORNE SOUND ATTENUATION RATING SYSTEMS.

Most effort has been directed towards the rating of satisfactory walls and floors in multi-storey residential buildings. As a result of social surveys and measurements made in attached houses and flats it was found in Britain that the traditional 9" brick party wall was acceptable to most tenants. The "House Standard" grading curve was based on sound transmission loss measurements of this type of wall. A slightly lower standard was found acceptable for flats and this is called "Grade I", shown on Fig. 3. In order to reduce errors the method of measurement and normalisation is standardised (7). Since different forms of construction may vary slightly from this curve but prove acceptable in practice, some deviations are allowed; not more than 23 dB adverse deviation (i.e. below the grading curve) is allowed over the sixteen, 1/3 octave bands from 100 to 3200 Hz.

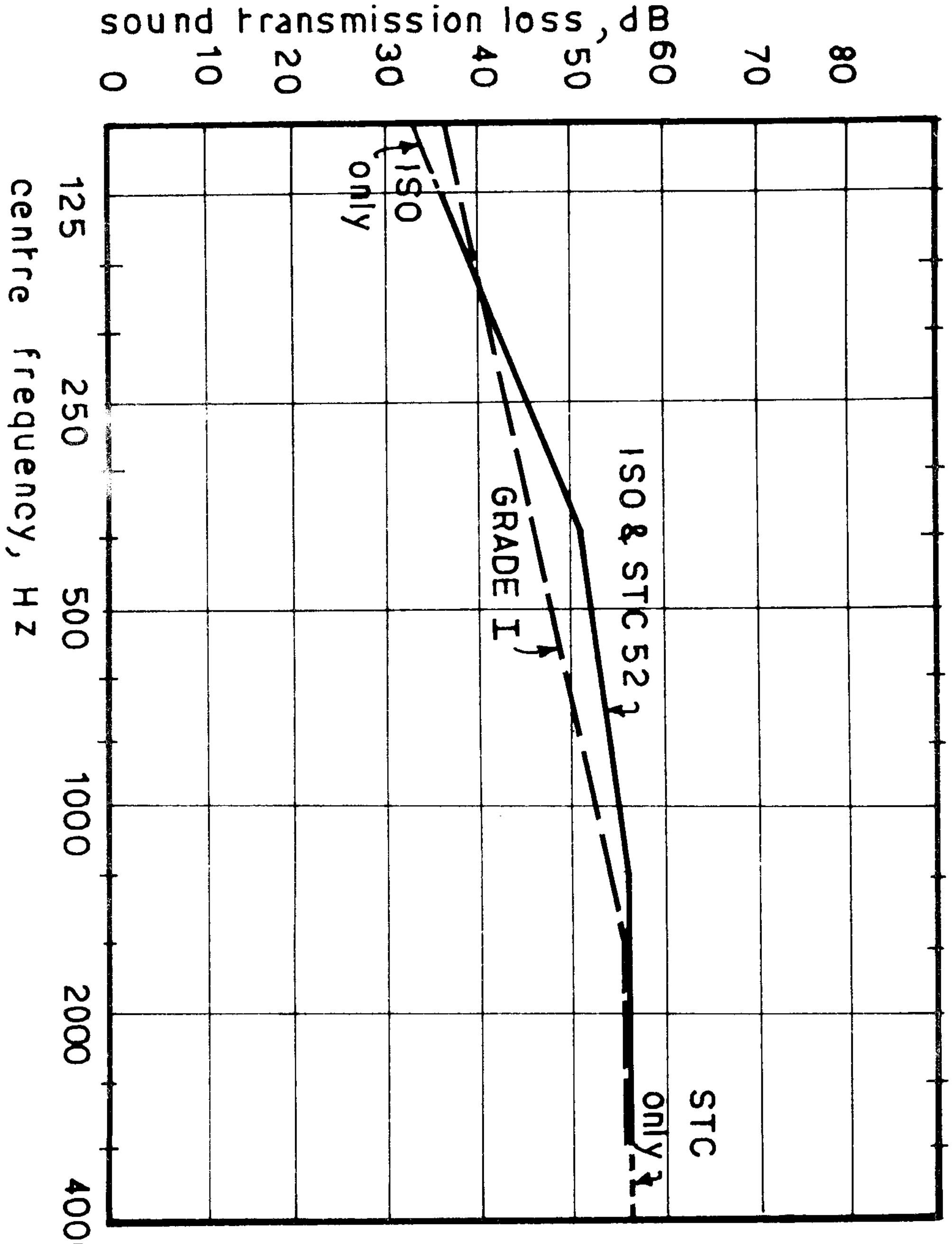

Fig. 3.

Standard airborne sound insulation grading curves. Note, ISO and STC measurements are normalised to $10m^2$ sabins absorption; British Grade I is normalised to 0.5 sec reverberation time.

A similar approach in other European countries produced a curve requiring somewhat more attenuation in the mid-frequencies. This curve is also shown in Fig. 3., labelled ISO. In the U.S.A. this same curve has been adopted, and called the Sound Transmission Class, STC (Note that this curve extends from 125 to 4000 Hz, the ISO curve extends from 100 to 3200 Hz). An average of 2 dB adverse deviation is allowed over the sixteen, 1/3 octave bands, but the maximum deviation in any band must not exceed 8 dB (or 5 dB if measurements are made in octave bands).

The actual curve shown in Fig.3. is that chosen for international comparisons of sound insulation for dwellings (8), a wall or floor complying with this curve would have an Airborne Sound Insulation Index, I_a, of 52. If the curve must be shifted for compliance with the deviation restrictions the Index is taken as the value of the shifted reference curve at 500 Hz. Measurements should be made in accordance with ISO R 140 (9).

The STC rating system employs a family of parallel curves, the rating being determined by the value of the reference curve at 500 Hz. The deviations allowed are as described previously for the ISO curve. (10) Measurements should be made in accordance with ASTM E-90 66T (11). Since most forms of construction provide greater attenuation in the higher frequencies, an STC rating may be slightly higher than the ISO rating. This system is used extensively for partitions in offices.

The limitation of 8 dB maximum deficiency was to avoid the possibility of annoyance being caused by high level sound transmission in a narrow frequency band.. This type of transmission is common in certain lightweight forms of construction which have large dips in their sound transmission loss curve due to the coincidence effect (12). However, there have been several criticisms of this restriction, both Gösele (13) and Northwood (14) have suggested that a deficiency of up to 20 dB is subjectively acceptable over two or even three one-third octaves, provided that the overall limit of an average 2 dB deficiency is retained.

A comparison of the shape of the ISO-STC curve with the curves of Fig.2. shows good correlation for household noise. For speech, too little protection is provided in mid-frequencies, and excessive attenuation is required in the high frequencies (intelligibility being rated against an NR shaped background noise). In the case of traffic noise correlation is poor, and it may be worthwhile to devise another grading curve for external walls (15).

IMPACT SOUND ATTENUATION RATING SYSTEMS.

These are more controversial than those for airborne sound. One difficulty arises in the method of measurement. As stated earlier, impact sound is a function of both the system being tested and the impacting force, thus it is necessary to standardise both the force and rate of impact for comparitive measurements. This has resulted in the ISO tapping machine (16). However, this machine has come in for much criticism owing to its lack of similarity to real impacting sources such as footsteps. The floor under test is subjected to blows from small hammers at about 10 blows per second, the resulting airborne sound levels (normalised) being measured in the room below. The levels obtained are in all cases far in excess of those measured when typical real impact sources are used. Fig. 4., adapted from Jørgen (17) shows comparisons between tapping machine and female footstep measurements on concrete floors with the specified finishes. Although the machine levels are some 20 - 30 dB higher than the footstep levels, the spectra are not too dissimilar in shape. One serious objection that could be raised is that if a floor's response to differing forces of impact is non-linear the difference in level could lead to invalid results. However, there are several reasons against using footsteps as a source; the difficulty of maintaining constant force and rate of impact; the difficulty of accurately measuring discrete impulsive sounds and the difficulty of measuring the low levels transmitted through a good floor in the presence of typical ambient levels in buildings.

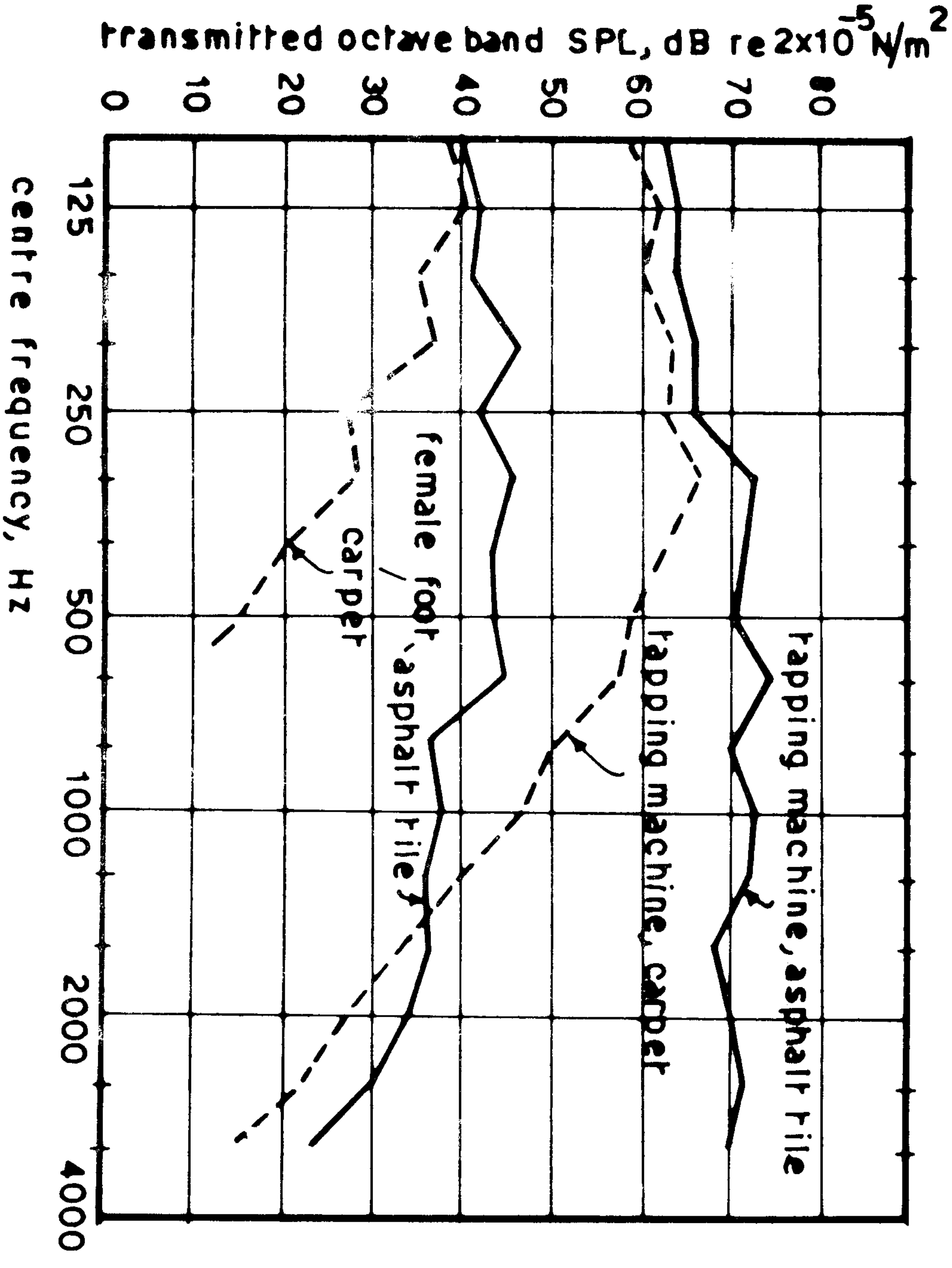

Fig. 4.

Impact sound levels measured below concrete floors with asphalt tile and carpet finishes; comparison between ISO tapping machine and female footsteps (after Jørgen).

Extensive research in Canada (18) into subjective ratings of floors using real male and female footsteps and the tapping machine as sources has shown that the machine places acceptable floors in the correct rank order; marginal and poor floors, such as concrete floors with thin vinyl or asphalt tile finishes may be misranked according to subjective assessment of their comparitive footstep noise transmission.

Fig. 5. shows some impact grading systems in use. The curve labelled ISO is for international comparison of the impact sound rating of floors for dwellings (19). The measured floor is compared with the given curve, and adverse deviations (in this case, above the curve) are restricted in the same way as for airborne sound. The unshifted curve has an Impact Sound Index I_i of 65. If the reference curve must be shifted for the floor to comply, I_i is the value of the shifted curve at 500 Hz. In this case the lower the value, the better the floor. Also shown in Fig. 5. is the British grading system, for floors in flats. In this system a total of 23 dB adverse deviation is allowed over the sixteen 1/3 octave bands. If the floor is already covered with lino when measured, the lower dotted curve should be used.

The shape of these grading curves has been criticised also. It has been suggested that a curve similar in shape to the dBA weighting network may be more logical - particularly as high-frequency noises are easier to localise and thus potentially more annoying than low-frequencies. (20). For comparison this A-weighting curve is also shown on Fig. 5.

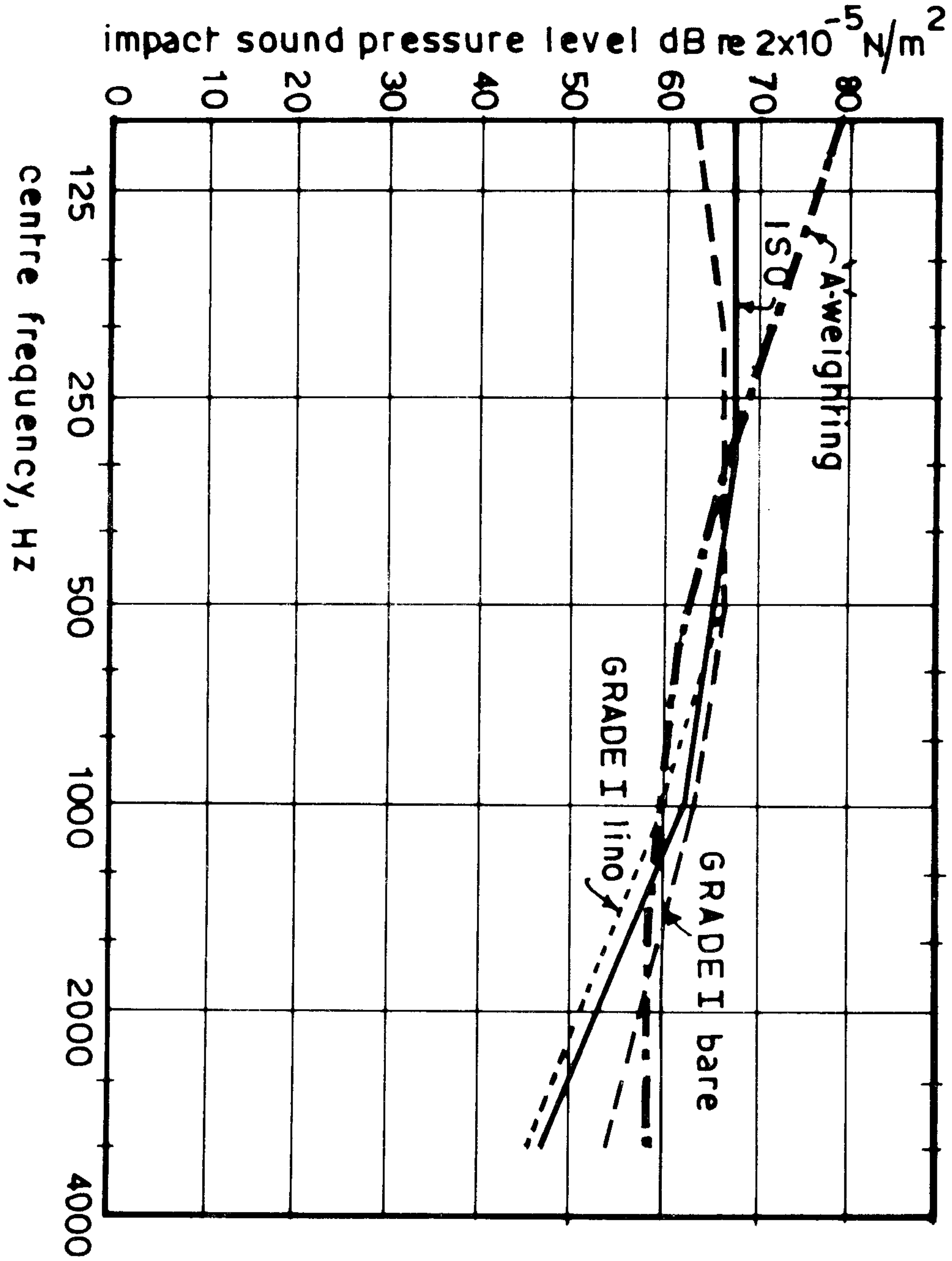

Fig. 5.

Standard impact sound grading curves. ISO measurements normalised to $10m^2$ sabins absorption; British Grade I normalised to 0.5 sec reverberation time. A-weighting curve shown for comparison.

CONCLUSION.

Rating systems for airborne and impact sound attenuation must take into account the sensitivity of the human ear to sounds of different frequencies as well as the typical spectra of incident noises. Some allowance for experimental and constructional errors must be made and the typical allowable deviations from grading curves serve this purpose. However, allowable deficiencies should be closely related to the subjective acceptance of increased sound transmission at certain bandwidths.

The derivation of some of the grading curves in use is important and they should not be indiscriminately applied to all situations. The ideal grading system is one which invariably selects a satisfactory wall or floor for a particular situation, and which also invariably rejects one that will not be satisfactory in practice.

REFERENCES.

1. BERANEK, L.L. Revised criteria for noise in buildings. Noise Control Vol. 3 (1957) Jan. p.19-27.

2. International Standards Organisation Draft Proposal ISO/TC 43/SC1. Noise assessment with respect to annoyance. Denmark, 1969.

3. Great Britain - Committee on the problem of noise; Noise - final report. H.M.S.O. London 1963.

4. LAWRENCE, A., HEGVOLD, L. and GREEN, R.C. Prediction of traffic noise spectrum levels for use in building design. Reports of the 6th International Congress on Acoustics, Tokyo 1968.

5. NORTHWOOD, T.D. Sound Insulation and the apartment dweller. Jnl. Acoustical Society of America Vol. 36, 1964, p. 725-728.

6. CAVANAUGH, W. J., FARRELL, W.R., HIRTLE, P. W, AND WATTERS, B.G. Speech Privacy in buildings. Jnl. Acoustical Society of America. Vol. 34, 1962, p. 475-492.

7. British Standards Institution. B.S. 2750,1956.

8. International Standards Organisation Recommendation R 717. Rating of sound insulation for dwellings. Geneva 1968.

9. International Standards Organisation Recommendation R 140. Field and laboratory measurements of airborne and impact sound transmission. Geneva, 1960.

10. American Society for Testing and Materials. Proposed classification for determination of sound transmission class (RM 14-2) Philadelphia 1966.

11. American Society for Testing and Materials. Tentative recommended practice for laboratory measurement of airborne sound transmission loss of building partitions. E-90-66T. Philadelphia 1966.

12. BERANEK, L. L. ed. Noise Reduction. McGraw-Hill, New York 1960. p.290.

13. GÖSELE, K. Zur Bewertung der Schalldämmung von Bauteilen nach Sollkurven. Acustica Vol.15, 1965, p. 264-270. (Evaluation of sound reduction in building structures by means of grading curves).

14. NORTHWOOD, T.D. Frequency considerations in the subjective assessment of sound insulation. Reports of the 6th International Congress on Acoustics, Tokyo, 1968.

15. LAWRENCE, A. The influence of traffic noise on the design of external walls of buildings. Proceedings, International Acoustics Symposium, Sydney, 1968.

16. International Standards Organisation Recommendation R 140. ibid.

17. JØRGEN, G. Ø. Some reflections on impact sound insulation of floors. Rapport 42, Norges Byggforskningsinsinstitutt, Oslo 1965.

18. OLYNYK, D. and NORTHWOOD, T.D. Subjective judgments of footstep-noise transmission through floors. Jnl. Acoustical Society of America Vol. 38, 1965. p. 1035-1039.

19. International Standards Organisation Recommendation R 717. ibid.

20. GÖSELE, K. ibid.

PAPER B.

METHODS OF ACHIEVING AIRBORNE SOUND INSULATION.

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METHODS OF ACHIEVING AIRBORNE SOUND INSULATION

1. THE EFFECT OF MASS

The mass relation or so-called 'mass law' has dominated all that has been written, said, or demonstrated with regard to airborne sound insulation for so long that its influence is all-pervasive. Indicative of this fact is that laboratories which determine the sound-transmission loss of walls and floors, i.e. partitions, almost invariably quote in their reports the weight per square foot of the constructions tested, irrespective of the type. Such statements of the weight are often required by the standards which lay down the methods of measurement and requirements of reports of airborne sound-transmission loss.

2. THE 'MASS LAW'

The mass law, or what is preferably termed the mass relationship, states that the insulation provided by single solid non-porous partitions against airborne sound of a given frequency depends entirely upon their weight per square foot. Supporting such contentions are curves of the type illustrated in Fig. 1. which shows the average sound transmission loss of partitions ranging in weight from $\frac{1}{2}$ psf to 200 psf.

The relationship is known also as a formula of which there are many variants. Discrepancies exist between results calculated from the different versions of the formula. Little is to be gained for present purposes from comparisons between them, or between the results obtained by calculation and by experiment. Discussion on this and other aspects is given in greater detail in Appendix A. The sole purpose of reference here to the formulae is to note that the sound transmission loss is determined from all, for whatever frequency is selected, from the weight per unit area of the wall.

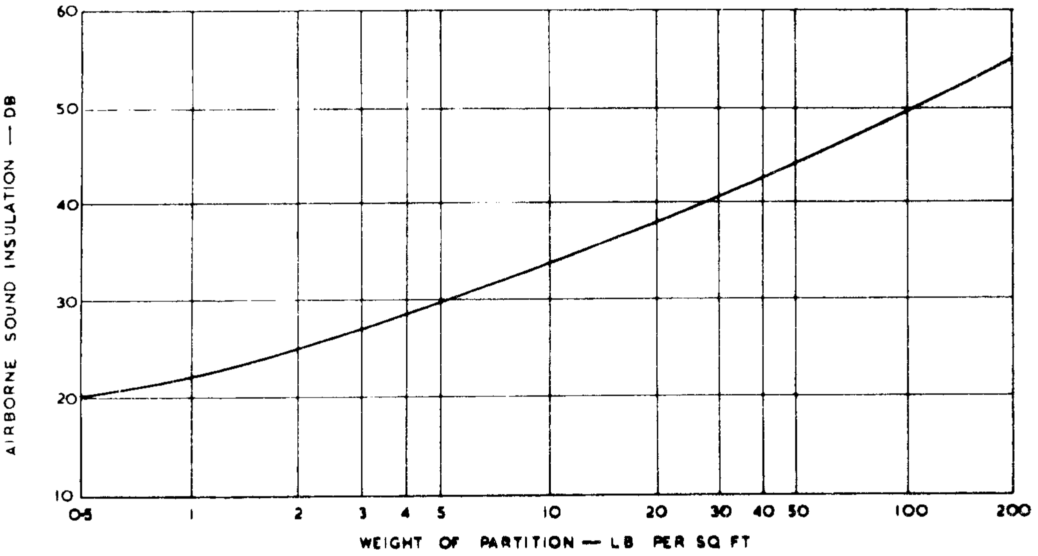


FIG 1 RELATION BETWEEN AVERAGE SOUND TRANSMISSION LOSS & MASS PER UNIT AREA OF PARTITIONS

3. MASS AND THE PRACTICAL PARTITION

Despite difficulties in establishing the exact relationship between the weight per square foot of a partition and its transmission loss there is clearly a dependence of the latter on the weight, so that, from the practical point of view, the use of a massive wall becomes a guarantee that good insulation may be obtained from the transmission of airborne sound. Inherent in this statement is the assumption that the wall is suitably erected, i.e. there are no serious flaws in the installation such as gaps between the components or around the perimeter. This is a fairly reasonable assumption with this type of construction because visual supervision can determine much. Other assumptions, such as the absence of gross flanking transmission, or of short-circuits through or around doors, hatches, or windows, apply equally to massive walls as to any other wall seeking to provide medium to high transmission loss.

The mass relationship is, strictly speaking, applicable only to single solid partitions as was stated above. Its use is, however, condoned (and often encouraged) as a means of assessing the effectiveness of other than single partitions. In this area the degree of uncertainty can become troublesome. The greatest value, and possibly the only value, of the use of the relationship might be to obtain some guide as to the extent of the advantage gained by the use of other than a single panel. The manner in which double panels function to reduce the transmission of sound requires to be explained in some detail before more is said.

4. DOUBLE PANELS

The use of double panels in partition construction offers the hope that the transmission losses of the individual panels can be added together. If this can be done the total insulation obtained will greatly exceed the transmission loss which is obtained if the mass relationship is applied to the combined weights per sq.ft. of the panels. Ideally then, two quite thin panels of asbestos-cement, plasterboard, or glass, each with a weight of about 2 psf would have an average sound transmission loss equal to that of a 9-in brick wall of 100 psf, assuming that the average transmission losses determined by the mass relationship for 2 psf can be added. Unfortunately, it is perhaps exceptional in common types of partitions for more than a small part of the individual reductions to be additive, which accounts for the statement above that the mass relationship has been considered to apply to most constructions and not merely to single solid walls.

The reason that the insulations of individual panels are not generally additive lies in the coupling that exists between them. Double walls have quite complex coupling. The most obvious is the mechanical connexion which is present around the perimeter and through any intermediate fixings. Less obvious, but of considerable importance, is the coupling via the air in the cavity between the panels comprising the double construction. There is a tendency to ignore air in cavities as a medium for the transfer of vibration. However, an analogy called up to show that it does is the pneumatic tyre, which is, of course, sufficiently rigid to transfer quite a lot of force. Ignoring the complexities of the edge and intermediate fixings, the simple analogy for a double panel is that the system can be represented by two masses on the ends of a spring. The air space may be considered to behave as a simple spring if the wavelength of the sound is much greater than the spacing between the panels, a condition which clearly applies when it is recalled that the wavelengths range from 11 ft at 100 Hz down to 3 in at 4,000 Hz, i.e. over the frequency band wherein the present problems arise. Vibration set up in one mass may be transferred by the spring to the other mass, often with little diminution at most of the frequencies of importance. Even worse, with certain combinations of masses and spacings, resonance may occur. Resonance causes reduced insulation, which, in theory at least, can result in insulation below the value expected from one panel alone. This effect is illustrated in a qualitative way in Fig. 2. (page B - 5.) which compares the performances of single and double walls if such walls acted in accordance with theory.

The resonance effect may not be evident for various reasons. Damping influences the nature of the dip in the sound transmission loss curve, sometimes to the extent that it may appear merely as an irregular flattened section. Above the region of the natural frequency of a double panel the transmission loss tends to rise

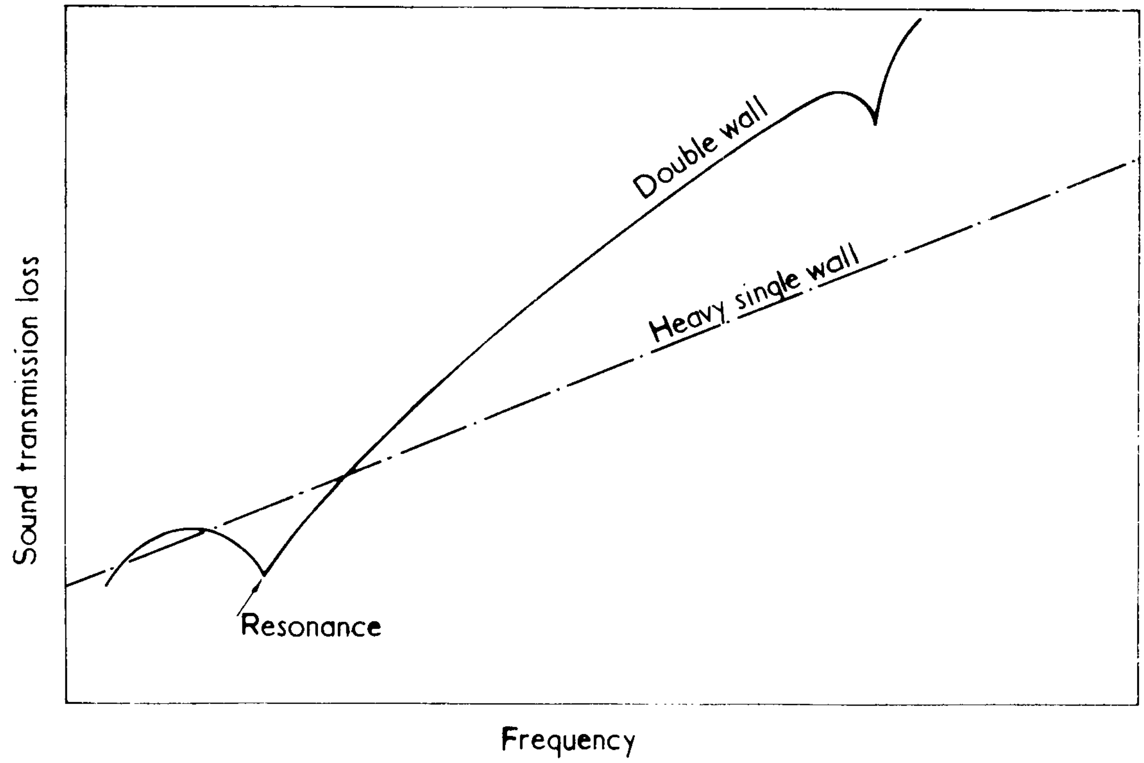


FIG.2. THEORETICAL PERFORMANCES OF SINGLE AND DOUBLE WALLS

steeply as Fig. 2. shows, and the slope of the curve approaches a value of twice that of a single mass controlled panel. In this region, therefore, the transmission loss should increase almost 12 dB each time either the frequency or the weight is doubled.

The foregoing discussion is patently a gross simplification applying to an idealized double panel situation. In practice, double panels can be most complex in their performance by reason of the use of panels of different thickness and/or materials which can produce different resonant frequencies. Additionally, both panels may exhibit reduced transmission losses by reason of coincident effects not discussed here but dealt with in the Appendix to this paper. Damping too, in the form of materials either adhered to the panels themselves, or applied in the cavity, play their part.

The basic principle that must be followed to gain additional insulation by the use of double panels is that of appropriate decoupling of the panels, i.e. by their isolation from one another when excited by sounds in the particular frequency range against which insulation is sought.

5. PRACTICAL DECOUPLING

Whenever insulation against sound transmission is sought by double panel construction the coupling between the panels is clearly critical, as has been indicated. The problem might be considered in two categories, viz. the design of systems, and their subsequent construction.

1. Design of Isolated Double Panel Constructions

The design of double panel constructions to provide high efficiency of insulation from the weight of material involved requires to be considered with care. Little reliance can be placed on estimates of the likely sound transmission loss on newly devised systems of construction. For assurance of success, or otherwise, it is almost essential to have reliable test data based on the construction of a specimen of reasonable size, and on the measurement of its sound transmission loss. Experience gained from having gone through this procedure many times is perhaps the next best substitute.

Where construction requires a sound-transmission class greater than about STC 45 to 50 the use of isolated double panel construction begins to look most rewarding because the weight of wall required according to the mass relationship becomes forbidding, as can be seen readily from Fig. 1. There are several reasonably reliable devices which can be used with double panel construction, but which are generally expensive in some way. Nevertheless, they are applicable in many of the situations, such as studios or auditoria, usually because good insulation simply must be assured. Wide cavities, for instance, will lessen air coupling, and widths as great as 10 or 12 in are used. It is considered they should never be less than 3 or 4 in. Non-parallel walls of cavities represent another means to decouple panels, although probably applicable only to double-glazed windows. Dissimilar thicknesses of the walls is another device, and various degrees of damping applied to the cavity or the walls of cavities are other measures.

The problem of achieving adequate isolation in double panel construction possibly becomes most difficult with what may be described as run-of-the-mill walls which are required to come up with a sound-transmission class in the range say of 40 to 50, or perhaps up to 55. The rewards are still high; to achieve the result with mass alone requires heavy walls and, in consequence, undesirably expensive supporting structures. The economies which can be made in the building structure can be considerable if lightweight partitions can be employed. Presumably however, these economies are not obtained if space is lost by the partitions requiring to be bulky to achieve decoupling, or if expensive use of materials becomes involved. The requirements are therefore conflicting. Slender partitions incorporating inexpensive materials and narrow cavities must provide the relatively high order of insulation sought. Other demands are that the partitions shall be simple to install, easy to alter, and reliable in performance. Further difficult requirements to be fulfilled are that the installed walls can withstand accidental bumping, and that they are adequately rigid, which requirements tend to be opposed to the acoustical need for lack of connexion between faces and frames. Impact sound, as well as airborne sound, should not readily be transmitted through the construction.

2. <u>Problems of Construction of Isolated Double Panels</u>

There are factors affecting coupling, which, although seemingly obvious, have a decided bearing on the practicality of double panel construction because of their demands on supervision during erection. These include inadvertent coupling caused by rubbish in cavities, and the incorporation of various forms of wall ties which, almost certainly, would not have been called for in the plan and specifications. In the same category comes bridging of the cavities by battens and blocks used to give support to cables, conduits, and other electrical and/or plumbing services.

Dangers occur, also, in that unless there is careful detailing and subsequent faithful supervision, rigid connexions may be created where doors and windows penetrate an otherwise satisfactory isolated panel system. The quest for good insulation by this form of construction clearly throws great emphasis on the need for good initial design, reliable detailing and specifying, and on capable and understanding supervision on the site. The reputation of the building industry in these aspects is not good. Nevertheless, there seems no reason why it should not be able to meet such a demand, as other industries have done when quality control has become necessary.

3. Typical Systems

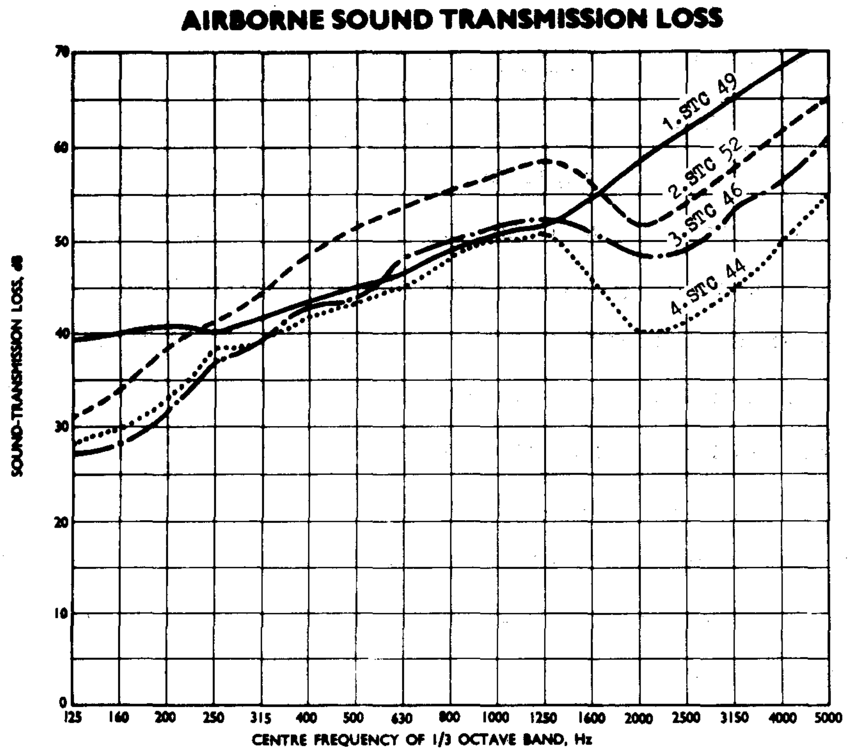
Double constructions comprising brick walls spaced, say, 12 in apart as have been used in broadcasting studios, and double-glazed windows with an average separation of a similar order between panes, inclined at an angle to one another are well known in connexion with special applications. In less demanding situations separate stud systems sheeted with plasterboard, plywood, or similar materials, and often with a mineral wool or glass wool blanket interlaced between the staggered studs, have also been in use for a long time. Less familiar are probably some systems with common studs which have been devised in recent years and offer prospect of general usage where insulation of the order of STC 40 to STC 50 is required.

The simplest of these, and offering the least insulation, include sheet steel on steel studs and hardboard on timber studs. Both systems adopt the simple expedient of incorporating softboard adhered to, or in contact with, the sheeting material. Presumably, the use of this material provides some damping of the cladding, and possibly some decoupling in the cavity. In the first case reduced rigidity of coupling is probably achieved with the metal studs and in the second by the presence of the softboard between the cladding and the timber studs. By whatever complex manner the softboard layers function, they increase the sound-transmission class from the mediocre value of about STC 34 to the noticeably improved value of about STC 40, or slightly below.

Of greater interest and application is a range of plasterboard partitions incorporating steel studs. Single and laminated double layers of 5/8-in. plasterboard on both sides of the studs employed with or without mineral wool in the cavity enable partitions to be constructed with insulation values ranging from STC 38 to STC 52. The sound transmission losses of several of these plasterboard partitions are plotted in Fig. 3. The superficial weights of the constructions range between about 6 psf and 14 psf, so that if only the mass relationship applied their transmission class ratings would be little better than STC 30 to STC 35.

4. Differences Between Double Panel and Solid Construction

In conclusion, it seems desirable to point out that, although a double panel system may provide a higher sound-transmission class than a single solid wall many times its weight, there are likely to be noticeable differences in the insulation at different parts of the audio spectrum. Fig. 3., setting out the sound transmission losses of the plasterboard partitions referred to above, also includes for comparison the values for a solid 9-in brick wall of about 95 psf. The insulation of the brick wall is obviously



1. 9-in solid brick wall, rendered ½-on both sides, 95 psf.
2. Two thicknesses of 5/8-in plasterboard on both sides of steel studs, with 2-in of mineral wool in cavity.
3. As for (1) above, without mineral wool in cavity.
4. Single thickness of 5/8-in plasterboard on both sides of steel studs, with 2-in of mineral wool in cavity.

FIG. 3. AIRBORNE SOUND TRANSMISSION LOSS OF PLASTERBOARD AND BRICK PARTITIONS.

superior, both in the high and low frequencies, to the best plasterboard partition included, although the sound-transmission class of the latter is higher than that of the brick wall. Care may be necessary to ensure that the insulation obtainable is the appropriate insulation for a particular type of application. The likely deficiency of double panel systems in the low frequencies may be the most troublesome problem.

REFERENCES

1. FURRER, WILLI. (1964) "Room and Building Acoustics and Noise Abatement" (Butterworths, London).

2. BERANEK, LEO L. (1960) "Noise Reduction" (McGraw-Hill, New York).

3. PARKIN, P.H., and HUMPHREYS, H.R. (1958) "Acoustics, Noise and Buildings" (Faber and Faber, London).

4. HARRIS, Cyril M. (1957) "Handbook of Noise Control" (McGraw-Hill, New York).

APPENDIX.

SOUND TRANSMISSION THROUGH SOLIDS

1. THE SEARCH FOR A COMPREHENSIVE TRANSMISSION EQUATION

A great deal of effort has been devoted to the study of sound transmission through partition materials in an attempt to relate the observed reduction in sound intensity caused by energy losses during transmission to measurable physical properties of the partition. The aim has been the production of a simple useful formula for estimating the transmission loss.

The efforts of many investigators all over the world have, so far, only produced partial success.

The problem is extremely complicated in all its parts.

2. SPECIFYING THE SOUND FIELD

For example, real sound fields are always variable with respect to time and space. We can identify frequency, pressure amplitude, density of the gas - (usually air) sustaining the field, velocity of sound in the gas.

From these primary properties of the field we can calculate, energy density, characteristic acoustic impendance of the gas (for air this constant is 415 MKS Rayls), intensity, and we can identify the phase state with respect to time or position. If we have a direct sound component we can speak of an angle of incidence also.

We even go so far as to postulate a so called steady-state condition in which the energy density is said to remain spatially and temporally constant, but this can only be inferred from isolated pressure measurements.

Everyone who has ever seen a sound field displayed on an oscilloscope will know that true steadiness is not typical and can hardly be said to occur in association with real life acoustical problems. It is only a concept.

So much for the sound fields on either side of the partition.

3. SPECIFYING THE PARTITION IN ACOUSTICAL TERMS

The partition itself is a much more complicated entity.

Although we would probably be able to reach an understanding about what constitutes a partition (or panel) in the architectural sense, we would have much more difficulty in identifying a partition in physical-acoustical terms.

Neglecting for a moment such obvious complications as lack of homogeneity, variations in thickness or the presence of holes or discontinuities (such as step-like variations in thickness) we have to assume some simple restraints. We may for example fix length, height and thickness. We may identify mass per unit area. But would this be enough to establish its acoustic behaviour?

Or, rephrasing the question, how many of the partition's physical properties may we ignore for the sake of simplicity when we are investigating its sound attenuating efficiency? It seems obvious that the surface colour will not affect the issue - nor should odour or taste.

But can we reject temperature altogether when it influences the sound velocity and amplitude of atomic oscillation within the material? Or can we reject electrical properties out of hand? What would happen in a partition made of a material with similar properties to the gramophone pick-up crystal? These substances when deformed mechanically (as by the impact of sound wave energy) will generate a voltage. This material could be incorporated into a partition which could turn sound energy into electrical energy, presumably at the enhancement of attenuation.

But these examples are merely proffered to draw attention to the fact that the partition is a complex concept possibly not yet fully specified in acoustic terms.

4. SOME PERTINENT PANEL PROPERTIES

However, our common sense tells us that heaviness is important because the very light weight partitions are noticeably inefficient sound barriers. We also know that frequency or pitch, is important because the high sounds are most readily stopped while low sounds, like thunder, penetrate all except the most attenuating structures.

And if we think of the whole surface of the partition acting like a drum as it vibrates, then it seems likely that the dimensions of the panel might play a part as well. When any movement of the panel occurs, its stiffness must also play some part. Consequently the Modulus of Elasticity and possibly the Poissons ratio are involved as well as thickness.

Energy absorbing processes within the material must affect the amount of energy emerging after transmission, so we need to consider the inherent damping properties of the partition material.

Although our senses are no guide here, it seems likely that the characteristic acoustic impedance of the material might also be important. This constant (the product of density and sound velocity within the material) determines the particle velocity of the wave motion, and thus also the intensity ratio at the transition interface between media.

5. ARE THERE STILL OTHER PROPERTIES INVOLVED?

Already we have moved some distance from the popular conception that mass is the only important factor.

Are there other factors still? There is no clear cut answer to this question yet.

For example, London[JRNBS 42 (605) 1949] has produced a most elaborate and rigorous mathematical analysis of partition behaviour and has developed a transmission formula based on Rayleighs Random Incidence Mass Law modified by an Acoustic Resistance term.

$$TL = 10 \log a^2 - 10 \log \left[\ln \left\{ 1 + \left(\frac{a}{1 + R} \right)^2 \right\} \right] \quad ..(1)$$

where $a = 2\pi fm/2\rho c$

f = frequency in Hz.

m = mass per unit area

ρ = density of wall material

c = sound velocity in the wall

$R = r/\rho c$

The above constant r is the acoustic resistance of the wall material.

The acoustic resistance constant is a value proposed by London which is defined as that constant quantity which makes his formula give the best results!

6. THE MASS LAW AND ITS INHERENT WEAKNESSES

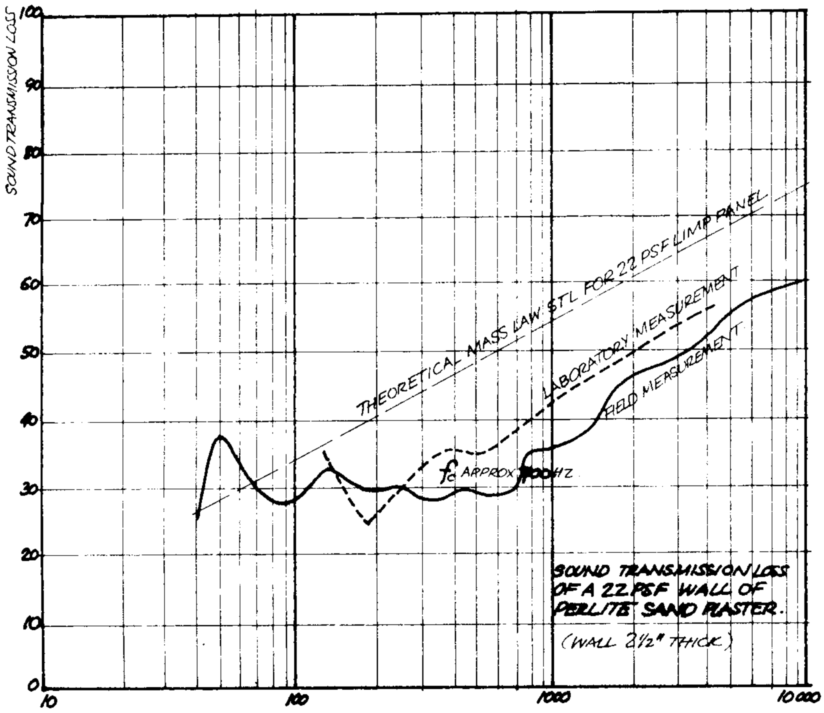
The earliest workers in the study of transmission were quick to recognise the important part that mass (or more accurately the log of mass per unit area) played in transmission and many empirical formulae were produced on this basis. (See dia 1B and dias 2A, 2B).

These were mostly of the form -

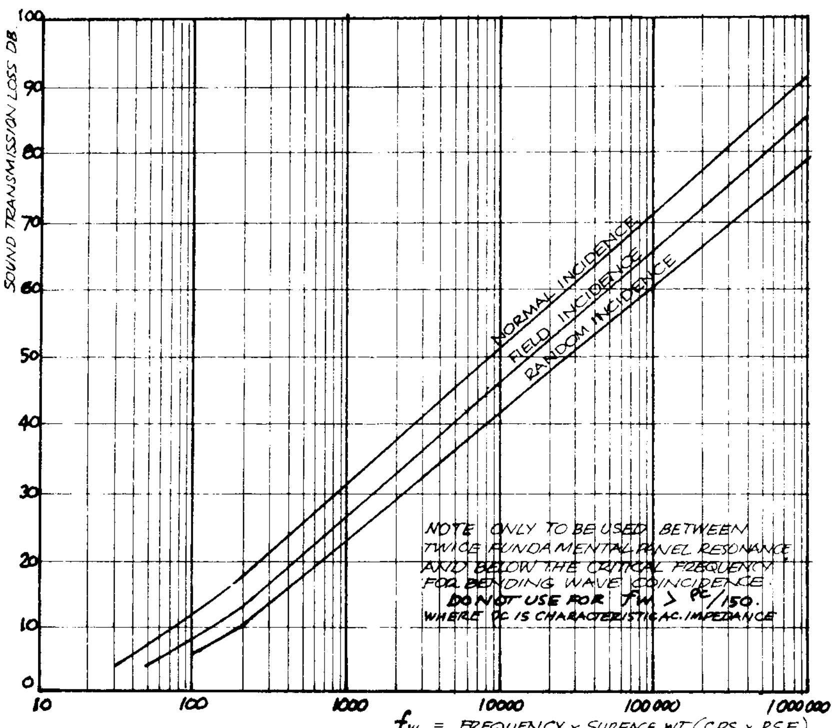
$$TL = 20 \log m + 20 \log f + \quad ....(2)$$

where m = mass per unit area.

f = frequency in Hz.



A MEASUREMENTS ON A SOLID REAL WALL COMPARED WITH MASS LAW.



B THEORETICAL LIMP PANEL MASS LAW TRANSMISSION LOSS.

DIA 1.

and C is a constant term depending on the units used. The value is usually about -30. The formulae were called Mass Laws and they were simple and useful estimators, particularly in comparisons.

The analysis on which the mass law was based was limited to normal incidence of plane waves on a "limp" material but the wisdom of this and other simplifications in the mathematics was not questioned at first because it did provide a very useful "order of magnitude" picture.

7. WEAKNESSES IN THE MASS LAW

Eventually it became apparent that in general most materials tended to depart from the mass law. (See diagrams 1A and 5A, 5B.

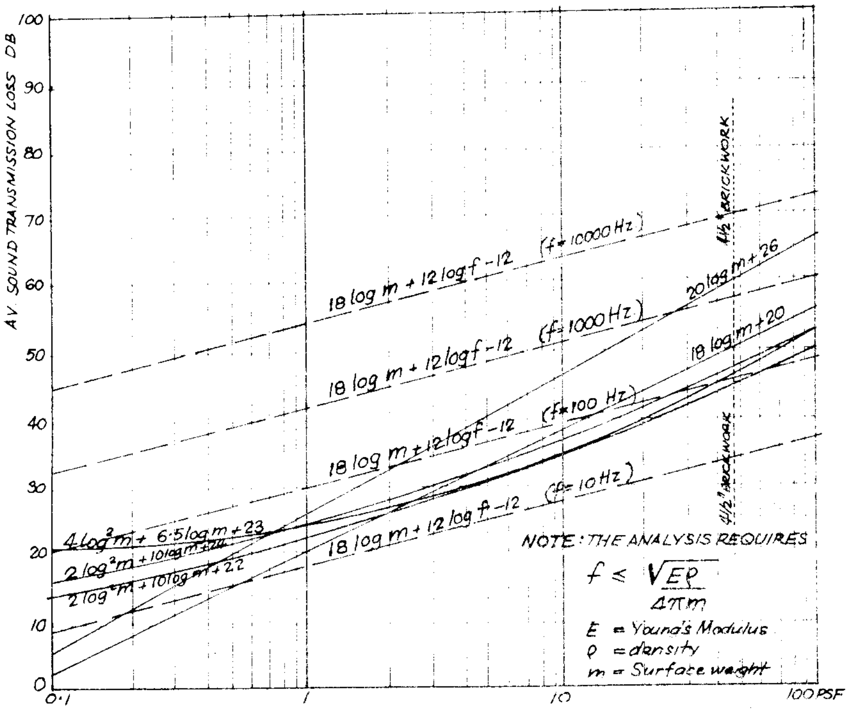
In fact few materials behave as well as this theory predicts; a very few seem to generate greater transmission loss than expected, and many materials display bad dips in attenuation at one or more frequencies.

A. WAVE COINCIDENCE EFFECTS

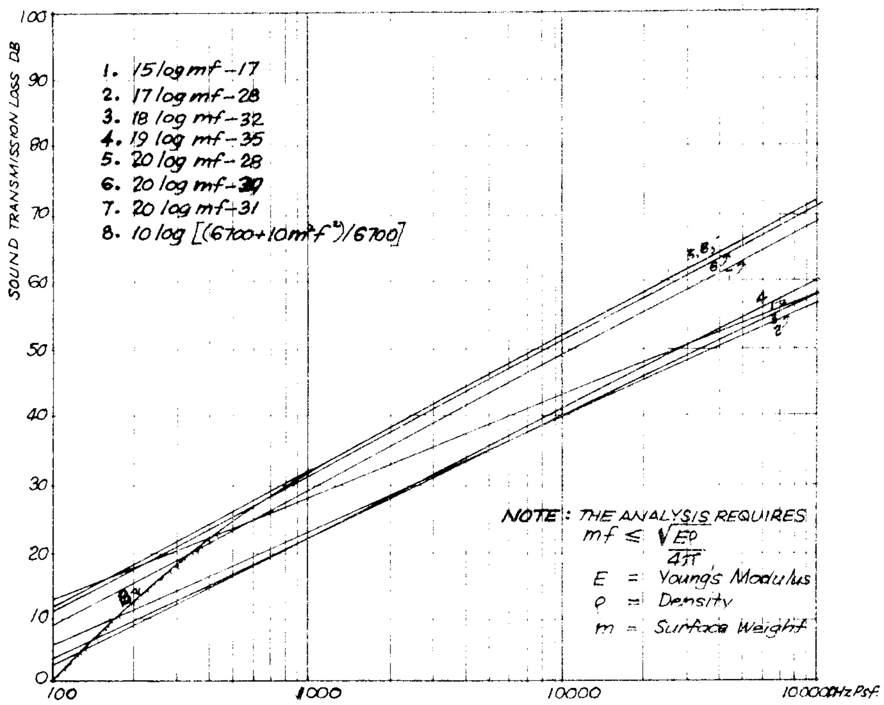
In the early 1940's Cremer in Europe, and other workers in America produced formulae which were useful in predicting the position of the dips - the so-called coincidence effect. The effect was explained as being due to the sudden increase of movement in a vibrating panel when the sound wavelength in air and the bending wavelength in the panel became equal so that the two vibrations "fall into step".

The theory postulates a minimum or critical coincidence frequency - usually the most marked dip, and this frequency fc is calculated as:-

.../ B - 19.



A. FORMULAE BASED ON THE SURFACE MASS ALONE



B. FORMULAE BASED ON THE SURFACE WEIGHT/FREQUENCY PRODUCT

A SELECTION OF PUBLISHED MASS LAW VARIANTS

DIA. 2.

$$f = \frac{c^2}{1.8t} \sqrt{\frac{\rho_p(1-\sigma^2)}{E}} \qquad \ldots\ldots(3)$$

where c = sound velocity in air.

t = plate thickness.

ρ_p = panel density.

σ = Poisson's Radio (usually about 0.3)

E = modulus of Elasticity.

(See diagrams 3B, 4A, 4B).

B. PANEL RESONANCE EFFECTS

Further departures from mass law were noticed in the lower frequency regions and these have been attributed to the existence of whole-panel motion. (See diagram 4A).

If the panel is free to vibrate, such as a drum or wobble-board might, its motion is determined, as already mentioned, by its size and its stiffness.

Obviously there will be many patterns of vibration possible, but in all the possible patterns of movement, there can only be an integral number of waves either across or up and down the plate.

We may calculate the family of frequencies from the formula:-

$$f_{ij} = 0.45t \sqrt{\frac{E}{\rho_p}} \left\{ \left(\frac{i}{l_x}\right)^2 + \left(\frac{j}{l_y}\right)^2 \right\} \qquad \ldots\ldots(4)$$

where f_{ij} = frequency of the (ij) th mode

l_x = panel width

l_y = panel height

i and j are always integers

and E, ρ_p and t have already been defined. (See equation (3) above).

When the sound field contains any of these frequencies, there will be enhanced panel movement and some increase in transmission.

This motion however is not very important except for the very lowest values of i and j. Apart from f_{11} when the whole panel moves as a unit, there will always be a simultaneous backward and forward motion of different parts of the panel: These tend to cancel out any resultant air movement.

C. PANEL DAMPING EFFECTS

On the credit side, better performance than the Mass Law had postulated, was often encountered in the higher frequency regions. (Dia. 3A, dia. 4B).

This appears to be due to the energy losses within the material itself.

On each cycle of deformation energy is absorbed in strain then returned on relaxation.

Because of molecular friction or friction between the particles of composites, some of this strain energy is lost as frictional heat. This rate of energy loss is a characteristic of a material referred to as the Damping Factor.

Most metals have a very low factor, for example steel at 0.0001, while gypsum board has a factor of 0.03. Lead is an exception at 0.015 which would help to account for its comparitively high attenuation factor.

The damping factor may be determined by forcing a sample of the material into vibration and measuring the rate at which the amplitude dies away, when:-

$$\eta = \frac{2.2}{T f_o} \qquad \text{......(5)}$$

where η = Damping factor.

f_o = resonance frequency.

T = time in secs. for 30 dB amplitude drop.

The rate of energy loss increases as the cycling rate increases.

This property of materials has been used by some experimenters (e.g. Kurtze and Watters JASA 31 (6) (59) to produce sandwich panels which display higher transmission loss than either material alone.

The effect of damping on transmission was envisaged by Cremer and extended by Feshbach in the formula -

$$\frac{1}{T} = \left[1 + \frac{\pi f m}{\rho c} \cdot \eta \left(\frac{f}{f_0}\right)^2 \cos\phi . \sin^4\phi\right]^2 + \frac{\pi^2 f^2 m^2}{\rho^2 c^2} \cos^2\phi \left[1 - \left(\frac{f}{f_c}\right)^2 \sin^4\phi\right]^2 \qquad \ldots\ldots(6)$$

where T = transmission factor.

η = damping factor.

f = sound frequency transmitted.

f_c = critical coincidence frequency.

m = mass per unit area.

ϕ = incidence angle.

ρ = density of partition.

It will be realized that the effect of the damping factor must increase with increasing frequency according to the first term, and in fact the TL slope above the coincidence region is nearer 10 dB per octave than the theoretical 6 dB per octave (See dia. 4B)

8. UNIFYING THEORIES OF BROAD BAND TRANSMISSION

So many transmission mechanisms intrude into the simple mass law behaviour, that it is obviously necessary to find a less complicated and unifying picture of the process.

Watters in a paper in JASA 31 (7) 1959 observed that the transmission behaviour of a panel could be roughly divided into three principle regions - 1. an upward slope of 6 dB per octave in the low frequency end, where something like mass law behaviour exists:

2. a steeply rising curve sloping at approximately 10 dB per octave in the higher frequencies and 3. a middle region of great irregularity which is beset by coincidence dips.

Watters called this central region the Plateau. (See dia. 1A and dia. 3A).

His studies enabled him to estimate this plateau height in dB of transmission loss, and to express its length in octaves. His formulae for the plateau levels are:

$$TL_p = 60 + 30 \log m - 10 \log B + 2 \log \eta \qquad \ldots\ldots\ldots(7)$$

and

$$TL_p = 71 + 30 \log \rho - 10 \log E + 2 \log \eta \qquad \ldots\ldots\ldots(8)$$

where TL_p = plateau level in dB.

m = surface weight per unit area.

B = Bending stiffness of wall about neutral axis.

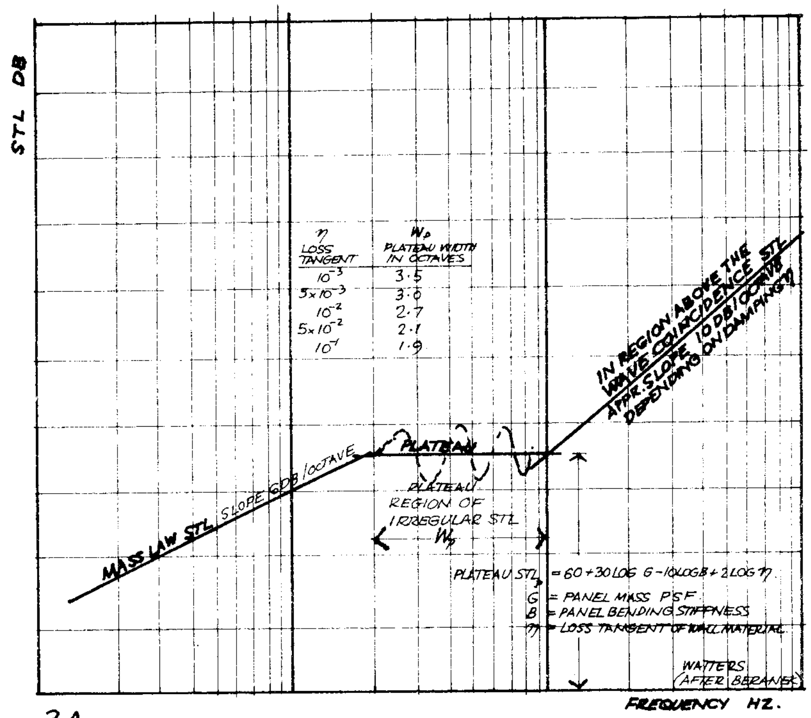
η = loss tangent of the wall material (damping factor)

E = modulus of Elasticity.

The plateau width is tabulated as a function of

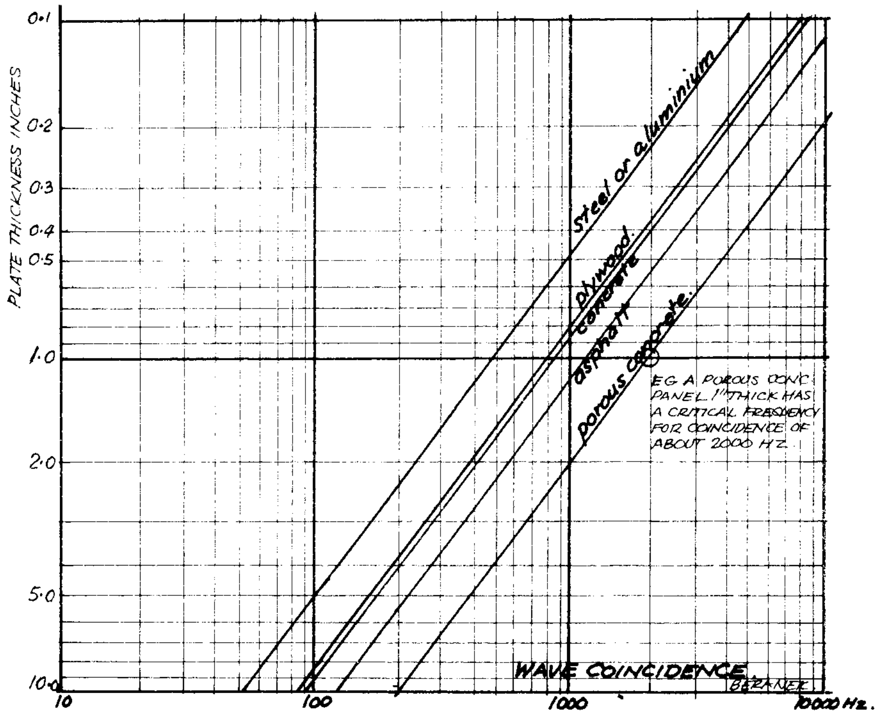
Damping factor η	Plateau width Octaves
10^{-3}	3.5
5×10^{-3}	3.0
10^{-2}	2.7
5×10^{-2}	2.1
10^{-1}	1.9

To use Watters graphical method for estimating transmission behaviour, it is customary to plot TL (in dB) to a linear scale on the vertical axis while the abcissa is a logarithmic plot of frequency.



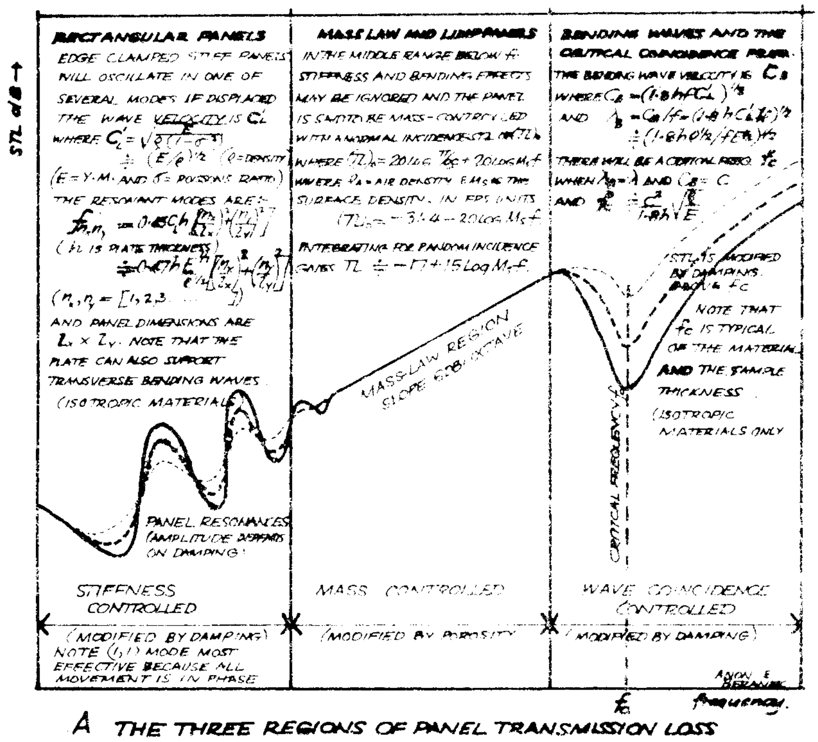
3A IDEALISED SHAPE OF STL CURVE FOR SOLID REAL WALLS.

NOTE: THE EXISTENCE OF A REGION OF IRREGULAR BEHAVIOUR IN THE REGION OF THE COINCIDENCE DIP MAKES IT UNDESIRABLE TO USE DOUBLE SKIN CONSTRUCTIONS OF MATERIALS OF SIMILAR CRITICAL FREQUENCIES.

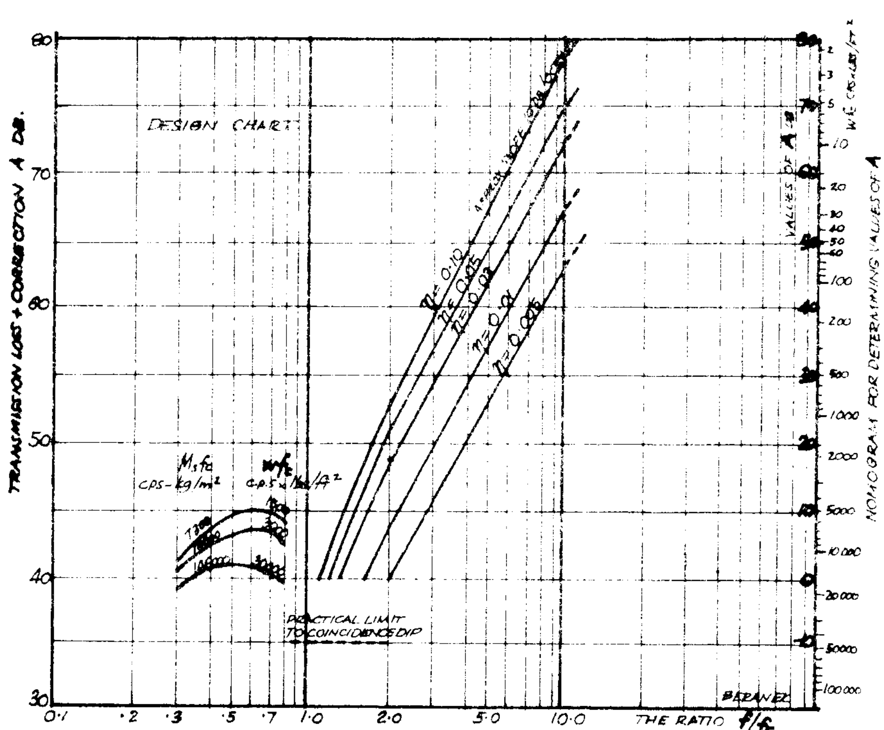


3B CRITICAL FREQUENCIES AGAINST THICKNESS - VARIOUS MATERIALS

DIA 3.



A THE THREE REGIONS OF PANEL TRANSMISSION LOSS



B BEHAVIOR IN THE OCTAVES BEFORE & AFTER COINCIDENCE

DIA 4.

The first step is to use to common random incidence mass law formula -

such as:- $$TL = 10 \log\left[\left(1+\left(\frac{\pi f m}{\rho c}\right)^2\right] + 6 \text{ dB.} \qquad \ldots(9)$$

(see formula 6 for meaning of symbols)

This produces a straight line sloping upwards from the left. (See dia. 1B).

If the plateau is then plotted as a horizontal line at a level calculated from Watters formulae (7) or (8), it will intersect the slope at some frequency.

At the intersection, read the corresponding frequency and extend the plateau width as octaves of this frequency as tabulated by Watters.

The final tail is then plotted at a slope of 10 dB per octave from the high frequency end of the plateau. (See dia. 3A).

9. THE BERANEK - WATTERS METHOD

Perhaps Watters' method is an over simplification. Beranek adds some variations; he accentuates the coincidence dip and gives a special graphical analysis of the region between 0.3fc and 3fc.

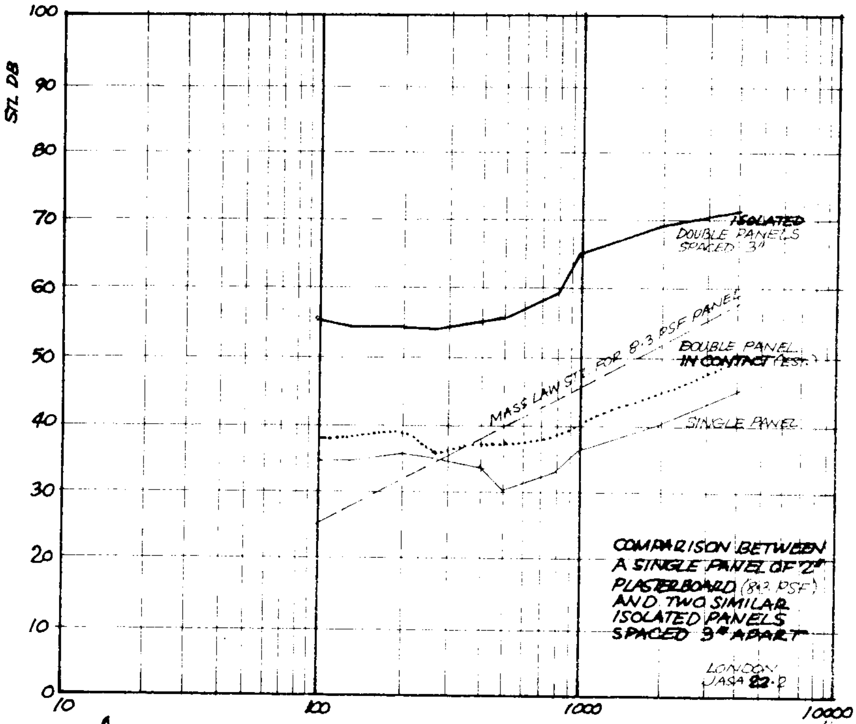
A coincidence dip of 15 dB is not uncommon in this region.

Of course fc is calculated as -

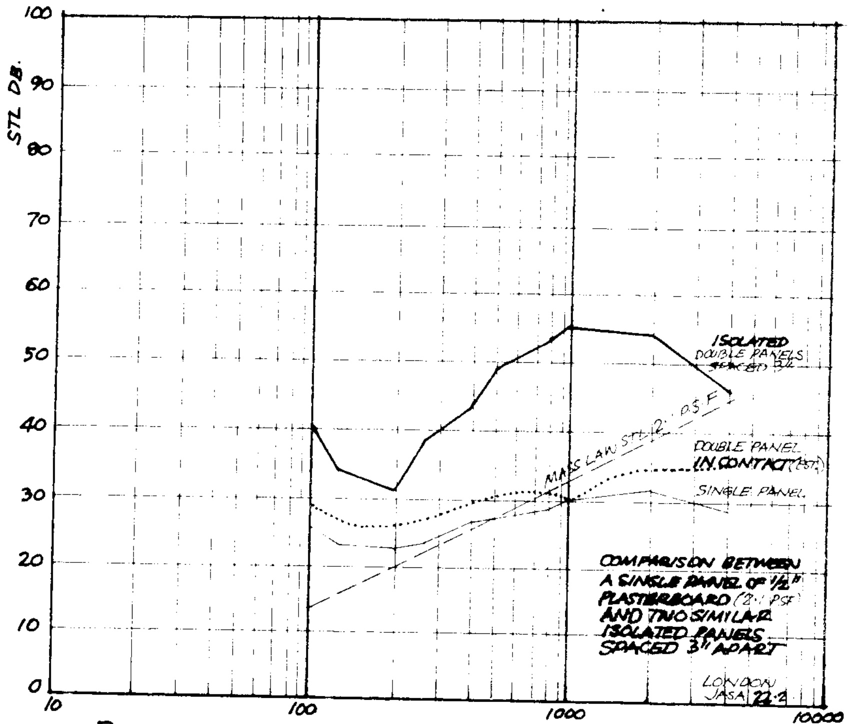
$$f_c = \frac{c^2}{1.8t}\sqrt{\frac{\rho_P(1-\sigma^2)}{E}} \qquad \text{see equation 3.}$$

He also suggests attention to panel resonances (see formula (4)) and expects dips at the first few modal frequencies.

At the present "state of the art" we can go very little further with single panel transmission.

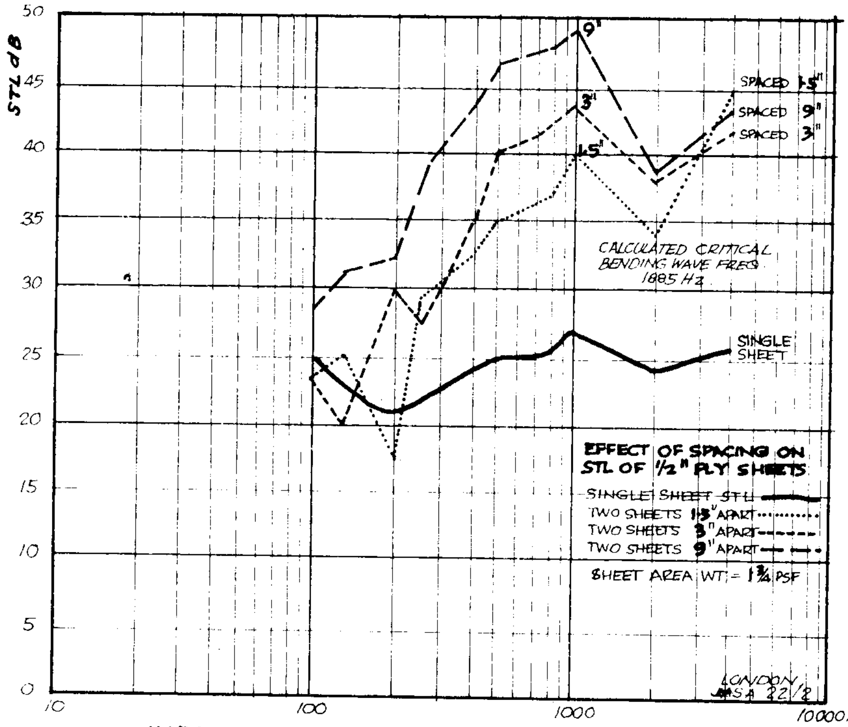


A. ISOLATED SPACED DOUBLE PANELS

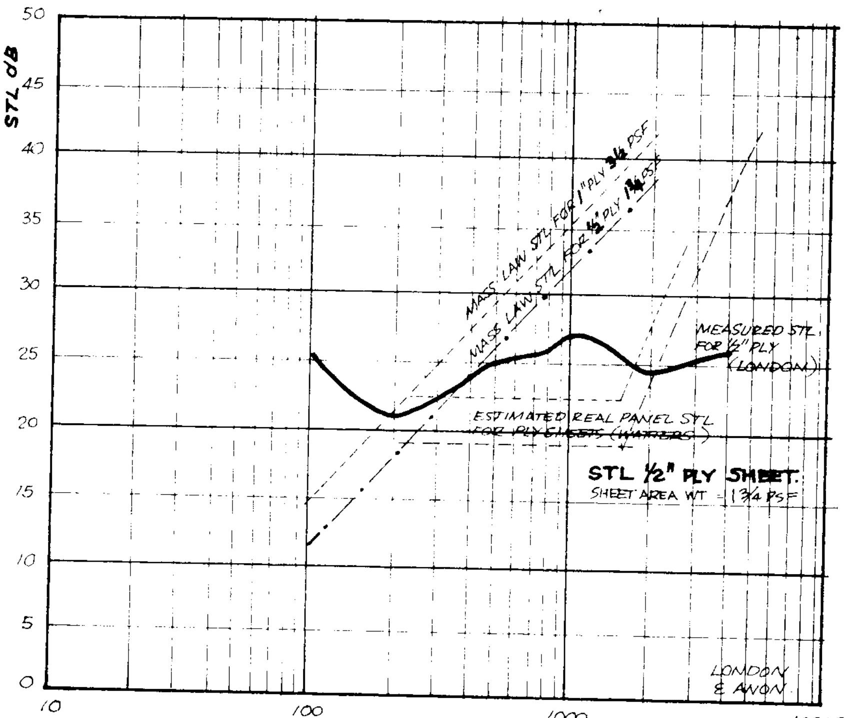


B. ISOLATED SPACED DOUBLE PANELS

DIA 5.



IMPROVEMENT IN STL DUE TO INCREASING SPACING
ISOLATED DOUBLE PANEL CONSTRUCTION



VARIATION BETWEEN THEORETICAL & REAL PANEL STL

DIA 6.

10. DOUBLE PANEL TRANSMISSION LOSS - LONDON

In the double-panel case, the situation is even less satisfying. There is no useful theory available.

London JASA 22 (2) 1950 has done extensive work in which he firmly establishes the superiority of the double panel construction, but the coupling factor remains elusive.

He demonstrates good correlations between theoretical and real panel behaviour and found a combined TL of as much as 1.8 times the TL of a single panel. But he does not produce a tractable equation. One of his transmission calculations involved 40 pages of work to produce a single point on a graph.

His theoretical approach again depends on the convenience of a postulated acoustic resistance term, but in this case, the resistance varies with frequency to achieve a good correlation between theory and measurement. Some double panel examples are plotted on diagrams 5 and 6.

11. FUTURE PROSPECTS

Can we look to further development, and, eventually a simple all-frequencies, unified transmission equation for single or multi-panel partitions?

Most probably not, already the uncertainties of edge fixing variations, non-linear panel behaviour and lack of homogeneity in the sound field, tend to hide the fine structure of the panel's response in a mass of irrelvancies.

The best conceivable hope for the future probably lies in an extension of the sorts of simplification proposed by Watters or Beranek, but, one hopes, modified to give a more accurate evaluation of the depths of the various dips.

However, this is not to deny that computer analysis is able to subdue London's sort of equations. No doubt this approach will lead to valuable refinements and eventually a tabular system for general use to cover homogenous materials.

12. MORAL

In the meantime, whenever the situation is critical, it is wisest to make measurements on a correctly mounted model to supplement the calculated transmission behaviour.

SUMMARY: Despite widespread efforts during the last half century, a simple comprehensive transmission equation adapted to all practical situations has not yet been developed. The article describes some of the many factors involved - such as mass, panel resonances due to size and stiffness, bending wave coincidence dips, inherent damping, sandwich damping. The limited value of the many Mass Law variants is highlighted. The article concludes with a glance at double panel behaviour and future prospects.

BIBLIOGRAPHY

KINSLER & FREY: "Fundamentals of Acoustics" WILEY.

BERANEK (Ed.) "Noise Reduction" McGRAW HILL.

HARRIS (Ed.) "Handbook of Noise Control" McGRAW HILL.

JOURNAL OF THE ACOUSTICAL SOCIETY OF AMERICA (MONTHLY).

PAPER C.

THE ROLE OF LABORATORY AND FIELD TESTS IN DETERMINING PARTITION PERFORMANCE.

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THE ROLE OF LABORATORY AND FIELD TESTS IN DETERMINING PARTITION PERFORMANCE

GENERAL

Measurements of sound insulation may be carried out for a number of reasons.

1. Laboratory tests under carefully standardised conditions allow fair comparisons to be made of competing materials and systems.
2. Laboratory tests assist in development work, by providing reliable indications of relatively small changes in performance.
3. Field tests may allow a judgment to be made as to whether the requirements of a tender have been met.
4. Field tests provide a measure of the sound reduction between two positions in a building, for comparison with criteria established to meet particular requirements.

RECOMMENDED TEST PROCEDURES

Procedures for laboratory testing have been standardised in such a way that the results for given materials or systems should be comparable wherever carried out.

Briefly, the test involves the use of two rooms, with the partition under test located between them. Noise is created in one room, measured in both, and the difference in level taken as an indication of the sound insulation offered by the specimen. Diffuse sound fields are aimed at in each of the rooms.

The International Standards Organisation (I.S.O.) has published Recommendation R140, based on the earlier British Standard BS 2750, setting out the basic principles to be observed in this kind of test. The American Society for Testing Materials (ASTM) has also produced and kept up to date an elaborate Recommended Practice E90-66T. There is agreement in all essentials between I.S.O., B.S. and A.S.T.M. Up to date there is no Australian

Standard, though one is in preparation.

The position with regard to field tests is much less satisfactory. Certainly, some standardisation of test procedure has been achieved, but the dependance of results on particular local circumstances makes their interpretation difficult.

I.S.O. and B.S. provide little guidance here, merely setting down a series of recommendations which virtually assume laboratory-type conditions. A.S.T.M., on the other hand, has adopted what appears to be a more realistic approach, and defines a number of categories within which useful tests may be performed. It also states clearly that reliable tests cannot always be made, and that it is better that this should be faced honestly than to quote undependable results.

ACCURACY AND PRECISION

In acoustic measurements of this type a statement of accuracy, for either laboratory of field testing, presents some difficulty because the theory of airborne sound transmission through barriers of solid material is somewhat arbitrary and certainly incomplete.

However, as with any other measurements it is absolutely essential that some estimate of precision shall be made, if the test results are to have practical value, whether obtained in the laboratory or in the field.

(a) Precision. By this is meant the degree of repeatability of the measurements.

The test consists, essentially, in obtaining the average sound pressure in each of the two rooms, this pressure varying from point to point and from moment to moment.

A first requirement for adequate precision is that the equipment be capable of operating with sufficient stability during the time taken to make the measurements. With first class modern equipment and care in maintenance, errors due to the instruments need not exceed about ± 0.1 dB, and can certainly be held within $\pm \frac{1}{4}$ dB.

A second requirement is that sufficient observations shall be made. The actual number needed depends on the variability of the local sound pressures within the rooms. This number may be up to 12 observations at the lowest test frequency, falling to only 3 at the higher frequencies. The techniques of statistical analysis are used to determine, for any particular conditions, the appropriate number of measurements.

(b) Accuracy. While there are no direct means of estimating the absolute accuracy of sound transmission loss measurements, nevertheless certain factors are known to affect it.

1. Calibration of the measuring equipment. This involves reference to various national standards such as length, frequency, voltage attenuation, and implies that the equipment can hold the calibration over a sufficiently long period. Frequent checks against sub-standards are needed to ensure that operation is being maintained as required.

2. The number of mechanical modes of vibration in the test specimen. In most real situations there are many such modes in partition installations, even at the lowest sound frequencies. Thus the test specimen must be large enough to give proper representation. One recommendation has been that the minimum lateral dimensions of the test specimen shall be in excess of the wavelength of the free flexural waves (transverse waves with particle motion perpendicular to the plane of the specimen) at the lowest test frequency. Unfortunately, many factors govern the length of such waves, and the actual dimension may vary from specimen to specimen. The size currently regarded as adequate by leading laborat-ries is about 8 or 9 feet for the shortest dimension. A size commonly used is 9 feet by 14 feet, which fits in with a ceiling sound insulation test specification, used widely in U.S.A.

3. Uniformity of exitation of modes of vibration in the specimen. The test is based on the assumption of complete uniformity, resulting from fully diffuse sound in the source room. Under such conditions the specimen would be exited by waves

incident from all possible directions. In the absence of this condition, some modes of vibration in the specimen may be exited more strongly than others, so that the "coincidence effect" may appear to a greater or lesser extent than it would otherwise ("coincidence" occurs when the angle of incidence of the sound wave is such that the projection of its wave length on the specimen is equal to the length of flexural waves in the specimen. A pronounced weakness in sound insulation occurs under these conditions).

4. Terminating conditions around the perimeter of the specimen (edge clamping). While further investigations are required, there is some evidence to suggest that performance is affected in some degree by this factor.

ROLE OF LABORATORY AND FIELD TESTS

Laboratory tests clearly have a most important role in characterising materials and constructions which offer sound control in buildings.

Field tests, on the other hand, must be regarded as playing a rather mixed role. Under the best conditions their precision can match that obtainable in the laboratory, and they can thus enable valid conclusions to be drawn regarding actual partition performance. Under the worst conditions, no field test can be carried out at all. In a number of intermediate situations, field tests are possible but with somewhat reduced precision.

It must also be considered that in order to obtain precision in field measurements of the same order as those from laboratory work, a costly operation is involved. Bulky and expensive equipment must first be transported and set up. Then, quite a few hours are required for the actual measurements. In addition, a necessary supplementary check (test for flanking) requires the transport and fixing of an extra barrier over the test partition.

If field tests are not performed with this degree of thoroughness the results will certainly fall far short of laboratory precision. This may not be serious for some purposes, provided the degree of uncertainty is appreciated. However, great care must be exercised when it is proposed to use the results to prove or disprove compliance with specifications.

Experience has shown that constructions whose performance under laboratory conditions is known usually provide a field result a few decibels lower. There are three main reasons thought to account for this discrepancy:

1. Existence of flanking paths in the real building. Such paths are, of course, carefully eliminated in the laboratory.
2. Inadequate diffusion. There is a body of evidence to show that relatively poor diffusion, particularly in the source room, may give lower ratings for sound insulation.
3. Mounting conditions. These may differ in the field from those applying at the time of the laboratory test. It is not definitely known in which direction the sound insulation may be affected, however.

It should not be concluded from the foregoing that field tests are affected by so many factors that it is a waste of time even to attempt such measurements. Given sufficient care in assessing the particular conditions prevailing, and with a clear understanding of the purpose of the measurements in each case, then useful work is possible.

Because of the complexities involved in tests for sound transmission, many of the details have been relegated to an Appendix, attached to this paper.

APPENDIX

TEST PRINCIPLES

Laboratory Tests

To quote ASTM Tentative Recommended Practice E90-66T (Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions).

> "The sound insulating property of a partition element is expressed in terms of the sound transmission loss. The procedure for determining this quantity is to mount the test specimen as a partition between two reverberation rooms, one of which, the source room (Room 1) contains one or more sound sources. The rooms are so arranged and constructed that the only significant sound transmission between them is through the test specimen. Then the transmission loss is given by:
>
> $$TL = NR + 10 \log S - 10 \log A_2.$$
>
> where
>
> log = logarithm to the base 10
> TL = transmission loss
> NR = noise reduction* between the two reverberation rooms.
> S = area of sound transmitting surface of test specimen.
> A_2 = total absorption of the receiving room (Room 2) expressed in units consistent with S.
>
> Since 10 log S is easily determined, the problems of measurement are associated with the sound reduction and 10 log A_2".

The value of A_2 is normally obtained from the measured reverberation time of the room.

*In American standard terminology the term "Sound Reduction" is used in preference to "Noise Reduction" (NR).

APPENDIX

A sketch may serve to illustrate the arrangement described on Page C - 6.

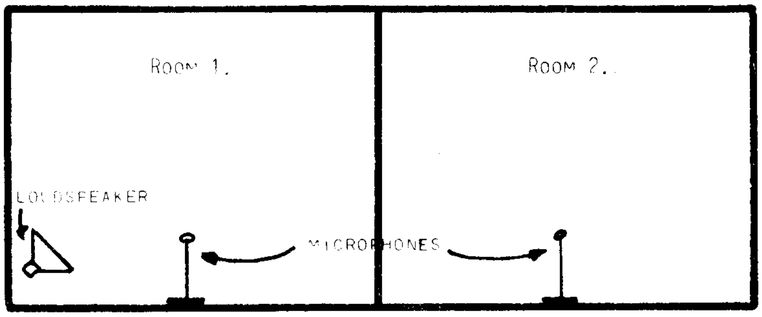

FIGURE 1.

SOUND TRANSMISSION LOSS MEASUREMENT

The loud speaker in Room 1 is the source of sound. The sound pressures are measured by microphones in each room, the difference between them being the noise reduction (NR).

The two correction terms in the formula (10 log S and 10 log A_2) make allowance for the specimen area and the sound absorption in the receiving room. In this way, tests carried out in various laboratories with different areas of specimen and room volumes, are made comparable.

To quote further from ASTM E90-66T:

> "Airborne Sound Transmission Loss (TL) of a Partition.
>
> The ratio expressed in decibels, of sound power incident on the partition to the sound power transmitted through and radiated by the partition. The unqualified term denotes that the incident field is diffuse".
>
> "Noise Reduction (NR) Between Two Rooms. The difference between the rms time-space-average sound pressure levels produced in the two rooms by a sound source in one of them."
>
> "Diffuse Sound Field. A sound field composed of many randomly oriented waves with equal probability of energy

flow in every direction. It follows that there is no correlation between instantaneous sound pressures at widely separated points."

"Reverberation Room. A reverberant room specially designed to facilitate the production therein of a diffuse sound field."

Certain assumptions which underly laboratory test procedures should be mentioned. They are:

1. That diffuse conditions in the test rooms result in specimen behaviour which is a fair representation of actual field situations.
2. That a measure of sound power, which forms the basis of the laboratory method, can properly be obtained from sound pressure measurements.
3. That the type of sound introduced into the source room, and the level of that sound does not effect the applicability of the test results to real situations.

Field Tests

There have been at least two approaches to the problem of field testing.

On the one hand, ISO has laid down a recommended procedure which virtually assumes the possibility of finding laboratory conditions in the field, when valid tests can, of course, be carried out. It must be presumed, though it is not clearly stated, that if such conditions do not exist, then tests cannot be made. No alternatives are offered.

On the other hand, ASTM, with what would seem to be greater realism, has recommended a number of procedures, one of which is in line with that of ISO. Others are designed to cope with different field situations. ASTM also clearly warns against attempting to carry out tests under certain unfavourable conditions.

To quote ASTM, Tentative Recommended Practice E336-67T (Measurement of Airborne Sound Insulation in Buildings).

APPENDIX

> "Measures of Acoustical Insulation This recommended practice establishes uniform procedures for the determination of field transmission loss, that is, the airborne insulation provided by a partition already installed in a building. It also establishes in Appendix A1 a standard method for the measurement of the noise reduction between two rooms in a building, that is the difference in average sound pressure levels in the rooms on opposite sides of the test partition. Where the test structure is a complete enclosure out-of-doors, neither the field transmission loss nor the noise reduction is appropriate; instead a method is established for determining the insertion loss, also in Appendix A1".

Thus, three quite different situations are visualised as being likely to occur. In the first, where "field transmission loss" is able to be obtained, the situation resembles that of the test laboratory (though procedures are given later in the recommended practice for other non-laboratory type situations). In the second situation, procedures are laid down for the measurement of "noise reduction", where this is all that is required. Noise reduction is the simple difference in space-average sound pressure level between two enclosed spaces, without adjustments for absorption or transmitting area. The third situation is that where only one enclosed space is available for sound pressure measurement, and special procedures become necessary.

In all cases where "field transmission loss" is being measured, a supplementary test must be performed to demonstrate the absence of any significant flanking transmission. The test frequencies to be used are 1/3 octave bands for the laboratory-type situations, but the use of 1/1 octave bands is permitted for the tests of field transmission loss under non-laboratory conditions.

Laboratory Tests

A considerable amount of electronic equipment and a very thorough checking routine are essential for reliable measurements of sound insulation.

APPENDIX

There are two main systems of measurement in current use in Australia and these may be called the "switching" system and the "two-train" system. The block diagrams in Figures 2 and 3 show the arrangement of equipment.

In both procedures a continuous signal of filtered random noise is fed to the loud speaker in the source room.

In the "switching" system, the sound pressure is noted first in one and then the other room, by switching the appropriate microphone onto the indicating system, (usually a microphone amplifier, a band pass filter set and then a meter and a level recorder in parallel). A precision variable attenuator, inserted in the source room microphone signal line, is adjusted until the electrical outputs of the two microphone channels are equal. Provided the sensitivities of the two microphones are equal, then the attenuator reading indicates the sound reduction between the two rooms for the particular microphone positions and frequency band.

In the 'two-train' system, the sound pressure in each of the two rooms is observed simultaneously. Once again, the signal from the source room microphone is attenuated until it is equal to that from the receiving room microphone.

Each system has advantages and disadvantages.

The "switching" system:

1. requires less equipment than the "two-train" system,
2. is subject to errors from short term variations in the level of signal fed to the loudspeaker,
3. eliminates errors due to drift in the measuring system performance (except the microphones).

APPENDIX

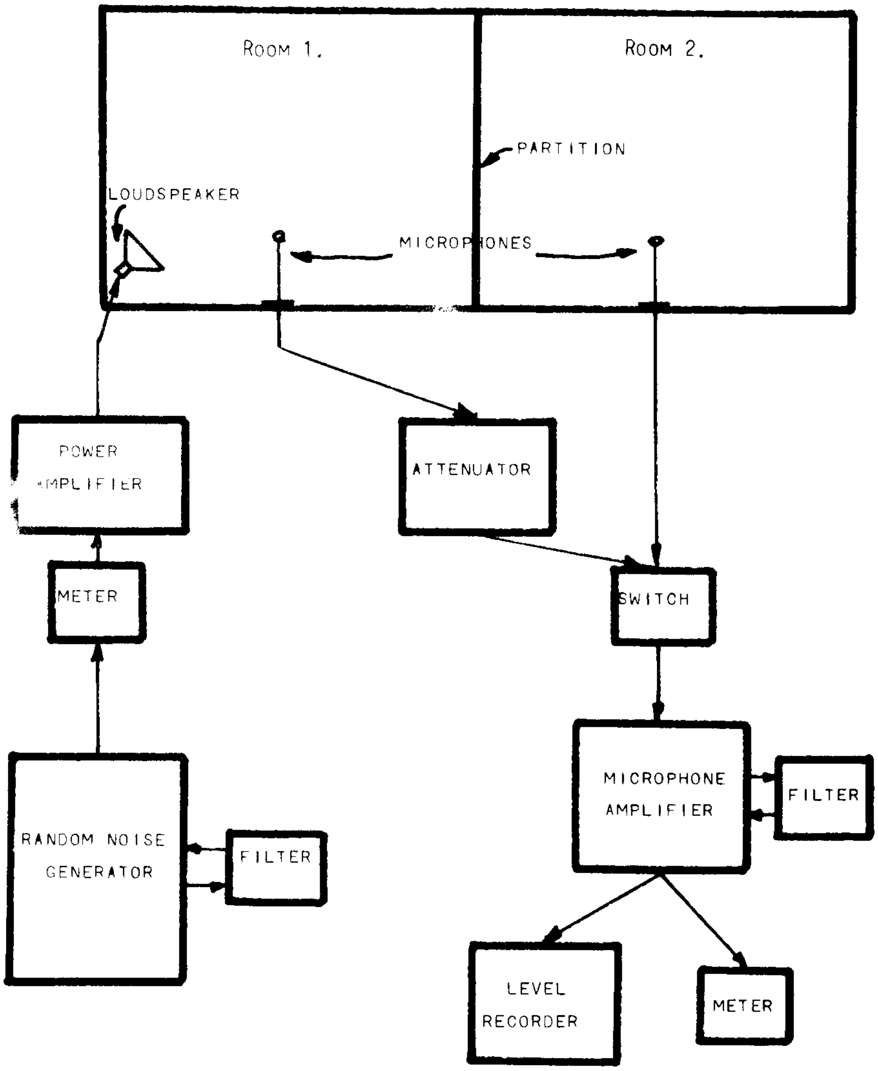

FIGURE 2. "SWITCHING" SYSTEM

EQUIPMENT LAYOUT

APPENDIX

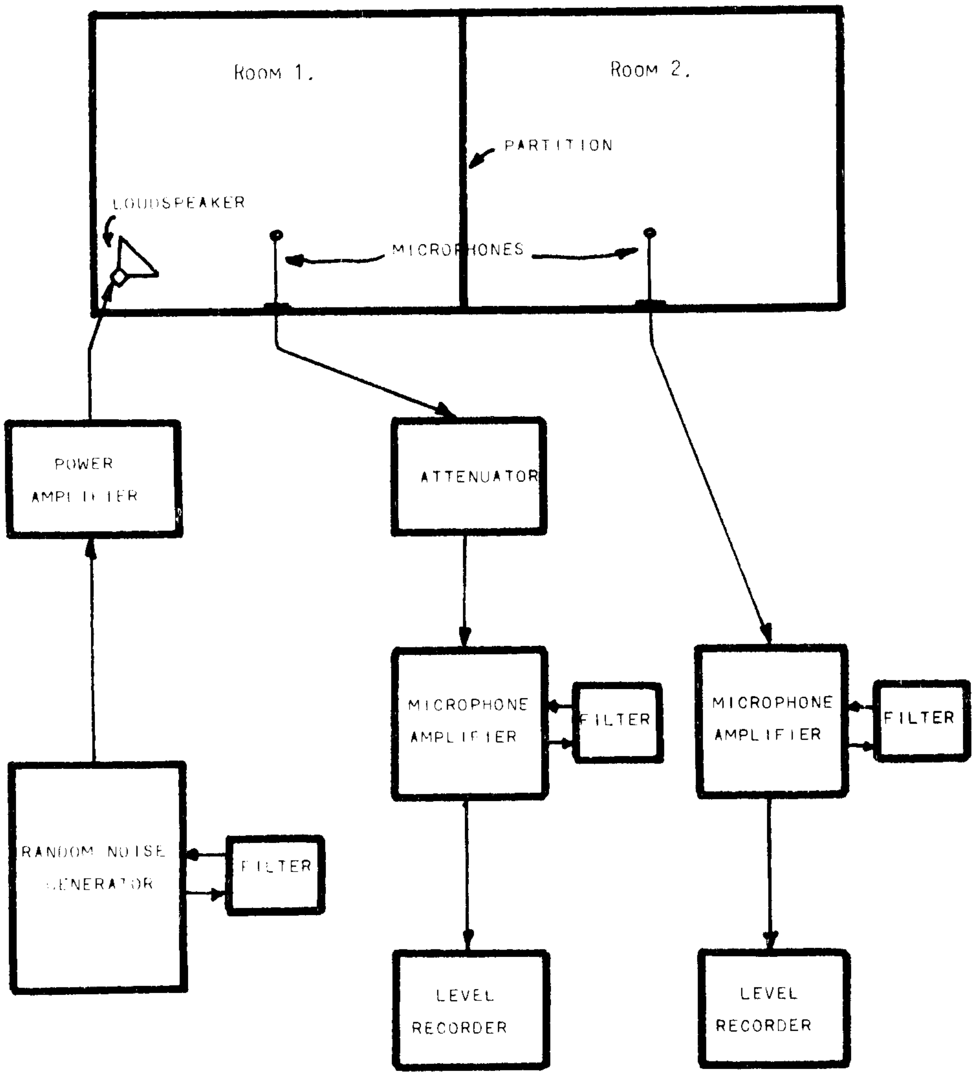

FIGURE 3, "TWO TRAIN" SYSTEM

EQUIPMENT LAYOUT

APPENDIX

The "two train" system:

1. requires more equipment than the "switching" system, but as a result enables a testing speed at least twice as fast to be obtained,
2. eliminates errors from short term variations in the level of signal fed to the loudspeaker,
3. is subject to errors due to drift in the measuring system performance.

Note that the errors, to which these systems are liable, can be avoided by the taking of suitable precautions, and both methods are capable of giving the precision required in these tests.

In either system a first essential is to check the relative sensitivities of the two microphones at frequent intervals. In the "two-train" system this sensitivity check must, of course, include the whole measuring set-up, right from the microphone to the level recorder. Procedures for carrying out these checks can readily be devised. Signal to noise ratios must also be checked for each measurement, to eliminate electrical breakdowns as a source of error.

In addition to the checks applied during the actual performance of measurements, other calibrations are required from time to time. These can be listed as follows:

a) Frequency response of microphone and microphone amplifier.
b) Band pass filter sets - pass bands.
c) Attenuators, including electrical flanking.
d) Level recorders, including range potentiometers.
e) Pistonphone.

It is not possible to state the accuracy of measurements of sound transmission loss because we lack any absolute method for comparison. The best that can be done is to estimate the precision, i.e.

the repeatability, of each test, on some rational basis. Here, the procedure given by ASTM, in E90-66T, seems a useful guide. A statistical calculation is recommended, so that precision of the mean value of the sound pressures in each room (at each test frequency) is known. It is required by ASTM that a sufficient number of sound pressure level measurements shall be taken so that the mean value of the differences between sound levels (i.e. the sound reduction) is known to within ± 1 dB (at 90% confidence) for all frequencies except the lowest, where a tolerance of ± 2 dB is permitted. When the same order of precision is able to be maintained in the measurement of the correction for sound absorption in the receiving room, the overall test precision, at 90% confidence, becomes ± 1.4 dB for all frequencies except the lowest, where it is ± 2.8 dB.

Direct experience, in at least one Australian laboratory, has shown that the ASTM requirements can be met. The lowering of test precision only at the one frequency is of course quite arbitrary. In fact there is a gradual falling off but this very rapidly increases between the two lowest test frequencies normally used, 160 Hz and 125 Hz.

Field Tests

The equipment and procedure for field tests will depend, of course, upon just what purpose the tests may have.

When conditions demand and permit, the same arrangements as are used in the laboratory would be employed. Tests would be carried out in 1/3 octave bands in the range 125 Hz to 4000 Hz.

If the recommendations of ASTM are followed for certain "non-laboratory" type situations, then 1 octave bands would be used, in place of the 1/3 octaves. Otherwise the equipment and procedure would be similar to that used in the laboratory.

Rough indications of sound reduction may be obtained by use of a hand held sound level meter, the source being provided by tape recorded bands of noise. Receiving room absorption may also be measured approximately by using a calibrated noise source. This procedure eliminates the need for an expensive and bulky high speed level recorder, though with a considerably reduced precision.

PAPER D.

THE ROLE OF ABSORPTIVE MATERIALS IN SOUND INSULATION AND NOISE REDUCTION.

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THE ROLE OF ABSORPTIVE MATERIALS IN SOUND INSULATION AND NOISE REDUCTION

1. INTRODUCTION

For the purpose of sound insulation, or noise reduction, sound absorbent materials and structures may be described as those which have the property of absorbing a substantial fraction of the energy of sound waves which strike their surfaces. They may be used in six main ways:-

as surfacing for walls, floors and ceilings,

as individual, suspended units,

as surfacing for barriers, partitions and enclosures used for shielding or confining the noise from specific sources,

as linings to reduce noise transmission through ducts or small passages....

as internal linings for partitions used for confining the noise of specific sources,

as vibration 'cushioning' used for confining structural-borne noise paths.

The last two named applications usually involve considerations of noise paths other than the airborne noise path and so may involve another slightly different property, fortunately possessed by some sound absorbent materials, this being the ability to dissipate or damp the vibrational energy of solid materials they contact. The main subject of this paper will be the effect of absorbers on the airborne noise path. Generally speaking, the primary function of sound absorptive materials in noise control is to counteract the undesirable effects of sound reflection by the hard, rigid, interior surfaces which these sound absorbent materials cover or replace. Excessive reflections may increase the annoyance of the room occupants by:

a) increasing the sound pressure level,

b) prolonging noise through reverberation,

c) causing noise to spread with little attenuation throughout the room.

Since sound absorptive materials are used as finished surfaces in many types of rooms, they must satisfy a number of structural and architectural requirements as well as provide usably-high sound absorption characteristics.

2. REFLECTION AND ABSORPTION OF SOUND WAVES

Figure 1 illustrates a typical sound source radiating sound waves outwards in all directions (not necessarily equal) from the source. When the sound waves encounter an obstacle or a surface, the direction of travel is changed so that they are reflected. As indicated in this figure, the reflection of sound, from a surface large in comparison with the wave length, follows the same laws as the reflection of light from a mirror.

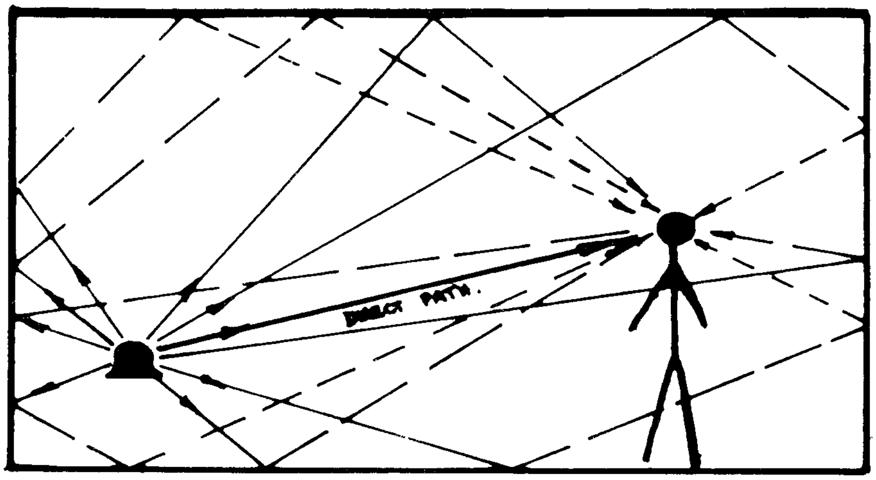


FIG. 1... The DIRECT and some of the REFLECTED Sound Paths between a Noise Source and an observer in the same room room or space.
(Reflected saves are shown dotted, Note Direct Path).

If the reflecting surface is completely impervious to air and also perfectly rigid, there will be negligible loss of energy due to reflection and the reflected wave will produce the same pressure at any given point as it would have if it had continued on in the original direction. However, no physical surface is a perfect reflector, but will either be set in motion by pressure of the incident sound waves, or, if it has a porous structure, will allow continued travel of the wave into the body of the material. If either of these processes results in setting up of frictional forces, or in the transmission of sound waves into a space on the opposite side, the reflected waves will have less energy than the incident waves and we say that part of the incident energy is 'absorbed' by the surface.

The fraction of energy not reflected by a material or surface when a sound wave is reflected from it, is called the 'Sound Absorption Coefficient' of that material. The Sound Absorption Coefficient of a material depends on the nature and mounting of the material itself, on the frequency of the sound, and on the angle at which the sound wave strikes the surface of the material.

Interior finish materials such as concrete, hard plaster, glass, masonry, wood and hard flooring materials are sufficiently rigid and non-porous as to be nearly perfect reflectors at most frequencies of interest, having Sound Absorption Coefficients generally less than 0.05. Thick porous materials such as carpets, drapes, upholstered furniture, sound absorbent ceiling constructions and even personnel may have Sound Absorption Coefficients in most frequencies in the order of 0.50 to 1.00.

The two main methods of measuring the Sound Absorption Coefficient of materials are the Reverberation-Chamber method and the Impedence-tube method. The Reverberation-Chamber method is generally preferred and provides results more typical of the 'as-installed' conditions.

In order for a material to absorb sound energy it is necessary that the surface of the material be relatively transparent to sound waves and that means be provided for the vibratory energy of the waves to be partially or fully transformed into heat energy by friction. Acoustical transparency may take the form of an exposed surface of a highly porous material, a perforated board or sheet used as a facing over a porous material, a light flexible air-impervious membrane, or integral mechanical perforations or fissures openings into the body of a porous material, the external surface of which may be impervious. When a sound wave enters a porous material, the amplitude of vibration of the air molecules is progressively damped out by friction against the surfaces of the fibres or particles forming the pore structure. The actual Sound Absorption Coefficient provided by a material at any particular frequency, depends on the air flow resistance, the mass and method of fixing of any surface material, the percentage perforation of any surface material, and the total depth of the air volume between the face of the sound absorbent material and any rigid backing surface behind it.

Homogenous materials that have both a high surface absorption (i.e. do not reflect) and high insulation (i.e. do not transmit) are hard to come by. In general it is necessary to provide, and pay for, the two functions separately.

3. NOISE CONTROL -- 'CONVENTIONAL' USES OF SOUND ABSORBENT MATERIALS

3.1. Noise Source in Room.

Figure 1. illustrates schematically the direct -- and some of the reflected, sound paths between a noise source and an observer located within the one room. The component of sounds arriving at the observer along any one of these sound paths is dependent on the distance travelled along that path (reducing at 6 dB per

doubling of distance), the number of reflections from room surfaces and the Sound Absorption Coefficient of these reflecting surfaces. As the direct path is obviously the shortest path between the observer and the noise source (and involves no reflection, or absorption, from an intermediate surface), this component is the strongest single component and usually (in typical rooms) is equal to or greater than the sum of the reflected components. Thus, we see that the usually-unpractical extreme of applying sound absorbent materials to all surfaces of a room has very little ability to reduce

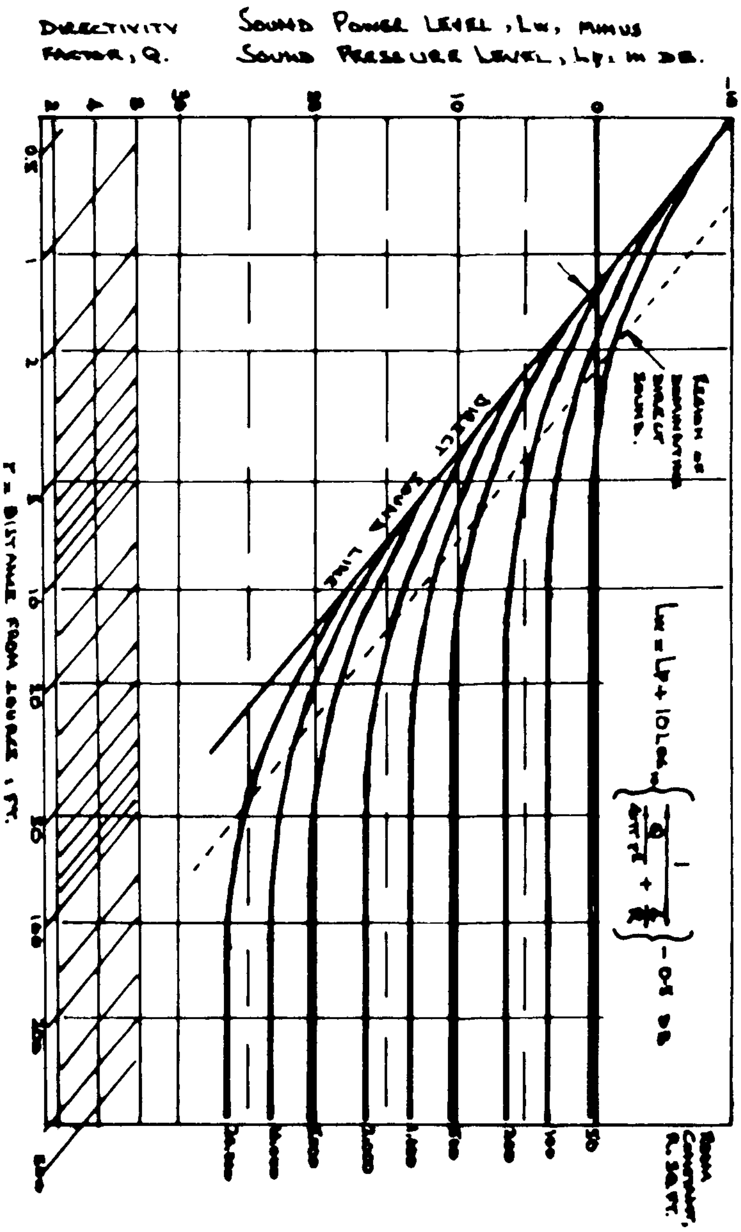


FIG. 2... Chart for converting Sound Power Level (DB.RE 10^{-12} Watts) into Sound Pressure Level (DB.Re 0.0002 Microbar) at a point in a room having a known room Constant, R, Source Directivity also known.

the actual sound level at the observer's position.

This limitation is illustrated in Figure 2, where the depreciation of Sound Pressure Level (with respect to the Sound Power Level of the device, re 10^{-12} watts) is plotted against distance from the source, for differing room acoustic conditions, described by the Room Constant, R, which is a convenient term for describing the 'liveness' or 'deadness' of an acoustical space,

where $R = \frac{S\bar{\alpha}}{1 - \bar{\alpha}}$ and $\bar{\alpha}$ = the average Sound Absorption Coefficient of all surfaces within the room

and S = the total surface area in the room. (2).

In this way the noise level or Sound Pressure Level at a point in the room is analagous to the temperature at a point in the room containing a heating radiator of a measurable B.T.U./hr. output. Just as the thermal properties of the room surfaces, the volume of the room and the distance of the thermometer from the radiator all affect the temperature measured by the thermometer -- the acoustical properties of the surfaces of the room, the volume of the room and the distance of the observer from the noise source each effect the Sound Pressure Level at that point. A full explanation of this phenomenon is available from the references. (1).

From Figure 2 we see that sound levels would depreciate with distance at 6 dB per doubling of distance (i.e. along with the direct sound line) if all surfaces of the room were fully sound absorbent, or radiated direct to the atmosphere. In normal-sized and furnished rooms, the Room Constant, R, is typically 150. We can see that increasing the room constant from 150 to say 500, (i.e. increasing the sound absorption in the order of 3 to 4) will only decrease the sound pressure level 4 to 5 dB for points eight feet and more removed from the noise source. Points closer than eight feet from the source experience even less noise reduction.

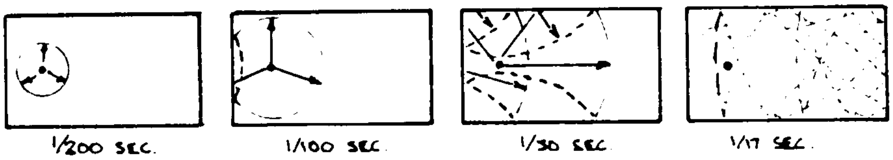
It is therefore apparent that the actual noise reduction or sound insulation provided by sound absorptive materials is limited when the noise source and the observer are within the same space. Even a poor-performance partition, barrier or enclosure separating the noise source and the observer would provide greater sound insulation.

However, sound absorptive materials are useful and frequently indispensable in controlling reverberant noise generated within a room and in reducing the transmission of noise through corridors, or from one part of the building to another. If the noise level is reduced 3 dB, the sound level of speech can be reduced about the same amount. Thus the acoustical power expended in speaking can be reduced by a factor of 2.

The installation of sound absorptive materials in a room has the following beneficial effects:-

a) it reduces the reverberation time,
b) it reduces the overall noise level maintained,
c) it tends to localise noise in the region of its origin.

Typical Activity Noises, such as speech and typing within an office space, are usually of a short duration (e.g. individual strikes of a typewriter) and their ability to annoy people within their vicinity can be significantly reduced by proper control of the reverberant sound field. Since transient and unexpected noises are particularly annoying, this reduction of remote sources of sound is especially helpful. Figure 3. illustrates the loudness build-up and reverberant sound before and after acoustical treatment of a highly reflective room, (3).



Progress of a single sound wave in a closed room showing the build-up of reverberant sound field.

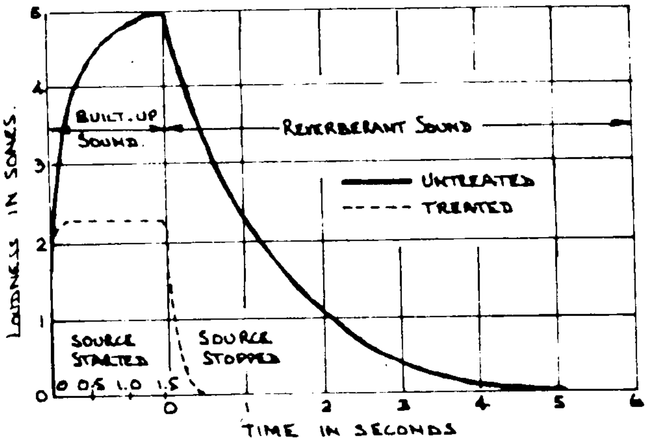


FIG. 3 ... Loudness of built-up and reverberant sound before and after acoustical treatment of a highly reverberant or reflective or 'live' room.

Another major use of sound absorbent materials is to control sound reflections, echoes and standing waves within a space requiring high intelligibility of speech and/or clarity of music. In this regard sound absorptive materials may be considered to provide 'Sound Insulation' by reducing the signal-to-noise ratio of the direct and early reflection paths compared with the reverberant sound field which would otherwise confuse the listeners during speech or musical performances.

In many cases, the relatively small calculated noise reduction afforded by the installation of sound absorptive materials is far exceeded by the 'subjectively apparent' (and therefore useable) noise reduction provided. This is particularly true of office spaces in which a carpetted floor has been selected to provide the sound absorptive requirements to control reverberation. In such cases the reduction afforded by control of the reverberation is further assisted by the control of foot-step and general activity noises, together with the added decorum associated with being in and working in a carpetted space. It should be emphasised that the control of reverberation is a three-dimensional problem, requiring consideration of the three axes of each space designed. In this regard Fitzroy's work (4) should prove of assistance in any deliberations.

3.2 Noise Source Shielded from Observer.

We have examined the value of introducing additional absorbent to reduce noise transmission from point to point in a room in which barriers or partitions may be undesirable for other than acoustical reasons. When these modest benefits prove insufficient to satisfy the needs of all the room's occupants, even when aided by segregation of activities or the use of masking sounds, recourse must be had to some form of barrier.

It is worth noting that the provision of even the most humble screens or partitions, solely to satisfy acoustical requirements, represents a discontinuous jump in the cost component of a building, chargeable to the 'acoustics' account.

The basic idea of a screen or part-height partition is that it will intercept the direct line-of-sight component of the noise from a nearby source, thus removing the major stumbling-block of the 'absorption-only' technique discussed above. There are two limitations to this stratagem.

Firstly, diffraction of 'direct' sound over or around the partial barrier would limit its effectiveness even if it were semi-infinite and located in open air (5). For example the insertion loss of a partition 7 ft. high on direct (i.e. shortest travel) speech between two persons seated 10 ft apart would be limited to about 15 dB.

Secondly, if a number of screens or low partitions are arranged to divide a space into cubicles, or to surround one major noise source, then reflections within a cubicle will also be diffracted over the partition. The use of absorption on the inner faces of the cubicle must be considered - to reduce the local reverberation within the cubicle.

Direct and cubicle-reverberated sound will not only be diffracted over the partition but will also be reflected over by a single reflection off the main ceiling (or the floor in the case of screens open at the bottom) into at least the adjoining cubicle.

When screens or low barriers are installed with the intention of providing a 10 to 15 dB insertion loss between nearby points, unattainable by the use of absorption alone in an open room, absorption on the ceiling and on the screens should be used if the full potential benefit of the barriers is to be attained. In a well-balanced installation the absorption would economically be required to contribute some 2 to 5 dB of the total, depending on the geometry. The total quantity of absorption employed in the optimum blend of absorption-cum-screens may turn out to be greater than that which would have been economically justifiable in the same room unpartitioned.

3.3. Noise Source separated by Complete Partitions or Enclosures.

In this context, any partition that provides an effective Noise Reduction of 15 dB or more will be regarded as a complete partition, though it could, in fact, be a much better partition partly by-passed by some opening, intentional or otherwise.

The essential point is that when the mutual coupling is as weak as 15 dB, the spaces on either side may be considered as distinct, separate rooms, and their respective quantities of sound absorption are not pooled. It turns out that the noise reduction or insertion loss between a source in one room and a receiver in the other depends on the product of the quantities of absorption in each, times the transmission ratio of the partition (provided neither point is very close to the partition).

It has been pointed out (6) that if a given final total of absorption must be shared out between the two rooms, then the product will be maximized if the shares are equalized. We should point out that violation of this 'total' rule to as far as a 3:1 disparity, would hardly be economically significant, but looked at in another way, the same principle is sometimes worth taking advantage of, as follows.

If two adjacent rooms had a 3:1 disparity in their casual absorptions (due to differences of size and/or of basic furnishing and finishes before paid-for extra absorption were postulated) then there would be a clear tactical advantage in devoting money for added absorption to the less absorbent (or barer) room, at least until equality were reached. Small enclosures around noisy machines are a noteworthy example: the first $5 worth of absorption inside the box may be equivalent to adding $100 worth to the outside room, or adding $40 worth of extra insulating skin on the enclosure itself.

The completely partitioned case is more amenable to a search for the optimum blend of expenditures on room absorption and partition insulation (6) than the case of partial barriers. Since the respective room absorptions will often be determined by their own 'internal room acoustics' requirements, the 'optimization' of the mutual Noise Reduction then reduces to a search for the most economical partition with a nominated Sound Transmission Loss (S.T.L.).

In cases where ventilation or other permanent openings must be introduced into a partition or enclosure, these should be designed to give comparable performance to the partition or enclosure. If this is not possible, significant noise reduction can be achieved by utilising the source space as a lined plenum.

4. NOISE CONTROL -- 'UNCONVENTIONAL' USES OF ABSORBENT MATERIALS

4.1 Absorptive Materials in the Insulating Partition.

We have used the term sound absorption in connection with that property of a surface measured by the fraction of incident airborne sound which is not reflected. Sometimes, when sound absorbers are used in partitions, floors and roofs it would seem that another property of materials - the ability to dissipate flexural vibrational energy of plates they adjoin - may be invoked as well as airborne sound absorption. Let us be grateful that some materials seem to have both properties, and not concern ourselves with any attempt to analyze the separate (?) roles here.

The essential feature of the use of sound absorbent materials, e.g., mineral wool, in or on single or multiple panel partitions, is that most practical, statically-stiff panel materials lack a significant dissipative component in their own make-up. When the inevitable interactions occur between the stiffness of a panel and its mass per unit area, giving sound an opportunity to pass through by resonant effects then dissipative or frictional processes must be present to control the decrease in sound insulation that occurs at resonances.

Resonances of single panels of finite size occur at special frequencies when the wave lengths of free bending waves in the panel satisfy modal relations with the dimensions of the plate. Airborne sound above a critical frequency and at appropriately oblique angles can couple efficiently with bending waves of the panel, causing a serious decrease in insulation known as the 'coincidence dip' extending continuously over a wide band of frequencies. In this band the dimensional resonances of the panel may be local low points, but sound transmission may be disappointingly strong throughout the whole band, despite quite a high mass in the panel.

In twin partitions the transverse component of the oblique sound passing the first leaf by coincidence effect may excite transverse resonant modes of vibration of the air in the cavity. Coupling to the second leaf will be very efficient at these modal frequencies, but also moderately efficient throughout all the coincidence range.

Introduction of sound absorption into, but not necessarily filling, the cavity can have a pronounced effect in damping the resonances described, and in dissipating the progressive transverse waves. Sound absorption in partitions has its most beneficial role in enhancing the S.T.L. of partitions that otherwise would evince a disappointing coincidence dip, most often at the high frequency end of the usual spectrum. Benefits up to 15 dB can be achieved, at these frequencies, more cheaply than by any other means at present available.

In double partitions there is another range of frequencies (usually low ones) and appropriate angles of incidence in which the stiffness of the oblique thickness of air cavity, coupled with the masses of the two leaves, can resonate as a mass-spring system. Sound absorption can be effective against this form of sound transmission through the partition, but because it is likely to occur at low or medium frequencies where the absorption coefficient is small, the benefit may be small, say 0 to 3 dB at 100 Hz. In a very light partition of course the mass benefit of the absorbent material could be added to the absorbent benefit.

Because of the diversity of possible combinations of panel materials and absorbers it is not easy to generalize existing knowledge on the subject, but reference (7 - 10) report some recent endeavours in this direction. The availability of sound absorption as an additive increases the number of candidate materials for panels when one is seeking a partition design of given S.T.L. characteristic, at minimum installed cost.

4.2. Sound Absorptive Materials in Ducts, etc.

Sound Absorptive Materials are extremely useful in controlling fan, air fitting and cross-talk noise within ventilation or air-conditioning systems encountered in most modern buildings. Acoustical analysis of such systems indicates the necessity, or otherwise, of additional sound insulation or noise control at various parts of the system. Depending on the attenuation required, selection of lined duct, lined bends, splitter silencers, packaged silencers or special-purpose silencers may be indicated. These attenuating devices, selected for acoustical performance, usually provide a secondary benefit such as reduction of duct wall vibration (and therefore sound radiated from ducts), or additional thermal insulation of ducts passing through unconditioned spaces. Interested readers are referred to the ASHRAE Guide (1) as a typical text for further reading.

5. SUMMARY

The role of sound absorptive materials in sound insulation may be described as limited but indispensable. For 'in-room' situations, the ability of absorptive materials to provide noise reduction is dependent on the distance of the observer from the noise source, the volume of the room and the Sound Absorption Coefficients of the room surfaces. By design, unwanted sound reflections can be reduced whilst maintaining any beneficial reflections to improve the acoustical environment of the observer.

When the more effective means of noise control are introduced, such as screens or complete partitions, sound absorbent materials are still essential to ensure maximum effectiveness of the installation as a whole. They are needed to control the reflected components of sound in the spaces so partitioned, and, in addition, can directly enhance the insulating performance of a partition or ceiling construction when incorporated in it. Sound Absorptive Materials provide effective sound insulation within ventilating and air-conditioning systems and may often be selected to perform, simultaneously, other functions.

Sound Absorptive materials therefore play a minor, but important, role in providing adequate sound insulation and noise reduction.

REFERENCES

(1) 'ASHRAE Guide and Data Book', (chapter on sound control).

(2) 'Noise Reduction' edited by L.L. Berank, Part II.

(3) 'Handbook of Noise Control' by Harris, edited by Harris, Ch. 18.

(4) D. Fitzroy JASA Vol. 31, p. 893, 1959.

(5) MAEKAWA, Z. Noise Reduction by Screens, Applied Acoustics I, 1968, 157-173.

(6) WALLER, R.A. Economics of Sound Reduction in Buildings. Applied Acoustics I, 1968, 205-213.

(7) MULHOLLAND, K.A. The Effect of Sound-Absorbing Materials on the Sound Insulation of Single Panels. Applied Acoustics 2, 1969, 1-7.

(8) FORD, R.D., LORD, P., and WILLIAMS, P.C. The Influence of Absorbent Linings on the Transmission Loss of Double-Leaf Partitions. J. Sound Vib. 5, 1967, 22-28.

(9) MULHOLLAND, K.A., PARBROOK, H.D., and CUMMINGS, A. The Transmission Loss of Double Panels, J. Sound Vib. 6, 1967, 324-334.

(10) UTLEY, W.A., CUMMINGS, A., and PARBROOK, H.D.
The Use of Absorbent Materials in
Double-Leaf Wall Constructions.
J. Sound. Vib. 9, 1969, 90-96.

PAPER E.

THE EFFECTS OF DOORS, RETURN-AIR GRILLS AND OTHER FLANKING PATHS ON SOUND INSULATION.

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THE EFFECTS OF DOORS, RETURN-AIR GRILLS AND OTHER FLANKING PATHS ON SOUND INSULATION.

INTRODUCTION

The sound insulation values for a partition, as published by the Manufacturer, are obtained in an approved Laboratory under specified test conditions.

In contrast to the idealised laboratory situation where sound is transmitted between rooms only THROUGH the specimen of partition under test is the field installation where the possibility exists for sound energy to pass from one room to another by many paths. (Ref. 1, p. 20-4; R.2, p.64).

The transmission by paths other than that through the common partition is defined as "Flanking Transmission."

The importance of flanking transmission cannot be over-emphasised. A flanking path will reduce the sound insulation of a partition to some value below the published laboratory results, and the partition will fail to achieve its full sound insulating capabilities.

A simple example is the loss of insulation caused by a 1 inch square hole in a 9 inch brick wall of 100 sq. ft. The 50 dB average insulation of the wall will be reduced to 40 dB. (R.3, p.183).

SOUND TRANSMISSION PATHS

There are two types of sound insulation that must be considered when investigating potential flanking transmission paths. They are:

Air-borne Sound Insulation; and
Impact Sound Insulation.

The content of this paper is directed primarily at the problem of insulation against the transmission of air-borne sound. This concerns noises originating in the air, e.g. voices, typewriters, traffic noise.

In brief, impact sound insulation concerns impact noises, footfall noise and noises from vibrating mechanical equipment that can be transmitted from one area to another (sometimes distant) area in the structure of the building. It can be of major significance when an area has or must have a particularly low ambient sound level and is often blamed for the apparent "failure" of a partition installation. (R. 1, p. 19-5; R. 2, p. 63).

AIR-BORNE FLANKING PATHS

Typical examples of air-borne sound transmission are illustrated in Fig. 1. The first and most obvious path for sound transmission is directly through the partition by Path A. Not as obvious are the flanking paths B and C (edge cracks and skirtings) and paths D and E (false ceiling space and cross-connected ducts). (R. 4).

Path F is due to sound falling on surfaces in the source room and travelling along in walls or floors into the receiving room and being re-radiated; it is of significance only when the overall sound insulation starts to exceed 50 dB. (R. 3, p. 178).

Some of the more frequently encountered air-borne flanking paths are listed below. (R. 5; R. 6, p. 343, 388).

- Cracks around the perimeter of a partition; Skirting and jacking strips at the floor; Infill panels between sides of partitions and recessed windows; Openings and cracks created by joints between prefabricated panels.
- Openings in partitions created by wiring, plumbing, power outlets, light switches etc.

../E - 4.

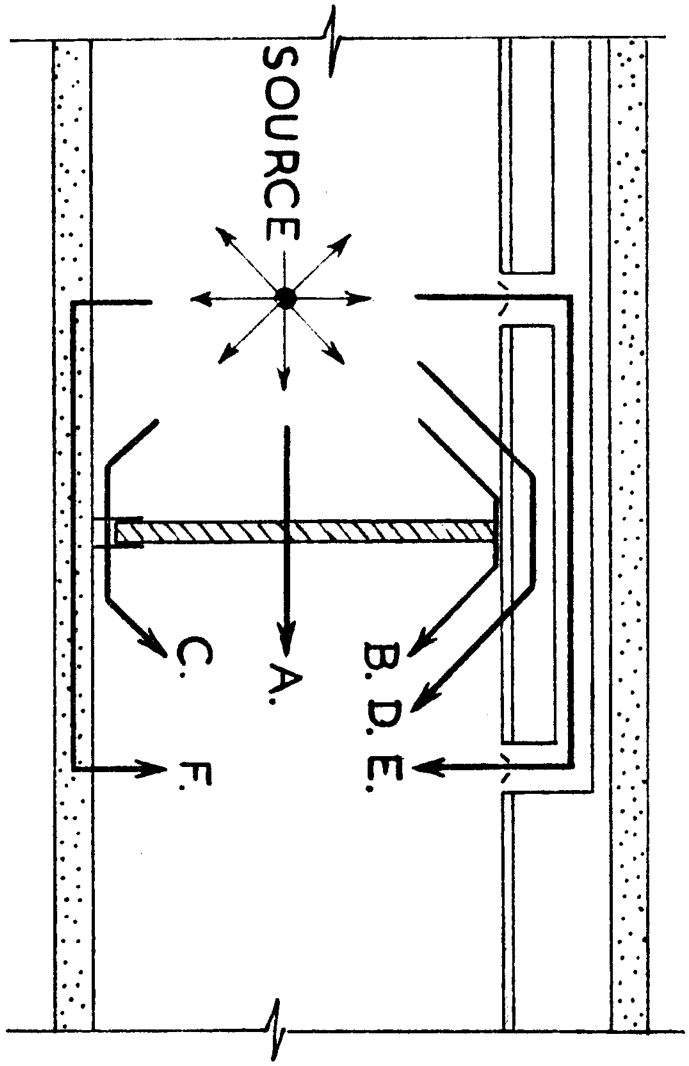

FIG. 1.

- Gaps and cracks around doors; Doors with a sound insulation rating lower than the partition; Return-air grills.
- Glazing with a sound insulation rating lower than the partition.
- Suspended ventilated and acoustic ceilings when the ceiling is continuous over the partition.
- Cross-connected ducts; Continuous light fittings; Skirting ducts and cross-connected (continuous) heating units; Spandrel beams.

At first sight this is an awesome list!. However, the attention to detail and careful planning that will result from an understanding of the problems involved should reduce the list to one or two clearly defined items (R.3, p. 216).

We shall therefore examine the results of some field and laboratory experiments carried out to evaluate particular air-borne flanking paths.

FIELD AND LABORATORY TEST RESULTS

1. Perimeter Cracks:

The effects of edge sealing were investigated in a series of field experiments using an STC 54 partition.

Edge Detail	STC Value
Unsealed	19
Single bead of caulking	30
Double bead to both edges	51
Heavily caulked	54

It was concluded that the sealing techniques required to achieve STC 54 were impractical and uneconomical, but that STC 51 could be achieved using a practical sealing procedure (R. 7.).

These results clearly illustrate why poor fixing and sealing is one of the main causes of failure when a high insulation rating is required. (R.1, p.20 - 13).

2. Doors:

A door is only as effective as the sealing arrangement which prevents sound leaking through any gaps between the door and the partition of which it forms a part. (R. 8, p. 617).

If the ratio of the gap open area to the door area is no higher than 1 : 5000 the effect on a 45 dB door is to reduce its performance to 36 dB. (R. 9).

Should this door form part of a 45 dB partition of area 80 sq. ft., then the effect of the door will be to reduce the acoustic performance of the partition to 41 dB. A graph for the rapid calculation of the composite insulation of a partition made up of two areas of different sound insulation is shown in Fig. 2. See also Appendix A. (R. 2, p. 130; R. 3, p. 272).

Hollow core doors should never be used in sound isolating walls. A gasketed solid core door is a minimal requirement. (R. 3, p. 203, 222). The results below are for a partition erected and tested at STC 48 prior to the installation of a series of 1 3/4 inch doors. (R. 10).

Description	STC Value
Partition only	48
Hollow core door	24
Hollow core with gaskets	26
Solid core door	27
Solid core with gaskets	33

Thus a gasketed solid core door in an STC 48 wall reduced the sound insulation of the wall to STC 33. However in an identical test, but using an STC 40 wall, the overall sound insulation of the wall was only reduced to STC 32.

../E - 7.

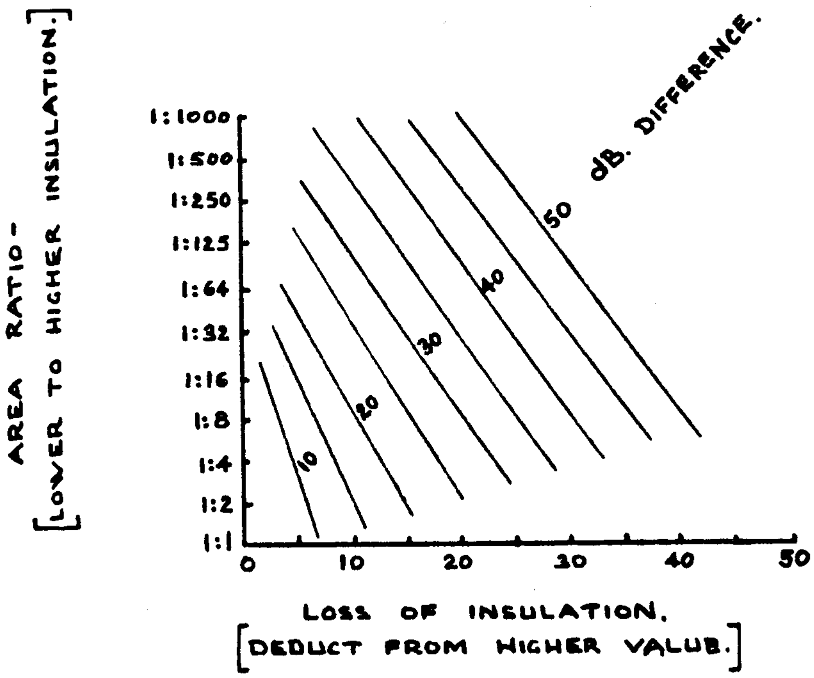
AREA RATIO -
[LOWER TO HIGHER INSULATION.]
1:1000
1:500
1:250
1:125
1:64
1:32
1:16
1:8
1:4
1:2
1:1
0
10
20
30
40
50
10
20
30
40
50
dB. DIFFERENCE.
LOSS OF INSULATION.
[DEDUCT FROM HIGHER VALUE.]

FIG. 2.

This illustrates that a wall including a door is influenced substantially more by the door than by the wall construction. (R. 11). The economic implications are obvious.'.

3. Return-Air Grills:

A return-air grill is acoustically transparent and provides virtually zero air-borne sound insulation. The use of W or other overlapping grills, felt lined or not, provides no significant increase in insulation.

A previous example illustrated that poor edge sealing reduced the performance of a 45 dB door to 36 dB, and the door in turn reduced the performance of a 45 dB partition to 41 dB.

However a 1 sq. ft. open area return-air grill in this door would reduce the door performance to 13 dB, and the overall partition performance to 21 dB.

Thus return-air grills are unacceptable in sound rated doors and partitions.

There are commercially available special return-air grill/sound traps. These are effective but bulky, and are therefore best installed in the partition. An installation of this type using an STC 41 partition, a return-air grill/sound trap and a very well sealed door achieved STC 39. With the door normally sealed the installation achieved STC 38. (R. 12; R. 13).

But problems can arise with ventilated ceilings, as the ceiling plenum pressure is not sufficient to overcome the static pressure drop through the return-air grill/sound trap.

4. Glazing:

If the sound insulation provided by glazing does not equal the sound insulation provided by the partition then the net insulation of partition plus window may be closer to the insulation value of the window than that of the partition.

The loss of insulation caused by an ordinary window is greater than would be expected for its relative size (R. 2, p. 71). A partition having 15% glazed area and constructed from 40 dB panels and 28 dB glazing (single sheet $\frac{1}{4}$" glass) will have a net insulation of only 35 dB. Thus double glazing is essential to achieve 40 dB.

The effects of glazing were investigated in a series of field experiments using a 50 dB brick wall (R. 13).

Description	Net Insulation (dB)
Brick Wall	50
Double Glazing	37
Single Glazing	25
Open Window	14

Single glazed walls therefore provide very little defence against modern traffic noise (R. 14).

5. Ceilings and Cross-Connected Ducts:

Ceilings that are continuous over partitions can provide a direct flanking path through the ceiling space. Therefore the room to room sound insulation of the ceiling must be equal to the sound insulation provided by the partition.

Perforated metal pan and ventilated ceilings, because of their open areas, have an obvious weakness. Compressed fibre acoustic tile ceilings offer a wide range of ceiling STC ratings and can provide excellent results. But it must be remembered that the term "Acoustic" refers to the sound absorbing and not to the sound insulating properties of the ceiling (R. 15).

Even a carefully selected ceiling may fail due to openings for light fittings etc., and a continuous light fitting passing over a partition can be disastrous. (R. 8, p. 624). Again cross-connected ductwork must be internally acoustically treated if this direct path for sound transmission is to be avoided. (R. 2, p. 73; R. 8, p. 550, 625). In one field test it was found that light fittings and cross-connected ductwork were responsible for a rated STC 43 partition achieving only STC 28.

An interesting point about ceiling flanking transmission is that it is difficult to detect by listening to speech. This is because of the Haas effect which, stated briefly, is that if speech is heard via two paths the speech that arrives first determines the apparent direction. In this case it will appear to the listener as if all the sound is coming through the partition and not through the ceiling, and that the partition performance is worse than it really is. (R. 16; R.3, p. 184).

CONCLUSIONS

The preceding examples illustrate that a reduction in insulation occurs in all cases where a "weaker" element is introduced in a sound barrier, or whenever a change of material or thickness occurs which results in a reduction of insulation over part of the area of the barrier.

The actual sound insulation obtained in practice is governed by the partition panel complete with its total associated elements and structure. It is therefore essential that the manufacturer supplies attenuation figures for the whole partition system and not just the basic infill panel.

Flanking transmission is not only undesirable, but is uneconomical. Thus there are two major alternatives for the designer.

1. To select less expensive materials having sound insulation values closer to the sound insulation of the "weaker" element.

2. To select a more expensive sound barrier system, using design techniques, materials and hardware that will ensure equal sound insulation via all paths.

ENVIRONMENTAL CONSIDERATIONS

The question must therefore be asked - "How much sound insulation is really required for each area?

The required amount of insulation depends entirely on the type of occupancy and usage of an area, and the background noise level in the area.

For example, between two offices both used for typing the insulation need not be more than 20 dB. But if one is for typing and the other is a private office, then some 40 dB would be required. (R. 3, p. 184).

Again, if one was a private office and the other a reception area having only normal glazing onto a busy street, then 30 - 35 dB should be sufficient. However if the rooms were on an upper level of a high rise air-conditioned building with double glazing some 45 dB might be required.

OVERALL DESIGN CONCEPT

In practice it frequently turns out that inherent flanking paths can set an upper limit to the total sound insulation that can be achieved.

Engineering economics then demands a balance in the design of the additional elements so that they are not wasted.

Standards for an acoustic environment should therefore be established at the outset of a project, having in mind the surrounding environment and the occupancy of the building (R. 17; R. 18). These Standards should be used in determining external walls, window design, air-conditioning, ceilings, partitions etc., and a proper balance established for all elements.

Thus every component of the sound insulating system must be considered in relation to the others and designed as part of an integrated overall scheme.

REFERENCES

1. HARRIS, C.M.: Handbook of Noise Control. McGraw-Hill Book Company, Inc., New York (1957).

2. MOORE J.E.: Design for Noise Reduction. Architectural Press, London. (1966).

3. PARKIN, P.H. and HUMPHREYS, H.R.: Acoustics, Noise and Building. Faber Ltd., London (1958).

4. KNOWLAND, P.: Sound Transmission Paths. "Australian Building Science and Technology Journal." Volume 6, Number 5 (1966).

5. KNIGHT, F.S. : Acoustics and the Architect. "Proc. 5th International HEVAC Sound Symposium," London 1968.

6. DOELLE, L.L.: Acoustics in Architectural Design. "National Research Council, Canada, Division of Building Research." Ottawa, 1965.

7. SEWELL, A.D.: Joint Sealants and Sound Insulation. "Insulation," Vol. 12, Number 5 (1968), pp. 199.

8. BERANEK, L.L.: Noise Reduction. McGraw-Hill Book Company Inc., New York (1960).

9. SOUND RESEARCH LABORATORIES: Sound-Resistant and Airtight Doors. "Insulation," Vol. 12, Number 6 (1968), pp. 257.

10. UNPUBLISHED FIELD TEST RESULTS, U.S.A.: Courtesy Insulwool Products Pty. Ltd.

11. FORD, R.D., LORD, P. and WALKER, A.W.: Offices with High Sound Insulation. "Applied Acoustics" Vol. 1, Number 1, (1968) pp.21.

12. LABORATORY TEST RESULTS: C.S.R. Building Materials Research Laboratories, N.A.T.A. Laboratory Registration No. 700. Test Partition, Door and Return-Air Grill/Sound Trap by Moyle Partition System P/L., Sydney.

13. SCHOLES, W.E. and PARKIN, P.H.: The Insulation of Houses against Noise from Aircraft in flight. "Applied Acoustics," Vol. 1, Number 1 (1968) pp. 37.

14. LAWRENCE, A: The Influence of Traffic Noise on the Designing of External Walls of Buildings. "Proc. International Acoustics Symposium, Australian Acoustical Society, - N.S.W. Division, Paper F." Sydney, 1968.

15. ACOUSTICAL MATERIALS ASSOCIATION: The Use of Architectural Acoustical Materials - Theory and Practice. Publication A.I.A. No. 39 - A, Second Edition.

16. BURD, A.N.: The Measurement of Sound Insulation in the presence of Flanking Paths. "Journal of Sound and Vibration," 7, pp. 13 (1968).

17. DOE, L.N.: The Establishment of Acoustic Standards in Buildings. "Proc. 5th International HEVAC Sound Symposium," London, 1968.

18. TAYLOR, H.V.: Design for Quietness.
"Australian Building Science and Technology Journal." Vol. 6, Number 5 (1966).

APPENDIX A

NET INSULATION OF A COMPOSITE WALL

In some of the examples given in this paper the sound insulation values of partitions have been discussed only as average values. However the air-borne sound insulation of any partition varies with frequency and it is therefore necessary to consider its performance over a range of frequencies.

Thus, in calculating the net insulation of a composite wall made up of two or more areas of different sound insulation it is again necessary to consider the performance over the frequencies range of interest.

1 GRAPHICAL METHOD

A graphical method for the rapid calculation of the composite insulation of a partition made up of two areas of different sound insulation is shown in Fig. 2.

Let us assume that, in a 9" brick wall of average insulation value of 50 dB, is a closed window having an average insulation value of 23 dB and that the ratio between the area of window and area of remaining wall is 1:3.

Ratio of Areas: 1:3 (lower insulation to higher insulation).
Difference in insulation: 50 - 23 = 27dB.
From Graph: Loss of insulation = 21
Therefore Net insulation of wall with window = 50 - 21 = 29dB.

This calculation gives the net average insulation value of the wall and window. A similar but more precise calculation gives the net insulation values over a range of frequencies. Taking the same example, the calculation is set out in the following Table.

../E - 15.

Octave Band Centre Frequency (Hz).	125	250	500	1000	2000	4000
Insulation Values of 9" brick wall.	41	45	48	56	58	61
Insulation Values of closed window.	17	21	25	26	23	27
Difference	24	24	23	30	35	34
Loss of insulation (from graph)	18	18	17	24	29	28
Hence net insulation of wall with window.	23	27	31	32	29	33

2. TRANSMISSION COEFFICIENT FORMULA

If a plane wave of sound is incident on a partition a certain fraction of the energy will be transmitted through the partition. This fraction will vary with frequency and the angle of incidence. At a given frequency the fraction which represents the average over all angles of incidence is defined as the Transmission Coefficient r.

The transmission loss or sound insulation value of a partition at a particular frequency is related to r by the formula.

$$T.L. = 10 \log_{10} \frac{1}{r} \text{ dB} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

(For example, if a wall has a high T.L., and thus transmits very little sound energy, its value of r approaches zero; in contrast the value of r for an open area or hole is approximately equal to unity. Again, if the T.L. or sound insulation value of a wall is 27 dB then $r = .002$).

The sound power entering a receiving room through a partition of area S sq. ft. is directly proportional to the Transmittance rS of the partition. When a wall is constructed of parts having different transmission coefficients r_1, r_2, r_3 etc., and corresponding areas S_1, S_2, S_3 etc., then the total sound power transmittance of the composite wall is

../E - 16.

$$\bar{r}S_T = r_1 S_1 + r_2 S_2 + r_3 S_3 + \text{etc} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

where S_T is the total area of the wall, and $\bar{r}$ is now the average transmission coefficient of the entire wall. Therefore from Eq. 1 the overall transmission loss for a composite wall is

$$T.L._{Net} = 10 \log_{10} \left(\frac{1}{\bar{r}}\right) \text{ dB} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 3$$

Let us assume that a partition of total area 200 sq. ft. contains a window of 40 sq. ft. and a door of 20 sq. ft. For the purposes of this example only the T.L. of the composite wall at 1000 Hz will be calculated. At this frequency the T.L. of the various components are: Wall - 50 dB; Window - 30 dB; Door - 26 dB.

Wall:		T.L.	=	50 dB
	therefore	r_1	=	.00001
		S_1	=	140 sq. ft.
	therefore	r_1S_1	=	.0014
Window		T.L.	=	30 dB
	therefore	r_2	=	.001
		S_2	=	40 sq. ft.
	therefore	r_2S_2	=	.04
Door:		T.L.	=	26 dB
	therefore	r_3	=	.0025
		S_3	=	20 sq.ft.
	therefore	r_3S_3	=	.05

../E - 17.

Total Area S = 200 sq. ft.

$$\text{Therefore T.L.}_{Net} = 10 \log_{10} \left(\frac{200}{.0014 + .04 + .05} \right) \text{ dB}$$

$$= 33 \text{ dB at } 1000 \text{ } H_z.$$

As described for the Graphical Method this calculation should be repeated over the frequency range of interest.

* * * *

An inspection of Eqs. 2 and 3 will show that the higher the Transmission Loss of a partition panel, the greater is the drop in sound insulation caused by an opening of a given size.

PAPER F.

SUMMARY OF PROCEEDINGS

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SUMMARY OF PROCEEDINGS

Mr. Chairman, Ladies and Gentlemen,

First of all I wish to say how much of a privilege it is to be given the opportunity of summing up this Conference of the Australian Acoustical Society. What a wonderful weekend we have had of interesting papers, of stimulating debates and discussions, and last but by no means least, the very enjoyable periods of social activity when common problems have been discussed in a convivial and relaxed atmosphere.

I have been told that the theme of my Summary should be "Where do we go from here?" So I thought that I should try to draw a few general conclusions from my impressions of the papers and the subsequent discussions, and perhaps try to knit them together into recommendation for future action.

The theme of our Conference this weekend has been "Noise Reduction of Floors, Walls and Ceilings" - in other words, the whole subject of optimum insulation against unwanted sound in buildings, particularly high-density multi-tenanted buildings.

I believe that in the long run, the best way of achieving sound insulation is to look beyond the immediate details of the problem. For I believe that the most effective method of achieving adequate and widely-applied sound insulation is by paying urgent attention to the three great pillars that support and strengthen the professions, namely Education, Standardisation and Legislation.

We must accept the fact that noise levels are on the increase in our modern society. But they should only be allowed to do so in a controlled manner. The pleasures of a high standard of living on the one hand and the annoyance of excessive noise in the community on the other, must be accepted as two inevitable concomitants that can only be tolerated by the establishment of the most careful control measures.

On the subject of Education we know that the all-too-obvious need for improvement is already giving rise to a new breed of acoustical and vibration specialists, interested not only in the basic theory of sound but also in the very practical art of noise and vibration control. But it cannot be said that this new breed is being created in anything like the quantity required in this country. What can be done to improve this situation? Is Industry doing its part? Apart from isolated firms it cannot be said that Industry is greatly concerned with helping the growth. The economic advantages are insufficiently obvious and too long-term in nature to fascinate the majority of Managing Directors. Is the Government doing its part? In recent years the bodies controlling Universities research grants have been supporting some good projects. However the system is somewhat passive in that encouragement is only given to those University projects for which support is requested. Overloaded as most academics are with formal duties, acoustical research has inevitably become a "catch-as-catch-can" business. It is a sober fact that Chairs in Acoustics in the British Commonwealth of Nations are almost non-existent. Indeed, there are none in Australia. The Government establishments are active in acoustical research although the proportion of work concerned with noise control is small and relatively unco-ordinated. I should like to see the establishment of at least one Chair in architectural acoustics and one Chair in engineering acoustics in this country. These would serve as nuclei to nurture and consolidate teaching and research activities at tertiary level. I should like to see the principles of practical noise control incorporated in the curricula of technical trade schools and high schools. Every centre should have a part of its teaching time and a part of its workshop and laboratory time set aside for this important aspect of modern technology.

Coming to the second pillar of Standardisation, there is an obvious and an urgent need in Australia for national standards in acoustics. They should be well-prepared and, most important, they must set limits that are attainable by current engineering practice. A great amount of important work is being done on an honorary basis by an enthusiastic band within the Standards Association of Australia. But I wish to plead that this work should be expedited with all possible urgency. For every day that industry is without guidance, confusion breeds more confusion.

Taking a point from Mrs. Lawrence's fine paper on rating systems, it would appear that we in Australia are still undecided whether to settle for the I.S.O. Sound Attenuation Rating System or not. The discussion has shown that there are many details yet to be hammered out. But I think that the important thing is that we, through the Standards Association, establish as soon as possible for Australia a Sound Attenuation Rating System that will cover the majority of practical cases adequately, that is compatible with the majority of other countries, and that is acceptable to the majority of concerned people in this country.

Criteria, or standards if you like, must ultimately always be a compromise between what people need, what they want, and what they or the nation can afford. While there is much that is not understood about the physiological and psychological effects of noise, enough is known for practical criteria or standards to be established. Imperfection is no excuse for delay when the urgency of the situation demands it. To take an example, a standard of recommended practice in building acoustics would be of immeasurable assistance in the elevation of the standards of noise control in buildings in this country. For professional and legislative guidance, such a standard could indicate reasonable noise levels that might be produced by noise sources internal to the building, such as air conditioning units, washing machines etc., and noise sources external to the building, such as road vehicle noise, aircraft noise etc. It could indicate reasonable values for the minimum desirable insulation against noise of floors, walls and ceilings in multi-storey, multi-tenanted buildings and other environments sensitive to noise. It could also indicate reasonable permissible noise levels to reach the ears of listeners.

In an applied science such as Acoustics where the theory is so complex and often intractable, it is important that there is plenty of well-documented experimental data collected both in the laboratory and in the field. The thoughtful paper on methods of achieving airborne sound insulation by Messrs. Weston and Green underlines the fact that there is a pressing need for much more experimental data for double-leaf acoustic barriers constructed with Australian materials, and Australian construction methods, decoupling devices and the like. Following on from this thought, the well-documented paper on laboratory and field tests by Messrs. Irvine and Riley also points up the need for more experimental evidence on the relative importance of the various paths of transmission of sound through buildings. In order to acquire this most efficiently, we should decide as soon as possible on Australian Standard methods for the measurement of air-borne sound transmission loss and for the measurement of impact sound transmission loss in buildings. I think that the idea expressed by one speaker of a standard noise source for the measurement of air-borne noise reduction is a good one. There are many situations where this would be useful.

Might I pause here for a moment to comment on the final two papers? The fine review paper on the role of absorptive materials by Messrs. Wilkinson and Dubout left me with a keen awareness of the paucity of test data readily available on the effect of internal sound absorption in changing the sound transmission loss of double-leaf partitions. It is yet one more indication that effective noise control must at this stage of our development be soundly based on documentation. I seem to be labouring this point, but it is almost axiomatic that well-documented test data, systematically published and widely disseminated, enable predictions to be made accurately enough for purposes of social and economic planning. Soundly based experience, derived from proven design schemes of the present, is one of the best aids to pragmatic development in this difficult science of noise control.

I cannot leave this paper without a mention of the use of masking noise in open-planned offices and work areas. While there is a tendency at first impulse to shy away from fighting fire with fire, nevertheless there are now a number of successfull installations and indeed successful where it counts most - in the acceptance by the employees affected. I think that this method of adjustment of the acoustical and visual environments could be profitably subjected to more intensive and widespread examination. Our knowledge of psycho-acoustics is indeed far from complete - in the words of Lavoisier - "What we know here is very little, but what we are ignorant of is immense".

The timely paper on the acoustical effects of doors by Mr. Madden shows up the Achilles Heel of acousticians - the common door. The time is long overdue when we should be seeing widespread use of acoustically efficient doors, with practical long-lasting, easy-to-operate-and-adjust edge-seals with, and this is important, a reasonable price tag. No architect or engineer is worth his salt who surrounds sensitive areas with acoustically adequate walls and then specifies acoustically transparent doors incorporating, horror of horrors, open air grilles. I feel that we may have a challenge here for the architect to ensure that the total building design is arranged in such a way that the flanking paths of transmission are nullified as much as practicable.

Coming to the subject of Legislation, I might paraphrase the Bible by saying "Education, when it hath conceived, bringeth forth Standardisation, and Standardisation when it is finished bringeth forth Legislation". I believe that comprehensive legal control of noise in our society is long overdue. Compliance with an Australian standard recommendation for the minimum sound insulation between dwellings should be made obligatory by law. Maximum permissible noise levels for road vehicles should be spelled out and control procedures established. It should be obligatory for manufacturers to supply noise level measurements, say at the operator's ear, for all major items of machinery, including building construction plant. State and Town Planning authorities should be directed by ministerial authority to investigate ways of defending the public against noise nuisance more vigorously than in the past. The administrative machinery should be established for the appropriate implementation of land-use zoning for noise. Implementation of such regulations would fall within the province of local authorities who already control building activities in their areas. Any new building, or extension of an existing building, would be required to possess adequate acoustical resistance to the background noise levels known to exist in that area. Operations generating excessive noise would where possible be isolated and concentrated into compact industrial zones separated from residential areas. It is all too patently obvious that the machinery does not exist everywhere for the effective co-ordination between those responsible for town planning in urban areas and those responsible for the establishment and development of large public airports and freeways. In the siting and construction of new factories likely to generate excessive noise, detailed conditions should be imposed - such conditions as, for example, the construction of appropriate acoustic screens walls and windows, limited working hours, etc. Because of the expense of high-quality acoustical measuring equipment and the need for experienced personnel to conduct the measurements, there is a strong case to follow European practice by establishing a mobile laboratory for each large urban area in Australia, as has been pointed out elsewhere by Mrs. Lawrence.

Finally, might I say that architects and engineers cannot claim for themselves alone that their duty is to ensure to the best of their ability that their work is directed, in Tredgold's words, "For the use and convenience of man". These things are of concern to all forward-thinking people. Man has certain needs, and if these can be met, then a vital step will have been taken towards his "use and convenience".

The major needs of man are food, shelter and health - probably in that order. Shelter may be defined as including housing, clothing and the provision of the facilities that are essential to make a dwelling tenable. I should suggest for your consideration that excessive noise qualifies for consideration in two aspects; firstly in the sense that in this sophisticated day and age excessive noise will make a dwelling un-tenable and secondly in the words of the World Health Organisation "Will contribute substantially to man's loss of well-being and health". I suggest then that we should be constantly relating our efforts to one or more of these needs of man. Our professional responsibility to society demands that we oppose with every means at our disposal the persistent erosion of civilized standards by the disastrous but continuing rise in noise levels, both in the home, in the street and in our places of work.

Leading, as we do, busy lives in various corners of this far flung continent, it is difficult to co-ordinate efficiently our individual efforts for the good of the nation as a whole. The Acoustics Standards Executive Committee of the Standard Association of Australia is doing a fine job within its terms of reference, but a broader base of reference and greater powers are needed.

The Australian Acoustical Society is a young and vigorous body, but it can become a strong and an influential body. Its prestige will become more widely recognised if it follows the guidance of the great institutions. It should take a decisive role in the elevation of professional standards within its province. It should speak occasionally on matters of public interest where it can make a constructive contribution towards important matters of policy for national development. Many opportunities for putting forward a professional view are lost by default. After all, most of us are busy men and women and we are reluctant to express views on matters which we have had sufficient time to study in detail.

One suggestion I have to make is that the Australian Acoustical Society should establish a central organisation, perhaps in the form of a National Acoustics Council, charged with the responsibility of reviewing proposals for major developments in which the views of members of the professions who are experienced in Noise Control and Acoustics could be relevant. This council should not concern itself directly with the specialised tasks for which the Acoustical Society may already have active committees. Its main function should be that of a watchdog keeping an eye on major developments. It must, of course, be advisory rather than executive, but a source of sound advice has a way of gaining in authority because of its soundness. The council could consider ways and means to encourage, co-ordinate and develop acoustical activities in Australia in the three great pillars of Education, Standardisation and Legislation.

I am reminded of the aims of the National Electronics Council, established in England in 1964 under the chairmanship of Lord Mountbatten for just such a purpose in the field of Electronics. By slight paraphrasing we could define the aims of such a National Acoustics Council as being somewhat as follows:-

"For the sole purpose of benefitting the public; to enquire into and encourage the applications of Noise Control and Architectural Acoustics, calculated to lead to the improvement of national life in all its aspects; to provide assistance, advice and information to Ministers of Government on the applications of Noise Control and Architectural Acoustics; to consider the requirements and priorities of research; and to advance education in the fields of Noise Control and Architectural Acoustics".

Professional Prestige can be improved only by public appreciation of the achievements of professional people. Unless professional people involved in the vexed business of noise control take an increased part, and a more obvious part, in guiding decisions on matters affecting the community, their appreciation by the public will always be limited. Needless to say, it will cost money to put this suggestion into effect. The Acoustical Society can be the voice of the professions in these matters but the wherewithall must be provided. Are we willing to pay for it? And who else will support us?

Let me conclude by emphasising that the suggestions I have made seem to be, in the main, directed at the Australian Acoustical Society, or perhaps, at Australian acousticians in general. I have been somewhat concerned with Acoustics for many years, and if my remarks are interpreted as too critical, then I am as much to blame as anyone. I have therefore put my ideas before you in a spirit of humility. I thank you for sparing the time to listen to them.

* * *

AUSTRALIAN ACOUSTICAL SOCIETY

N.S.W. DIVISION

1969 CONFERENCE : TERRIGAL

LIST OF DELEGATES

Name	Address	Affiliation
J.A.Rose	120 Brush Rd.,W.Ryde,2114	Comm.Acoustic Labs.
E.T.Weston	P.O.Box 30, Chatswood, 2067	C.E.B.S.
J.A.Irvine	Oulton Ave.,Concord West,2138	C.S.R.Building Mats.
G.C.Pickford	" "	" " "
P.F.Howarth	" "	" " "
J.Trenning	" "	" " "
C.Smith	Grand Ave., Camellia, 2142	Australian Gypsum Ltd.
K.H.Davis	" "	" "
D.F.Pryor	" "	" "
P.Scrivener	" "	" "
E.Taylor	Prudential Bldg,University Ave. Canberra City, A.C.T. 2601	Godfrey, & Spowers, Hughes, Mewton & Lobb
R.Wilkinson	36 Valerie Ave., Chatswood,2067	Carr & Wilkinson
P.Knowland	17 Sagars Rd.,Kenthurst, 2154	P.Knowland
L.A.Challis	158 Queen St., Woollahra,2025	L.A.Challis & Assoc.
R.A.Piesse	39 Medusa St.,Mosman, 2088	Comm. Acoustic Labs
A.B.Lawrence (Mrs.)	25 Warrawee Ave., Warrawee,2074	University of N.S.W.
J.C.V.Anderson	17 Explorer's Rd.,Glenbrook,2773	Comm.Dept.Works,Sydney.
J.R.Andrew	30 Wallalong Cres.,W.Pymble,2073	McConnel Smith & Johnson
D.W.R.Cale	44 Woronora Pde.,Oatley,2223	D.S.Thomas & Partners
R.J.Carr	444 Burwood Rd.,Hawthorn,Vic.3122	Carr & Wilkinson
D.Chesterman	235 New South Head Rd.,Edgecliff,2027	McConnel Smith & Johnson
J.Clarke	1 Havilah Ave.,Wahroonga,2076	Sydney University
A.Clutterbuck	350 Latrobe St.,Melbourne,3000	Australian Gypsum Ltd.
P.Dubout	Graham Rd.,Highett, Vic.3190	CSIRO Div.of Bldg Res.
W.A.Davern	" "	" " "
J.A.E.Hutchinson	" "	" " "
I.P.Dunn	" "	" " "
R.C.Green	41 North St.,Fairfield,2165	A.B.C.
G.E.Harding	480 Clayton Rd.,Clayton,Vic.3169	Nonoys Pty.Ltd.
M.E.Nelmes	" " "	" "
M.A.Jefferies	" "	" "
R.B.King	41 Parade,Norwood,S.A.5067	Noise Suppression & Acoustics Pty.Ltd.
I.J.Lawrence	31 Florizel St.,Burwood,Vic.3125	Aust.Fibreglass Pty.Ltd.
J.A.Madden	160 Pacific H'way,N.Sydney,2060	J.A.Madden & Assoc.
K.G.Parsons	12B Ferdinand St.,Hunters Hill,2110	Moyle Partition Systems
D.J.Pickwell	C/- 500 George St.,Sydney,2000	Angus & Coote Acoustics
J.A.Rickard	4 Albert St.,Sydney Cove,2000	Cemac Brooks Pty.Ltd.
P.Reid	" "	" "

J.L.White	4 Albert St.,Sydney Cove,2000	Cemac Brooks Pty.Ltd.
J.Olphert	" "	" "
J.Dew	" "	" "
N.Roscoe	" "	" "
G.A.B.Riley	46 Riversdale Rd.,Camberwell,Vic. 3124	Australian Acoustical Lab.
J.Scott	16 Hills Ave.,Epping, 2121	IDAC Pty.Ltd.
W.A.Selle	Box 373 P.O.Canberra City,A.C.T. 2601	N.C.D.C.
T.E.Taylder	26 Church St.,Mt.Kuringai,2080	P.W.D., Sydney
H.V.Taylor	47 Hopetoun Rd.,Toorak,Vic.3142	H.V.Taylor
K.Troy	C/- 90 Collins St.,Alexandria 2015	Aerex (Aust.) Co.
A.Whitting	48 Chandos St.,St.Leonards,2065	Taylor-Thompson-Whitting
D.Littlemore	60 Hunter St.,Sydney 2000	Rudder,Littlemore & Rudder
W.Hudson Shaw	70 Hunter St.,Sydney,2000	Qantas Airways Ltd.
K.Digby	Pacific Hway,Gore Hill,2065	A.B.C.
G.Setchell	Aust.Square Tower,George Street, Sydney	Comm.Dept.Works
J.C.Emmerig	1-3 O'Connell St.,Sydney,2000	C.S.R.Co.Ltd.
J.R.B.Deck	129-141 Woodpark Rd.,Smithfield 2164	John Deck & Sons
J.C.Booth	" " "	" "
W.T.Mansell	Box 142 P.O.Artarmon,2064	Specialised Building Materials Pty.Ltd.
J.B.Wilson	" "	" "
C.Johnson	" "	" "
M.H.McMurran	101 Burns Rd.,Wahroonga,2076	Frank G.O'Brien Ltd.
F.B.Haven	120 Dunning Ave.,Rosebery,2018	Hardboards Aust.Ltd.
A. O'Shea	" "	" "
J.W.Black	" "	" "
V.Wittick	692 Pennant Hills Rd.,Beecroft 2119	Monier Brick & Precast
K.Twigg	Box 3935 G.P.O.,Sydney 2001	Jas.Hardie & Co.Pty.Ltd.
R.A.Swane	" "	" "
P.Kendall	Box 123 P.O.Artarmon,2064	Assoc.Insulation Pty.Ltd.
G.Reed	" "	" "
R.Fields	" "	" "
G.Condon	" "	" "
A.Sorenson	" "	" "
P.Hunkin	" "	" "
R.B.Randall	1 Nicholson St.,Melbourne,3000	I.C.I.A.N.Z.
R.Weir	330 Ballarat Rd.,Braybrook,Vic. 3019	D.Richardson & Sons P/Ltd.
G.Milne	" " "	" "
J.J.Greenland	13 Headland Rd.,E.Roseville,2069	N.S.W. I.T.
T.D.Hewitt	3 The Close,Frankston,Vic.3199	P.M.G.Dept.
T.M.Hughes	390 George St.,Sydney,2000	Stel-Aid Pty.Ltd.
J.F.McDermott	" "	" "
K.Murphy	" "	" "
G.T.McAleer	120 Briens Rd.,Northmead,2152	Fler Co.(NSW) Pty.Ltd.
L.Hegvold	P.O.Box 1, Kensington,2033	Univ.N.S.W. (Archit.)
P.S.Dunn	61 Alexander St.,Crows Nest,2065	Hewlett Packard Aust.
G.Simpson	32 Roseview Ave.,Punchbowl,2196	Wunderlich Ltd.

A.Yates	6/22 Queenscliffe Rd.,Queenscliff 2096	Kell & Rigby Pty.Ltd.
M.Sharp	C/- Central Technology, P.O.Box 589, Newcastle, 2300	John Lysaght (Aust.)
T.Godbee	Box 66, P.O.Lidcombe, 2141	J.Connolly Ltd.
L.Mahoney	" "	"
G.W.Harries	2 Sycamore Ave.,Mentone,3194	Hall-Thermotank (Aust.) P/Ltd.
H.R.Weston	53 Rickard St.,Bankstown,2200	NSW Div.Occupational Health
B.J.Barker	21 Water St.,Caringbah,2229	Philips Elec.Pty.Ltd.
B.McKee	9-11 Dickson Ave.,Artarmon,2064	Armstrong Cork (Aust) Pty.Ltd.
B.Green	" "	" "
F.McGhie	" "	" "
A.Colburt	" "	" "
P.Collins	" "	" "
F.J.Reece	120 Dunning Ave.,Rosebery 2018	Hardboards Aust.Ltd.
K.T.Barrack	" "	" "
D.Best	P.O.Box C352,Sydney,2000	Cunic Industries Ltd.
J.Eastwood	" "	" "
B.C.Lumsden	" "	" "
N.L.B.Anderson	1 Backhaus St.,Hampton,Vic.3188	Massey-Ferguson
R.Symington	P.O.Box 435,Gosford,NSW,2250	Kahibah Constructions
G.I.O.Grenfell	" "	" "
F.R.Fricke	Clayton,Vic.3168	Monash Univ.(Mech.Eng.)
J.L.Fullagar	Box R63,P.O.Royal Exchange, Pitt St.,Sydney 2000	Hardboards Aust.Ltd.
A.McBurney	River Road,Parramatta,2150	C.A.Freestone Pty.Ltd.
T.Ryan	371 Queen St.,Brisbane,Q'ld 4000	Hardboards Aust.Ltd.
W.M.Cooney	40 Miller St.,Nth Sydney 2060	Stephenson & Turner
H.L.Durant	Box 57 St.Peters, 2044	Aust. Fibre Glass
L.I.Goff	Box 1291K, GPO, Melbourne, Vic. 3001	Broken Hill Assoc. Smelters Pty.Ltd.
M.G.Barnes	29-33 King Road, Hornsby, 2077	Plastyne Products
W.N.Rendell	143 Woronora Cres.,Como,2226	Rendell Industries P/Ltd.
J.Cameron	57 Halstead St.,S.Hurstville,2221	" "
A.F.Vineburg	126 Tompson Rd.,Panania 2213	Rintoul Pty.Ltd.
A.Loxley	13 Forbes Cres.,Engadine,2233	" "
P.J.Martin	11A Boulevarde,Epping,2121	Norman & Addicoat
M.Frost	27 Grandview Drive,Newport,2106	" "
A.Gibson	393 Cleveland St.,Redfern,2016	Wunderlich Ltd.
T.J.Arnold	Box 232 Crows Nest, 2065	Chadwick Industries
J.K.Rae	P.O.Box 463,Nth Sydney 2060	W.E.Bassett & Ptners
G.E.Verey	" "	" "
T.R.Marish	" "	" "
H.J.Stoddard	17 Austral Ave.,Beecroft,2119	CSR Building Materials
P.Gibbs	9-11 Dickson Ave.,Artarmon,2064	Armstrong Cork (Aust)
R.Leonard	" "	" "
B.Ledden	" "	" "
B.Schemel	" "	" "

R.R.Blewett	Box 411C, GPO, Adelaide, 5001	Public Bldgs Dept.
R.W.Richardson	" "	" " "
C.Van Blerk	Percy St., Auburn, 2144	Bradford Insulation
B.Sutherland	48 York St., Sydney, 2000	Moyle Partition Systems
G.A.Barnes	12 Curlewis St.,Mont Albert,3127	Australian Gypsum
A.L.Christie	5 Essen Place, Garran ACT 2605	Comm.Dept.Works
R.F.Burton	50 Railway Pde, Pascoe Vale,Vic. 3044	R.M.I.T.
K.M.Kusmierski	5 Hainsworth St.,Westmead,2145	Comm.Dept.Works
M.D.Lambert,Mrs.	480 Clayton Rd.,Clayton,Vic.3169	Nonoys Pty.Ltd.
R.A.Taylor	Council Chambers,Sutherland,2232	Sutherland Shire Council
R.Parker	" " "	" "
A.S.Bennett	Comm.Centre,Spring & Latrobe Sts., Melbourne,3000	Comm.Dept.Works
F.Emanuelle	Box 4325 GPO,Melbourne,3001	Australian Gypsum
I.R.Branson	P.O.Box 352C,Sydney,2000	Cunic Industries
D.Foreman	" "	" "
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D.Martin	1-3 O'Connell St.,Sydney,2000	CSR Building Materials
R.W.McLeod	340 Chesterville Rd.,E.Bentleigh, Vic.3165	State Elec.Comm.,Vic.
M.M.Taeker	8 Chelsea Ave.,Baulkham Hills, 2153	M.M.Taeker & Co.
W.R.Collishaw	Flat 2A, Meeks St.,Kingsford, 2032	Colman Pty.Ltd.
R.Satory	P.E.L., D.S.I.R.,Private Bag, Lower Hutt, New Zealand	D.S.I.R. (N.Z.)