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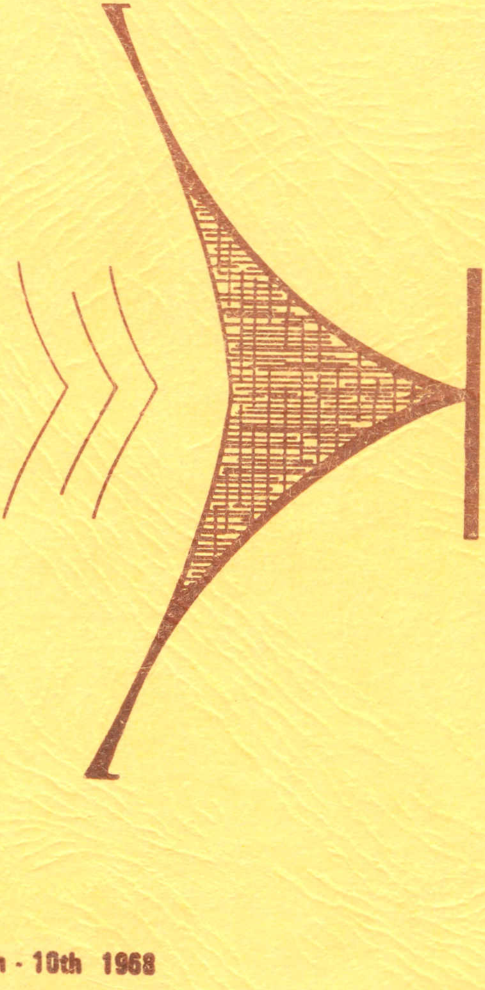

Papers Presented

September 9th - 10th 1968
WENTWORTH HOTEL – SYDNEY

AUSTRALIAN ACOUSTICAL SOCIETY

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A STUDY OF NOISE IN OFFICE BUILDINGS

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SUMMARY

The purpose of this investigation was to examine the existing acoustical conditions in four modern office buildings in Sydney, and to find out how managerial, professional and typing staff were affected by these conditions. A comparison of the resulting data with some existing overseas criteria was made, particularly with the N.C. Curves developed by Leo L. Beranek.

INTRODUCTION

Sound is one of the environmental factors contributing to the overall user evaluation of an office building, but a given sound environment does not have a given stimulus on the office user.

By definition, it is noisiness rather than loudness that is of most importance in the context of estimating adverse reactions to sound. Judgments about the noisiness of a sound are thought to represent a general "bothersomeness" level, resulting from the combined or separate functions of the following:-

- concern about damage to one's hearing (conscious or unconscious)
- the masking of speech or other auditory signal
- the interference with sleep.

It is generally accepted that noise which was initially annoying becomes tolerated and even unobtrusive after a sufficient period of exposure due to a process called habituation. However, there is also evidence that after initial habituation, a person becomes less, rather than more tolerant to the continued noise.

Noise can influence work output in many ways. Broadbent (and others) found the effect of noise on work output depends greatly on the nature of the work - a long term job requiring constant alertness being especially susceptible. It seems the effect of noise is more likely to cause a higher rate of errors than reduction in total output.

In offices noise isolation and insulation are the principal tasks, but in modern office buildings the tendency is towards lighter construction, which is at variance with the acoustical requirements of the occupants.

THE SURVEY

This study was directed towards developing an understanding of office workers' attitudes to the noise levels existing in their working environment.

The survey was conducted throughout as an investigation into the functional efficiency of modern office buildings. A selected sample of managerial, professional and typing staff from each of the four buildings chosen was interviewed during normal office hours. In the majority of offices examined, only one person occupied the area, hence there was very little interruption to the usual background noise level while the respondent filled out the questionnaire. When more than one person occupied the area (e.g., typing pools and sales administration areas) never more than one quarter of the room's occupants were given a questionnaire simultaneously, so the general level of noise from office activities remained uninterrupted.

Noise measurements, using a calibrated sound level meter to record through to a tape recorder, were made concurrently with the answering of the questionnaire. Measurements were taken at the respondent's desk at ear level, the number of measurements in any one area being governed by the number of respondents using that area. Each recording was of approximately $1\frac{1}{2}$ minutes duration.

The tapes were analysed using a graphic level recorder coupled to an automatic frequency spectrometer which analysed the various noise spectra in one-third octave bands. From this analysis the S.I.L. in dB and the L.L. in Steven's phons were computed for each noise spectra.

The questionnaires were analysed by computer, programmed for the desired correlations.

THE RESULTS

1. Rating of Background Office Noise

The modal rating for the background noise within the offices of the four buildings was, with the exception of Building 1, "average", which corresponds with the modal rating for the entire sample of respondents. The modal rating for Building 1 was "quiet", which was probably due more to the fact that these respondents had recently moved to this prestige building from an old building with many defects, rather than the background noise level which, in many offices, was relatively high.

The modal rating of the background noise level in the offices occupied by the three different groups of respondents, (managerial, professional and typing), was again "average", showing a comparatively even distribution of opinion about the noise conditions regardless of which group the respondent belongs to. This is in agreement with Beranek's and Keighley's findings. (Refs. 1, 2)

2. Age

A comparison of the response to background noise with age was computed as a percentage of the total percentage of each age group within the sample. This indicates people are capable of regarding an area is noisy regardless of their age and corresponding hearing loss. This is again in agreement with Keighley's findings.

The dominant frequencies of the background noise in the offices examined were between 20 H_z and 2000 H_z, except in typing pools which partly explains why age (which with increase attenuates the frequencies greater than 2000 H_z by the greatest amounts) does not help in making the older respondent less conscious of background office noise.

Also, at higher levels, the masking effect of sound spreads out to cover a wide range, mainly for frequencies above the frequencies of the dominant components. Therefore, in most of the offices examined (except typing pools), the higher frequencies do not contribute significantly to the unacceptability of background noise.

3. Height Above Ground Level

For this survey there tended to be a decrease in complaint about external traffic noise with increase in height above ground level, which is at variance with many overseas findings. This trend is partly because two of the four buildings are not surrounded by main traffic routes. Also the double glazing used in two of the buildings seemed efficient in excluding all but the street noise of greatest intensity and lowest frequency. One building had its exterior glazed walls protected by a projecting, continuous sun screen, hence the upper floors were largely protected from the impinging street noise.

4. Exclusion of Voices from Adjacent Offices

The results of this survey indicate a full height partition appears to be one of the best methods for controlling the noise of voices from neighbouring offices, however lining the full height partition with lead does not significantly decrease the rate of complaint This is partly explained by the type of respondent occupying the lead lined partitioned office - normally one of the organisation's leading executives. As such he tends to be more critical of all aspects of his office environment, expecting "the best" in accord with his position.

The rate of complaint of voices from neighbouring offices falls off by nearly 50% when a suitable false ceiling treatment is employed, as opposed to a sprayed acoustic plaster treatment to the structural slab.

Carpet used in an office area substantially increases the frequency of complaint of voices from adjacent offices. This is partly explained by the absorbent nature of carpet, which reduces the amount of noise originating in the office under examination, and consequently the transmitted noise is not masked to the same degree as in the office with a harder, more reflective floor finish. This aspect has been more thoroughly investigated by Keighley (Ref. 2)

There is generally an overall decrease of complaint of voices from neighbouring offices as the number of persons using the same office increases mainly due to the greater amount of masking.

5. Exclusion of Noise From Office Equipment

Noise from office equipment in adjacent offices, although reduced by a full height partition, is not excluded, partly because of the high component of low frequency noise from most office equipment, for which most partitions are poor insulators, and partly because the partition is often not adequately sealed around its connecting edges

The frequency of complaint about noise from office equipment in adjacent offices rose by nearly 50% when a metal hung false ceiling was used. This is a complete reversal of the results obtained for voices from neighbouring offices, which suggests the flanking sound path problem with equipment noise is far greater than with voices.

The frequency of complaint about external equipment noise again rose sharply when the office had a carpeted floor. The same comments apply here as for voices from neighbouring offices.

As soon as more than one person uses the same office, the use of equipment by other occupants interrupts and distracts the respondent not involved in using that particular piece of equipment.

6. Air Conditioning Noise

The largest source of complaint in this survey came from offices within twenty feet of large package units which supplied one whole floor of a building. These units were inadequately isolated and insulated from the surrounding areas and emitted a continuous, distracting roar.

The smaller package units designed to serve a much smaller area, but which were located in the same office as the respondent, again had a high rate of complaint. Because of their noise output, they were left switched off as often as possible by the majority of respondents with this type of air conditioning.

7. Effects of Office Noise

The various effects office noise had on the respondents are listed below in order of frequency of complaint:-

- interruption to concentration on work
- interference with office conferences
- interference with telephone conversations
- physical effects (e.g. headaches)
- caused a lot of work to be done away from the office
- confidential meetings overheard.

THE NOISE CRITERIA CURVES

The Noise Criteria (N.C.) Curves were developed by Leo L. Beranek, and are used to specify the maximum permissible or desirable levels in various occupancies. They give a favourable relationship between the low and high frequency portion of the noise spectrum.

Using the results from this survey a detailed comparison was made with Beranek's N.C. data. The median rating of the noise environment by each group (managerial, professional and typing) of respondents within each of the four office buildings was computed and compared with its corresponding median S.I.L. (dB) and L.L. (O.D. phons). To consider how well a straight line explained the relationship between the subjective noise rating and the S.I.L. and L.L., the equations for the least square regression lines were calculated and are as follows -

for S.I.L. - Rating = 0.035 (S.I.L.) + 1.26

for L.L. - Rating = 0.044 (L.L.) - 0.12

where the ratings are very quiet, quiet, average, noisy and very noisy.

The rank order correlation coefficient for S.I.L. versus subjective noise rating is 0.94 compared with 0.85 obtained by Beranek. The rank order correlation coefficient for L.L. versus subjective noise rating is 0.97 compared with 0.95 obtained by Beranek. Using the Students' t distribution, we obtain t approximately equal to 9.8 for both rank correlations. Thus the probability that the distribution of these results differ from the results that would be obtained from the population as a whole is less than 0.01.

As no day-long level recordings were made in this survey, it was not possible to do a statistical description of the variations in day-long levels, and hence obtain a relationship between responses to the background noise environment with the measured day-long S.I.L's and the calculated L.L's (O.D.) as done by Beranek.

For this survey, to obtain a further comparison with Beranek's findings, a correlation was made between the way all respondents (regardless of building or group) rated their office (very quiet, quiet, average, noisy or very noisy) and the corresponding median and mean S.I.L. and L.L. From this, the general increase in S.I.L. and L.L. as the subjective noise rating increases towards very noisy is readily seen.

Quietzsch (Ref. 3) found the correlation between S.I.L. and L.L. of a given noise was very high, the difference between them being about 20 units, but there were some marked discrepancies. Beranek used this fact in addition to his survey data in stating office personnel seem to desire a loudness level in phons (O.D.) that does not exceed the speech interference level by more than about 22 units, with a maximum difference of 30 units.

Of the 10 offices in this survey where the L.L. exceeded the S.I.L. by more than 26 units and less than 34 units, only one respondent rated his office very noisy, two rated their offices average, and the other seven said their offices were quiet or very quiet. The median and mean differences between L.L. and S.I.L. were computed for all respondents rating their office very quiet, quiet, average, noisy or very noisy. This illustrates that for this survey there is no significant increase in the difference between L.L. and S.I.L. as the respondents' ratings of their office noise environment increase from very quiet to very noisy.

As there were insufficient offices in this survey where the L.L. exceeded the S.I.L. by more than 30 units, no comment can be made here on the unacceptability of a noise environment with these conditions.

The results of this survey indicate that provided the L.L. does not exceed the S.I.L. by more than 30 units, the background noise environment will be satisfactory, provided the L.L. and S.I.L. are not excessive in intensity.

It is recommended the S.I.L. and L.L. should not exceed 40 dB and 62 phons (O.D.) respectively, which is in agreement with Beranek's findings. For typing staff the recommended limits are a S.I.L. of 45 dB and a L.L. of 68 phons (O.D.).

CONCLUSION

There is good agreement between the findings of this survey and Beranek's Noise Criteria data. However, the use of the median values in the derivation of the N.C. Curves is equivalent to designing for the 50th percentile, which would seem to indicate that 50% of the population are not being taken into consideration.

Much more research needs to be carried out into this form, and others, of noise tolerance levels within the population.

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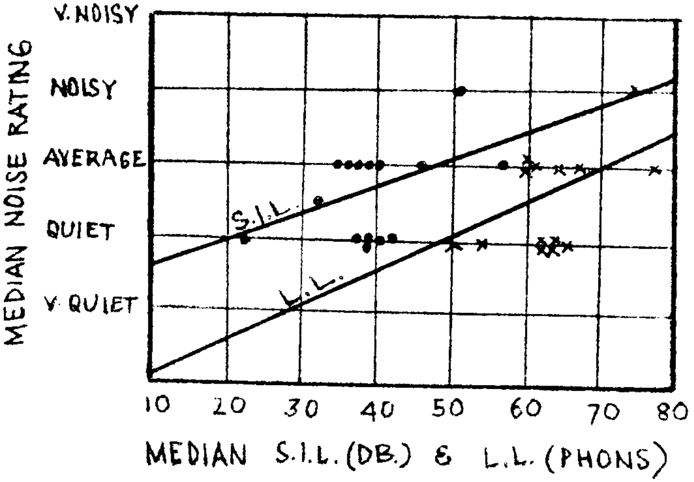

FIG. 1. The median subjective noise rating vs the median S.I.L. (dB.) and median computed L.L. (O.D.) in phons for all four office buildings.

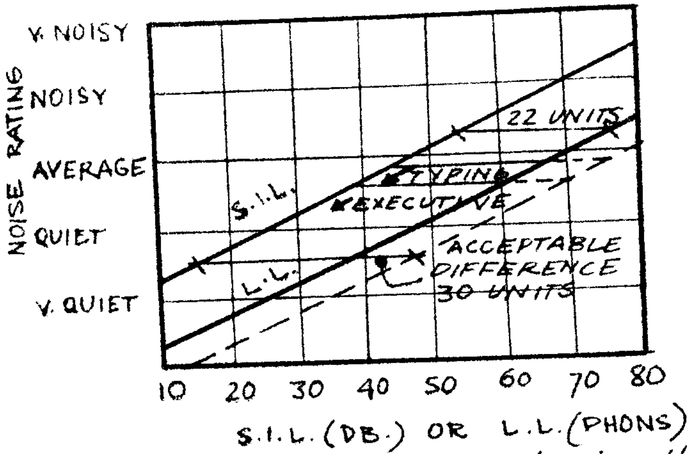

FIG 2. Summary graph showing the favourable acoustical environment for managerial, professional and typing staff in the four offices examined in this survey.

THE SOUND CONDITIONING OF SPACES

By ROGER WILKINSON
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SUMMARY

This Paper summarizes the main features and advantages of a fully-zoned Sound Conditioning installation and shows how such a system can provide effective noise control in many commercial and residential spaces with minimum cost and maximum architectural freedom and flexibility.

. . . .

Amongst the problems facing Architects, Owners and Managers of large commercial buildings, partitions must rank high in terms of annoyance, wasted space, cost and inconvenience.

..How to provide the visual and speech privacy required by occupants and executives of the building's tenants without becoming involved with costly and inconvenient partitioning systems?

..What class of Speech Privacy should be provided for all probable occupants anyway?
What dead load do these types of partitions impose on the building's structure and how much does that cost?

..How flexible are these 'demountable' partitions - especially those having reasonable-high Sound Transmission Class ratings?

..How many spare partitioning components should be kept in store for the project - our store or the partition contractor's?

..Who will carry the cost of partition alterations?

..How long will these partitions be "fashionable" in style and function?

..What maintenance is required?

..How easily can alterations be made to services which either pass through or are housed within the partition structure?

The answers to all of these questions usually cause the Architect, the Owner, the Building Manager and the Tenants to wish for some almost-miraculous method of eliminating partitions from their project. Yet, how can this be done and still provide the visual privacy and speech privacy so necessary to the creation of an acceptable working environment?

A successful solution to these problems is now available which virtually eliminates the acoustical necessity of partitions, allowing open-space office layouts with screens and/or planter-boxes, etc, to provide the visual privacy required to executive areas. Recent installations utilising this Sound Conditioning technique have proved most successful from the Architectural, Acoustical, Owner and User viewpoints.

SPEECH PRIVACY is a term used to describe an environment where conversations and/or equipment activity can be conducted without being overheard by, or causing annoyance to, neighbouring workers or residents. Speech Privacy is dependent on the facility or ability of an observer to decipher speech etc. above his background sound level. This ability is influenced by the level of the source of sound (e.g. speech, typing, etc.) the Sound Transmission Loss between the source and the observer, and the background sound level in the observer's space. Corrective control over any of these three factors can improve the Speech Privacy conditions attained.

The achievement of satisfactory conditions in this regard is normally a two-way problem, firstly Speech Privacy is required from an executive area to the outside areas and secondly, freedom from annoyance and distraction from outside noises transmitted to the executive areas is required.

THE APPROACH outlined in this Paper is to provide effective 'masking' of unwanted sound by introducing a neutral, unobtrusive background sound level which is free from any annoying, distinctive, descrete frequencies. This unobtrusive sound is made even more unnoticeable by use of special 'loud Speaker' arrangements which can usually be fully concealed to 'bathe' the areas in an even sound level, zoned to suit the activities and requirements of the respective areas. Smooth transitions from one zone to another avoid noticable changes in zone levels.

In addition, these lower NC levels are created by sounds having their NC rating determined by the lower frequency bands; Sound Pressure Levels in the mid and higher frequency bands being much lower than the rated (and specified) NC curve's spectrum levels. This, of course, is a very poor foundation for the creation of Speech Privacy conditions and the masking of Activity Noises.

Also arising from on-site investigations is an approach to the calculation or assessment of Speech Privacy conditions which cast doubt on the validity of the current and "conventional" method of calculation of Articulation Index and thence the derivation of Speech Privacy rating. Whilst the latter point is beyond the intent of this Paper, experience shows that an increase in background masking sound level is more effective (db for db) than an equivalent increase in Sound Transmission Loss between the noise source and the observer. That is, the Intelligibility of Speech is more readily spoiled by a properly designed background sound, than is contended by other writers on this subject.

THE COST OF SOUND CONDITIONING is only a fraction of the cost of the types of partitioning which might provide the same acoustical effects. For guidance only, the cost of Sound Conditioning usually works out to be between 30 cents and 50 cents/sq.ft. of floor area treated - the larger the area the smaller the cost per square foot. Space-divider requirements can now be reduced to the 'planter-box' or filing facility types or eliminated completely if desired - depending on the interior effect and Speech Privacy rating required.

In many instances Sound Conditioning can save money on other components apart from partitioning. Just as the system effectively masks-out annoying intrusions from neighbouring activities (without preventing across-the-desk or telephone conversations) it also masks out noises emanating from airconditioning and air distribution equipment or external traffic and activities. Hence the noise levels created by these factors can now be higher than previously acceptable, because they are now

The electronic generator used to provide the signal to these speakers can be adjusted at the control point to balance, blend, supplement, or optimise the existing background or activity noise level spectrum.

THE MASKING provided by this supplementary, zoned, background sound level drastically reduces the Sound Transmission Loss requirements of partitions to achieve the desired speech privacy conditions. In fact, this system often eliminates acoustical justification for partitioning and allows open office layouts, uncluttered by the forest of heavy, expensive partitions previously required to provide adequate Speech Privacy and freedom from distraction. In executive offices, where partitions may be required for Visual Privacy, these partitions need have no special acoustical properties and can thus be selected for best architectural effect.

Further, many EXISTING SPEECH PRIVACY AND ACTIVITY NOISE PROBLEMS can be overcome by installing Sound Conditioning within and/or surrounding the problem areas. For instance, many commercial buildings have partitions which are either part-height only or which go up to a false-ceiling having poor "Room-to-Room via Ceiling" Sound Transmission Loss characteristics. Acoustical correction of these conditions to allow attainment of good Speech Privacy or the control of Activity Noises usually involves a messy, costly and inconvenient extension or reconstruction of partitions to more effectively close-off acoustically critical areas from their surrounds.

Installation of a designed Sound Conditioning System can usually alleviate (and often eliminate) the necessity of any changes to the existing partitioning and, in fact, has allowed the removal of existing partitioning, as functionally required, whilst still providing the Speech Privacy control desired.

FIELD EXPERIENCE shows that the commonly specified NC levels, as maximum allowable noise levels (from say Airconditioning equipment), usually lead to the creation of steady background noise levels significantly lower than the NC level specified.

blended into the overall background sound. This can often lead to significant savings in air silencing equipment and external building components by an integrated design of the acoustical performance of air-conditioning, building and sound conditioning systems.

THE TECHNICAL DETAILS of this Sound Conditioning system are the subject of a patent application but a brief outline of the components follows:-

..THE GENERATOR used to create the background sound is an electronic random noise generator capable of simple, knob tuning to achieve a wide range of spectrum shapes and levels. This generator is transistorised and assembled on a printed circuit to give reliable service and minimum space requirements

..THE AMPLIFIER used to provide the signal power to the system is a good quality commercial amplifier to suit the power requirements of the installation. Operating costs are low and are roughly equivalent to the running costs of a three lamp fluorescent light fitting for each floor treated (i.e. approx. 4 cents/hr.).

..THE SPECIAL SPEAKER ARRANGEMENTS used can usually be selected and placed in conjunction with architectural, lighting or airconditioning components to provide concealed, wide-angle diffusion of the background sound into the occupied areas. Wiring to the speakers can normally be in 'figure 8' wire. Individual speaker or whole-zone 'volume controls' can be supplied to suit the current or future requirements of the respective areas. Experience to date indicates that Sound Conditioning system background sound levels, in the order of 5 to 10 Noise Criteria curves higher than those normally acceptable, can be created at the working level without causing offence or annoyance. This, of course, is a very 'usuable' foundation for the creation of good Speech Privacy conditions.

MECHANICAL VERSIONS of the electronic generator-amplifier are currently undergoing development and final trials. These devices are intended for the creation of Sound Conditioning effects for small areas where fully-zoned, variable-spectrum, variable-level Sound Conditioning requirements are not warranted. Such areas, already treated successfully during trials, include Board Rooms and Chief Executive offices having somewhat public-adjoining areas (two-way control provided), Private Residences with excessive traffic noise and Home Units having intruding noises from fellow unit occupiers. The mechanical Sound Conditioning devices available can either incorporate a Supply (or Exhaust) Air System or not, and the Supply Air type may have a Heater fitted if required.

The basic concepts involved in this Sound Conditioning principle are by no means new. What is perhaps new is the ability to create, adjust and control an unobtrusive background sound and to introduce it into large (if necessary) spaces, in zoned levels appropriate to the requirements of the respective areas, with concealed and/or disguised, wide-dispersion "loudspeakers".

The full possibilities of Sound Conditioning are not realised until this concept is considered and treated as an integral component in the environment to be created. Then, at the design stage of a project, the full acoustical, functional and economic benefits of utilising this system can have their maximum effect. It is at this design stage that decisions can be made to:-

..Relieve the structure (and the Owner!) of the dead load imposed by partitions.

..Alleviate the necessity for rigid architectural restraint and limitations on space utilisation and space-dividing techniques.

..Relieve the structure of the dead load imposed by a heavy Plant Room Floor at its top which is often provided, whether needed or not, for noise attenuation to a prestige area immediately below.

..Reduce the acoustical requirements of external building components for adequate control of external noises.

..Reduce the quantity (and possibly quality) of "silencing" equipment in the Airconditioning system.

..Provide complete flexibility, for all probable usage and occupation of building space, by a simple knob-turning operation at the control point.

CONCLUSION

This Paper describes an effective method of creating Speech Privacy conditions and reducing the annoyance of Activity Noises within spaces in general and open-office layouts in particular. The technique employed masks, rather than reduces, speech and activity noises by introducing a steady, unobtrusive background sound to supplement, balance, blend or optimise the existing background noise level spectrum.

TRANSDUCER TECHNIQUES FOR MEASURING THE EFFECT OF SMALL-ARMS' NOISE ON HEARING

by

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This study investigated several types of transducers which might be considered for use when evaluating the hearing hazard of pressure waves that small arms produce. In measuring the small arms' peak sound-pressure level, error was directly proportional to the measured rise time and inversely proportional to the positive pressure duration of the wave. The most accurate results were obtained by positioning the transducers vertically, with the pressure wave grazing the sensing surface at 90^{o} incidence. Moreover, there was good agreement between measurements made with a wide-band piezoelectric transducer and those made with a wide-band condenser microphone. Finally, pistonphone calibrations at low levels (127 dB) compare favorably with shock-tube calibrations at high levels (170 to 180 dB).

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Improvements in small arms, within recent years, have raised the sound pressure level (SPL) at the operator's ear until many firers show large hearing losses. The purpose of this report is to help establish a uniform procedure for measuring small arms' pressure waves accurately -- the primary requirement for evaluating how such weapons affect hearing.

One of a transducer's most important characteristics when measuring impulse noise is its rise time capability. Although no present-day transducer can follow the pressure rise exactly, the device chosen must be able to reach a peak before significant pressure decay occurs. In order to evaluate this characteristic, several pressure transducers were exposed to the pressure produced by a shock tube. The shock tube nominally produces a shock wave which rises "instantaneously" to a preselected pressure, remains at that pressure for a short time, then gradually returns to ambient pressure. When a transducer measures the shock-tube pressure wave, the pressure-vs-time history oscillogram is an accurate index of the transducer's rise-time capability for a given pressure and a given angle of incidence. Moreover, the shock tube produces an accurate, preselected pressure, which is a useful reference for verifying other calibration methods. The transducer's ringing and overshoot characteristics may also be evaluated. The results indicate that at a grazing transducer incidence angle, rise time for different transducers varied from 10 to 170 μsec; it can be seen that at this incidence angle the shortest possible rise time will be determined by transit time -- the time it takes the pressure wave to cross the face of the transducer. At normal incidence all transducers exhibited wave distortion due to overshoot and several showed severe ringing.

It was determined that the overshoot at normal incidence was produced by reflections off the face of the transducer. Therefore, it was decided to investigate how intermediate incidence angles affect measured pressure-time histories. The wave shape chosen for the investigation was the shock wave of a supersonic 7.62mm projectile in flight which produces the classic "N" wave.

This wave shape was measured with two transducers: a) a BRL[1] 250-kc lead zirconate pressure gauge and b) a Bruel & Kjaer (B&K) type 4136 capacitor microphone. Both transducers were oriented at incidence angles varying in 30° increments from 0° to 90° with reference to the bow wave of the supersonic projectile. The resulting oscillographic wave shapes are shown in Fig. 1 for both transducers at 0° and 90° incidence. Ideally, the "bow wave" of the projectile should produce an instantaneous increase to some positive amplitude, P_1. The pressure then decreases linearly until it reaches a negative value, P_2, where ($|P_1| \approx |P_2|$), and then the "stern wave" instantaneously returns the pressure to ambient. The important point here is that the pressure decrease from positive to negative pressure (P_1 to P_2) should approach a straight line, and have no overshoot when returning to ambient. The two

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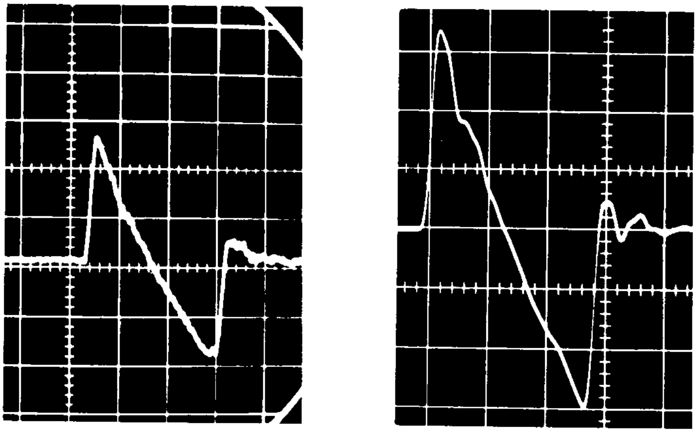
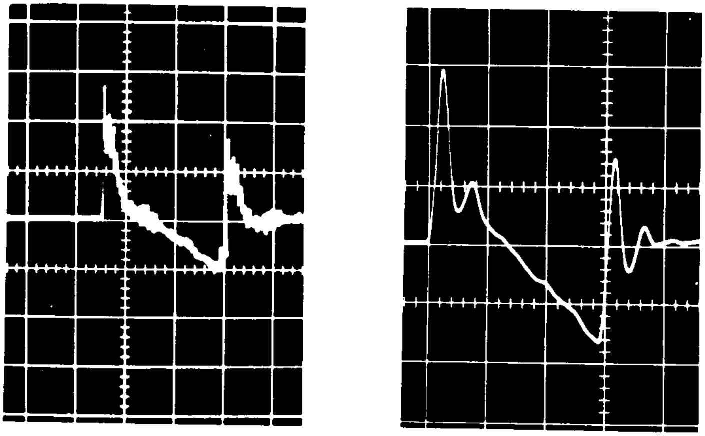
[1] Ballistics Research Laboratories, Aberdeen Proving Ground, Md.

transducers, when positioned at 90° incidence, agree within 0.3 dB when measuring the peak pressure produced by the "N" wave; and its duration is the same (150 μsec). Also, the wave shapes produced by the two transducers are very similar, and both have the required straight line between P_1 and P_2.



BRL @90° B&K @90°



BRL @0° B&K @0°

Fig. 1. Pressure vs Time History Produced by the Shock Wave of a 7.62mm Projectile in Flight When Measured with BRL 250-kc and B&K 4136 Transducers at 90° and 0° Incidence (sweep time = 50 μsec/major division).

As the transducers are rotated from an incidence of 90° to 60° several changes occur. The peak-pressure measurements are higher than at 90° incidence. The increased peak is caused by the pressure reflected off the transducer's face. Also, the decay from P_1 to P_2 is no longer linear and a peak is created as the pressure returns from P_2 to ambient. This smaller peak is due to reflection from the transducer's face as the stern wave passes, as well as slight transducer overshoot. The reflected pressure phenomenon may be seen clearly in Fig. 2 which shows a projectile's shock wave striking a transducer. A small spherical shock wave is generated, expanding until it reaches the corner of the transducer, and then dissipating, since there is no surface to support this reflected pressure.

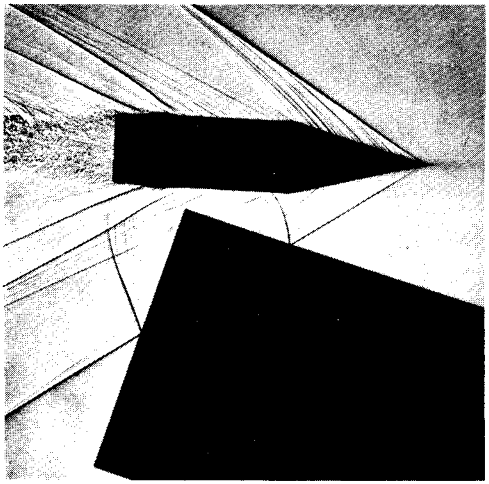


Fig. 2. Spherical Shock Wave Being Reflected Off Face of a Transducer as a Shock Wave Strikes It.

Table 1 shows how peak SPL increases over the 90° incidence measurement as the transducers are rotated from an incidence angle of 90° to 0°.

Table 1

Variation in Peak SPL at Different Incidence Angles for the BRL 250-kc and B&K 4136 Transducers

Incidence Angle (degrees)	Peak SPL Deviation from 90° Incidence (dB)	
	B&K	BRL
90°	---	---
60°	1.1	3.3
30°	3.6	5.0
0°	3.6	9.0

The B&K 4136 produces smaller variation from the 90° measurement at 0° than the BRL 250-kc since it has a lower frequency response (70 kHz vs 250 kHz) and also is more heavily damped. These characteristics can be readily seen in Fig. 1 where the BRL 250-kc transducer produces minor higher frequency deviations during the pressure decay than the B&K which averages these variations into a smoother decay curve.

Fig. 1 also indicates that the BRL 250-kc transducer at 0° incidence creates additional difficulties -- the measured peak SPL includes overshoot inherent in the design of the transducer, as well as reflected pressure. The net result is a misleading incident pressure-time history. The B&K transducer's record at 0° incidence indicates that its best rise time is about 10 μsec, which agreed with the shock tube measurements. Because of this poorer rise time capability, reflected pressure and overshoot will not increase peak SPL at 0° as much as with the BRL 250-kc transducer.

Thus far in evaluating a transducer's ability to accurately measure small-arms' pressure waves, angle of transducer incidence has been found to be very important. Also, since the pressure wave we are measuring is of such short duration, rise time must be kept as short as possible. Therefore, we also investigated the rise time capabilities of various types of transducers at different pressures. This was accomplished by measuring the pressure time history of the expanding muzzle gasses of a 7.62mm rifle at points 0.25, 0.5, 1, 2, 4, and 8 meters to the side of the muzzle. The transducers were placed at 90° incidence and tested individually starting at 8 meters.

The results indicate that at the higher pressures the rise time of the capacitor microphones became longer. Some exhibited rise times as long as 200 μsec and measured pressures of 167 dB when in actuality the rise time was less than a microsecond and the pressure was 180 dB.

The design and operation of a capacitor microphone are such that the output signal is proportional to diaphragm displacement when displacements are small. Measuring high pressures forces the diaphragm into relatively large displacements. Then the diaphragm does not move linearly and the rise time capability deteriorates. The B&K 4136 began to exhibit rise time deterioration at 170 dB. The BRL 250-kc piezoelectric transducer did not show this non-linearity and consequent rise-time deterioration; it rose to a peak in less than 10 μsec at all pressures tested.

For acoustical transients such as those produced by small arms which have positive pressure durations in the order of 200-300 μsec and rise times of less than 1 μsec, assuming there is a linear decay, the percent error can be written as:

$$\text{Percent error} = \frac{Tr}{Td} \times 100$$

where: Tr = rise time measured by the transducer

Td = duration of the transient.

Therefore, if a transducer's rise time is 10 μsec, the error when measuring small arms will be 3.3 to 5.0 percent (about 0.3 to 0.5 dB).

In summary, our recommendations for measuring small-arms' pressure waves are:

a. Use a transducer which has a rise time capability of ten microseconds or less at the pressure being measured.

b. Transducer ringing and overshoot should be less than 1.5 dB at the pressure being measured.

c. The transducers used should have (a) enough sensitivity to allow a signal-to-noise ratio of 25 dB or greater, and (b) minimum drift caused by temperature instability.

d. In relation to the weapon, the transducer should be where the left ear of a righthanded firer would be (firer not present). It should be oriented (a) at 90° incidence, and (b) with its sensitive surface approximately parallel to the ground (Fig. 3).

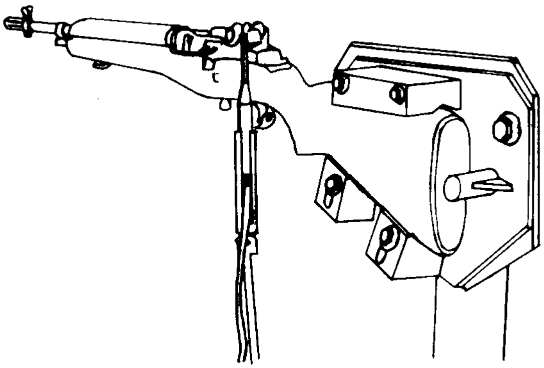


Fig. 3. Recommended Transducer Orientation for Measurements Made at the Operator's Left Ear Position.

ACOUSTICAL HORTICULTURE, OR HOW TO GROW A TTS

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ABSTRACT

A procedure has been developed to observe the growth of temporary threshold shift (TTS) which circumvents problems of individual differences in susceptibility to impulse-noise-induced TTS. Using this method each subject is exposed only to the minimum noise conditions required to induce a criterion level of TTS. The method has been employed to compare effects of monaural vs. bianural exposures, and is presently being used in a study of recovery from TTS.

INTRODUCTION

One of the significant procedural problems in investigating the effects of impulse noise on hearing is that the range of INITTS is far greater than is the case with steady noise. This makes it necessary to select exposure conditions very carefully. If the conditions are too severe there is considerable risk of (a) permanently damaging the subject's hearing, or, at the very least, (b) the receovery time will be lengthy (3). On the other hand, if the number of impulses in an exposure is selected to protect the most susceptible subjects, the least susceptible subjects will demonstrate either zero TTS or, as we have observed, negative TTS (2). Exposing all subjects in an experiment to the same number of impulses is advantageous when the purpose is to establish the distribution of TTS resulting from a given set of noise parameters. However, when the purpose is to study more general features of the hearing mechanism's response to noise, or when several conditions are to be compared, it would be more beneficial to obtain a measurable, positive, TTS from each subject. To accomplish this end the amount of exposure would have to be tailored for each individually; then the dependent variable would be the amount of exposure required to produce a set criterion level of TTS.

This paper relates experiments in which a procedure was developed for observing the growth of INITTS from zero to a criterion level. The approach was somewhat akin to that employed by Elwood, et al. (1), in their method for separating subjects into categories of susceptibility.

PROCEDURE

The subjects were first trained to give reliable audiograms with a discrete-frequency Bekesy audiometer. They were then exposed to groups of impulses produced by a .30 cal. small arm. (The impulse waveform is shown in Fig. 1.)

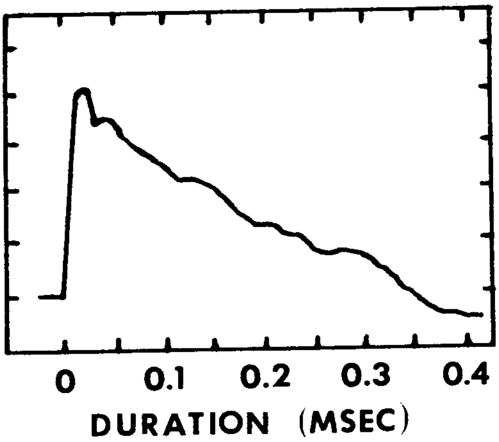

FIG. 1: IMPULSE WAVEFORM

The peak level of each impulse was 155 dB re 0.0002μbar and the A-duration was 0.35 msec (free-field measurements; subject absent). During the exposure the subject was seated in a position such that his left ear was oriented at normal incidence to the oncoming shock wave. After each group of impulses the subject's thresholds at 2, 4, and 6 kHz were measured. This alternation of noise exposure and threshold measurement was continued until the left ear demonstrated 15dB TTS_2 at one or more of the test frequencies. When the criterion was reached no further noise exposure was administered. Post-exposure adiometry varied according to the purpose of the experiment. Sometimes complete audiograms were taken on both ears. In other cases only the left ear was tested, repeatedly, to establish recovery functions for INITTS.

EXPERIMENT #1

32 subjects were exposed to group of 10 impulses. A maximum of 20 such 10-impulse groups was administered; thus the least susceptible subjects were exposed to no more than 200 impulses. A monaural exposure was used.

The distribution of INITTS growth rates is shown in Fig. 2. 56% of the subjects reached criterion after exposure to only three groups of impulses. We concluded that this particular procedure would not be suitable for use in a future study of, for example, higher peak levels, since the higher levels might be expected to cause more rapid TTS growth. If TTS grew more rapidly than it did in the present case it probably would not be possible to discriminate among the growth rates.

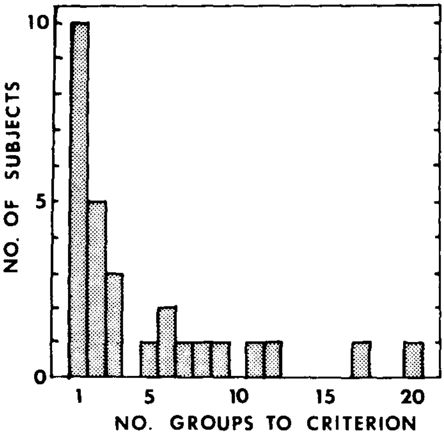

FIG. 2: TTS GROWTH RATES (EXP. NO.1)

Another question which arose during this first investigation was whether there would be any difference in TTS growth rate in the test ear when binaural, rather than monaural, exposure was given. To test such a possibility, 19 subjects were given binaural as well as monaural exposures. The distributions of growth rates are shown in Fig. 3. The distributions are remarkably similar. The mean number of groups of impulses to criterion was 4.11 for the binaural exposure and 4.53 for the monaural exposure. The difference between these means was not significant. Four subjects demonstrated identical growth rates under the two conditions; 8 subjects' TTS grew more rapidly under the binaural condition; the remaining 7 subjects' TTS grew more slowly under the same condition. Hence, we concluded that, while there might be individual differences in rates of growth under the two conditions, there was no consistent or obvious trend favoring either approach.

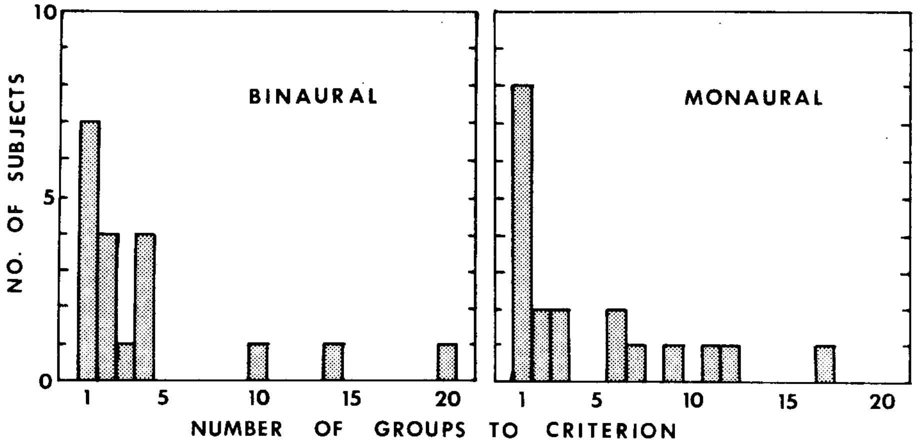

FIG. 3: TTS GROWTH RATES FOR BINAURAL AND MONAURAL EXPOSURES

ent or obvious trend favoring either approach.

EXPERIMENT #2

To better define the initial portion of the TTS growth function, 31 subjects were given binaural exposures to the same peak level and duration used in the first study. The numbers of impulses in the groups was changed: the first four groups contained 5 impulses each; the next four, 10; the next four, 15; the last four, 20. The distribution of growth rates is shown in Fig. 4. Compared to Fig. 2 and Fig. 3, the distribution is skewed to the right. The number of subjects reaching criterion in the first few groups has been reduced and a more nearly rectangular distribution of growth rates resulted. From this we concluded that the procedure used in Experiment #2 was more nearly acceptable for our purposes.

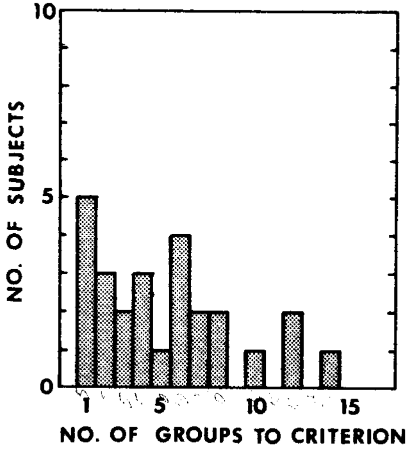

FIG. 4: TTS GROWTH RATES (EXP. 2)

CONCLUSIONS

1. It is possible to monitor, within a single test session, the growth of TTS from zero to a criterion level, examining enough frequencies to obtain a general picture of the effect of impulse noise on the ear's sensitivity.

2. A procedure has been developed to compare the effects of various combinations of noise parameters which may be expected to cause different rates of TTS growth.

3. We have eliminated, for practical purposes, the problem of individual differences in susceptibility to INITTS as a limiting factor in designing impulse-noise studies.

4. No consistent differences in rate of TTS growth resulted from binaural vs. monaural noise exposures.

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A COMMUNITY ANNOYANCE PROBLEM OF MODULATED LOW FREQUENCY NOISE

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In 1965 the Dutch dredge H.A.M. 208 was involved in dredging sand from Botany Bay for the extension into the Bay of the North-South runway at Kingsford Smith International Airport.

These operations were carried out on a 24 hours per day basis, and resulted in a large number of complaints that the dredge noise was causing loss of sleep and general annoyance at distances as great as 4 miles from the dredge.

Interviews with some of the complainants showed that the complaints were not that the noise was loud but rather that it was "pulsating". This pulsating or modulated characteristic of the noise produced by the dredge was confirmed and two distinct primary modulation components were isolated. These were found to be a 4 to 5 Hertz modulation component, and a 0.5 to 0.6 Hertz modulation component.

A 1/3rd octave band analysis of the engine noise showed that the two main pumping engines each 14 cylinder, 2 stroke diesels of 1750 horsepower produced their main acoustical outputs in the 40 Hertz to 50 Hertz bands.

The modulation depth at these frequencies was measured and the difference between peak and minimum signal was typically 12 decibels for the 50 Hertz and 14 decibels for the 40 Hertz band.

Night measurements were conducted on the shore at a distance of one mile from the dredge under nominally free field conditions, and the results plotted on normal equal loudness contours for pure tones as details in I.S.O. Recommendation R 226. These showed peak levels of 60 phons and minimum levels of approximately 40 phons in the critical 50 Hertz band as shown in figure 1.

Because the modulation component was the primary source of annoyance, it was resolved that the problem could be best solved by reducing the carrier level, to the background level. Thus the modulation level would in theory still have the same relative peak to minimum level but would be virtually inaudible.

An investigation was made into the possible causes of the low frequency modulation components. The 4 to 5 Hertz component was found to be caused by non-linear flow patterns in the exhaust manifold. This resulted from the varying distances of the respective cylinders from the common junction of the dual exhaust manifold on each engine. Thus this component occurred at shaft speed in the range 240-260 r.p.m.

The 0.5 to 0.6 Hertz component was the result of the variation between the respective engine speeds. Differences in engine speed of the order of 4 to 5 r.p.m. were common and synchronisation of the two engines was not readily possible. The difference in shaft speed, when compared to the basic exhaust gas flow variations of each engine exhaust resulted in a 0.47 Hertz modulation component for 4 r.p.m. difference, and 0.585 Hertz modulation component for 5 r.p.m. difference.

The required minimum insertion loss was determined to be 22 decibels for the 1/3rd octave bands centred on 40 Hertz and 50 Hertz. To provide insertion losses as high as this at such low frequencies presented a problem as a silencer offering this performance would need to be physically large. Even more important, tests were conducted on the exhausts of the engines using orifice plates to determine the effects of increasing back pressure on the engines. These tests showed that provided the increase in back pressure did not exceed 5.5" W.G. the engine performance would not be affected.

In analysing the performance of the silencers small perturbation theory was not applicable as the pressure changes produced by the engines was of the order of half an atmosphere and the large changes of density which accompanied the unsteady flow, resulted in increases in the actual pressure drop over those calculated by steady state flow conditions.

The design configuration finally selected as being the most practical utilised a two stage modified expansion chamber design. The first chamber being designed primarily to attenuate the 1/3rd octave bands centred on 40 Hertz and 50 Hertz, and the second stage to provide broad band attenuation to the noise components above 80 Hertz. The silencers were 10'8" high by 6'10" in diameter and each weighed two tons.

The design of the silencers was complicated by the limited lifting facilities on board the dredge, and as a result the silencers were designed to be fabricated in three sections which would be assembled in situ. This however provided the opportunity to test each section as it was assembled and enabled us to compare the actual pressure drop with that previously calculated.

The silencers actual insertion loss was determined by measurements made 2 diameters above the exhaust outlet under conditions of full load both before and after the fitting of the silencers.

The silencers measured insertion loss was as shown in figure 3, and was 27 decibels in the 40 and 50 Hertz bands. This was better than calculated, and this is believed to be partially due to a snubbing action of the silencers on the 4 Hertz modulation component. The difference between the peak and minimum modulation signal being reduced to approximately 8 decibels for the 40 and 50 Hertz bands.

The actual pressure drop achieved was 5.6" W.G.

Night measurements were again conducted on the shore with the dredge at a distance of 2700 feet away. With the dredge working at this distance it was not readily possible to detect the engine noise nor the modulation components above the background noise level.

No further complaints of noise were received by the dredging company, or by the local Councils for the remainder of the project, even though the dredge worked at distances as close as 1800 feet to the shore line.

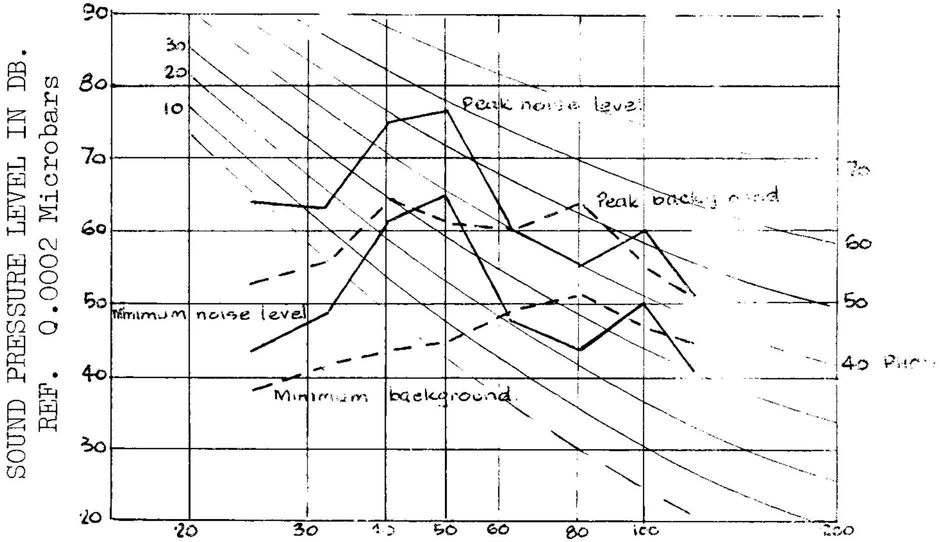

Fig.1. THIRD OCTAVE BAND ANALYSIS OF DREDGING NOISE ON SHORE WITHOUT SILENCERS. DISTANCE APPROX. 1 MILE

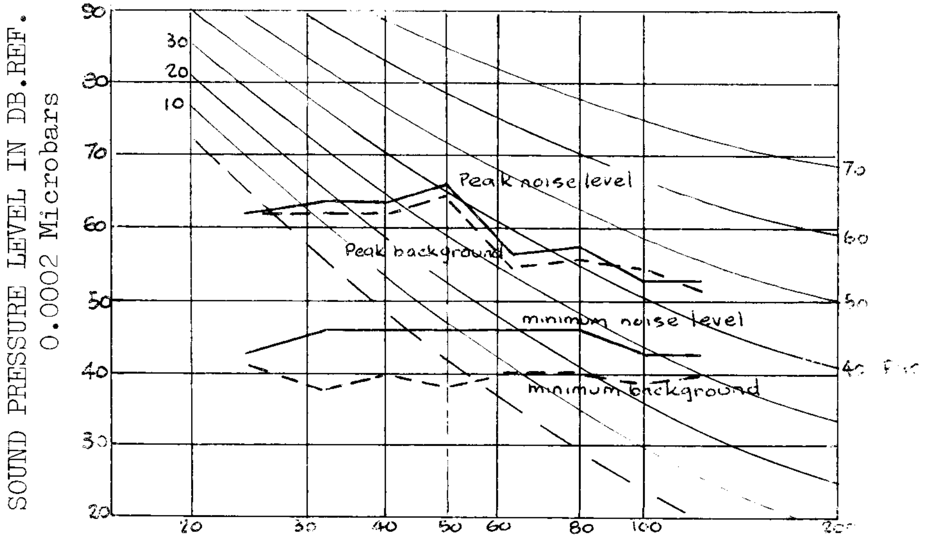

Fig.2. THIRD OCTAVE BAND ANALYSIS OF DREDGING NOISE ON SHORE WITH SILENCERS FITTED. DISTANCE APPROX. $\frac{1}{2}$ MILE.

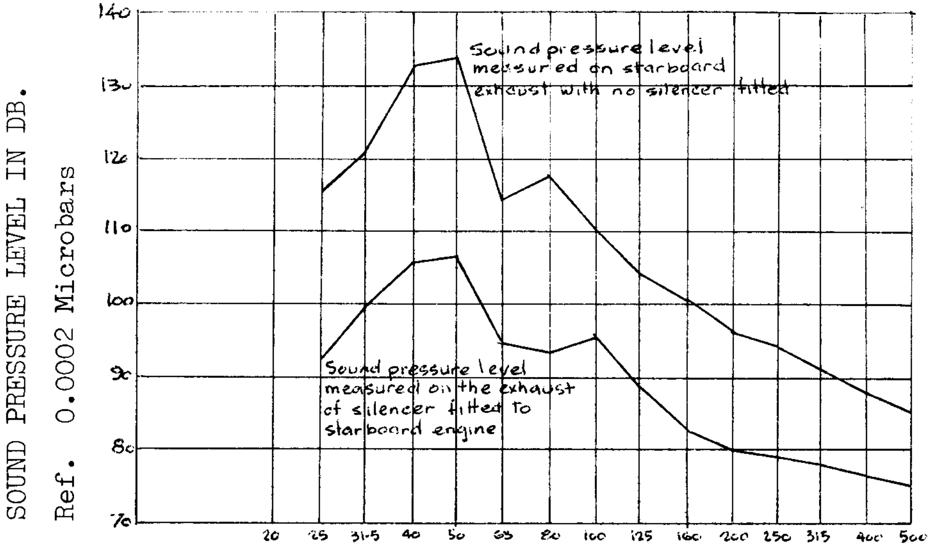

Fig.3 THIRD OCTAVE BAND ANALYSIS OF EXHAUST NOISE AT A DISTANCE OF TWO DIAMETERS ABOVE EXHAUST

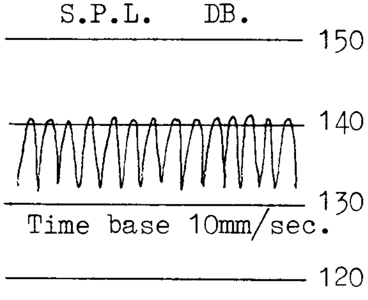

Fig.4
Linear S.P.L. Microphone
Two Diameters above
Exhaust. No Silencers.

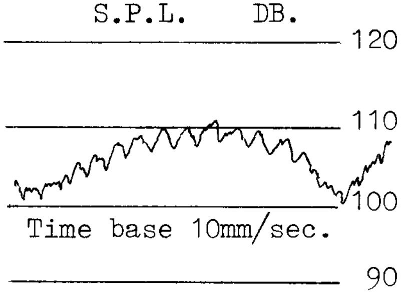

Fig.5
Linear S.P.L. Microphone
centre of deck, both
engines pumping water.
One Silencer fitted.

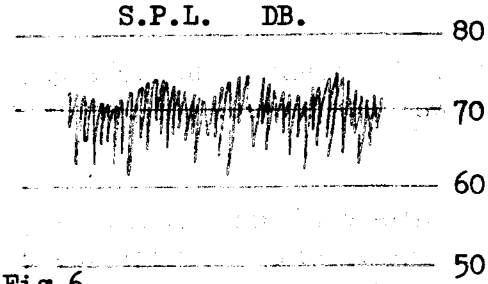

Fig.6
No Silencers Fitted
40Hz, $\frac{1}{3}$ Octave Band
Analysis 1 mile away on
Shore both engines
dredging sand.

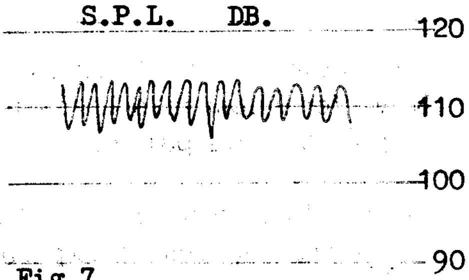

Fig.7
Both Silencers Fitted
50 Hz, $\frac{1}{3}$ Octave Band
Analysis, Microphone
above starboard silencer.
Dredging sand.

* * * * *

ACKNOWLEDGEMENTS

We would like to thank Hollandsche Aanneming Maatschappij. N.V. for whom this investigation was conducted, for permission to present this paper.

We would like to thank Vokes Australia who constructed the silencers and whose experience in the field of silencer design and construction was invaluable, and finally would like to thank Mr. A.F. Kaldor of A.F. Kaldor and Associates who conducted the original surveys and whose cooperation was of material assistance to us.

* * * * *

THE INFLUENCE OF TRAFFIC NOISE ON THE DESIGN OF EXTERNAL WALLS OF BUILDINGS.

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Building, University of New South Wales.

SUMMARY.

A statistical analysis of Sydney traffic noise has allowed mean and maximum spectrum levels to be determined with sufficient accuracy for design purposes. These levels are compared with acceptable background noise levels inside buildings so that the required sound transmission loss of external walls of buildings adjacent to highways may be determined.

INTRODUCTION.

Whilst the most severe external noise problem today is undoubtedly due to aircraft, and in some areas the noise may be primarily the result of heavy industrial processes, at the majority of urban sites the most important source of external noise is road traffic.

Because of its fluctuating nature, road traffic noise is difficult to measure, except on a statistical basis. For example, an individual vehicle will differ in its overall noise level and spectrum according to the engine speed, and the general state of repair of the engine, transmission, exhaust muffler and body. When to these variations are added the wide range of vehicles in use, from Minis to semi-trailers, it will be realised that any statements made regarding traffic noise must lack precision. However, from measurements made, both in Australia (1) and overseas (2), it is found that certain conclusions may be drawn about probable noise levels due to traffic.

NOISE LEVELS OF FREELY FLOWING TRAFFIC.

In order to eliminate some of the variations outlined above, measuring sites may be chosen on flat, straight stretches of road away from intersections. In the Australian measurements (1) sites were chosen on the Hume Highway and Anzac

Parade Sydney. The roads were three lanes wide in each direction (usually with traffic only on the four centre lanes) and had median strips. Total road widths were about 66 ft. (20 m) and a sound level meter was set up 10 ft. (3 m) from the kerb. The traffic noise was recorded and simultaneous traffic counts were made. Most of the vehicles were private cars but from 5% to 15% of the total was composed of commercial vehicles ranging from delivery vans to semi-trailers. Roadside conditions varied between three-storeyed buildings to relatively open country.

The recorded noise levels were subsequently analysed in the laboratory using a high speed level recorder and statistical distribution analyser. Traffic flow rates fluctuate considerably, even under freely-flowing conditions and it was found that individual noise samples should be limited to about 10 min. for consistency. (1). The means 'm' as sound pressure level, dB re 2×10^{-5} N/m^2 and as the weighted sound level, dBA, together with the standard deviations 's' were computed for each sample. These levels were then related to the measured vehicle flow rates and compared with an empirical equation derived by Lamure (2):

$$N = 72 + 10 \log \frac{V}{1000}$$

where N is the mean sound level dBA
V is the number of vehicles per hour.

A similar relationship was found for Sydney traffic, except that the resulting levels were slightly lower than those calculated using the equation.

Although mean values give a reasonable idea of the overall external background noise level near a highway, it is also of interest to know the maximum levels. It is found that the maximum level tends to be nearly constant, whatever the flow rate of vehicles, since maxima occur whenever an individual vehicle passes the measuring position. From the statistical analysis it was found that there is a 96% probability that levels will remain within the range (m+2s), (1), thus the (m+2s) levels have been taken as the maxima for design purposes. For Sydney traffic the value of (m+2s) is about 90dB re 2×10^{-5} n/m^2, sound pressure level, or approximately 84 dBA sound level. (The sound levels, dBA show more variability than does the sound pressure level.) Fig. 1 shows the results of the measurements of Sydney traffic noise.

SPECTRUM LEVELS OF FREELY FLOWING TRAFFIC.

For design purposes it is necessary to know the variation of sound pressure level with frequency, in order to select walls or other elements having suitable sound transmission loss of characteristics.

The recorded noise levels were filtered into one-octave bandwidths, and again these were analysed statistically. (A one-third octave analysis would be preferable, but even a 1-octave analysis proves extremely time-consuming, each 10 minute sample requiring 1 hour for data extraction alone.) It was found that different traffic flow rates had the greatest effect in the high frequency part of the spectrum. Fig. 2 shows the average spectrum values, both mean and (m+2s) levels.

EFFECT OF DISTANCE.

A point source of sound in a free field is attenuated by a 6 dB every time the distance from the source is doubled. However, a stream of traffic behaves analogously to a line source, not a point, and in this case the attenuation with distance is about 3 dB when the distance is doubled. Maximum levels, which occur when an individual vehicle passes the microphone do tend to approximate the attenuation of a point source. Thus it is found that as the observation point moves further from the source (the road), there tends to be less difference between the mean and maximum levels. This effect was measured with the microphone situated about 100 ft. (30m) from the road. At the measuring height of 3 ft. (1m) above the ground, which was grass-covered, an additional absorption occurred in the 500 Hz octave band, (Fig. 3). This effect would be less pronounced at greater heights above the ground. It was found that the reduction of level with distance was less than would be calculated from the 6 dB, 3 dB theory, particularly at higher frequencies.

EFFECT OF ACCELERATION.

The case of freely flowing traffic, although of importance, is not the most common type of traffic found in urban areas (in fact it is difficult to find suitable sites for this type of measurement). Adjacent to most urban sites traffic is subjected to slowing and acceleration due to traffic conditions, pedestrian crossings, etc. Many of these intersections are controlled by traffic signals which means that all traffic proceeding along one road stops, and then accelerates as a group when the signal changes.

Since low gears are used when accelerating from a stationary position, and since petrol engines make more noise the faster the engine speed, it was decided to make some measurements near traffic signals. Signals controlling a pedestrian crossing where chosen so that all nearby traffic halted and then accelerated together rather than the condition that occurs when two opposing traffic streams are controlled. As the mean noise level is a function of the number of times the traffic is halted in a given period an analysis was made only of the starting conditions of the traffic. It was found that in this case the Maximum level spectrum (m+2s) varied somewhat from that found for freely-flowing traffic; low frequency sound pressure levels were greater and high-frequency components lower. (Fig.3). Traffic flow rates are meaningless in such a case, but it is of interest to note that the (m+2s) maximum sound pressure level was 93 dB, which is higher than in the freely flowing conditions, but the (m+2s) sound level was 82 dBA, which is slightly lower (due to the change in spectrum as mentioned above.)

DESIGN CONDITIONS.

In order to determine the degree of sound insulation required for the external walls of a building it is necessary to decide on acceptable levels inside the perimeter rooms. It is common to specify these levels by using Noise Criteria (NC) curves, developed originally by Beranek (3). These are closely related to the ability to converse and use telephones. NC curves are also used to specify acceptable levels in other types of rooms, for example bedrooms, theatres, etc. Typical requirements are from NC 25-35 for bedrooms, NC 30-40 for offices, NC 15-20 for theatres and concert halls. As an example it will be assumed that a maximum level, within a room adjacent to a highway, of NC 30 is required.

So that a factor of safety may be incorporated, it is proposed that an average of the (m+2s) spectrum levels measured near the kerbside be used as design values. If, on the other hand, it is considered sufficient to maintain the mean background noise level at the designed Noise Criteria, then the mean spectrum levels may be used Unless the building is situated a considerable distance from the road it does not seem necessary to make a reduction of level to allow for attenuation.

The required sound transmission loss (S.T.L.) of the external wall may be found by deducting the acceptable background levels from the measured traffic noise levels. In this example, NC 30 levels are used.

a) Using maximum noise levels.

	frequency, Hz.					
	125	250	500	1000	2000	4000
m+2s level	85	80	76	76	74	72
NC 30	48	41	35	31	29	28
required S.T.L.	37	39	41	45	45	44

b) Using mean noise levels.

	frequency, Hz.					
	125	250	500	1000	2000	4000
mean level	75	70	66	65	64	61
NC 30	48	41	35	31	29	28
required S.T.L.	27	29	31	34	35	33

If these required sound transmission loss values are compared with the insulation provided by common forms of external wall construction, it will be found that systems such as 11" cavity brick walls or double-glazed windows of ¼" plate glass, having 8" air space between the sheets, are necessary. If the mean levels are used, 6" concrete is satisfactory, but stud-framed construction provides insufficient insulation. 24 oz. single-glazed windows satisfy the mean-level criterion provided that they form only 1% of the total wall area and that the remaining wall is of masonry construction. So-called thermal glazing units, having only about ½" air space between the glazing leaves do not satisfy either criteria.

THE USE OF NATURAL VENTILATION.

It will be apparent from the above that satisfactory conditions for domestic or commercial buildings cannot be obtained if natural ventilation is used for rooms facing a highway. If it is necessary to use natural ventilation, as in many cases, it is desirable to limit the area of the opening to the minimum consistent with health regulations. Typically 10% of the floor area is required to be window, half of which must open. As an example, a living room of 180 ft^2 is assumed to have a 12 ft.x 8ft. wall facing a highway; the required opening window is then about 9.5% of the wall area. It can be shown that in this case the sound insulation of the wall would not exceed about 10 dB at all frequencies. This would give a mean background noise level within the room of about NC 55 (telephone use slightly difficult, raised voice necessary at 3 to 6 ft.), and a maximum level of about NC65.

ARTICULATION INDEX.

An alternative method of finding the required sound transmission loss of a wall in cases where natural ventilation must be used is based on the Speech Articulation Index (4). The contribution to intelligibility of each one-third octave band of the speech signal is defined numerically and may be expressed graphically as a "dot-field". The articulation index (A.I.) of speech in the presence of noise is then found as the ratio of the "dots" above the noise spectrum to the total dot field. A value of A.I. = 0.8 corresponds to about 100% sentence intelligibility. In order to obtain this intelligibility in the presence of the (m+2s) spectrum levels for freely flowing traffic it is necessary to use a wall having a rating of STC 28; the background noise level would correspond to NC 60, (1).

Conversely, if the sound transmission loss of the wall that is to be used is known, an estimation of the A.I. and the speech intelligibility in the room may be made using the dot-field approach.

USE OF THE SOUND TRANSMISSION CLASS TO SPECIFY SOUND TRANSMISSION LOSS.

The sound transmission class (S.T.C.) is commonly used to specify and rate the sound insulation of an element of construction. However, this is not an economical method of specifying the losses required when the insulation is against traffic noise. In order to obtain sufficient low-frequency insulation using this STC curve it is found that much more insulation is provided at the higher frequencies than is necessary. If a standard curve shape is used it would be preferable to use a curve having more low-frequency insulation, for example shaped rather like the British Grading Curve. This is particularly important in the case of accelerating traffic.

CONCLUSION.

As mentioned at the commencement of this paper it is difficult to be precise when dealing with a fluctuating sound source such as traffic. However, it is believed that the results presented may be of value when chosing suitable systems of construction for the external walls of buildings on main highways.

ACKNOWLEDGEMENT.

The measurements referred to in this paper were made by the author with the assistance of students of the Architectural Acoustics Graduate Diploma course; in particular thanks are due to Mr. Hegvold, and to Mr. Jones, lab. assistant for their help in processing the data, and to Mr. Green for the statistical analysis.

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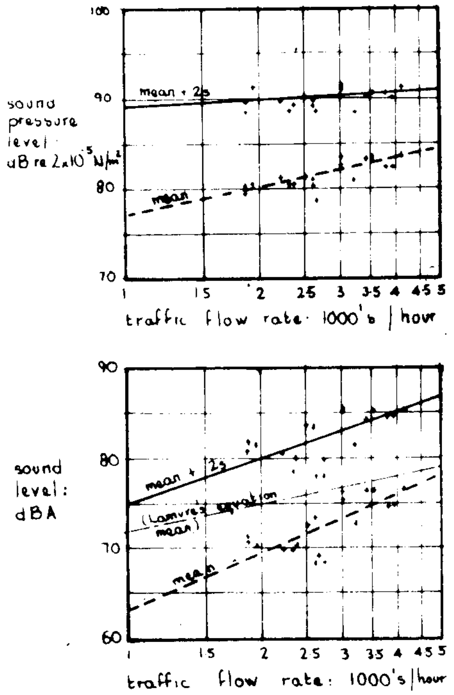
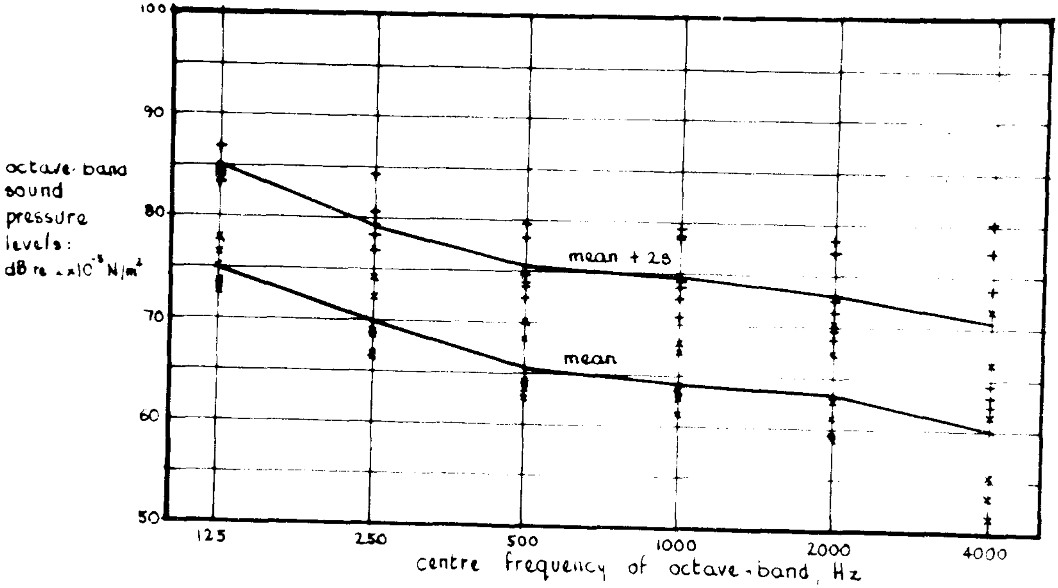


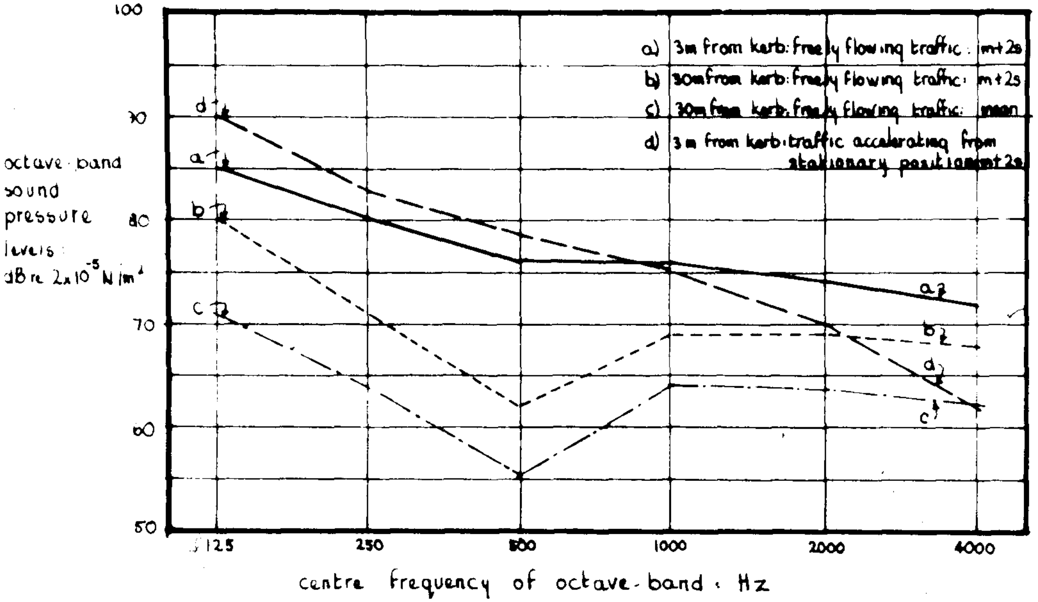
MEASURED SOUND PRESSURE LEVELS & WEIGHTED SOUND LEVELS, dBA OF FREELY FLOWING TRAFFIC: SYDNEY (3 M, 10 FT; FROM KERB: SPEEDS ≃ 60 KM/HR)

FIG. 1.



TRAFFIC NOISE SPECTRUM LEVELS : 3 m from kerb : freely flowing traffic : flow rates 2,500 to 4,000 vehicles/hour

FIG. 2



TRAFFIC NOISE SPECTRUM LEVELS
EFFECTS OF DISTANCE & ACCELERATION

FIG. 3.

PROBLEMS ASSOCIATED WITH THE APPLICATION OF LABORATORY DATA AND HEARING DAMAGE RISK CONTOURS TO NOISE FROM MILITARY VEHICLES

by

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The paper draws attention to some conditions which may invalidate the use of laboratory data and damage risk contours when applied to the noise from tracked military vehicles. Some new data are presented in support of this view and a method of arriving at an estimate of the auditory hazard in spite of these difficulties is described.

Some problems to be considered in the application of laboratory data on temporary threshold shift (TTS) and industrial damage risk contours (DRC) to noise from military vehicles are :

(i) variations in schedule of exposures from those typically provided for in the criteria, e.g. noise exposures may not occur daily nor extend over as much as 10 years.

(ii) variations in the baseline acuity level, or 'resting threshold' of the populations of people to be exposed to the noise.

(iii) limitations in the capacity of octave band analysis to give information about the noise on the following matters :

  (a) momentary fluctuations in noise level and frequency composition;

  (b) the presence of pure tone components (Kryter, 1966);

  (c) the presence of impulsive components (cf. Cohen, 1966);

  (d) other relevant conditions of exposure, e.g. whole body vibration, which could affect threshold shift directly by eliciting the acoustic reflex (AR) and possibly by other means (Guignard, 1965; Farrant, 1966), or indirectly by affecting the sound attenuation provided by ear defenders (Jacobson, 1962);

(iv) the appearance of low frequency hearing loss as a result of exposure to some spectra. Data on the effects of low frequency noise are scarce and even when included in the formulation of damage risk contours are often evaluated from their effect at test frequencies of 500 Hz, 1,000 Hz and above (Kryter, 1965).

(v) the lack of reliable information on the actual conditions of use of ear defenders by personnel. This is related to (iii) (d) above.

The present paper will illustrate some of these problems in connection with the evaluation of the noise hazard and the requirements for auditory protection presente by a tracked military vehicle (an armoured personnel carrier (APC)). The remarks will mainly concern the application of one set of hearing damage risk contours (DRC) those proposed by the (U.S.) National Academy of Science - National Research Council Committee on Hearing, Bioacoustics, and Biomechanics (CHABA) (Kryter, 1966).

In Fig. 1 is shown an octave band analysis carried out at the Commonwealth Acoustic Laboratories (CAL) of the average noise level encountered in the interior of a diesel powered armoured personnel carrier travelling at cruise speed. Also shown in this figure are two damage risk contours. It will be seen that the noise level exceeds both of the criteria and it would appear therefore that some form of hearing protection should be used by persons habitually exposed to the noise.

Other questions raised at the time this analysis was carried out required that we evaluate the temporary hearing loss of personnel exposed to the noise as well and an attempt was made to calculate, from experimental data reported in the literature, what the average temporary hearing loss would be 6 seconds, two minutes and one hou after exposure to the noise for a period of approximately one and one half hours (Piesse, 1965). The results of one of these calculations, made on the basis of the octave band analysis (Fig. 1) together with equations given by Ward (1959) are shown in the next figure (Fig. 2).

It was subsequently considered that the calculations could have overestimated the expected temporary hearing loss because the conditions of exposure in the personnel carrier are quite different from the experimental conditions under which Ward arrived at his equations (Carter, 1966). These sources of error were :

(i) The driving conditions in the vehicle would not normally be the same as those predicated in the earlier CAL report.

(ii) The calculations of hearing loss were based on Ward's experiments using a number of young normal hearing university students as subjects. Effects of the same magnitude would not be expected in a random sample of trained soldiers because of the better hearing acuity of the students to start with (Hecker, 1965; Fletcher, 1963).

(iii) The interior noise of an APC has characteristics not evident from the octave band analysis but which are quite apparent to the ear. In particular it fluctuates rapidly with time both in intensity and frequency composition. The relevance of this for the present study depends on some data by Fletcher, who showed that acoustical stimuli vary in their effectiveness in eliciting and maintaining the aural reflex (AR). These and other investigations (Reid, 1946) suggest that the general characteristics of stimuli most effective in maintaining the reflex are rapid frequency or amplitude variations with time and a complex spectrum. This is typical of APC noise.

(iv) the personnel in the vehicle are simultaneously exposed to noise and to fairly severe whole body vibration. Data by Farrant (1966) have shown that the AR can be elicited by vibration stimuli (of much higher frequency) applied to the external canal, and it is possible that whole body vibration may have a sufficient component at these frequencies present in the canal to at least facilitate contraction of the AR. If this were so it would add to the likelihood of an aural protective effect not accounted for in Ward's data and therefore our calculations based on them.

In view of the relation between temporary and permanent hearing loss shown by Nixon and Glorig (1961, 1962), the above reservations could be applied to estimates of permanent hearing losses resulting from daily exposures to APC noise, and it was decided to carry out an experimental study of the effect of the noise on 14 assault troopers under simulated operational conditions. The hearing of these troops and four crewmen was tested accordingly before and after two one-hour and two one and one-half hour periods in the vehicle in the course of one day. Measurements of hearing acuity used pulsed tone, Bekesy audiometry covering the frequency range 2,000 to 6,000 Hz inclusive (Carter, 1966).

Fig. 2 gives the obtained hearing losses measured two minutes after exposure (TTS_2) together with the calculated hearing losses. Clearly the obtained losses are far less than those predicted on the basis of Ward's equations. The study cannot, of course show which of the hypotheses presented earlier, (baseline acuity of the subjects, fluctuating noise levels etc.) if any of them, would account for the differences between the calculated and obtained results.

The calculated TTS_2 values are, of course, averages and when taken together with data on the dispersion of TTS_2 values about the mean imply that some troops will have losses exceeding 40-50 dB two minutes after exposure, the amount of TTS_2 which is generally regarded as the level at which some residual PTS (permanent threshold shift) becomes possible after a single exposure. Our experimental results reversed these conclusions by showing that given the obtained average losses, no assault troopers (exposed to the noise for possibly five days per month and therefore given adequate time for recovery) should incur losses of this magnitude from single exposures.

However these results also suggest that compensable hearing losses may occur in a small proportion of APC crewmen if they are exposed to the noise daily or nearly daily for periods up to 10 years, when the data are taken together with some information by Nixon and Glorig (1961) on the relation between temporary threshold shift measured two minutes after one day's exposure and permanent threshold shift, measured after 10 years of exposure. Our recommendations were based on this data and not on damage risk criteria available at that time.

A further and somewhat unexpected finding from this study was that more temporary hearing loss occurred at 2,000 Hz than would normally be expected to accompany the obtained losses at higher frequencies and this raised the suspicion that hearing for even lower frequencies may be involved as well. The importance of the frequencies below 2,000 Hz for speech perception is well known and there is the additional possibility that if high frequency hearing loss from other sources, either temporary or permanent, is combined with low frequency loss due to the armoured vehicle the consequences for the person concerned would be quite serious (cf. Coles, 1965).

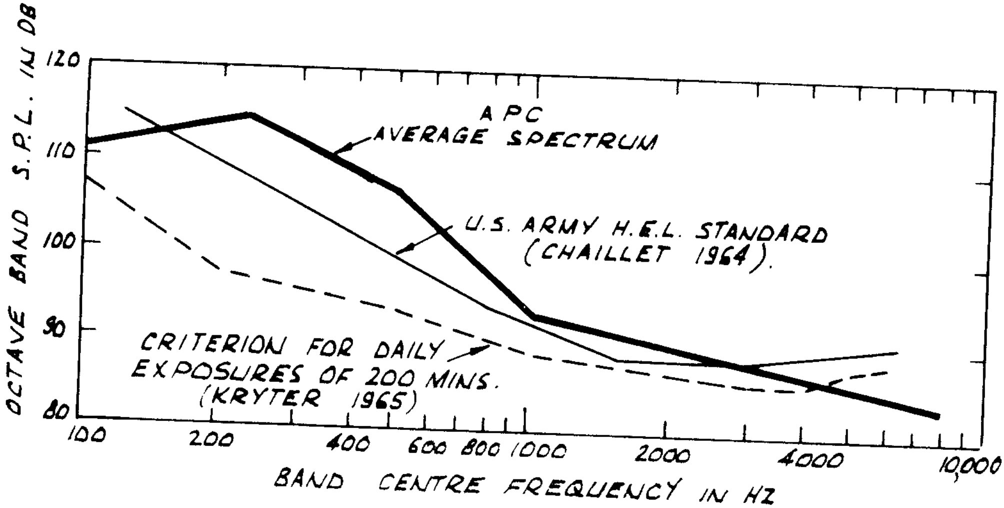

FIG. 1. Comparison of the average interior noise spectrum of an armoured personnel carrier (APC) with two damage risk contours.

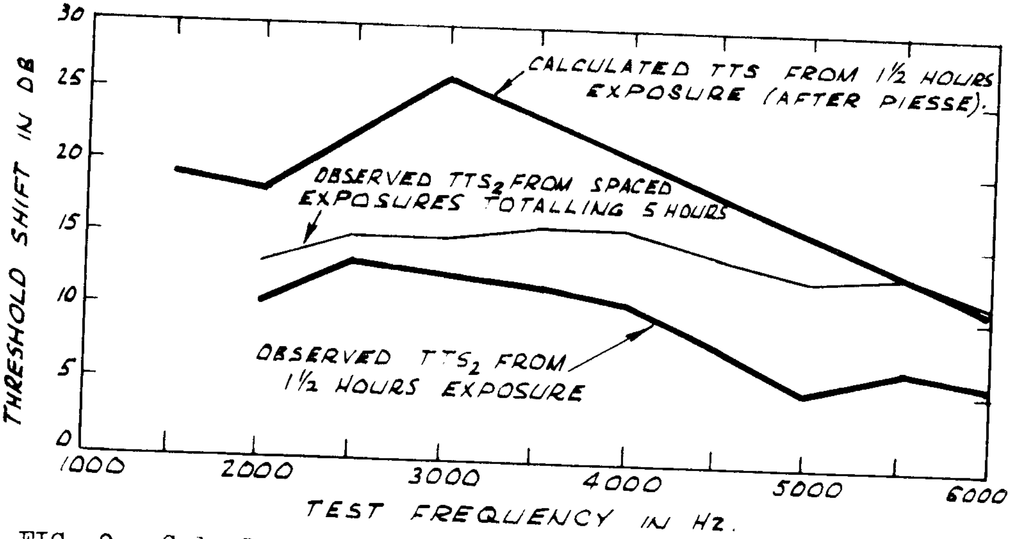

FIG. 2. Calculated and obtained TTS two minutes after exposure (TTS_2) to the interior noise of an armoured personnel carrier for 1½ hrs.

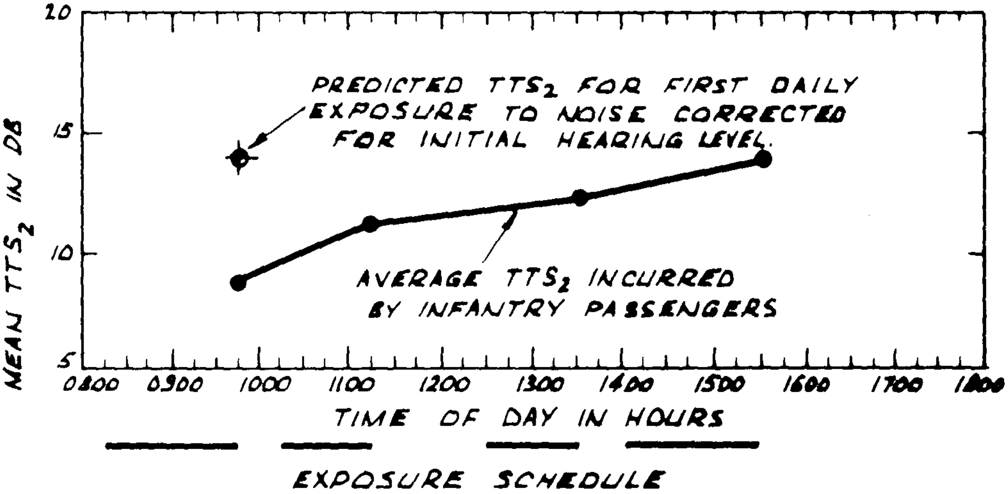

FIG. 3. Obtained average TTS_2 incurred by infantry passengers during exposure to APC noise. TTS_2 is averaged over several test frequencies from 2,000 to 6,000 Hz.

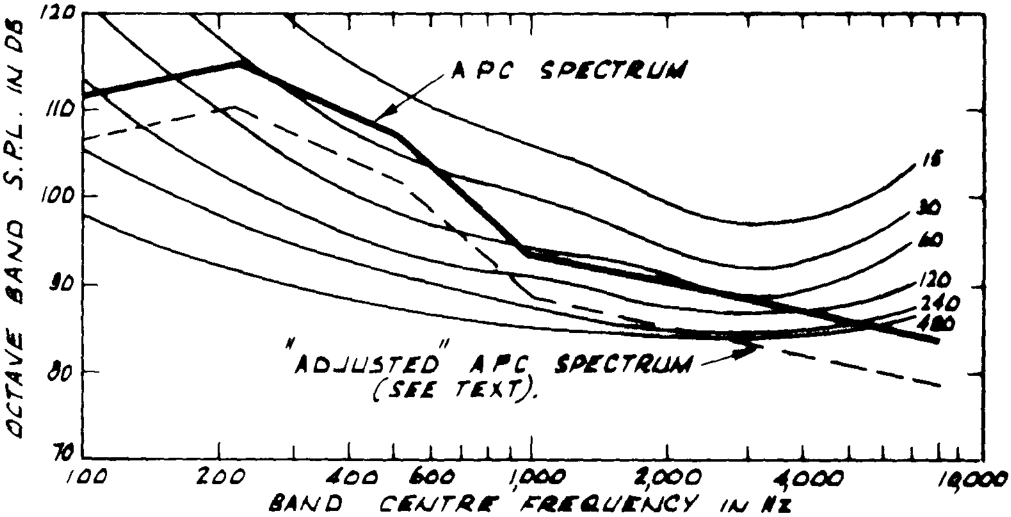

FIG. 4. Comparison of the noise spectrum of the APC and the CHABA damage risk contours. Parameter is the permissible continuous daily exposure in minutes.

In the abovementioned study temporary hearing loss was the main concern the possibility of permanent hearing loss of passengers being remote because the noise exposures were repeated very infrequently, allowing good time for complete recovery. In considering the effect on crewmen, these priorities are reversed, firstly because regular exposures are likely and secondly because operating the vehicle requires hearing for speech only in the vehicle's own noise, so that the effects of temporary threshold shift on efficiency of communication would be submerged in momentary masking effects.

Since the permanent effects on hearing of daily exposures is the main point at issue the application of damage risk contours (Kryter, 1966) is appropriate.

The applicability of the DRC's for the prediction of permanent hearing loss is questionable however because of the results of the study already referred to, of the effects of the noise of the APC on TTS since the CHABA DRC's are based to a considerable extent on the type of laboratory data provided by Ward's experiments. In Fig. 2 of a 1965 paper by Kryter for example there is almost exact agreement between the curves of sound pressure level as a function of frequency and duration that produce an equal amount of TTS (i.e. the minimum amount of temporary threshold shift for speech impairment to be noticed), and DRC's for daily exposure. This could be regarded as completely acceptable if the industrial noise and the laboratory noise are similar and can be shown to produce similar amounts of TTS but the criterion as given must be unacceptable in the present context for the same reason, since the noise produced by the APC differs from that used in Ward's experiments in the way described earlier.

As noted earlier, although the TTS data verify our suspicions that neither Ward's equations for the calculation of TTS nor the CHABA DRC's are directly applicable to the effects of tracked armoured vehicle noise on the hearing of the troops using them, the experiment cannot show what characteristics of the noise, the subjects or the other conditions of exposure are responsible for their non-applicability. However, values of theoretically calculated temporary hearing loss corrected for differences in baseline acuity between Ward's experimental subjects and our troops (the corrections were based on further work by Ward (1963), Glorig et al (1961), and Nixon and Glorig (1962)) are also shown in Fig. 3. Clearly the differences are not solely attributable to this source and even if the other contributing factors were as we suggested earlier, there is no quantitative data which would enable us to make the additional corrections necessary to the hearing losses predicted on the basis of Ward's equations or the CHABA criteria.

A defensible procedure which would enable us to use the obtained TTS data and retain the CHABA damage risk contours without full understanding of these causal conditions can, however, be developed from the obtained TTS data as follows.

Ward's equations contain, besides a number of constants, three variables. These are the SPL of the traumatizing octave band of noise, the duration of exposure, and the amount of TTS produced. Normally (as in our preliminary calculations) the SPL and the duration of exposure are known and the amount of TTS is calculated from the equations.

Of course, Ward's equations can be solved for any of the three variables mentioned above provided that the values of the other two can be determined. Here it was decided to treat the SPL in certain octave bands of the noise spectrum as unknowns and to derive an "equivalent SPL" for each of the octave bands.

The calculated SPL for each octave band can then be compared with the measured SPL for the band and the difference in level noted. These differences can be averaged to obtain a correction factor to be applied to the whole spectrum.

The above procedure assumes (i) that equal TTS is predictive of equal ultimate PTS (permanent threshold shift) and (ii) that the noxiousness of this atypical noise heard under unusual conditions could be equated with the noxiousness of industrial type noise by calculating what the level of the noise spectrum would have to have been had the exposure conditions been the same as used by Ward, to produce the amount of TTS measured.

An estimate of the amount of attenuation at any frequency required of ear defenders under these noise conditions to ensure that the hearing of crewmen be adequately protected is given by the difference between the adjusted noise spectrum and the appropriate CHABA damage risk contour at that frequency. (See Fig. 4).

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SOME PRACTICAL ASPECTS OF HEARING CONSERVATION

BY

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This paper is based on industrial experiences. Prevention in the buying stage is stated as the most important factor in reducing occupational deafness. A noise specification is suggested.

Reference is made to noise reduction by enclosure, with some reasons for failures, and practical difficulties which are often overlooked by well meaning enthusiasts. A practical illustration is given and it is pointed out that enclosures can be used more extensively in industry with a combination of technical advice and operation know how.

Finally the author discusses ear protection as a last resort but, nevertheless, an essential part of hearing conservation. Some reasons, for objections and suggestions for motivation are given.

Prevention by Design and Purchase

Prevention in the design purchasing and planning stage is by far the most important single factor with which we can hope to reduce occupational deafness. It is the only way in which we can overcome inconsistencies with human behaviour. To a large extent customers control what the engineers and equipment manufacturers are going to do; in the past they have not asked for noise reduction. Users can motivate and assist manufacturers of equipment by including noise in buying specifications.

As a guide to industry, when ordering new equipment the following figures, which correspond to N.R.85 (I.S.O.) are suggested as the maximum desirable levels in the vicinity of the operator's ear, under operating conditions, with a sound level meter on fast response.

Desirable Maximum Level for New Equipment

Octave Band Mid Frequencies (Hz)	63	125	250	500	1000	2000	4000	8000
Maximum S.P.L. in Decibels	103	96	91	87	85	83	81	79

While this is considered a reasonable practical limit it will not eliminate all risk and it should not be regarded as final. Efforts should, of course, be made to attain lower levels where practical.

If the noise requirements cannot be met manufacturers should be asked to supply particulars of the noise from their machines so that the user can take it into account in his proposed design, location and building.

Reduction by Segregation and Enclosure.

When there are existing sources which constitute a risk and which cannot be reduced, industry should very thoroughly examine means of segregating and enclosing noisy processes and machines if practical.

It is unfortunate that situations occur where one or two noisy operations which could be isolated, such as engines on test, are permitted to create a hazard for many personnel who are themselves on relatively quiet work.

However, enclosure should not be taken for granted. We sometimes hear that it is easy to reduce industrial noise by barriers and enclosures. This form of publicity by would-be noise abaters, although well meaning, is most inadvisable and misleading. It fails to recognise the problems involved, it tends to embarrass rather than to encourage industry and ill advised action may result in unnecessary waste of money. In some cases it appears to encourage resistance to protection in a situation which is virtually impossible to reduce.

In some cases the ultimate action is a compromise.

If an enclosure is to be effective it is desirable that it should be impermeable and sealed to eliminate leakage paths. In practice many attempts fail in this respect. Openings may be required for adjustment, maintenance, material handling, pipework ducts, operating levers, etc. It is futile to expect a high transmission loss where there has to be a large area of opening.

If designed to meet acoustic requirements operational problems may be introduced such as obstruction, additional movements, heat and ventilation and restricted vision; in practice vital doors and closures are removed and are not replaced. However good a design is acoustically, usually if it hinders the operation in any way it will not be successful. Speaking ergonomically, it must be designed to suit the worker as he cannot be expected to readily adjust to suit the machine.

The efficiency of enclosures, requiring a lining of porous absorptive material, is sometimes quickly reduced by coatings of oil, cement, metal splashes, etc. In some cases perforated replacement panel covers have been successfully used to overcome this problem and splash plates may be applicable.

Operations such as heavy type hot forging do not readily lend themselves to suitable enclosures.

It should be emphasised that enclosures may be complicated, costly and often futile. There are situations where they are neither practical nor economical. It seems preferable to be realistic.

However, the author is of the opinion that if management is sufficiently motivated, acoustically designed enclosures can be and should be applied in industry much more extensively than they are at present.

They must be compatible with operational requirements. This requires the application of sound control principles together with with a complete understanding of practical operation. It would seem desirable for the acoustics engineer to work in consultation with the plant manager, engineer and particularly operation personnel concerned.

As an illustration, a 6 header wood moulder would be classed as difficult, perhaps quite correctly, by many woodworking shop managers. There are exhaust ducts, feed openings, finished product openings, it requires ready access for adjustment, etc. Nevertheless, it has been done.

There have been illustrations of enclosures with spring loaded doors for this type of machine. In this particular case, shown in sketch, the operators felt that hinged doors could not provide the desirable flexibility but sliding doors were found to be practical.

Without any refinements such as overlap or sealed doors, lined ducts for feed-in or acoustic lining inside it gave an effective improvement of 10 dBA.

In another case a plastic granulating machine was enclosed in a ply-wood box lined with porous absorptive material. A suspended rubber sheet three-sixteenths of an inch thick provided a suitable closure for the feed chute opening which otherwise would have been an escape route.

If they are to be effective, barriers need to be close to either the machine, or the operator.

Mechanical handling methods enable the use of barriers with glass vision panels for operators, such as in timber mills, where the sources are limited and the noise is more or less directional. Barriers are usually ineffective if there are numerous sources, perhaps in a large and reverberant building, particularly if the operator has to make frequent excursions to various parts of the mill.

Situations where a noise source does not require frequent access, such as tin cans crashing together in a can chute, can readily be treated by a duct lined with sound absorptive material.

Ear Protection.

Ear protection has often been described as a "last ditch stand". However, it must be considered a most important part of hearing conservation as there are still many cases where reduction to a safe level is either not practical, or it is a low range matter. The object is to reduce to a safe level noise entering the ear. For most industrial purposes the following kinds are available, vix:-

(a) Ear muffs are supported by a band over the head, a neck band suitable for wearing with a safety hat and some are attached to a safety hat.

They are convenient and do not require individual fitting.

(b) Ear canal caps are held firmly against the entrance to the ear canal by a small lightweight head band but they do not enter the ear. They do not require individual fitting. A suitable fit depends on the employee adjusting them correctl

(c) Ear plugs fit into the ear canal. There are many types of prefabricated plastic plugs which are made in a range of sizes. The correct size is important, and individual fitting of each ear is required. In order to obtain a good seal there will be some pressure on the ear and consequently discomfort can be expected initially. They are easily carried and also easily lost or left in the "other pocket".

(d) Fibreglass Wool is available from which fresh ear plugs can be made up daily by the employee. There are differences of opinion on these but, providing care is taken to make them up to fit the ear canal they will provide a suitable attenuation. A disadvantage is that it is dependent on the employee to ensure that it is made up correctly. It has the advantage that prior fitting is not required.

This material is being used widely in many industries here and overseas and in the Armed Services. There are indications that employees will accept it more readily than many permanent types.

Typical attenuations in dB are as follows:-

Frequency Hz	250	500	1000	2000	4000
Fibre Glass Wool	11	13	17	29	35
Normal Ear Plug	16	17	24	28	27
Medium Ear Muff	18	26	43	43	46

Fitting and Indoctrination

It is desirable for the employee to select from a range of protection the type that suits him best.

The most logical place for initial fitting at first thought might appear to be in the plant medical centre. While this is suitable for giving instructions on the correct use and reasons for protection, ear protection will make a quiet situation quieter and it will not give the employee a true indication. On the other hand, if fitted in the work environment there are advantages, the reduction is dramatic, the benefit obvious, and it gives a better understanding of the changes of levels involved. Introduction of noise into the fitting room is a suitable compromise. Often employees will not accept ear protection readily. There are a number of reasons some of which are as follows:

* Management has not taken the trouble to provide it properly. It must be suitable for the job and for the employee. He must be taught how to use it, how to adapt to a new level of sound and how he should adjust his own voice level.
* Discomfort. Protection must be suitable for the situation. It will require some time to become accustomed to it. If it hurts, the ear should be given a rest for a few days.
* Indifference, or a resistance to a change. With the insidious onset of hearing loss he is not aware of the importance.
* Fear of missing speech, warning signals, or roof movement in tunnels. Usually in a noise such sounds are heard as well or better.
* Ability to hear changes in the sound of machines.
* Annoyance by low frequency drumming and resonance in muffs.
* Irritants, chemical vapours and heat.
* A large difference between the noise and the quiet periods.
* He is "tough" and does not require protection.
* A routine approach without recognition of differences in individuals and in situations.

Some reasons for non-acceptance may be based on false conceptions. Objections should never be overlooked. There may be a good reason, or a fear that can be explained. Management should find out why, and either correct the difficulty or explain it.

When fitted well the improved comfort in his work will go a long way to gain acceptance.

Fortunately many of the industrial noises which are difficult to quieten will lend themselves to ear protection but some exceptions are likely.

It is the responsibility of management to educate and motivate the employees so that ear protection is used. This will require personal attention by a responsible person, frequent follow up, the co-operation of foremen together with patience and understanding by all concerned.

Union leaders, in the interest of the welfare of their members, also have a responsibility to encourage them in the use of ear protection. The industrial manager is usually in a position to know the "industrial climate" and to decide on the approach which is appropriate to his problem. Efforts to achieve the successful adoption of a hearing conservation scheme may well be rewarded by an improvement in plant operation and morale.

Summary.

Prevention is the most important part of hearing conservation. Users must demand and specify quieter machines.

Industry should give more thought to segregation and enclosure but false conceptions should be avoided. It is often a complicated problem requiring close co-operation between the sound engineer and the production management.

Ear protection remains an essential part of the program. It's acceptance will depend largely on the ability of management to provide it properly and to resolve difficulties, either real or false, that they may encounter.

If a hearing conservation scheme is to be successful, as with any safety programme, it requires the sincere interest and support from the highest levels of management and the co-operation of the union.

Acknowledgement.

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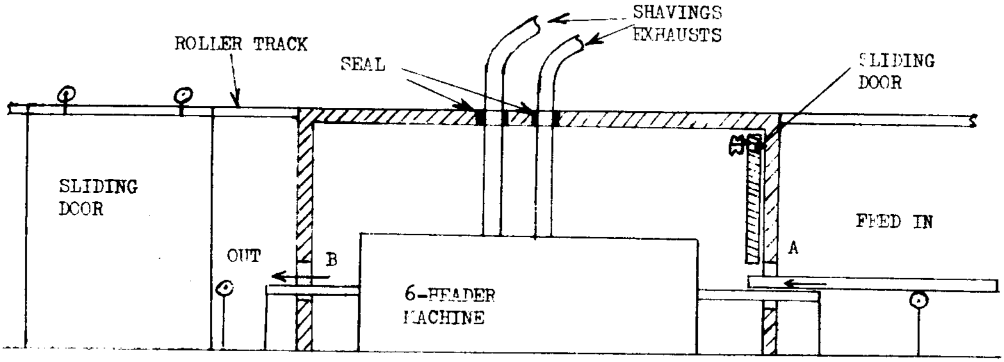

SKETCH OF ENCLOSURE

THE REDUCTION OF AIRPLANE JET NOISE

by

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ABSTRACT

The noise from the growing number of flights of jet powered aircraft of ever increasing size has produced a public nuisance. It is difficult to assess this nuisance and a brief mention is made of the techniques presently available.

Reduction of the exposure of people to this noise can be accomplished by a number of techniques, such as the removal of airports to less densely populated areas, a change in airplane flight patterns and a change in the airplane jet engines.

The last method is examined in some detail and the theory of aerodynamic noise generation as it applies to the suppression of jet noise is discussed.

1. INTRODUCTION

The ever growing number of airplane flights with their attendant noise radiation has produced an increasing nuisance to people exposed to this noise. In order to be able to discuss this nuisance in a quantitative manner, a meaningful measure of the noise nuisance is required. The number of attempts to do this have been few but we have, in this paper, adopted the index of community nuisance proposed by Richards (1967) as such a measure.

The factors in determining the community nuisance are inter-related in a complex manner but two factors are obviously of importance, the number of people affected and the intensity of the noise at its source. Most of this paper is devoted to examining this last factor, the efficiency of the aircraft engine as a noise generator.

Changes in design have led to a reduction in the noise generated from an engine of constant size, but because of the ever increasing size of the modern aircraft engine, the overall noise has remained much the same.

In order to maintain even this trend on future engines which undoubtedly will be larger, all the favorable changes in engine and nozzle variables will have to be used to best advantage. The aim of this paper is to consider these changes.

2. A MEASURE OF NOISE NUISANCE

The intensity of acoustic radiation which is often expressed in terms of the logarithmic scale, the decibel, is an exact measure of the sound but it is not directly related to the response of the human ear. The "annoyance" of sounds of equal intensity but different frequency is not constant and so the perceived decibel unit (PNdB) was introduced to take into consideration the different response of humans to broad band noise of different spectral content. This scale, however, does not take into account the two other factors, the duration of the sound or the effect of discrete frequencies superimposed on broad band noise. It appears that doubling the duration of a noise makes the "annoyance" greater than that of a noise of twice the intensity for the original duration.

As a measure of the "annoyance" to a community due to airplane departures from an airport Richards (1967) has proposed the ICN (index of community nuisance). The ICN is proportional to the population density times the total static daily thrust at take off, times the acoustic conversion factor, times the path factor, times the forward speed factor.

Richards (1967) shows that the total static daily thrust at take off is almost directly proportional to the number of passengers per day since the installed thrust per passenger varies little from airplane to airplane. Thus the total thrust and so the ICN do not change if one has a large number of departures of small aircraft or a small number of departures of a few jumbo jets.

The path factor and the speed factor take into account the different departure procedures the airplane can use. The pilot can use the thrust of the engines to increase altitude or to increase speed. An increase in altitude puts the aircraft further from the people on the ground while an increase in velocity changes the speed factor by reducing the exposure time of people on the ground and reducing the intensity of the noise source. Still another technique is to reduce the thrust of the engines as the airplane crosses the community boundary. By this technique the maximum noise on the ground is reduced but, because of the decreased rate of climb, the area exposed to this lower noise is increased.

The proposed supersonic transports provide more flexibility than subsonic planes for adjusting the departure procedure because they have excess installed thrust at take off. The noise contours on the ground for an SST of gross weight 600,000 lb. were estimated for three cases:

(i) The aircraft was flown at full power and maximum rate of climb

(ii) The aircraft was flown at full power and at the community boundary the rate of climb reduced to 500 ft/min.,the forward speed being held constant

(iii) The aircraft was flown at full power and at the community boundary the rate of climb reduced to 500 ft/min.,the extra power being used to accelerate the aircraft.

The ICN was calculated for these three cases with the assumption that the community boundary was 3 miles from brake release and that the population density was constant over the rest of the flight path. For case (ii) the ICN was increased 4 dB over case (i) and for case (iii) was increased 1 dB over case (i).

Thus it appears that the improvement in ICN by changing the path and speed factors is small. The changes in flight path for subsonic aircraft, within the restrictions imposed by safety considerations, will lead to smaller changes in the ICN than in the above example.

The two remaining factors in the ICN over which we seem to have direct control are the population density and the acoustic conversion factor.

3. POPULATION DENSITY

The number of people affected by aircraft noise is dependent on the density of people within the areas exposed to such noise and so by reducing the population density within the areas exposed to the most intense noise, the community nuisance is reduced. This would require the zoning of land use around future airports and the purchase of existing properties at present airports. One must bear in mind that as the Wilson Report (1963) pointed out, some people may still choose the convenience of living in the vicinity of the airport over the inconvenience of the noise nuisance.

Greatrex (1966) has examined the cost of purchasing the existing land around airports and has concluded that the cost is no less than the current cost of fitting noise suppressors to jet aircraft.

Providing acoustic insulation for the houses near airports reduces the nuisance to the people. This, however, is only a partial solution that is not directly considered in the ICN but can probably be best considered as a change in effective population.

4. ACOUSTIC CONVERSION EFFICIENCY

The other factor in the ICN over which we have direct control is the acoustic conversion factor or intensity of noise radiated per unit of engine static thrust.

There are two types of jet engines currently in use on commercial airplanes, the turbo jet engine and the turbo fan engine. In the case of the turbo jet engine the noise at high power settings is generated in the exhaust gases while in the case of the turbo fan engine where a large mass of slow moving air is produced by the fan, the radiated sound is mostly dominated by the noise of the machinery. In this paper we are considering jet noise which makes the results applicable to the first kind of engine although with recent advances in fan design jet noise may soon predominate in turbo fan engines.

The noise from an engine exhaust is generated by the turbulent fluctuations within the flow and with a complete specification of the flow, the radiated noise can easily be calculated using Lighthill's equation. To date, however, this description of the turbulence in a jet has not been available.

Lighthill was able to describe the gross changes in noise radiated without a complete description of the flow by using dimensional arguments. We will use these arguments to examine the changes in noise from jets of different size, velocity and temperature. In a later section we will examine a more detailed model to make deductions about the changes in noise that can be achieved once the primary exit conditions, such as size, velocity and temperature have been chosen.

Lighthill's (1952) dimensional arguments can be used to show that the total noise intensity, P, is

$$P \doteq K D^2 U_o^8 T^{-2}$$

where D is the jet diameter,

U_o is the jet exit velocity

T is the jet static temperature

and K is a coefficient that experimentally appears to vary as T^2.

Thus the total noise becomes

$$P \sim D^2 U_o^8 T^o \qquad \text{.......4.1}$$

The thrust, F, from a subsonic nozzle, or a correctly expanded supersonic nozzle is

$$F \quad \frac{D^2 U_o^2}{T} \qquad \text{.......4.2}$$

For a choked nozzle, there is an additional pressure term in the expression for thrust and now the effective diameter and velocity need to be carefully defined.

Consideration of the above equations shows that the total noise intensity may be reduced by decreasing the jet exit velocity, diameter, temperature, or thrust. The change in intensity obtained by adjusting the thrust (holding diameter and temperature constant) is shown in Fig. 1. This is approximately the same change as achieved by "throttling back" a turbo jet engine. The change in total acoustic intensity as a result of variations of the quantities in Eq. 4.1, holding the thrust constant, is shown in Fig. 2. Notice, for example, that a 40% increase in the diameter leads to almost -9 dB reduction in total noise. In perceived decibels, the magnitude of the changes will be different because of variations in the frequency distribution of the noise. In the following section we will examine the noise intensity in terms of the PNdB scale.

5. PERCEIVED DECIBEL CHANGES

The perceived decibel scale was developed by Kryster (1959) to be a measure of the subjective "noisiness" of a broad band noise. The "annoyance" of a sound is greatest when it lies near a frequency of 3,400 cps. and so the different frequencies are weighted in the calculation of the perceived decibel to take into account this varying response of the "average" human ear.

The curves presented in Sect. 4 were in terms of acoustic power and so to assess the changes in "noisiness" brought about by changing the flow variables, it is necessary to know the correction that must be applied to the curves in Fig. 1 and Fig. 2 in order to have the changes in PNdB. To do this, we must choose a spectrum for the noise radiated from a jet. Howes (1960) has collected a number of spectra of the <u>total</u> power radiated and he shows that for turbo jet engines these spectra are universal when plotted against Strouhal number $\frac{fD}{U_o}$, f being the frequency. We have used the curve in Fig. 3 to represent the noise spectrum in the rest of this paper. It should be pointed out that there are variations from this spectra at different angles to the jet axis but in order to make definite statements we have ignored these variations.

Increasing the diameter or lowering the velocity moves the peak in the spectrum to lower frequencies and towards or away from the most "noisy" frequency bands. The change in "noisiness" or perceived decibels about $10^3 D/U_o = 1$, keeping the total noise intensity constant but changing D or U_o, is shown in Fig. 4.

There is not much change in the "noisiness" until the jet diameter is much lower than that of the usual aircraft engine. (For example an exit velocity of 1500 fps and an exit diameter of 2.3 feet are typical values for a JT4A engine installed on some Boeing 707 aircraft.)

For the example considered in Sect. 4, a 40% increase in the diameter leads to a 96% increase in D/U_o (at constant thrust). The change in PNdB is the sum of -8.8 dB.* for total noise intensity from Fig. 2 and -0.4dB* due to the subjective correction for human response from Fig. 4. Thus the change in perceived noise is -9.2 PNdB.

6. ATMOSPHERIC ABSORPTION

While the propogation of sound waves through a non-uniform medium is very complex, one effect is fairly well understood. This is the reduction of sound intensity due to molecular damping of the sound. We have used the Knudsen-Kneser curves, see Knudsen (1935) to describe the increasing attenuation with distance, frequency and decreasing relative humidity.

Using the spectrum in Fig. 3 and calculating for a standard day (70% relative humidity), we have determined the change in total intensity due to atmospheric absorption. Results are presented in Fig. 5 for distances of 2,000 feet and 3,000 feet as a function of D/U_o. Since the maximum intensity along a sideline occurs at about 45° to the jet axis, these curves are representative of attenuation at 1,000 feet and 1,500 feet sidelines. Note we have used the overall noise spectrum in these calculations and have not considered the extra reduction occurring on a PNdB. scale, over and above that shown in Fig. 5, as a result of the preferential absorption of high frequencies.

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*for values typical of JT4A engine

7. FLOW DISTURBANCES

In an attempt to change the acoustic efficiency of the jet once the primary engine exhaust variables were chosen, nozzles have been designed which disturb the flow in a manner disadvantageous to noise production. It is interesting to examine the changes in the flow that bring about these changes in noise. To do this we will require a more detailed model of noise generation than that used in Sect. 4.

First let us consider the mixing process given a fixed rate of mass flow at a fixed velocity. The mixing occurs as the result of the diffusion of mass and momentum between the moving stream and the surrounding air. The diffusion rate is a complicated function of the flow but amongst other things is proportional to the level of the turbulent fluctuations. Consider an irregular nozzle as in Fig. 6 from which air leaves at a velocity U_o. The air with zero momentum diffuses into the jet from all sides until the velocity at the centre of the moving flow begins to fall off because the velocity scale (the maximum velocity difference across the mixing region) begins to decrease.

The noise is generated within a jet by the turbulent fluctuations or to be more precise fluctuations of turbulent stresses. A turbulent stress is the product of density and two velocity components, i.e.,

$$\rho u_i u_j$$

where u_i is the fluctuating part of the velocity in the i direction. Each stress has a directionality pattern associated with it and the directivity of the resultant sum of all the stresses is strengthened in the downstream direction and reduced in the upstream direction because of the convection of the stresses by the mean velocity. The sound rays, because they are generated within the moving jet, are refracted as they travel through the jet by the velocity and temperature gradients somewhat in the manner shown diagramatically in Fig. 7. The resultant directivity pattern is substantially changed because of refraction from that of the sources within the jet.

Now changes in noisiness of a jet can be considered the result of three effects; changes in total power, changes in directivity and changes in the perceived decibel correction (which is a function of characteristic frequency).

The expression for the total power generated within the jet (see for example Jones (1968 a)) contains two "types" of terms, those expressing self noise and those expressing shear noise. Both terms lead to the same expression in a simple model for noise generation. We will use the expression for the noise from unit volume of turbulence discussed previously (Jones (1968b)) so that

$$\frac{\partial P}{\partial \underline{y}} \sim (\overline{u^2})^2 \left(\frac{\partial U}{\partial r}\right)^4 V \qquad \text{.......7.1}$$

where $\frac{\partial U}{\partial r}$ is the gradient of the mean velocity across the flow and represents the characteristic frequency of the stresses,

V is the characteristic volume of the stresses and $\overline{u^2}$ is the mean square of the turbulent velocity.

The total noise is then the integral of Eq. 7.1 over the whole of the jet, i.e.,

$$P \sim \int (\overline{u^2})^2 \left(\frac{\partial U}{\partial r}\right)^4 V \; d\underset{\sim}{y} \qquad ....7.2$$

If we perform the integration of Eq. 7.2 in the two directions across a jet such as that in Fig. 6, we have the noise from a slice of the jet. As discussed in Jones (1968b) the characteris ic width of the region of turbulence is best represented by

$$U_{℄} \Big/ \frac{\partial U}{\partial r}$$

i.e., the inverse of the mean velocity gradient normalized by the velocity on the jet centre-line at that cross section. The cross sectional area of turbulence in an irregularly shaped jet is then the product of some perimeter (or wetted surface), C, and the characteristic width of the turbulence and so the noise from a slice of the jet becomes

$$\frac{\partial P}{\partial y_1} \sim U_{℄} \, (\overline{u^2})^2 \, V \left(\frac{\partial U}{\partial r}\right)^3 C \qquad ....7.3$$

In a jet from a round nozzle the characteristic volume of the stresses appears to be proportional to the cube of the characteristic width of the turbulent region but in some disturbed flows the characteristic volume of the stresses has been reduced while maintaining $\frac{\partial U}{\partial r}$ constant. The product

$$\left(\frac{V}{U_{℄}} \frac{\partial U}{\partial r}\right)^3$$

in Eq. 7.3 would be constant if V was proportional to $U_{℄}^3 \Big/ \left(\frac{\partial U}{\partial r}\right)^3$ and so it is convenient to measure the changes of noise in terms of the variation of V away from

$$\left(\frac{1}{U_{℄}} \frac{\partial U}{\partial r}\right)^3$$

Also in Eq. 7.3 we have the circumference of the turbulent region. An increase in C leads to more surface area through which diffusion can occur. Thus the velocity at the centre of the jet begins to decay in a shorter distance and the number of slices from which significant noise is radiated decreases. The combined effect of these counteracting trends will result in very little change in the total noise (although the other variables in Eq. 7.3 may depend implicitly on C).

The changes in the total power, P, as a result of changing the two quantities $\sqrt{\overline{u^2}}$ and $V U_{℄}^3 \Big/ \left(\frac{\partial U}{\partial r}\right)^3$ over the whole of the mixing region is shown in Fig. 8. An alternative is to attempt to change $\sqrt{\overline{u^2}}$ not over the whole of the jet, but just at positions of greatest magnitude. The turbulence $\sqrt{u^2}$ varies across the flow and so a redistribution of the fluctuations towards the edges of the mixing region could lead to a substantial reduction in the total power radiated.

The level of turbulence in a mixing region is described by a complex set of equations which to date have not been solved (although it appears possible with present knowledge). In practical jets the flow will always be turbulent (because of the high Reynolds Number) but the level of this turbulence may be changed. By suitable disturbances to the flow the author has been able to achieve reductions up to 20% in the turbulence level and at the same time a 40% reduction in the volume factor

$$VU_c^3 / \left(\frac{\partial U}{\partial r}\right)^3$$

From Fig. 8 these combined changes would amount to a -6dB reduction in noise. An optimistic value for changes in turbulence and volume is probably twice those above and so about -12 dB would be a practical limit to the noise reduction that can be achieved by changes in the turbulence.

The second effect that can lead to a change in sideline noise is the directivity.

The maximum noise along a line parallel to the axis of a jet occurs at a position downstream of the exit nozzle, the maximum being a function of the jet directivity and the distance to the sideline at each particular angle. A typical directivity curve for a turbo jet reproduced from Howes (1960) is shown in Fig. 9. It is possible to have different directivities that lead to a changed noise level along a sideline and the directivity that we are seeking is that which produces the lowest sideline maximum.

The directivity pattern is determined to a large extent by the refraction of the sound waves. Since the sound that is generated in the forward direction cannot be refracted into the rearward direction by the gradients that exist in a jet, we need only consider ways to optimize the directivity in the downstream direction. It is, of course, conceivable that the noise generating mechanism could be changed so that more noise is generated rearward. This is very unlikely to be a significant change because most of the noise sources are symmetric in the forward and rearward directions.

The directionality factor that leads to the smallest sideline maximum is

$$\text{Direc}(\theta) \sim \frac{1}{\sin^2\theta} \qquad \text{.......7.4}$$

since the intensity at a sideline h units of distance from the jet axis is

$$\text{sideline intensity} \sim h^2 \sin^2\theta \quad \text{Direc}(\theta)$$

The directivity in Eq. 7.4 unfortunately produces infinite radiation along the jet axis. However, exploiting the form of Eq. 7.4 but using a uniform directivity near the jet axis gives a workable expression.

Thus

$$\text{Direc}\ (\theta) \sim \frac{1}{\sin^2\theta} \qquad |\theta| > \theta^*$$

$$\sim \frac{1}{\sin^2\theta^*} \qquad -\theta^* < \theta < \theta^* \qquad ....7.5$$

The maximum sideline intensity from the directivity of Eq. 7.5 is a function of θ^*. In Fig. 10 we have plotted this maximum sideline intensity relative to the maximum that results from the directivity in Fig. 9, keeping constant the total power radiated in the forward semi-circle. From this figure one can see that if the constant portion of the directivity was confined to the first 5° from the jet axis, a reduction over the existing directivity of the maximum sideline noise would be about -7dB. This reduction of the sound, however, does not change the ICN which depends upon the total exposure.

A third effect on which the "noisiness" of a jet depends is the characteristic frequency of the radiated sound which in turn depends upon the characteristic frequency of the turbulence in the mixing region. For the turbulence that develops within a jet from a round nozzle, the changes in "noisiness" as a function of D/U_o, (assuming the intensity of the sound is constant) are shown in Fig. 4. If the nozzle is not circular but some other shape, the turbulent structure is initially controlled by the characteristic width of the nozzle, but as diffusion of the momentum proceeds, the jet begins to take on a characteristic width equal to that of a jet from a circular nozzle of equivalent exit area. Let us assume for the moment that diffusion has reduced the strength of the noise sources to a negligible magnitude before the jet begins to go into the second phase above. If we also assume that the diameter in Fig. 4 can be replaced by the characteristic width of the jet (and for example in the case of many small jets well separated this is a very good approximation) then the perceived decibel correction begins to decrease at $10^3\ D/U_o = .05$. This is the point where a significant fraction of the noise is radiated above the audible range. Also as Fig. 5 shows, atmospheric attenuation will lead to an increased reduction in intensity at these high frequencies.

The maximum attenuation that can be achieved by increasing the characteristic frequency can be calculated from a combination of Fig. 4 and Fig. 5. From these figures one can see that by breaking the jet into units about 1/50 the original size, a reduction of "noisiness" of about -12PNdB. results. The alternative approach of moving the characteristic frequency to values lower than the audible range has not been investigated as it appears very difficult to do once the total exit area is fixed.

8. SHIELDING

In the above discussion we have been implicitly assuming that the observer is exposed to all the mixing of the high speed jet with the surrounding air. If some or all the mixing occurs within an acoustic shield, then the radiated sound could be significantly changed.

The ejector nozzle is an attempt to take advantage of this concept, some of the mixing occurring within a shroud. Of course much the same amount of noise is generated and unless it is absorbed within the shroud it emerges from the ends of the ejector.

CONCLUSIONS

An examination of a measure of the public nuisance of jet aircraft, the index of community nuisance, shows that for a given number of passengers transported, the two most promising ways to make a significant change in the environment around an airport are to control the population density around the airport and to change the acoustic efficiency of aircraft engines.

A reduction in population density to 10% of its present magnitude reduces the ICN by -10dB. A reduction in acoustic efficiency depends upon the flow variables and the most practical change in the primary variables is to increase the engine diameter. A 40% increase in the diameter, keeping the thrust constant, can lead to a -9.2dB. change in the ICN. A change in acoustic efficiency can also be achieved keeping the primary flow variables constant by using "suppressor nozzles" which can modify the turbulence structure Reasonable values for a change in turbulence level and volume suggest a reduction of -12dB. in the ICN, while a change in the characteristic frequency of the turbulence, another -12dB. Finally a change in the directivity can give a -7dB. change in <u>maximum</u> sideline noise but little change in the ICN.

ACKNOWLEDGEMENTS

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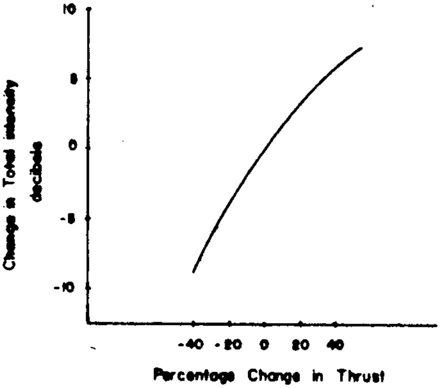

Figure 1 Change in total intensity for a change thrust

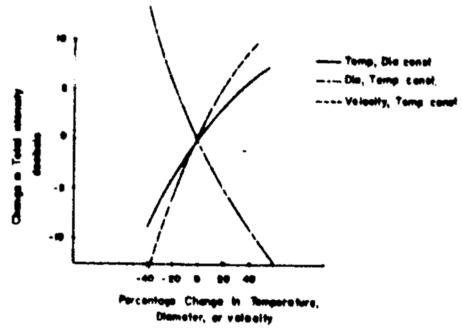

Figure 2 Change in total intensity for change in temperature, diameter, or velocity. Thrust constant.

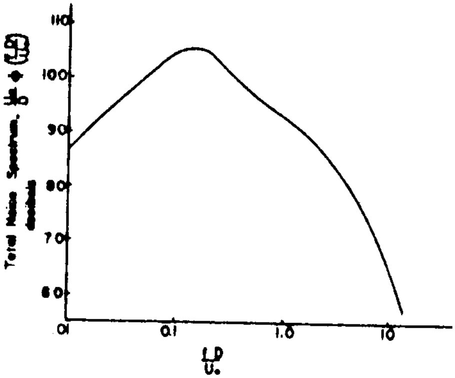

Figure 3 Spectrum of total sound radiated from a turbo jet engine after Howes (1960)

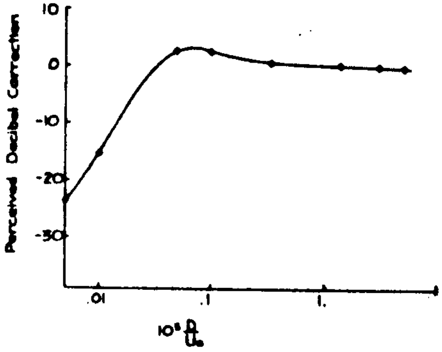

Figure 4 Change in perceived decibels, relative to 1000 D/U_e = 1 for the spectrum of Fig 3. Acoustic intensity constant.

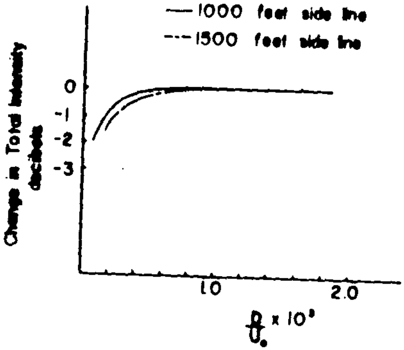

Figure 5 Change in acoustic intensity, relative to $1000\,D/U_o = 1$ for the spectrum of Fig 3 as a result of atmospheric absorption. Standard day.

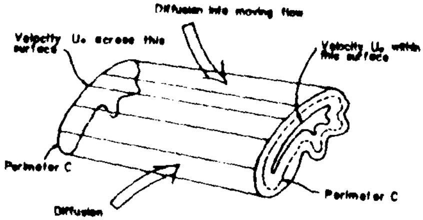

Figure 6 Diffusion of momentum in an irregular jet

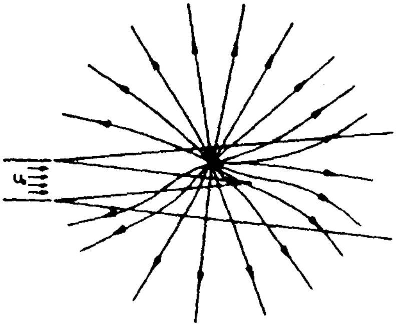

Figure 7 Diagrammatic representation of refraction of sound waves generated within a jet

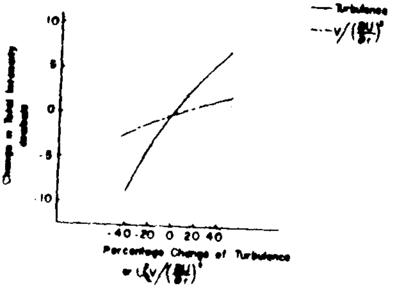

Figure 8 Change in total noise as a result of a change of turbulence or $U\left(v/\left(\frac{\partial U}{\partial r}\right)\right)^3$, keeping U_e, D & T constant

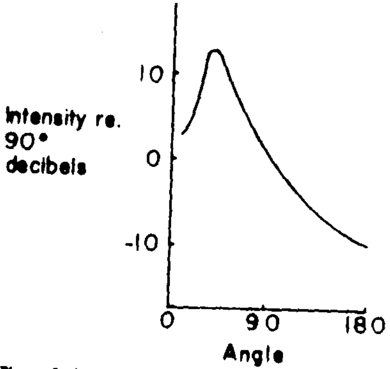

Figure 9 Angular distribution of intensity of sound for a turbojet engine, after Howes (1960).

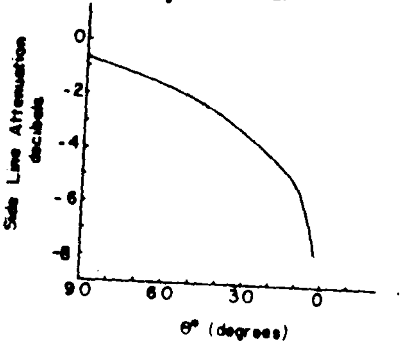

Figure 10 The change in sideline maximum of directivity of Eq. 7.5 relative to sideline maximum of directivity in Fig 9.

AERODYNAMIC NOISE IN SEPARATED FLOWS

by

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SUMMARY

This paper contains a review of the available measurements of the fluctuating pressures that occur at boundaries in separated flows. These pressures are measured with a microphone set flush into the wall. The actual noise transmitted through the wall will depend on the noise transmission characteristics of the wall.

The definitive flow models and results described are for forward and backward facing steps and a fence normal to subsonic flows and for supersonic flows over steps. Less definitive flow models and results from several workers (including separated flow in water conduits) support the results.

There is a paucity of both quantitative results suitable for engineering applications and theoretical analysis which would help the understanding of the noise producing process.

1.0 INTRODUCTION

Flow separation occurs in many practical situations and may be a source of noise or fluctuating loads on a structure. In many cases a separated flow is avoided because of power loss or increased flow resistance, but there are many examples where economic and practical considerations are more important. Separated flow often occurs behind canopies, cowlings, cut-outs, corners, steps, etc. - on missiles, light aircraft, motor and rail vehicles and in ducts and components in heating and ventilation systems.

Early studies carried out by Garrick, Hilton and Hubbard[1] showed that fluctuating surface pressures in a separated region could be many times greater than those for an attached turbulent boundary layer for similar flow velocities. Their results were obtained from aircraft and rockets in which the type of flow separation and details of the nature of the flow could not easily be defined or measured.

Probably the first definitive study on surface pressure fluctuations in separated boundary layers was carried out by A. L. Kistler,[2] his results being for supersonic flow.

As far as the authors are aware, apart from their own work, the only specific study on pressure fluctuations in subsonic separated flow has been carried out by A. M. Mohsen[3] in which he considers flows over backward and forward facing steps as well as fences. H. H. Schloemer[4] has carried out work on effects of pressure gradients on turbulent boundary layer wall pressure fluctuations, but in this case the boundary layer was not separated. Other studies relating to wall pressure fluctuations in separated supersonic flows have been carried out by Speaker and Ailman.[5]

In a report by Bull and Willis[6] concerning experimental investigations of the surface pressure field due to a turbulent boundary layer brief mention was made of pressure fluctuations in the region downstream of a small step. Their results were carried out in a 2" diameter water tunnel. H. Boerner[7] also reports results in water conduits in which flow separation is deliberately induced.

2.0 TYPES OF SEPARATED FLOW

2.1 Some General Comments:

One of the difficulties is that of defining a separated flow either in terms of flow properties or experimentally in choosing a typical model to represent flow separation.

The problem of separated flow has attracted workers for almost 100 years, the first paper being written by Kirchoff in 1869 when the classic model of flow separation behind a cylinder was discussed. The analysis was repeated by Lord Rayleigh in 1876, but both Kirchoff and Rayleigh assumed that the wake downstream of a cylinder did not close.

The circular cylinder model fortunately has many practical applications such as air flow over heat exchangers wires, etc., as well as being a well defined theoretical model. However there are many other types of boundary conditions that give rise to separated flows which may not be so easily defined, but which are of practical importance. Examples in practice abound, the separated flow over steps, fences and around corners, are typical examples of practical importance and only recently have workers such as A. Roshko[8] and G.K. Bachelor[9] pointed out that an important condition not previously considered is that of closure of the wake or separated flow.

It seems that the behaviour of a separated flow in terms of boundary layer theory is still not well understood. In many studies a relatively long time average is taken so that the flow presents an apparently steady picture. This approach is inadequate when studying pressure fluctuations in a separated flow.

2.2. Flow over Forward Facing Steps:

In an investigation at supersonic speeds Kistler has measured the fluctuating pressures in the separated regions ahead of a step at Mach numbers of 3.01 and 4.54. The step was 2" high and the boundary layer thickness before separation 1.5" and 2.05" thick respectively. Figure 1 shows the type of flow investigated by Kistler and the pressure fluctuations were found to be up to 20 times as great as in the undisturbed boundary layer ahead of the separated region.

The variation of the fluctuating pressure with time showed that at the point of separation upstream of the fence a type of random square wave modulation occurred. (See Fig. 1). This indicated that the separation point was moving over a certain region. For this area the spectral density was very high at low frequencies and within the separated area this large low frequency peak disappeared.

Speaker and Ailman also carried out tests in a supersonic flow over a step in a wind tunnel. At Mach numbers of 1.4 and 3.45 they found that the fluctuating pressure in a separated region upstream of the step could be over 20 times the undisturbed value and was dependent on the thickness of the upstream boundary layer. As might be expected, as the relative thickness of the boundary layer increased the value of the pressure fluctuations decreased. In their case the thickness of the boundary layer varied from about the same thickness as the step height to about twice the step height.

The work so far described has obvious applications to aircraft and missiles and gives vital information concerning not only noise that might be transmitted to the inside of the craft, but also gives a measure of the fluctuating or buffetting load on the skin itself which is important when considering the fatigue life of the structure.

At subsonic speeds up to 375 fps Mohsen reported pressure fluctuations in the region forward of a step 1" high. He found that the value of the maximum pressure fluctuation was about 10 times that of the undisturbed flow. In subsonic flow there is a further separated region, although smaller in area, at the top of the step and in this region Mohsen reports pressure fluctuations 25 times as high as in the undisturbed flow.

For supersonic flow Kistler found that the separation point was approx. 4-5 step heights in front of the step. In the case of subsonic flow Mohsen found the separation point to be approx. 3-4 step heights in front of the step. Both workers found that the fluctuating pressure levels increased above the undisturbed flow levels at the separation point.

On top of the step Mohsen found the reattachment point to occur between 2 and $2\frac{1}{2}$ step heights downstream of the step face. When the pressure fluctuations are expressed as the ratio p^2/q they are found to be independent of air speed. Similarly the separation point is also found to be independent of air speed.

Figure 1 shows the variation of p^2/q with x/h. There is a slight variation with h which is thought to be due to interference effects from the sidewall and roof.

In the case of subsonic flow typical spectra at the upstream separation point show that most of the energy is spread over a wider band and behind the flow reattachment point the low frequency energy begins to drop in magnitude.

2.3 Backward Facing Step:

Figure 2 shows the approximate flow configuration downstream of a backward facing step at subsonic speeds. Reattachment occurs between 4 and 5 step heights and is found to be independent of flow velocity.

For this flow there are two different regions that produce aerodynamic noise. The first region is in the turbulent shear layer leaving the edge of the step, which is somewhat similar to the turbulent mixing region of a jet. In the neighbourhood of the reattachment point a different and stronger type of noise generation occurs as the turbulent flow is now able to generate a dipole type of noise. There is a third source of noise which arises from the boundary layer noise in the reverse flow behind the step but this has been found to be insignificant.

The values of the wall fluctuating pressure levels when normalised by the free stream dynamic pressure rise gradually from their undisturbed flow value, just behind the fence, to a value over 10 times the undisturbed flow level near the reattachment point. Thereafter they subside gradually. Speaker and Ailman found similar behaviour for supersonic flow over aft facing steps at Mach numbers of 1.41 and 3.48.

Immediately behind the step most of the energy is contained in the low frequency end of the spectrum. As the region of reattachment is approached, more energy is added to the higher frequencies, the levels measured depending very much on the transducer diameter (that is its resolving power).

2.4 Flow over a Fence:

Both Mohsen and Fricke and Stevenson[10] have shown that in subsonic flow the pressure fluctuations downstream of a fence are about 10 times their undisturbed value. The separated region is much larger than in the case of forward or backward facing steps. The flow reattaches at about 13-17 fence heights behind the fence and the peak fluctuating pressure occurs in the neighbourhood of the reattachment region. The reattachment point has been found to be dependent on interference and blockage effects in the particular experimental arrangement.

There will be an upstream region of separation for flow over a fence and the behaviour of the flow will be similar to that of a forward facing step. Downstream of a fence the flow separates at the top of the fence and the separation line extends above and behind the fence into the stream before reattaching at a point much further down than in the case of a backward facing step.

Fricke and Stevenson found that the reattachment point and pressure spectral densities showed no significant variation with Reynolds number or boundary layer displacement thickness upstream of the fence. Using a similarity method they were able to give reasonably accurate predictions of sound pressure level behind fences. Provided interference effects and transducer resolution were kept constant the variation of the spectral density with frequency (both non-dimensional) and the variation of $\sqrt{\overline{p^2}}/q$ with x/h collapse satisfactorily into one curve.

As in the case of flow over a backward facing step they were able to distinguish between different types of noise generation downstream of the fence. There was a jet noise or quadrapole type of sound generation in the free shear layer just downstream of the fence and a dipole type of noise generation near the reattachment point.

Figure 3 shows the variation of the pressure fluctuations with distance downstream of the fence. These are in fair agreement with results obtained by Mohsen. Spectral analysis showed that at the point of reattachment there was an increase in spectral density at low frequencies. The size of the microphone is important - its resolution being increased with decreasing diameter.

2 5 Separated Flow in Water Conduits:

Bull and Willis in a brief investigation measured pressure fluctuations behind four different sized circumferential steps in a 2" diameter water tunnel. It is possible from consideration of the spectral density plots that Bull and Willis took measurements in the recombined or perturbed boundary layer.

H Boerner carried out a fairly complete investigation on the origin of noise from water flow in conduits. His results for turbulent boundary layers agreed generally with those obtained for air flows. Measurements were carried out in flows behind orifices. In the case of water there is an added complication in that cavitation may occur downstream of the orifice.

3 0 SUMMARY OF RESULTS

The table below presents a summary of the magnitude of the pressure fluctuations discussed earlier:

Flow Model	Research Worker				
	Kistler	Speaker Allman	Mohsen	Boerner	Fricke & Stevenson
	$\sqrt{\overline{p}^2/\overline{p}_o^2}$	$\sqrt{\overline{p}^2}/q$			
Forward facing step	19.0 (M= 3.01) 12.3 (M= 4.54)	.029 (M= 1.4) .046 (M= 3.45)	.040		
On top of forward facing step			.100		
Backward facing step		.028 (M= 1.4) .0088 (M= 3.48)		.04 (2.1 m/sec) .10 (6m/sec)	
Behind fence			.06 (170 ft/sec) .08 (375 ft/sec)		.040
Unperturbed boundary layer	?	.042 (M= 1.4) .017 (M= 3.48)	.004	.007	.006

where $\sqrt{\overline{p}_o^2}$ is the undisturbed boundary layer pressure fluctuation. All values are the maximum recorded in the area being considered.

4.0 CONCLUSIONS

The magnitude of the pressure fluctuations in a separated flow may be up to 25 times that of an undisturbed flow. The results obtained from laboratory experiments are in good agreement with those found on missiles and aircraft. Mach number does not appear to have a significant effect on both boundary layer and separated boundary layer type of noise production.

There is a shortage of data for subsonic separated flows and in the case of water the effect of cavitation is worth further investigation.

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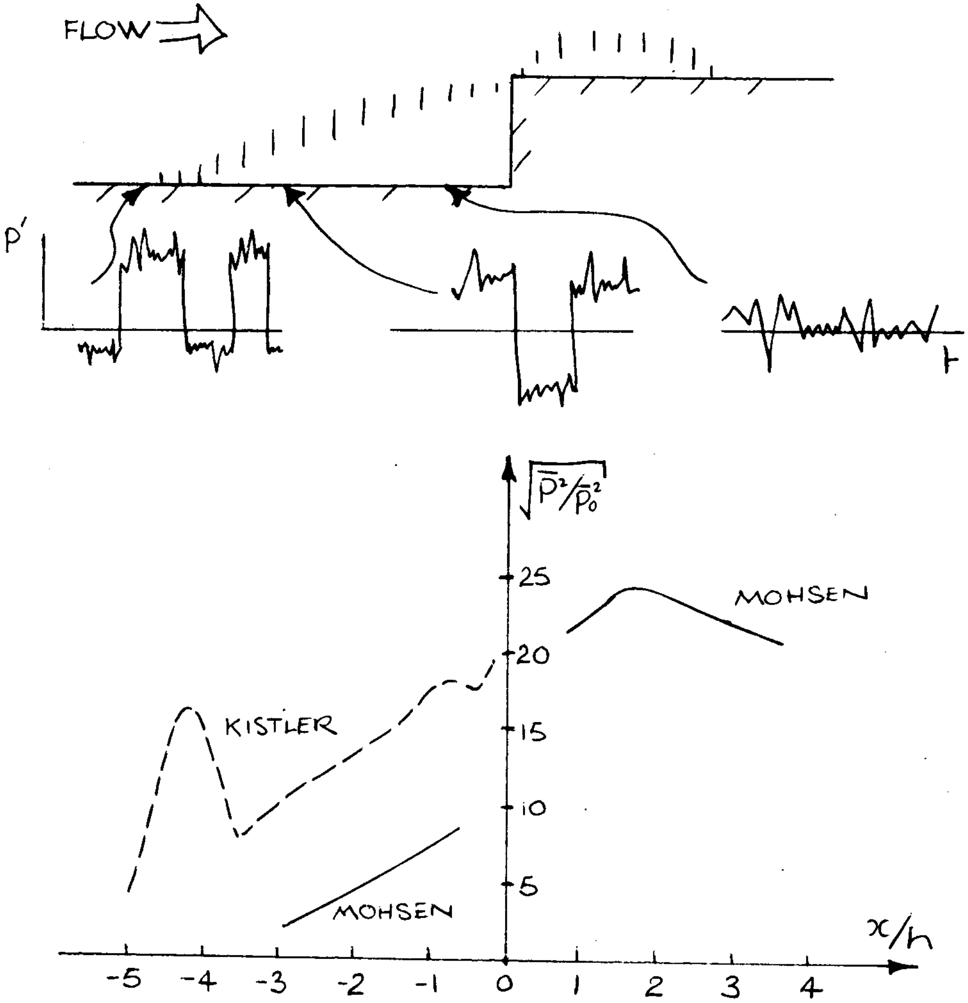

Fig. 1 Upstream Facing Step

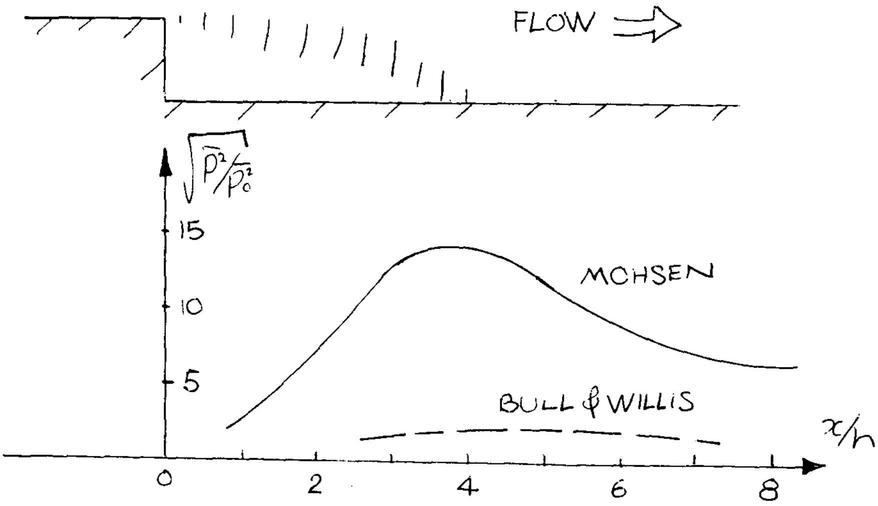

Fig. 2 Downstream Facing Step

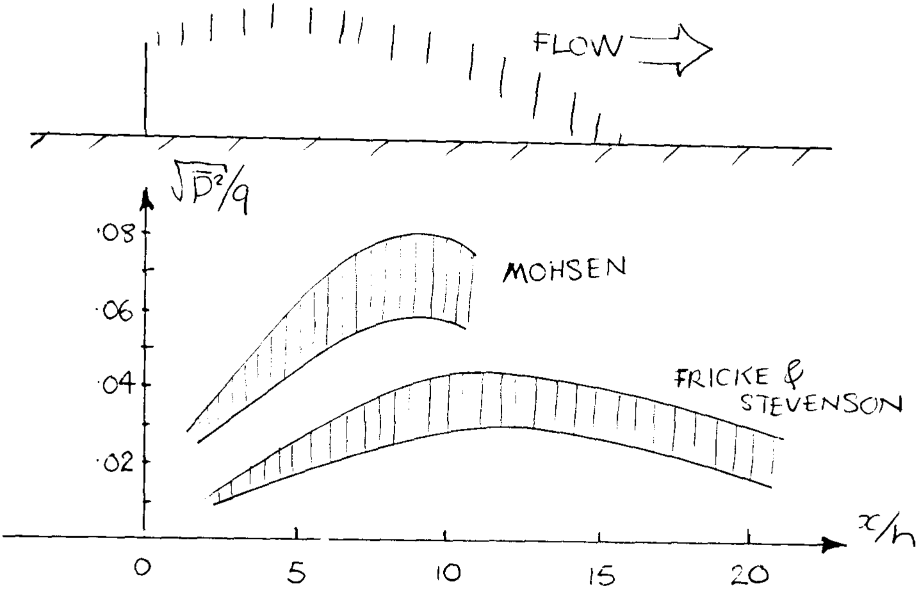

Fig. 3 Flow behind a Fence

ACOUSTICAL FEATURES OF A NEW TELEVISION STUDIO

M.H. Stevenson*

SUMMARY

Factors effecting acoustical conditions in a television studio are discussed and measures adopted to provide a desirable acoustic environment in a new studio designed for the recording of television programs on film are described. Compromises which became necessary to keep the cost within economic limits and to produce a studio which, initially intended for the recording of drama, may ultimately be required for the recording of music are described. The measured performance characteristics of the studio are quoted.

The acoustical design of a television studio usually involves a number of compromises, since in most instances the studio must be suitable for a variety of uses which call for conflicting acoustical conditions. These requirements broadly involve firstly isolation from unwanted sound, whether originating outside the building or within it, secondly the achievement of a reverberation period characteristic which will permit satisfactory recordings to be made of different types of sound, and thirdly, cost.

Acoustical Isolation

In order to achieve quiet conditions within the studio, it is necessary to isolate it from both external noise and from noise created within the building. When there is a high level of external noise a more expensive type of construction is necessary than would be the case for quiet locations and this can greatly affect the cost. In some areas it may be assumed that quiet conditions will prevail for most of the time and that the likelihood of a thunder storm or other loud inter-

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fering sound occurring at the time of recording is sufficiently remote to justify taking advantage of the economies that can be effected by the adoption of a lighter type of construction than would otherwise be necessary.

Isolation of the studio from noise created within the building can be made effective at minimum cost if the spaces adjacent to the studio are used for the accommodation of offices associated with the administration and program building activities associated with studio production. It is, of course, necessary to take steps to isolate plumbing and water services from direct contact with the studio floor or walls so that sounds from water flowing in pipes is not telegraphed into the studio area.

The ATN studio complex is built in an area in which the ambient noise level is low. In the initial construction, a relatively simple method of construction was adopted and this proved so satisfactory that it has been adhered to in subsequent additions, the latest of which is Studio C, the subject of this paper. The ATN building is a steel frame structure, sheeted on the outside with 20 gauge ribbed steel sheets fixed to horizontal girts at approximately 4'6" centres. On the inside of the steel sheeting there is a 1" layer of rockwool batts supported by the girts or between them by horizontal brackets spot-welded to the inside of the steel sheeting. They are further held in position with wires stretched between the girts.

Further acoustic isolation is provided by a 1" thickness fibrous plaster board fixed to the inside surfaces of the girts. Joints between the plaster boards are roughly "set" so that there are no cracks left through which sound may readily pass. As the girts are 5" x 3", the air space between the steel sheeting and the outside face of the plaster is 5". 1" of this is used for the rockwool insulation on the back of the steel sheets.

The construction of the roof is slightly different, weather protection being provided by corrugated asbestos cement under which there is a 2" layer of rockwool batts. These rest upon 1" fibrous plaster sheets which are similar to those used for the lining of the walls. The difference in construction for the roof was adopted to minimise the noise from rain.

In order to minimise noise from activities within the building all occupied areas adjacent to studios are used for quiet activities such as offices associated with studio operations. When additional studios are added, these office areas help to maintain a high degree of isolation between studios built on either side of them.

Reverberation Characteristics

1. Absorbing Surfaces

The optimum reverberation period for a studio is determined by the volume of the studio and the purpose for which it will be used. A studio built in a television station will have a known volume but it cannot be assumed that it will always be used for the purpose for which it is originally designed. Studio C at ATN was intended for the performance of drama but there is no certainty that it will not at some time be required for musical performances. Studios intended for the performance of musical and variety programs should have a longer reverberation period than those intended purely for drama. As it is possible to add reverberation to a performance recorded in a relatively dead studio, using one of the reverberation units now readily available, it was decided to design the studio with a relatively low reverberation period and to artificially add reverberation when necessary for musical recordings which may be made in the studio at a later time. This technique is now commonly used for normal music recording in which numerous microphones are used to give better control of separation between instruments than can be achieved with a single microphone pick-up of a large orchestra. It makes the recording largely independent of the reverberation period of the room in which the recording is made.

According to BBC authors[1], the reverberation time for a television studio having a volume of 235,000 cubic feet, should fall

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[1] Bird, Guildford & Spring, Research Department, BBC Engineering Division. Data for the Acoustic Design of Studios. BBC Engineering Division Monograph No. 64, November, 1966.

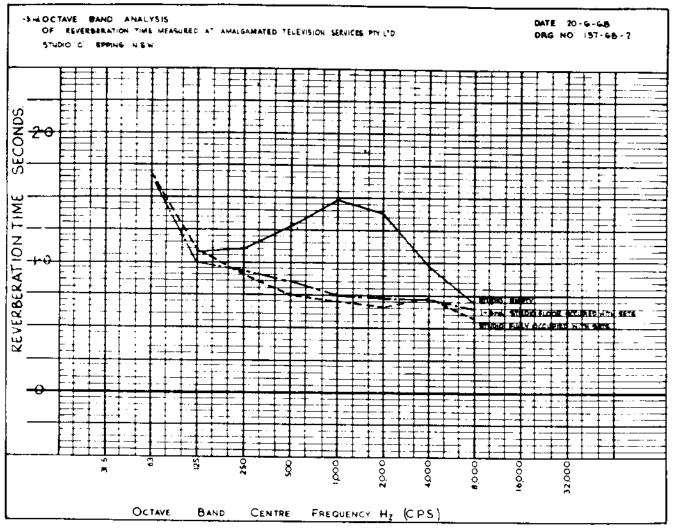


Fig. 2.

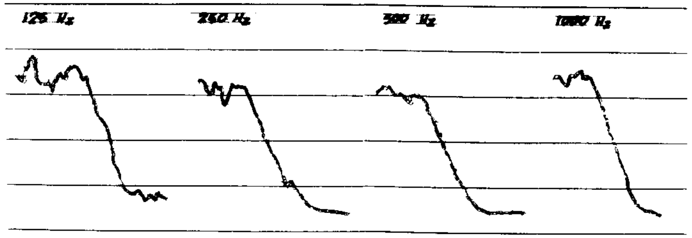
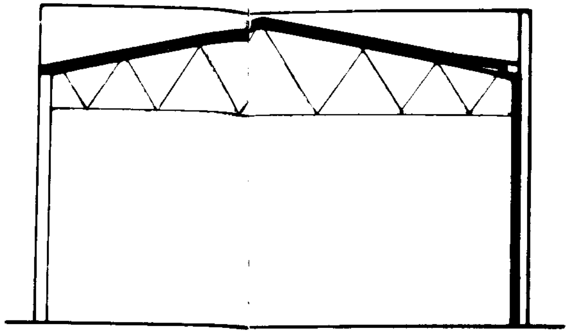


Fig. 3.



END EVATION

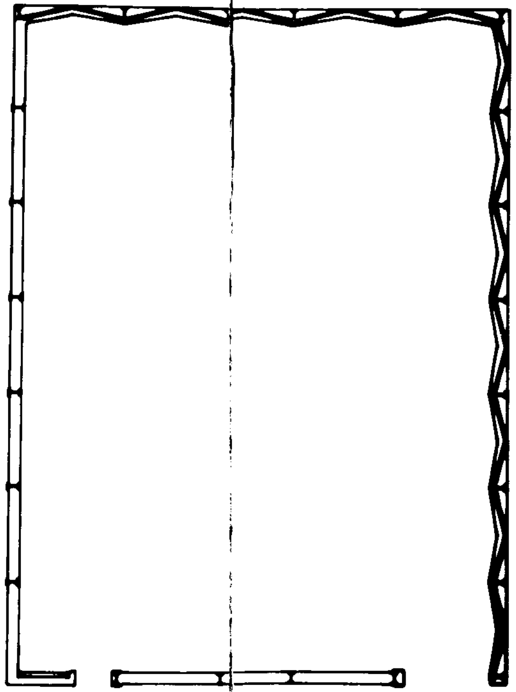


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Fig 1.

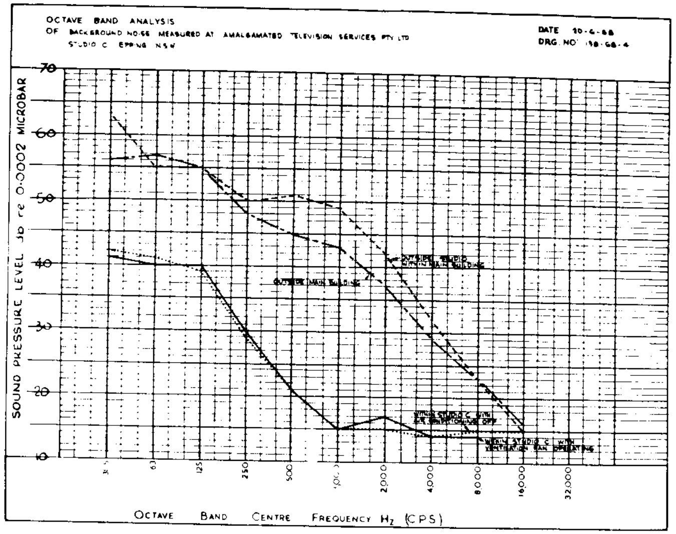

Fig. 4.

Fig. 5.

between the highest acceptable time of 0.98 seconds and the lowest practicable time of 0.67 seconds, with the optimum being 0.7 seconds. According to the same authorities, the optimum reverberation time for music in the same studio would be 1.7 seconds. Calculations indicated that a reverberation period of 0.7 seconds would be achieved if all of the treated surfaces of the studio had an absorption co-efficient of 0.75.

After considering a number of absorbing materials, it was decided to adopt an absorbing blanket comprising 2" thick 4-6 lbs. per cubic foot mineral wool with unperforated "Sisalisation 450" on the back and perforated "Sisalisation 450" on the front face. If suspended in front of a 9" air space it was estimated, based on available tests of other similar materials. that this treatment would provide the following absorption co-efficients:

250 Hz - 0.65
615 Hz - 0.75
1,000 Hz - 0.85
2,000 Hz - 0.8
4,000 Hz - 0.7

These absorption co-efficients were higher than those required to produce an optimum reverberation period for the studio but measurements of the completed studio indicated that the estimated values were high and that the effective absorption co-efficient in practice was nearer to 0.6.

Acoustic blankets do not stand up to the wear and tear of studio operations so it was decided to provide brick surfaces up to a height of 6 ft. Remaining walls and ceiling surfaces, except those necessary for control booth windows, lighting control equipment and doors, were treated with absorbing material

2. Sound Diffusion

In addition to having acoustic absorbing material in a studio, it is also necessary to provide some means of ensuring that the sound within the room will be diffuse[2]. This condition is

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[2] Vern O. Knudson, PhD: Syril M. Harris, PhD. Acoustical Designing and Architecture. John Wiley & Sons Inc. 1950.

assumed in the Eyring formula used for the calculation of reverberation time. Design features adopted in the studio under review to achieve diffuse sound distribution involved the shape of the ceiling and two adjacent studio walls, shown in Figure 1. Although the external appearance of the building suggests that the roof may be flat, the supporting trusses provide a fall from the longitudinal centre line to the side walls of approximately 6 ft. The 1" plaster board lining and acoustic blankets follow this shape so that the interior of the studio roof has the form of an inverted V which is approximately 6 ft. higher in the centre than at the sides. This shape avoids the likelihood of standing waves that would be expected between a horizontal ceiling and the floor, which is a flat and fully reflective surface. At the same time, some diffusion of sound is effected.

The end wall opposite that in which the control room is located and the adjacent external side wall are both designed to produce diffusion of sound and at the same time reduce the possibility of flutter which would be expected between parallel surfaces, especially in the 6 ft. high brick section nearest to the floor. Diffusion is effected by constructing these two walls in the form of a series of V's with a pitch of 12.5 ft. and a depth of 15 inches. The depth of the V's was reduced to 10" above the 6 ft. level to enable the 9" spaces between the back of the blanket and the wall at the apex of each of the V's to be used as a series of return-air ducts for the studio air conditioning system.

Results

The surface area available for treatment in the studio amounted to 14,000 sq. ft. In order to achieve a reverberation period of 0.7 seconds, the absorption required would be 11,000 Sabines so that the average absorption co-efficient required for the absorbing material would be 0.79. Measurements[3] of the

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[3] Measurements of the acoustical characteristics of the studio were made by Louis A. Challis, Acoustical Engineering Service, 210 New South Head Road, Edgecliff.

acoustical characteristics after the completion of the studio indicated a reverberation period at 500 Hz of 1.28 seconds with the studio floor clear of sets. This corresponds to an effective acoustic absorption co-efficient of 0.58.

Further tests made with the studio floor fully covered by drama sets indicated a reverberation period of 0.7 seconds. Figure 2 shows the reverberation characteristic of the studio with the floor cleared and also with the floor half occupied or fully occupied by sets. It is interesting to note that there is little difference in the performance for a partly occupied or a fully occupied studio. The higher reverberation period measured with the studio floor clear of sets is an advantage for musical recordings, which would benefit from the additional reverberation time.

Typical decay characteristics for several frequencies are shown in Figure 3. The linearity of the decay is attributed largely to the effect of diffusion achieved by the shape of the walls and ceiling.

Figure 4 shows the effectiveness of the isolation from external noise. When the studio was completed it was found that in one case a water pipe had been bonded to one of the studio walls, causing a noise when water flowed, and rectification of this became necessary. In addition the door seals proved ineffective after some wear and are being replaced.

Figure 5 is a general view of the studio showing the staggered walls.

A DISCUSSION ON ROOM ACOUSTICAL CRITERIA AND MODEL TECHNIQUE

BY

DR. J.L. JORDAN AND P.R. KNOWLAND

Introduction

There has been considerable research and practical observations by a number of workers in the field of acoustics in the past ten years concerning the process of sound generation and decay in auditoria.

The classical concept of reverberation as originally proposed by Sabine has proved to be inadequate as a design criterion and much recent work has been carried out in an attempt to correlate the measurable acoustic process occurring within a room to the subjective listening assessment.

These workers have illustrated the important effect of:

(1) Dependence of laterial reflections which convey to the auditor the feeling of space and ambience of the sound.

(2) The effect of strong overhead reflections on the clarity of sound.

(3) The process of the building up and initial decay of sound pulse.

This latter situation has been of particular interest to the authors. Investigation carried out in the early part of this decade showed that the building up of a sound pulse and in particular the build-up of the last 10DB before the peak level was achieved appeared to relate to the subject assessment of the room acoustics. In particular it appeared to have a bearing on the feeling of response from a hall, a condition which is of special significance to musicians. This lead to the concept of "Rise Time" which is defined as the time length of a noise pulse sufficient to reach a level 3DB below the stationary level. An investigation carried out in the Concert Studios in Copenhagen showed that improved conditions for the musicians on the Orchestral platform improved with decrease in rise time. The decrease was achieved by use of acoustical baffles above the stage area. A result of these measurements and other investigations confirmed that the values of rise time on stage should be less than the values within the auditorium. The reverse was a condition known as inversion and considered undesirable. Lately a new consideration of "Rise Time" has been defined as "Steepness" which means the slope in (DB/msec) of the build up curve. A low value of "Rise Time" corresponds to a large value of "Steepness". Ideally a concert hall is desired to have a large value of "Steepness" with the value on stage exceeding the values in the auditorium.

Notwithstanding the importance of other evidence it seems that research carried out M.R. Schroeder et al 1) has provided most useful information. This research showed clearly that for artificially reverberated signals (observed in an anechoic chamber) a close corelation existed between the assesment of Subjective Reverberation and the so called "Initial Reverberation Time" (determined from the initial slope of the decay curve). Less convincing was the evidence obtained when listening to recorded music from actual concert halls. However this may be partly due to the limited number of tests of this kind actually performed. This has lead to a concept which we wish to call "Early Decay Time" (EDT) and is defined here as the average slope of the decay process between the levels -5 and -15 below the starting level. 2) The measurement of this quantity has been made possible as a result of the theoretical and experimental work done by M.R. Schroeder on pulse-intergration. 3) A single integrated curve of a very short pulse (shot or tone burst) will, in fact, correspond to the ensemble average of a large number of decay curves produced by interrupted random noise. Thus avoiding the random fluctuations the integrated curve of a short pulse shows only few and limited irregularities and therefore lends itself readily to the evulation of the EDT. Curves of this kind have already been published by several authors. 4, 5, 6.

As before in the case of "Steepness" a relationship between the Early Decay Time on stage as compared to the audience is of importance.

It appears that it is desirable for the average value of EDT in the audience area to exceed the average value of EDT on stage.

To examine these consideration during the process of design of an auditorium, a problem exists in that the "Early Decay Time" is not calcuable by emipirical means. This is because the value of EDT is dependent on the actual reflection pattern that occurs at the point of measurement. To determine "EDT" during the design of an auditorium an acoustical model, to duplicate the reflection pattern, is required. This model could be a computor programmed as required, or an actual say 1/8 to 1/16 scale model. The scale model is felt to present many more advantages than a computor programme and accordingly has been used as the basis of acoustical design on a number of recent projects by the authors.

At present there are two scale sizes which could be considered, this is 1/8 or 1/10. An 1/8 model has the advantage of having an octave relationship. That is if measurements were carried out at 16KC octave band then the corresponding octave at full scale would equal 2KC. However reverberation times achieved with the model would have to be multiplied by 12.5. The other size 1/10 has advantages of being cheaper to construct than the 1/8 model and that reverberation times involve shifting of the decimal point. On the other hand the 16KC octave band used for original measurement corresponds to a new octave of 1.6KC. This particular situation does not present a major problem as existing 1/3 octave band filter sets can be modified to give an octave with centre frequency of 1.6KC.

The main frequency used for measurement is 16KC corresponding to 2KCor 1.6KC full scale. This particular frequency is considered to represent an important rejoin in terms of auditory perception and results determined for 16KC (model scale) reflect the characteristic to be anticipated at other closely related frequencies.

There appears to be no point in testing past 30KC (3KC or 4KC full scale) as the effects of humidity on the acoustic conditions in the model together with the limits in the acoustic instrumentation make testing conditions complicated above this frequency.

The feasibility of model testing is dependent upon the use of multispeed tape recorders, the speed originally used were $37\frac{1}{2}$" per sec/$3\frac{3}{4}$" per sec for 10:1 or 30" per sec/$3\frac{3}{4}$" which gives 8:1.

It is a fact that 30" per sec is a standard tape speed used for broadcast tape recorders and that no special modifications are necessary, on the other hand $37\frac{1}{2}$" per sec is a no~~w~~n standard speed and special modifications to the tape recorder are required.

In the last year we have seen the introduction of a small number of highly developed tape recorders which make it feasible to use tape speeds of $18\frac{3}{4}$/1 7/8 or 15"/1 7/8" to achieve the scaling required.

Results to date have shown good similitude between the acoustic model and the final constructed hall 3). In some cases there have been small variations but these have appeared to be contributable to the particular audience used in the model being slightly over absorbent.

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