THE BULLETIN

OF THE

AUSTRALIAN ACOUSTICAL SOCIETY

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A.A.S. ACTIVITIES

INTERNATIONAL CONGRESS ON ACOUSTICS

Planning for the 1980 I.C.A., to be held in Sydney, has been continued, and a standing committee set up to assist the Convenor, Mr. J. Rose.

It has been agreed that an account for the preliminary I.C.A. expenses be set up under the control of Council, and that the monies in this account be invested in secure high-yield securities, in accordance with the constitution of the Society. This account is to be financed by a levy of the equivalent of $5 per member per annum on each Division. This amount is to be reviewed annually.

Further details of the progress of arrangements will be included in the next issue of the Bulletin.

REPORT OF THE FEDERAL COUNCIL
For 1973 - 1974

Presented to the 4th Annual General Meeting of the Society on 20 September 1974.

The Federal Council of the Society for the period assumed office at the 9th Meeting held in Melbourne on 15 September 1973.

MEMBERSHIP

N.S.W. DIVISION	VICTORIA DIVISION	W.A. DIVISION
J.I. Dunlop	G.E. Harding	R.A. James
P.R. Knowland	J.A. Moffatt	C.E. Mather
A.B. Lawrence	G.A.B. Riley	
E.T. Weston	H.V. Taylor	

OFFICE BEARERS

The office bearers elected at the 9th Meeting for the ensuing year were:

PRESIDENT	P.R. Knowland
VICE PRESIDENT	G.E. Harding
GENERAL SECRETARY	E.T. Weston
SOCIETY REGISTRAR	G.E. Harding

MEETINGS

The Council held three meetings during the year, on 15 September 1973, in Melbourne, on 10 December 1973, in Sydney, and on 25 May 1974, in Melbourne.

SOCIETY ACTIVITIES

From the reports submitted by the Divisions, Council considers that the period under review can be regarded as a particularly fruitful one, and highly satisfactory in all major respects.

MAIN CONFERENCE

The main event in which the Society participated, through the Victoria Division, was the Noise Shock and Vibration Conference held at Monash University, Melbourne, on 22, 23, 24 and 25 May 1974.

Overseas speakers who addressed the Conference or presented papers included Dr. Beranek, Dr. Ward, Dr. Rice, Dr. Price, Professor Bishop, Mr. Fidell, Dr. Tondl, Mr. Randell, and several others. Attendance at the Conference exceeded 350, with many others seeking to attend but who were unable to be accommodated. At least one of the State Divisions was able to take advantage of the presence in Australia of the overseas visitors to hold a special technical meeting for the benefit of those members of the Society who could not get to the Melbourne Conference.

Mr. Riley, Chairman of the Victoria Division, in his report to Council, pointed out that the success of the Noise Shock and Vibration Conference was the culmination of three years of organisation.

MINOR CONFERENCES

The N.S.W. Division has been organising a one-day conference to be held in Sydney on 21 September 1974, in conjunction with the 4th Annual General Meeting of the Society scheduled for that weekend. Work on this conference has been proceeding over the past year.

TECHNICAL MEETINGS

During the review period there has been a noticeable upsurge in interest in the Society's activities, as evidenced by the numbers of technical meetings. The Chairman of the N.S.W. Division, Professor Lawrence, reported to the 11th Council Meeting that the programme of technical meetings was so full that there was difficulty in finding dates to accommodate all the speakers and subjects that were available.

Of particular satisfaction to Council was the active interest demonstrated by the Society's youngest division in Western Australia. Dr. Mather, the Divisional Chairman, reported on 6 technical meetings at the 9th Meeting of Council, and at the 11th Meeting on a further 3 held in the intervening period.

PROJECTED ACTIVITIES

A major Society conference is intended to be held in N.S.W. during September 1975.

The N.S.W. Division has undertaken to organise the Conference and arrangements are already in progress.

MEMBERSHIP

Membership of the Society continued to increase although one division expressed some disappointment at its rate of growth during part of the review period.

The Society's Registrar notified the 10th Meeting of Council of a total membership of the Society of 232. Since that report a further 20 members have been elected, raising the total to 252. Under consideration at the time of the last meeting of the Membership Grading Committee were 6 applications for membership, and further applications have been received since at the divisional level.

Council expects a continuance of applications for membership as people already in the field of acoustics learn of the growing importance of the Society, and as more enter to work in the field.

On behalf of the Council,

P.R. Knowland
President

E.T. Weston
General Secretary

LEICHHARDT COUNCIL

Noise Abatement Committee

The N.S.W. Division of the Society was asked, back in 1968, to nominate an acoustic engineer to assist the Leichhardt Council in Sydney, by serving on their proposed Noise Abatement Panel (later known as Noise Abatement Committee).

Mr.J.A.Irvine accepted this nomination, and has served on the Leichhardt Committee since that date. Some four or five meetings have been held in each year, the sittings lasting usually from 2pm till 5pm, with a very well prepared agenda. In addition, perhaps a dozen "on-site" attendances have been involved over this period, when first hand knowledge of a situation was felt to be desirable, or where it appeared that the problem could be solved by brief advice to the person concerned.

The achievements of this Committee are considerable, and it is still very active in its efforts to solve local noise problems. The emphasis has always been upon persuasion - court action has been avoided. At times, the two parties concerned have been invited to attend together for an "across the table" discussion and this approach has been highly successful.

Mr. Irvine plans to leave, later this year, for an extended overseas visit, and will thus not be available to the Leichhardt Council for a time. The Council would like to have the continued assistance of the Society in this matter. The Society would therefore be pleased to hear from any member who may wish to become involved in this work.

RATING SOUND INSULATION BY USE OF dBA

The use of "A" weighted sound pressure measurements as an approximation to subjective response has very general acceptance.

It is not surprising, therefore, that attempts have been made to use such measurements to indicate the degree of sound insulation between spaces, as for instance within buildings. The reduction in sound pressure, expressed in dBA (as measured under certain conditions), appears to offer a very convenient "single-number" for the rating of performance or for the statement of requirements.

The most extensive use of this rating system at the present time seems to be in France, where, in fact, it forms the basis of the regulations dealing with acoustics in buildings (especially residences). Consideration has also been given to the use of dBA ratings by workers in the UK and USA.

Mr.J.A.Irvine, a member of the AK/4 Committee, Standards Association of Australia, is making a study of this matter, with the ultimate aim of drafting a standard if the system continues to show promise. To this end, he will discuss it later this year with acoustical workers in Europe (especially in France). Comments, either for or against the system, would be most welcome. They should be forwarded to:

Mr.R.Nagarajan
Engineer-Secretary
Committee AK/4 - Architectural Acoustics
P.O. Box 458
NORTH SYDNEY N.S.W. 2060.

MINUTES OF THE 4TH ANNUAL GENERAL MEETING

The 4th Annual General Meeting of the Australian Acoustical Society was held at the North Sydney Club, 88 Berry St., North Sydney, on Friday 20 September 1974.

PRESENT

37 members entitled to vote were present. The President of the Society, Mr.P.R.Knowland, was in the chair.

PROXIES

Proxies had been received from James McNulty, Dennis Clements, Jack Sunderman, and John Benson.

OPENING

The meeting was declared open at 7:10 pm.

APOLOGIES

Apologies were received from:

Mr.K.Cook
Mr.J.Kirkhope
Mr.J.Lyons
Mr.B.Murray
Mr.R.Snow

MINUTES OF PREVIOUS MEETING

The meeting was reminded that the minutes of the 3rd Annual General Meeting held on 14 September 1973 in Melbourne had been distributed previously to members of the Society.

It was moved by Mr.G.A.G.Riley, seconded by Mr.J.A.Irvine, that the minutes be taken as read.

Carried.

REPORT OF THE COUNCIL FOR THE YEAR 1973-1974

The President read the report (appended to the minutes).

He reported further on the additional items of the 10th ICA, the AAS Bulletin, the position with regard to agents of the Society in the various States, affiliation with the National Science Foundation, and on acoustics standards and the relations between the Society and the Standards Association of Australia.

It was moved by Mr.D.Gray, seconded by Mr.G. Harding, that the report of the Council be received.

Carried.

FINANCIAL REPORT

The Treasurer, Dr. Dunlop, stated that the Society's books were being audited, and reported on the financial position of the Society. The report is appended to these minutes.

It was moved by Mr.D.Gray, seconded by Professor Lawrence, that the audited statement of the Society's finances be distributed with the minutes of the Annual General Meeting.

APPOINTMENT OF AN AUDITOR

It was moved by Dr. Dunlop, seconded by Mr. G.C.Pickford, that Mr.F.J.Morton, of Elanora Road, Elanora, N.S.W., be appointed the Society's auditor.

Carried.

AUDITORRS FEE

It was moved by Mr.R.James, seconded by Mr. J.A.Irvine, that the fee to be paid to the Society's auditor not exceed one hundred dollars.

Carried.

REPORT ON ICA

Professor Lawrence reported to the meeting that the Society could expect formal acceptance of its submission that the 10th ICA be held in Australia in 1980. The favourable consideration of the submission and the attentive interest accorded the Society's representatives at the meetings held with the Commission at the 8th ICA in London was regarded as very gratifying.

The 8th ICA was attended by Messrs Taylor, Vass and Piesse, and , of course, by Professor Lawrence herself. It was the biggest acoustics conference ever held, with some 1300 delegates. There was certain criticism of the large size, but it was not thought that the problems created by such an attendance were likely to arise in the case of an Australian ICA, which it was estimated might attract only about 800 delegates because of the distance overseas delegates would need to travel.

Professor Lawrence concluded her report by emphasising the need for the Society to make an immediate start on the planning of the conference.

Discussion by the meeting on the 1980 ICA included the possibility of use of the Sydney Opera House. It was pointed out, however, that this would be unsuitable as a venue for other than the plenary

session as the usual need was for rooms suitable to accommodate audiences of appro

session as the usual need was for rooms suitable to accommodate audiences of approximately 200.

MOTION SUBMITTED BY COUNCIL ON ENTRANCE FEES

There was considerable discussion on the motion of Council which was as follows:

"That the entrance fee payable by applicants shall be equal to the annual fee at the grade applied for, or $25.00, whichever is the lesser."

This motion submitted by Council resulted from the direction given by the 3rd Annual General Meeting that the motion on entrance fees presented at that meeting be referred to Council to be redrafted. Council had taken the action required.

After considerable discussion on the implications likely to arise should the Society require entrance fees it was moved by Dr. Dunlop, seconded by Mr.P.Dubout, that the motion be put.

Carried.

The motion before the meeting that the resolution of Council be adopted, which had been moved by Mr.G.A.B.Riley and seconded by Mr.R.A.James, was then put to the vote and carried. (Proxies were recorded as having voted in favour).

The meeting closed at 8.10 pm.

(E.T.Weston)
General Secretary

AUSTRALIAN ACOUSTICAL SOCIETY
INCOME AND EXPENDITURE ACCOUNT
FOR YEAR ENDED 30th JUNE 1974

EXPENDITURE			INCOME		
To Members Subscriptions.	700	00	By Postages.	21	30
Division Levy	2000	00	Travelling Expenses.	100	00
Balance being Excess Expenditure over Income for year	849	50	Duplicating	356	50
			Formation Legal Costs.	1049	36
			N.S.W.Division	2000	39
			Bank Fees.	4	25
			Conference Expenses	17	70
	3549	50		3549	50

BALANCE SHEET
AS AT 30th JUNE 1974

LIABILITIES					ASSETS		
ACCUMULATED FUNDS					Commercial Banking Co. Of Sydney Crows Nest.	395	48
Balance as at 30th June 1973	1244	98					
Less Excess of Expenditure over Income for year	849	50	395	48			
			395	48		395	48

AUDITORS REPORT

Ireport that I have examined the records of the Australian Acoustical Society for year ended 30tb June 1974 and in my opinion the above Balance Sheet and Income and Expenditure Account are properly drawn up so as to give a true and fair view of the state of affairs of the Society.

Elanora. 5th February 1975

F.J.Morton
Registered under the Public Accountants
Registration Act,1945,as amended.

THE AAS 1975 CONFERENCE - "PLANNING FOR NOISE"

The AAS 1975 Conference, organised by the N.S.W. Division, is to be held at the Hydro Majestic Hotel, Medlow Bath, Blue Mountains, N.S.W., during the period of the 19th - 21st September, 1975.

The conference is to take the form of discussions and debates, each session being organised by an appointed convenor, who is to select a panel of specialists to assist. The aim is to generate new ideas for future planning against noise. The existing noise problems will be identified, attempts to overcome them to date considered, and ways of avoiding problems in the future discussed. Emphasis will be placed on the cost implications and on the social responsibilities of planning decisions. Typical solutions to be considered are legislation, land use planning and incentives.

All types of annoying noises will be considered; industrial, transport, residential, office, sporting and construction. Delegates are expected to be drawn from many disciplines; acousticians, town planners, transport engineers, architects, industrial engineers and economists, and this multidisciplines approach should ensure that noise is treated in its true perspective.

The conference also promises to be an outstanding social event. Excursions are being arranged for delegates and their families in the scenic Blue Mountains, sporting events are being organised, and, of course, the usual evening entertainment will be on tap.

The Society Annual General Meeting will be held during the evening of Friday 19th September, and on Saturday a Dinner Dance will be held.

Programmes and registration forms will be available shortly and will be sent to all Society members. Enquiries to the Conference Registrar, Denis Pickwell, P.O. Box 80, Crows Nest, NSW 2065, or telephone 02-428-3009.

NOISE CONTROL

JOHN SPILLMAN

Consulting Engineer
W.A. Chamber of Manufactures Inc.

SUMMARY

Following a brief discussion of the three phases in the creation of a noise problem, this paper reviews the various types of solution which must be considered in any noise control programme. Finally, the procedure necessary to avoid creation of a noise problem in any new development is outlined, and the importance of considering potential noise problems at the planning stage is emphasised.

INTRODUCTION

Previous speakers in this Symposium have outlined the effect of the community's growing awareness of noise problems and some of the reasons for this awareness and concern. The legislation which is an expression of this concern places another constraint on the continued operation of industrial enterprises and it is the object of this paper to outline the engineering procedures which may be necessary in order to avoid the penalties which non-compliance with this additional constraint will incur.

It would be foolish to imagine that compliance with any worthwhile noise regulation, either community or industrial, will not involve industry in additional costs. However, it is certain that these additional costs will be minimised by some understanding of the problems involved, by a continual awareness of noise as a problem or a potential problem, and by seeking competent advice.

HOW A NOISE PROBLEM IS CREATED

There are, in general, three phases in the creation of a noise problem:

1. Initial disturbance at the primary source.
2. Modification (usually amplification) of the disturbance at a secondary source.
3. Transmission of sound from the immediate vicinity of the source to a receiver, where it becomes a noise problem.

Brief discussion of these three phases will be worthwhile because it will provide a frame of reference for subsequent discussion.

Initial Disturbance

The initial disturbance is the ultimate source of the noise and it is important to realise that in many instances the intrinsic noise associated with the initial disturbance may not be a problem. It is what happens to it between the ultimate source and the receiver which transforms it into a problem.

The main types of initial disturbance or primary source are:

- (i) Explosive or pronounced pressure pulses. Typical industrial occurrences of this kind include internal combustion engines, reciprocating compressors, and cartridge operated hand tools.
- (ii) Solid friction, either rolling or sliding. Examples include bearings, gears, couplings, and most materials handling systems.
- (iii) Aerodynamic or hydrodynamic (fluid flow). Usually associated with turbulence of some sort and common examples occur in fans, pumps, centrifugal compressors, valves, vents, and burners.
- (iv) Impact. The impulsive contact between two bodies, typical examples of which include riveters, chippers, saws, pile drivers, presses, punches, and some vibratory machines.
- (v) Electromagnetic. Associated with variations in electromagnetic forces and examples are found in motors, transformers and bus bars.

Many machines will provide sources for several of these types of initial disturbance but usually one or two types will dominate.

Modification of Initial Disturbance

The existence of secondary source which modifies the initial disturbance is often vital in the production of an industrial noise problem. Many of the sources of an industrial disturbance would never result in a noise problem if it were not for the fact that some amplification always occurs between the source and the system (machine) boundary. For example, the impact of a circular saw tooth on the workpiece would produce little noise if no other mechanism were involved.

However, the initial disturbance will always excite vibration in surrounding machine parts and surfaces, which will then radiate sound energy to the immediate machine environment. Considerable amplification of sound may be produced in this process, particularly when resonances are involved. In the case of the circular saw, the impact between the tooth and the workpiece excites vibration in the saw which then forms an efficient radiating surface for sound energy. The impact will also excite vibration in other parts of the machine and in the workpiece and these will add to the sound energy radiated by the machine as a result of the initial disturbance produced by the impact or series of impacts.

Transmission to Receiver

No matter what sound pressure levels exist in the immediate vicinity of a machine, there is, by definition, no noise problem unless they are transmitted with sufficient magnitude to a receiver. Usually, airborne transmission is the most important mechanism, but sometimes a combination of transmission through solids and air may be involved. Some attenuation will always occur between the machine and the receiver, the amount depending on distance and the physical components of the transmission path.

SOLVING A NOISE PROBLEM

Once it is established that a noise problem exists the optimum solution will involve careful consideration of three possibilities:

1. Reduction or elimination at the source.
2. Isolation in the immediate vicinity of the source.
3. Reduction in transmission to receiver.

The distinction between 2 and 3 is somewhat arbitrary in that they both involve a reduction in transmission to the receiver. However, since isolation in the immediate vicinity of the machine usually involves treatment of individual machines it will be considered here as a separate possibility.

Reduction or Elimination at Source

In this context it is probably best to consider the first two stages in the production of noise and think of the initial disturbance as the primary source and the modification mechanism as a secondary source.

Reduction of the noise at source will always be the most satisfactory solution although it may not always be possible and even where possible may not be the least expensive solution. It will usually involve design modifications which tend to be expensive and difficult once the machine is commissioned.

Analysis of the primary noise sources may suggest a beneficial change. For example, in many electric motors a significant primary noise source (aerodynamic) is the cooling fan. Most motors are fitted with a fan which is capable of providing adequate cooling for both directions of rotation. In comparison to a uni-directional fan these fans are inefficient and therefore inherently noisier. Since most motors run in the same sense throughout their life the fitting of a uni-directional cooling fan may help solve a noise problem by reducing the noise at the primary source.

Most design modifications which are likely to be practicable involve concentration on the second phase in the production of a noise - that part of the process in which the initial disturbance is modified and secondary noise sources are created. These secondary noise sources will, typically, have relatively large surface areas, and in the worst cases will be constructed of relatively light gauge material. Useful reduction in noise levels can sometimes be achieved by reducing the response of these secondary noise sources to the primary excitation. This could involve increased thickness, stiffeners, changes in support, or provision of additional damping.

It should also be appreciated that surfaces remote from the actual machine in question may become secondary noise sources if vibration from the machine is transmitted to them. In this way surrounding floors, walls, and equipment may be significant secondary sources unless effective vibration isolation is incorporated between the machine and any duct or pipework to which it is connected.

An important solution in this category which is often overlooked is good maintenance. Restriction of machinery vibration levels to accepted industrial limits can result in significant reduction in noise levels, at both primary and secondary sources. If, for example, a rotating machine such as a blower is maintained in a state of good dynamic balance, bearing noise will be reduced and the sound energy radiated from the casing, ducting and supports will be reduced. Similarly, machine covers, panels and other "static" items should be securely maintained to eliminate unnecessary noise sources such as rattles and squeaks. While good maintenance may not completely solve a noise problem it will often make a solution by other means easier and therefore less expensive.

Isolation in Immediate Vicinity of Source

If the sound energy produced by a machine or process cannot practicably be reduced it may be possible to prevent it becoming a noise problem by ensuring that it is substantially contained within the immediate vicinity of the machine. For example, it may be possible with some automatic and semi-automatic machines to construct an acoustic enclosure around each machine. Even where provision must be made for material feed or cooling requirements, careful attention to acoustic design can produce effective enclosures. In one section of a factory where ten automatic presses operate, acoustic enclosures have reduced noise levels in the area from about 90 dBA to about 70 dBA, despite the fact that provision had to be made for continuous feed of raw material to the presses.

Another instance of this type of solution is the use of sound attenuators in the inlet and exhaust systems of engines, compressors and fans. These attenuators, or "silencers" limit the sound energy which is transmitted beyond the immediate environment of the machine, and are in effect much the same as acoustic enclosures, although the mechanism by which the attenuation is achieved may be quite different. Because the sound attenuation may involve significant pressure drop it can sometimes be difficult to obtain optimum attenuation in an existing system.

Reduction in Transmission to Receiver

Solutions which fall into this category are probably those most commonly attempted, partly because they are perhaps more obvious and partly because once a machine or system is operational they may provide the only practical answer. However, it should also be emphasised that many expensive attempts at this type of solution have failed because of insufficient understanding of the problems involved.

It is important to have a clear understanding of two basic processes - sound absorption and sound insulation. The process of sound absorption is used to control the reflection of sound within a room or enclosure and materials used for sound absorption are relatively light and porous. Sound absorption material has been called "acoustic brown paper" in an analogy between reflection of light and sound.

The process of sound insulation aims at controlling the sound transmitted through a structure from one space or enclosure to another. The effectiveness of a structure or a material as a sound insulator is dependent primarily on the mass per unit area, but also on stiffness and damping characteristics. The best sound insulating material will be heavy, inelastic, and possess high internal damping - which looks like a general specification for lead sheet.

Since a material providing good absorption will probably be a poor insulator, it becomes necessary to distinguish clearly between the two processes of control and to relate them to the control objective. In some cases a composite structure combining good absorption with good insulation will be used.

In considering a solution in this category a variety of possibilities exist, of which the most common are:

Absorption: Increased acoustic absorption within an enclosed space, such as a workshop, will reduce the noise level within the space. However, in most cases it is necessary to double the total absorption in order to produce a noticeable reduction, so that increased absorption becomes an expensive means of achieving a small reduction. In industrial situations where hazardous noise levels exist it is unlikely that reduction to safe levels can be achieved by increased absorption.

Barriers or Screens: Can be a useful solution particularly in situations where the source has pronounced directional characteristics or the receiver is fixed relative to the source. This type of solution will generally be more effective with high frequency noises than low frequency noises.

Operator Enclosure: More applicable in continuous process industries where it is often not necessary for operators to spend significant time in hazardous noise locations. In this situation suitably designed control rooms with appropriate instrumentation can eliminate a noise problem as far as the operator is concerned.

Ear Protection: A type of operator enclosure of which ear muffs are the most common form. This solution should be considered as a last resort but in many situations, particularly for maintenance personnel, it is the only practical solution. They will be uncomfortable for the user in hot, humid conditions, and achievement of a solution by this method will generally require an effective safety education programme.

Buildings: May be regarded as an acoustic enclosure for the whole process, so that when community noise problems arise with existing industries it may sometimes occur that relatively minor modifications to existing buildings will provide the solution.

AVOIDING A NOISE PROBLEM

As effective noise legislation approaches reality in this State the prudent manufacturer will be giving some thought to the question of avoiding noise problems in any new developments or extensions to existing plant. It will probably be less expensive to avoid creating a noise problem at the planning stages of a project than to solve an existing noise problem.

Careful attention should be given to equipment selection or specifications. Potentially significant noise sources will be identified and some consideration can be given to alternative means of achieving the same manufacturing objective. Noise data on particular machines and processes should be requested from equipment suppliers and in some cases consideration should be given to writing maximum acceptable noise levels into equipment specifications. At the present time in Australia it is likely that some difficulty will be experienced in obtaining satisfactory noise data from equipment suppliers but it is also likely that unless users begin to request this data it will never become available. It is of some relevance to note that in the United States, the Federal Noise Control Act of 1972 will require labelling of machinery to show maximum noise emission

Once potentially significant noise sources in a proposed development have been minimised and quantified planning can include action to avoid creation of a noise problem. Plant layout may be an important variable at this stage as it will often be possible to avoid or reduce a noise problem if noise is one of the criteria on which the layout is based. For example, it may be possible to group noisy machines and processes so that the potential noise problem is more economically solved. Areas where measures such as machine enclosures or operator enclosures may be necessary will become evident so that provision may be made for this type of solution while the project is still on paper and there is some chance of economic optimums being attained. Finally the measures necessary to conform with community noise legislation on a particular site will be highlighted so that in extreme cases an alternative site may be considered.

CONCLUSION

There can be no doubt that the introduction of noise control legislation, either community or industrial, will produce problems for manufacturers. In some fields they will be subjected to increasing commercial pressures to produce equipment that will enable their clients to conform with environmental requirements. In others they will find that their existing and planned manufacturing facilities will have to be carefully assessed and in some cases modified, if they are to avoid the risk of restrictions on their use.

This paper has briefly outlined the main options available to the manufacturer in his efforts to comply with the additional constraint which noise legislation will place on his operations. Occasionally an awareness of noise as a serious problem and a simple understanding of the principles involved in noise control will be sufficient to enable the manufacturer to cope with the legal requirements. More often it would be in his best interests to obtain specialist advice.

RECOMMENDED READING

"Noise" Rupert Taylor,
Penguin Books Ltd, 1970.

AN EXPONENTIAL HORN LOUDSPEAKER

P. L. Rossiter

Department of Materials Engineering
Monash University, Clayton. Vic. 3168

SUMMARY

The calculated amplitude and phase responses of a high-quality horn loudspeaker system are compared with the measured responses. The frequencies of the well damped horn resonances are found to be in good agreement if end corrections of about 15% of the physical horn length are applied. The calculated phase responses are in agreement with experiment but the magnitudes of the amplitude fluctuations are found to be slightly larger than expected. The frequency dependence of the voice coil impedance of the bass driver is considered and found to be in qualitative agreement with the measured dependence.

1. INTRODUCTION

The basic theory describing the behaviour of a finite exponential horn loudspeaker has been reviewed in (1) and in that paper the design for a four-way horn loudspeaker system was given. The low frequency horn was designed to radiate into the conical area expansion of a trihedral room corner and has a cutoff frequency of 35Hz. This horn is decoupled from a smaller horn having a cutoff frequency of 120Hz by an acoustic low-pass filter. An electrical crossover is used to divide the signal between the bass unit and a midrange horn with a cutoff frequency of 270Hz. A commercial horn tweeter is used at frequencies above 7KHz. The throat impedances of the upper and lower bass and midrange horns were calculated in (1) to give some indication of the designed horn responses but no detailed comparisons with measured responses were given. In this paper the theory is extended to allow a direct comparison between the calculated and measured horn responses.

The importance of determining both amplitude and phase responses is stressed in section 2 and the calculations given in (1) are extended to give both responses for the upper-bass and midrange horns. The results of these calculations are compared with the measured responses in section 3 and the correction of an anomalous phase response in the midrange unit is described. The amplitude and phase responses of the lower-bass unit will be largely affected by room resonances and a full calculation of these is not attempted. Instead, the effects of horn loading on the driver voice coil impedance is determined in section 4 and compared with its measured frequency dependence. In this calculation the effects of the throat reactance at very low frequencies which were not considered in (1) are included and found to be quite significant. Finally, in section 5 the overall response of the loudspeaker system is discussed and the measured amplitude response using $^1/_3$ octave pink noise is given.

2. CALCULATED AMPLITUDE AND PHASE RESPONSES

A loudspeaker's transfer function should contain all factors relating the output sound pressure level to the electrical excitation. In general this may be written as

$$S(\omega) = e^{a(\omega) + i\,\phi(\omega)}$$

where $a(\omega)$ is the logarithmic amplitude response and $\phi(\omega)$ the phase respons and plots of both $a(\omega)$ and $\phi(\omega)$ are then necessary to completely characterize the loudspeaker. The measurement of one of these responses is sufficient to characterize the loudspeaker only if it acts as a minimum phase network since the two responses are then directly related via Hilbert transforms (2). However, most loudspeakers depart considerably from minimum phase behaviour (3) so that the usual practice of measuring amplitude response alone is inadequate. In any case, both responses are required to check the minimum phase characteristic of any deviation from ideal behaviour. Furthermore, there is evidence to suggest that phase-shifts between components of a complex signal affect its perceived tonal quality (4,5). It has also been suggested that the spatial localization of two equally intense signals is strongly affected by their phase difference (6). An irregular phase response of a loudspeaker may therefore cause a tonal colouration and spatial smearing of the sound image. Phase response specifications are therefore assuming increased importance in psychoacoustic studies of sound reproduction as well as systems analysis studies, and both will be considered in the discussion of the horn loudspeakers which follow.

The relationship between the horn throat impedance and amplitude and phase responses is not well described in the standard texts (see references cited in (1)) and so will be derived here. The same notation used in (1) will be adopted and the relevant symbols are defined in the Glossary of Terms. In this section discussion will be limited to cases where the horn cutoff frequency is higher than the driver cone resonance. This applies to the upper-bass and midrange horns; the lower-bass horn being discussed in section 4. With this assumption the effects of C_{MS} and C_{MB} may be neglected without introducing any great error. Furthermore, this analysis will only apply to the "piston range" of the driver cones. This is the region where the circumference of the cone is less than the wavelength of the radiated sound, i.e. below 400Hz for the bass driver and below 1.5KHz for the midrange driver.

For the horns under consideration, $S_D = S_T$ and with the above assumption the mobility equivalent circuit for the midrange horn is as shown in figure 1. If we assume that the driver is operating at frequencies below the upper cutoff determined by M_{MD} in parallel with M_{MB}, the equivalent circuit is as shown in figure 2. Here the complex throat impedance z_{MT} has been expressed as the parallel combination of r_{MT} with x_{MT}.

The mobility equivalent circuit for the bass unit is given in figure 3. Again we are interested in the frequency range below that limited by M_{MD} and M_{MB}. At frequencies above the pole of the acoustic low pass filter, the reactance of M_{MB} is less than that due to C_{MB}, r_{MB} and the rear horn loading and so the equivalent circuit is given by figure 2 with $r_{MB} = \infty$.

The impedance r_{MT} and x_{MT} are frequency dependent and have been calculated in (1). The results are shown in figures 4 and 5. [Figure 9 of (1) is incorrect, it being appropriate to a shorter horn. The correct diagram is given in figure 5 of this paper and will be used in this study].

A calculation of the power dissipated in r_{MT} then gives a measure of the amplitude response of the horn and $\mathrm{Tan}^{-1}\left(\frac{r_{MT}}{x_{MT}}\right)$ gives its phase response. (In the impedance representation the series combination of $R_{MT} = \frac{1}{r_{MT}}$ and $X_{MT} = \frac{1}{x_{MT}}$ would be used for $Z_{MT} = \frac{1}{z_{MT}}$ leading to the same result.) An analysis of the circuit in figure 2 gives

$$i_3 = \frac{E_g}{r'_{MT} + R_1\left[\frac{r'_{MT}}{r_1'} + 1 + \frac{j r'_{MT}}{x'_{MT}}\right]} \qquad \ldots\ldots (1)$$

where

$$R_1 = R_g + R_e$$

$$r_1' = B^2 \ell^2 r_1$$

$$r'_{MT} = B^2 \ell^2 r_{MT}$$

$$x'_{MT} = B^2 \ell^2 x_{MT}$$

$$r_1 = \left({}^1/r_{MS} + {}^1/r_{MB}\right)^{-1}$$

As noted previously, $r_{MB} = \infty$ for the bass unit and so $r_1 = r_{MS}$. The midrange horn has an open back and $r_{MB} \approx 2.5$MKS mechanical mohms at 1.5KHz and so is negligible compared to r_{MS}. The power dissipated in r'_{MT} is then

$$i_3^2\, r'_{MT} = \frac{E_g^2\, r'_{MT}}{\left[r'_{MT} + R_1\left(\frac{r'_{MT}}{r'_1} + 1\right)\right]^2 + R_1^2\,\frac{(r'_{MT})^2}{(x'_{MT})^2}} \qquad \ldots\ldots (2)$$

and the phase angle is

$$\phi = \mathrm{Tan}^{-1}\left(\frac{X_{MT}}{R_{MT}}\right) = \mathrm{Tan}^{-1}\left(\frac{r_{MT}}{x_{MT}}\right) \qquad \ldots\ldots (3)$$

If the normalized acoustic impedances shown in figures 4 and 5 are called REST and REACT, then

$$r'_{MT} = \frac{B^2\, \ell^2}{\rho_o\, c\, S_D\, \mathrm{REST}} \qquad \ldots\ldots (4)$$

$$x'_{MT} = \frac{B^2\, \ell^2}{\rho_o c\, S_D\, \mathrm{REACT}} \qquad \ldots\ldots (5)$$

Some values of the loudspeaker parameters required for the calculations are given in Table 1. All values except those for L_V were obtained from Beranek (7). Substitution of these values into equations 2-5 gives the required relative amplitude and phase responses which are shown in figures 6 and 7. (Over the limited ranges of frequencies involved it will be assumed that the directivity of the horns does not change significantly).

3. MEASURED AMPLITUDE AND PHASE RESPONSES

3.1 Midrange Horn. The sinewave amplitude and phase responses of the midrange horn obtained in the anechoic chamber at Monash University with the equipment listed in Appendix 1 are shown in figure 8. These plots reveal a number of interesting features:

(i) the fundamental horn resonance at 360Hz and series of peaks and troughs as the frequency then increases.

(ii) a broad dip in amplitude at about 1.5KHz and corresponding inflexion in phase.

(iii) a sharp dip in amplitude at 11KHz and corresponding 540° phase shift. (The phase meter used (8) resets to zero after the ± 2π range is exceeded and continues to plot from that point).

The first feature arises from the finite length of the horn giving the amplitude and phase oscillations shown in figure 4. It appears however that the principal horn resonance is about 25% lower than that calculated.

The predicted magnitude of the 1dB peak-to-trough ratio is less than found experimentally even if the general downward trend to the broad dip at 1.5KHz is taken into account, giving a measured 4dB peak-to trough ratio. However, the calculated phase fluctuations are in agreement. The difference in frequency between experiment and theory is probably due to a neglect of end effects which would effectively lengthen the horn and shift the resonances to lower frequencies. Using an effective length of 0.32m brings the two sets of results into good agreement. This represents a 17% increase in length over the nominal value of 0.27m.

The anomaly (ii) appears to be due to a broad resonance between the near parallel top and bottom planar surfaces of the horn and is modified by insertion of some light acoustic absorbent material into the horn.

The rather alarming behaviour (iii) was found to be due to a high Q resonance associated with the dome over the voice coil. Removal of this dome resulted in the amplitude and phase responses shown in figure 9, and while the troublesome anomaly at 11KHz has been removed the response has become generally more irregular. A series of further cone modifications were then carried out and tests performed at each stage. After many trials the following procedure was found to give an optimum effect : replace dust cap with a disc of thin expanded polystyrene lightly coated with a damping compound; coat the cone lightly with epoxy resin; apply a bead of damping compound to the cone surround. These modifications give the responses shown in figure 10. The broad dip at about 1.5KHz remains but, as indicated by the amplitude and phase responses, is evidently a minimum phase anomaly (2) and so may be equalized electrically (9). This may be done with the simple passive network shown in figure 11, giving the amplitude and phases responses shown in figure 12. The insertion loss associated with such a network could of course be avoided by using an active equalizer. The remaining response irregularities are within the limits expected.

The modifications to the midrange driver are quite extensive and have been carried out mainly in the interests of finding the best performance using the small horn and cone driver. While the modified unit is audibly superior to an unmodified unit in a direct A-B comparison, the differences are not great. A midrange horn using an unmodified driver gives a very acceptable standard of reproduction and is good testimony to the advantages of horn loading with very good transient response as shown in (1).

3.2 Upper-Bass Horn

The amplitude and phase responses of the upper-bass horn obtained in the anechoic chamber with the test equipment listed in Appendix 1 are given in figure 13. In this case an electronic cross-over (fo = 360Hz) was employed. Again it was found that the neglect of end effects gives an error in the horn resonance frequencies : the measured principle resonance occurring at about 200Hz compared with the calculated value of [illegible]00Hz. This indicates an effective length of 0.53m compared with the nominal value of 0.46m, a 14% increase. Again, the frequencies of the subsidiary maxima and minima are brought into agreement with this correction. As in the case of the midrange horn the measured peak-to-trough ratio of 2db exceeds the calculated value of 0.5db but the magnitudes of the phase fluctuations are in agreement.

4. LOWER-BASS HORN

Many of the assumptions used to simplify calculation of the amplitude and phase responses in the previous section are not valid for the lower-bass horn, and in any case the measured responses of the horn in any normal listening environment will be strongly affected by that environment.

In an attempt to avoid the effects of standing waves in the measuring room the amplitude response of the horn was taken in (1) as the pressure response at its mouth. In order to compare theory with experiment for this horn then, a different approach will be adopted. This is to calculate approximately the frequency dependence of the voice coil impedance and compare it with experiment.

The frequency dependence of the throat resistance and reactance derived in (1) are given in figure 14. From these results it is clear that the assumption of the throat impedance of a horn being well represented by a resistance in series with a negative compliance is not valid for the finite horn under consideration and that here we must consider the effects of the mass reactance on the low frequency sides of the horn resonances. Accordingly, the throat impedance of the lower bass horn will be considered in three regions:

I, $f < 40\text{Hz}$
II, $40\text{Hz} < f < 60\text{Hz}$
III, $60\text{Hz} < f < 90\text{Hz}$

(If end effects were taken into consideration, these regions would be shifted to lower frequencies.) In regions I and II we assume $M_{AT} \sim 10^4$ MKS acoustic ohms and in region II we assume that $M_{AT} \sim 0$.

The mobility equivalent circuit for the bass unit has been given in figure 3 but now in regions I and III the effects of the compliances C_{MS} and C_{MB} and the masses cannot be neglected. The resonant frequencies of the parallel and series branches of the equivalent circuit are given by

$$f_P = \frac{1}{2\pi\sqrt{M_M C_{MS}}} \quad \ldots\ldots (6)$$

where $M_M = M_{MT_1} + M_{MD} + M_{MB}$ and

$$f_S = \frac{1}{2\pi\sqrt{C_{MB} M_{MT_2}}} \quad \ldots\ldots (7)$$

The calculated values are

$$f_P = 50\text{Hz}$$
$$f_S = 20\text{Hz}$$

The calculated upper and lower resonant frequencies of the combined network are then (p. 244 of (7))

$$f_L = 16\text{Hz}$$
$$f_H = 65\text{Hz}$$

and the voice coil impedance is expected to peak at these frequencies.

In region II, the voice coil impedance should pass through a minimum at the principal horn resonance which is calculated to be $1.5f_c = 50\text{Hz}$. Smaller dips should occur at the subsidiary resonances at about 100hz, 150Hz, 210Hz etc.

The magnitude of the voice coil impedance has been measured as a function of frequency over the range 10-300Hz. The results are given in figure 15 and show that the general predicted behaviour is observed. A more complete analysis of the equivalent circuit in figure 3 would give quantitative data about the magnitude of the voice coil impedance fluctuations but this has not been performed.

It is interesting to note that the effect of horn loading (without the acoustic low pass filter) is to add the mass reactance of the horn throat to the mass reactance of the diaphragm/voice coil assembly and air loading on the rear of the cone and thus lower the fundamental cone resonance. It would appear that the effect of adding compliance with a sealed enclosure at the rear of the driver would be to keep this resonance in a useful rather than subsonic frequency range and not give any effective cancellation of a negative throat compliance (as might occur in the case of an infinite horn).

5. OVERALL RESPONSE

All multiple source loudspeakers, whether horn loaded on direct radiating, will introduce a time delay distortion because of their spatial separation and differing bandwidths. There has been much written about the perceptibility of such time delays (10, 11) and it appears that the minimum perceptible time delay depends upon the complexity of the signal and in particular on the transient nature of the material (12).

This horn system has been designed so that the propagation delay between wavefronts emerging from the different horns is less than 2.5ms, this apparently being less than the minimum perceptible delay (11). However, because of this delay a measurement of the overall phase response of the horn system would contain apparently inaudible but measurable terms of the form

$$\Delta\phi = \omega\tau$$

where τ is the difference in propagation delays (8). These terms would tend to mask the detail revealed in the individual phase responses given in this paper if the overall phase response was measured.

The amplitude response of the complete horn system obtained from measurements of $^1/_3$ octave pink noise intensities with a Band K 2203 S.P.L. meter is given in figure 16 and indicates excellent amplitude response of the system over a very wide bandwidth.

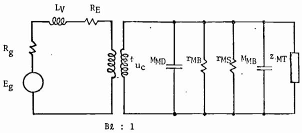
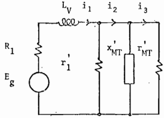


Figure 1. Mobility equivalent circuit of midrange horn for frequencies above the principle driver resonance.



$r'_1 = B^2 \ell^2 ({}^1/r_{MS} + {}^1/r_{MB})^{-1}$

$R_1 = R_g + R_E$

$x'_{MT} = B^2 \ell^2 x_{MT}$

$r'_{MT} = B^2 \ell^2 r_{MT}$

Figure 2. Equivalent circuit of horn loudspeaker in the middle frequency range.

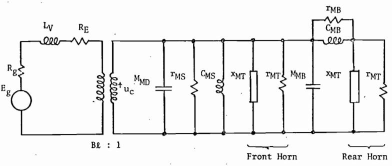


Figure 3. Mobility equivalent circuit of bass unit.

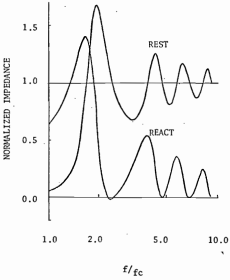


Figure 4. Normalized acoustic throat resistance and reactance calculated for midrange horn.

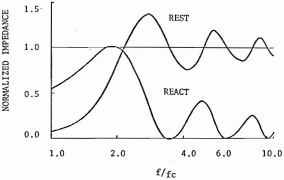


Figure 5. Normalized acoustic throat resistance and reactance calculated for upper-bass horn.

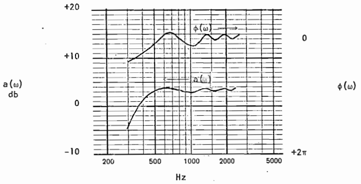


Figure 6. Calculated amplitude and phases responses of midrange horn.

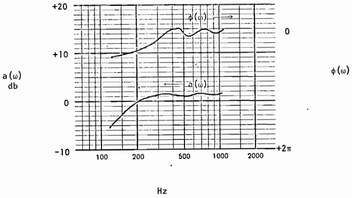


Figure 7. Calculated amplitude and phase response of the upper-bass horn.

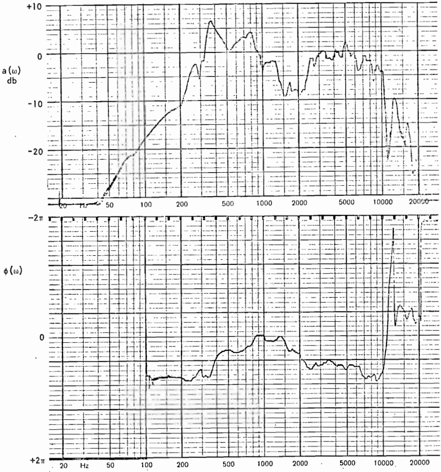


Figure 8. Measured amplitude and phase response of midrange horn.

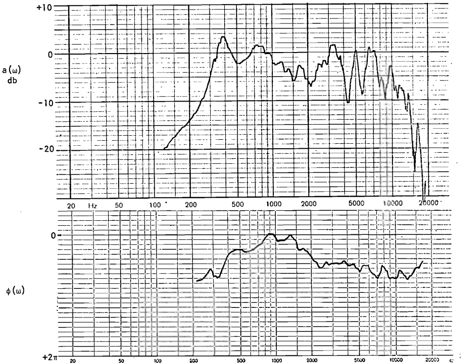


Figure 9. Amplitude and phase response of midrange horn after removal of dome over driver voice-coil.

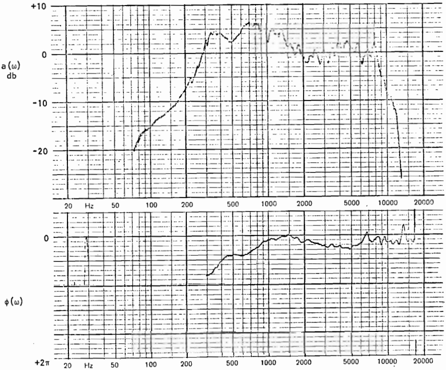


Figure 10. Amplitude and phase response of midrange horn with modified driver cone.

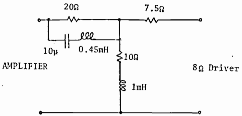


Figure 11. Passive equalizer network.

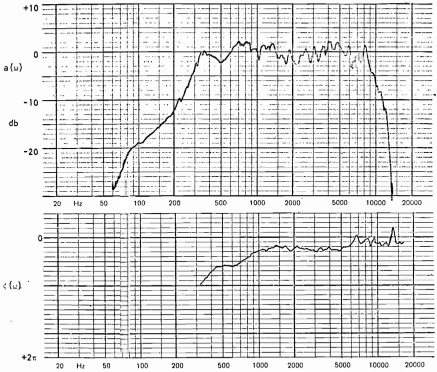


Figure 12. Amplitude and phase response of midrange horn with modified driver and electrical equalization.

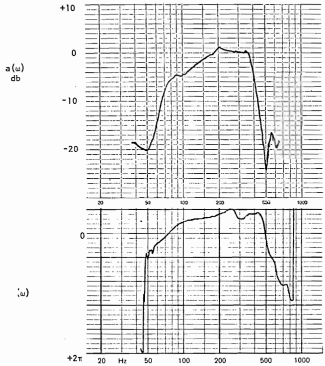


Figure 13. Measured amplitude and phase response of upper-bass horn (measurements taken with electronic crossover fo = 360Hz in circuit).

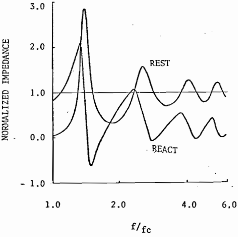


Figure 14. Normalized acoustic throat resistance and reactance calculated for lower-bass horn.

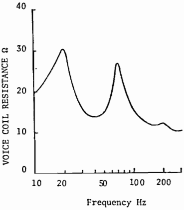


Figure 15. Measured frequency dependence of voice-coil impedance of bass driver.

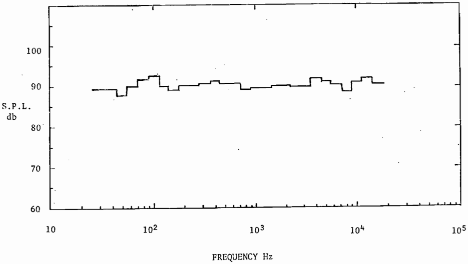


Figure 16. Amplitude response of complete horn system obtained from 1/3 octave pink noise measurements.

TABLE 1

DRIVER	12UX	FE103	UNITS
M_{MD}	1.65×10^{-2}	1.85×10^{-3}	KG
a	0.13	0.04	M
Free air cone resonance	50	80	H_Z
r_{MS}*	0.15	0.47	MKS.Mech. mohms
L_V†	10^{-3}	10^{-4}	H
B	1.4	1.0	W/M^2
ℓ	12.4	2.5	M
R_E	14	5	Ω
S_D	0.053	0.005	M^2
Q_{eff}	0.53	0.3	
Nom. Imp.	15	8	Ω

TABLE 1: Horn driver parameters. * Calculated from Q_{eff}. † Estimated from values given in (7).

APPENDIX 1

List of test equipment used:

B & K 1022 BFO

B & K 2203 SPL meter

B & K 2305 recorder

Phase meter described in (8).

GLOSSARY OF TERMS

ρ	density of air
c	velocity of sound
S_T	throat area
S_D	diaphragm area
f_c	horn cutoff frequency
u_c	particle velocity at cone
E_g	voltage of signal source
z_{MT}	complex mechanical throat mobility
r_{MT}	mechanical throat responsiveness
x_{MT}	mechanical throat reactance
r_{MB}	mechanical responsiveness of air in box
r_{MS}	mechanical responsiveness of suspension
C_{MB}	mechanical compliance of air in box
C_{MS}	mechanical compliance of suspension
M_{MB}	mass of air load on rear side of diaphragm
M_{MD}	mass of diaphragm and voice-coil
M_{MT1}	mass of aid load at throat of front horn
M_{MT2}	mass of air load at throat of rear horn
R_g	output resistance of signal source
R_e	D.C. resistance of voice-coil
B	magnetic flux in voice-coil air gap
ℓ	length of voice-coil
L_V	inductance of voice-coil
a	effective diaphragm radius

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John Spillman is a Consulting Engineer. His paper forms the text of an address which he gave to the We tern Australian Chamber of Manufactures Inc.