

Internoise 96 issue



Institute of Acoustics

Technical Contributions

A Quarter Century of Noise Control – A Historical Perspective

William W Lang FIOA

Aspects of Research on Acoustics in the UK

Jon Silverman MIOA

Health Effects of Community Noise

Birgitta Berglund

Towards a Standardised Descriptor of the Impulsive Noise

Caused by Low-altitude Military Aircraft

Bernard F Berry FIOA

Electromagnetic Compatibility & CE Marking of

Acoustic Instrumentation – What does it all mean?

Richard Tyler FIOA

High-sided Vehicles and Road Traffic Noise Barriers

David C Hothersall FIOA & S A Tomlinson

Finite Element Modelling of Dissipative Silencers

Keith S Peat MIOA & K L Rath

Sound Intensity Measurements For Building Acoustics

Carl P Hopkins AMIOA & Tina A Emmanuel MIOA

Consultancy Spotlight

The New Manchester Concert Hall: The Bridgewater Hall

Rob Harris FIOA

Noise in a Hydro-electric Power Station

Philip Dunbavin MIOA

Acoustic Performance – Exploding the Myth

Philip E Jones MIOA

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Mike Heath CB CBE CEng

New Chartered Engineer

CPD

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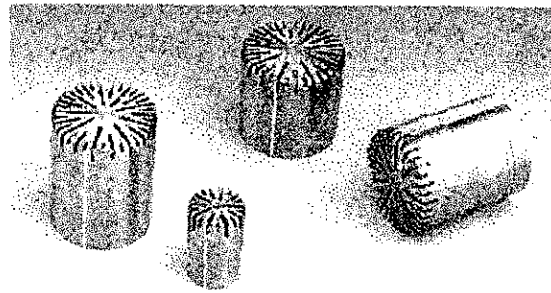
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BULLETIN

Volume 21 No 4
July - August 1996

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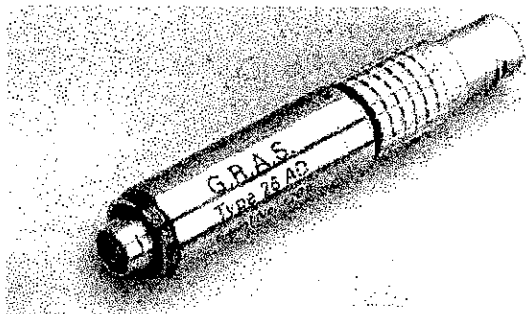
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Volume 21 No 4
July - August 1996

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The Institute of Acoustics was formed in 1974 through the amalgamation of the Acoustics Group of the Institute of Physics and the British Acoustical Society and is the premier organisation in the United Kingdom concerned with acoustics. The present membership is in excess of two thousand and since 1977 it has been a fully professional Institute. The Institute has representation in many major research, educational, planning and industrial establishments covering all aspects of acoustics including aerodynamic noise, environmental, industrial and architectural acoustics, audiology, building acoustics, hearing, electroacoustics, infrasonics, ultrasonics, noise, physical acoustics, speech, transportation noise, underwater acoustics and vibration. The Institute is a Registered Charity no. 267026.

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Sound performance

Nick Smith looks at a way of silencing noisy neighbours with a board-based floor insulation system

The introduction of more stringent sound insulation for the conversion of existing buildings into flats, as required by Part E of the Building Regs, has put the onus very much on the environmental and building services departments of local authorities to find economic, yet effective, means of curtailing sound transmission.

One of the key areas targeted in the Building Regs was that of the floor/ceiling partition. The requirement here is for airborne sound insulation of not less than 52dB and for insulation against impact sound, a value of not more than 61dB. Though sound insulation between new flats has long been a necessity, it is only recently that sound in the conversion of existing buildings into flats has become an issue.

Clearly, in a conversion any acoustic deadening needs to be a fit-and-forget operation. Tenants will be none too pleased to experience the inconvenience of further remedial work.

Flooring systems

One solution to just this problem that is being specified increasingly by local authorities is a gypsum fibre-board flooring system.

Comprising two laminated gypsum fibre-boards with a mineral wool layer bonded to the underside, the 1500 by 500 by 30mm sheet has a 50mm stagger between top and bottom board to create a broad, stable supporting seam and, more importantly, to prevent acoustic bridging.

The simplicity of installation belies the system's effectiveness in improving acoustic performance. A credible example of the system's capabilities was recently demonstrated for Waveney District Council, where a bed & break-



fast hotel was being refurbished to provide several private flats.

In order to verify claims for attenuation for both airborne and impact sound transmission, an independent test body, Sound Research Laboratories, was commissioned to carry out tests to BS 2750: Pt 4 (airborne) and to BS 2750: Pt 7 (impact) and to evaluate the performance figures using guidelines contained within the Building Regs (1991). These measure performance as a mean value for tests carried out on pairs of rooms as well as individual value.

The existing floor/ceiling construction was a 1/2 in. lath/plaster ceiling below 9 by 2 in. timber joists at 400mm centres. Laid on top was 22mm square edged floor board that had seen better days, but fairly representative of floor constructions throughout Britain for pre-60's buildings. With the initial 'before' tests completed it was evident that much remedial work needed to be done.

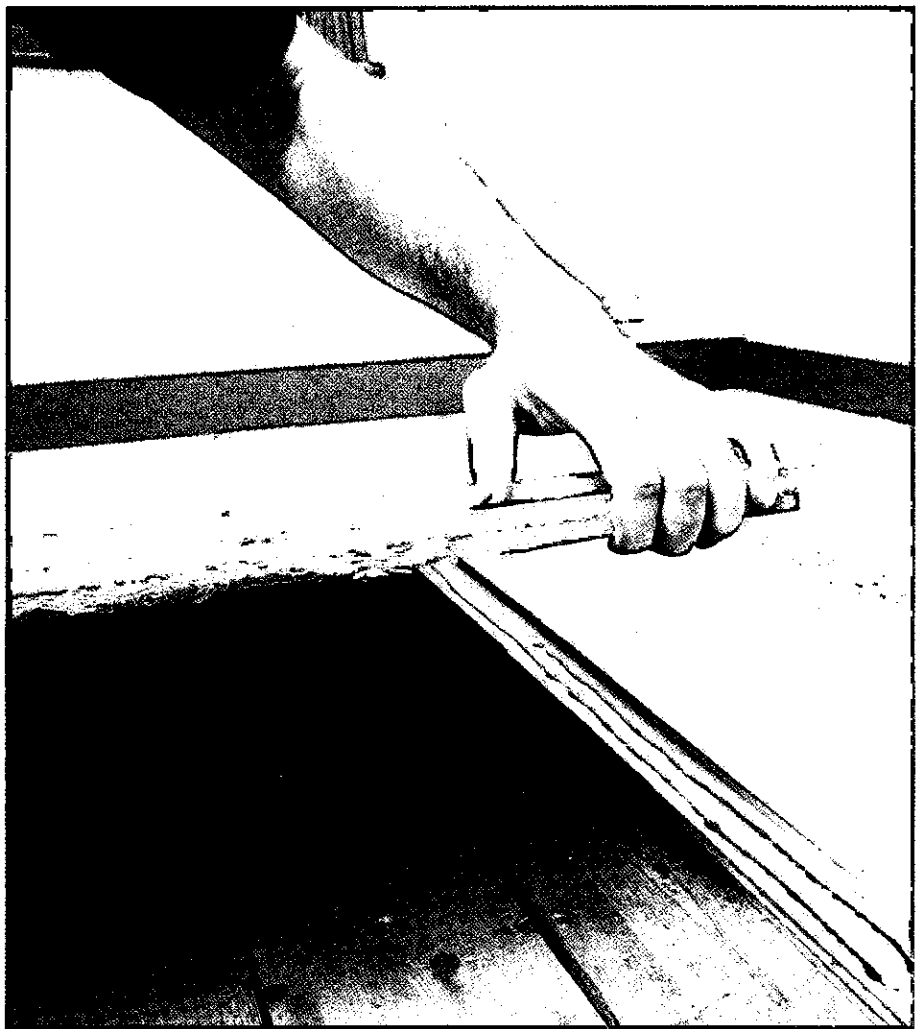
For airborne sound transmission, a measured mean of 44dB was obtained. This fell far short of the required criterion of 52dB minimum for tests in up to 4 pairs of rooms. All individual values also fell short of the minimum requirement of 48dB.

Testing

Similarly, impact transmission, *ie.* sound from footsteps, *etc.* fared little better in the 'before' scenario. A measured mean figure of 66dB failed to satisfy the criterion of 61dB maximum for tests in up to 4 pairs of rooms. Only one individual test met the maximum individual value of 62dB.

Prior to the second set of tests to measure the effectiveness of the gypsum fibre-boards flooring system, a little preparation was undertaken, including the use of an acoustic foam strip applied to the base of the walls to prevent 'flanking' sound transmission. The boards were then simply laid directly on the existing decking with the overlapping seams being glued and screwed to prevent joint movement.

With the increase in overall density of the floor/ceiling construction one would expect results for both airborne and impact sound transmission to be better. This was certainly the case, but it was



the magnitude of the improvement that was notable.

The reduction in impact sound transmission was impressive, showing a measured mean of 55.7dB and satisfying the criterion of 61dB maximum for tests in up to 4 pairs of rooms. The improvement over the 'before' test was a decisive 10.3dB. All individual values met the maximum requirement of 62dB.

The results for the airborne tests were better still. The 'after' installation test gave a measured mean of 56.7dB, exceeding the criterion of 52dB minimum for tests in up to 4 pairs of rooms and improving the 'before' figure by a staggering 12.7dB. Once again all individual values met the minimum requirement of 48dB.

Most importantly, this application of such boards measuring only 30mm in height, has converted the typically worst

case, but ironically most common, example of noisy flooring without the time consuming need to fit floorboards, to apply insulation between the joists.

For the end user or tenant, the advantages of this kind of system are abundantly clear. It can help provide a quality living space by containing noise transmission, an important factor in light of the soaring figures for noise pollution.

For local authorities the simplicity and speed of installation make it an attractive product for refurbishment and rehabilitation contracts. No messy liquid flooring screeds to worry about, no lifting of floorboards, no drying out time. Just minimum preparation, direct laying onto existing wooden or concrete floor and immediate use, so shortening contract times.

Nick Smith is customer services technician at FELS.

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8th INTERNATIONAL MEETING

on

LOW FREQUENCY NOISE & VIBRATION

to be held in

GOTHENBURG

on 3rd, 4th and 5th June 1997

at HOTEL 11, MASKINGATAN

Sponsored by:

The Journal of Low Frequency Noise & Vibration

ORGANISING COMMITTEE

Chairman: Dr. W. Tempest, University of Salford, with Members of the Editorial Board of the Journal of Low Frequency Noise & Vibration. The local organising committee is chaired by Dr Kerstin Persson Waye.

The 8th International Meeting on Low Frequency Noise & Vibration is to be held in Gothenburg, at Hotel 11. The meeting is sponsored by the Journal of Low Frequency Noise & Vibration. The topics of the Conference will be those of the sponsoring Journal, amongst which are:

- Sources of infrasound, low frequency noise and vibration, including hand-arm and whole-body vibration.
- Detection, measurement and analysis.
- Control, especially active control.
- Propagation.
- Perception and subjective effects.

CALL FOR PAPERS

The Organising Committee welcomes contributions on, or related to, the topics listed under section titled "Organising Committee", or any other area of low frequency noise and vibration. An abstract (with title) of about 200 words should be submitted to:

Dr. W. Tempest, Multi-Science Publishing Co. Ltd.
107 High Street, Brentwood, Essex CM14 4RX, United Kingdom

to arrive before December 31st, 1996.

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A programme of tours and visits is being arranged with an attractive programme for accompanying delegates. Details will be announced at a later date.

ACCOMMODATION

There is accommodation available within Hotel 11. Details and room prices of this and other hotels will be given in a subsequent leaflet. Student-type accommodation at moderate cost is also being arranged for those who prefer it.

BANQUET

A Conference Banquet will be arranged for the evening of June 4th, location to be announced.

REQUEST FOR FURTHER INFORMATION

I am interested in attending the 8th International Meeting on Low Frequency Noise and Vibration in Gothenburg, June 3rd-5th 1997.

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☐ I shall/shall not be submitting a contribution

☐ An abstract of my paper is enclosed

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The author

After 15 years as a lecturer, still with a keen appetite for conveying knowledge, Bernard Gréhan entered the world of industry and research for which he had already prepared generations of students, and is now Director of Research at SOMFY.

SOMFY is an international organization and a world leader in designing, manufacturing and marketing motors and switching and control systems for mobile envelope elements used in the building industry. The group devotes a large part of its activities to research and development.

Contents

Part One The Tools

Vibrations

Oscillatory movement * The sinusoid: a step towards harmony * Spectral analysis * Damping * Forced oscillations and resonance * Mechanical impedance

Propagation

Propagation of a disturbance * Alternating and sinusoidal waves * Influence of distance from the source * Interference * Directivity of a source * Reflectors * From waves to beams and rays * On reflection * Stationary waves and modes

Sound as a phenomenon

What is sound? * Sound sources * The human ear: structure * The human ear and frequency analysis: octaves * The human ear and sensitivity to sound intensity * Power, intensity, amplitude, level: decibels * Comparison and addition of levels * Physiological correction * Typical values of sound levels L_W and L_p * Logarithms

Sound propagation and attenuation in rooms

Attenuation and distance * Reverberation * Absorption * Sound transmission loss of a wall or partition * Wave-wall coupling: real mass law * Double walls * Non-uniform walls * Lateral flanking transmission * Airborne and solid-borne transmission

Noise

Sound source, noise source * Spectral analysis of noise * Health effects of noise * Auditory effects * Prominence * Defining sound comfort * The trends of new sound regulations: French NRA * Improvement of comfort: the capital label of approval * Noise standard SIA 181 * Equipment noise

Measurement and characterization methods

Measurement of sound pressure * Intensity measurement * Sound power measurement * Vibration measurement * New methods in development

Viscoelastic suspensions and transmissions

Advantage of viscoelastic or suspension transmission * Choice of the natural frequency * Choice of the damping rate * Adaptive and active suspensions * Degrees of freedom of the suspended system * Influence of the support * Choice of viscoelastic materials * Example of suspension and transmission design

Part Two Improvement

From motor to building

Considerable potential advantages * The motorized unit installed * Mix of approaches for combating noise

Improvements at the source

Arrangement of a tubular motor * Causes of vibrations and noise * Experimental results and interpretation * Preliminary improvement of the motor * Another improvement approach * A continuing process

Improvement of the moving unit

CSTB testing methods * The basic unit: the motorized tube * PVC window-shutter unit * Aluminium window-shutter unit * Venetian blind * Projection screen

Improvement of installation conditions

Products and installation conditions * Choice of field test sites * Field test FT1 * Field test FT2 * Field test FT3 * Field test FT4 * Field test FT5 * Field test FT6 * Installation of window-shutter units

Part three Recommendations

Product design

Incorporation of noise control parameters * General rules * Specific products

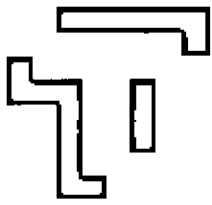
Installation of products

Influence of installation conditions * Sound leaks * Fixing to a heavy structure * Fixing to a lightweight wall or partition

Consequences for architectural design

Architecture and the active façade * The best choices * Regulations * Shared tasks and interacting roles

Appendices References Useful addresses Notation Index



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ACOUSTICS IN BUILDINGS

Bernard Gréhant

This book presents a strategy for optimizing a building's internal environment in terms of noise and its associated problems by taking the particular examples of motorized installations such as blinds and shutters and solar protection screens. It addresses all stages of the process, from the motor design to installation, incorporating the views of architects and equipment manufacturers.

This book guides non-specialists through all of the phenomena and empirical methods associated with acoustics, and addresses the principles and implications of noise regulations.

Analysis of several studies, conducted with the scientific and technical support of the French Centre Scientifique et Technique du Batiment, provide a wealth of useful advice and recommendations.

This book is as invaluable to those in the relevant professions as it is to those who need to develop an understanding of the potential problems encountered when building services and associated equipment are to be incorporated in a structure.

Provisional price, extent and size

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new book information

Aluminium Noise Barrier



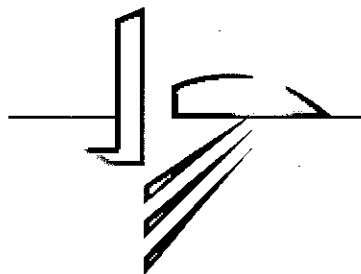
Case History



The Problem

One of Britain's largest dairy products companies needed to re-route incoming milk tankers in order to create a traffic-flow with a minimum of vehicle manoeuvring on site.

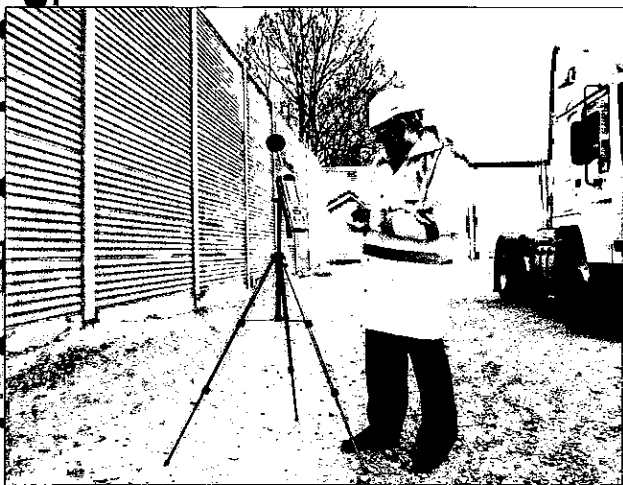
The new traffic-flow entailed change of use Planning Permission regarding a previously unused section of the site. As the site was next door to a residential area, a way had to be found to avoid causing a noise nuisance to the neighbours.



Baco
Contracts

Analysing the Solution

Advice was sought from the University of Salford, Department of Applied Acoustics, and a maintenance-free, aesthetically attractive noise barrier was identified as the most cost effective means of solving the dairy's noise pollution problem.



The advantages of aluminium were convincing:

- effective performance - noise energy levels reduced 200 times
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- choices of finishes, colours
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- pleasing appearance
- damage repairs easily carried out

The Proof

Independent tests conducted on site, after installation, have proved that the noise barrier provides an average insertion loss of 22.8 dB(A) using a typical HGV vehicle noise source - a performance which is addressing the envisaged noise pollution problem.

The barrier is obviously very effective, having reduced the noise energy levels by the equivalent of 200 times.

Noise measurement tests were carried out using a typical diesel tractor unit as noise source. This extract from the tests demonstrates that the results were more than satisfactory.

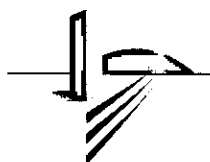
Providing the Answer

As Britain's foremost designers and manufacturers of sound absorbent aluminium noise barriers, Baco Contracts were awarded the contract. Their services included panel and component design, supply and project management of all stages of installation.

The results, all measured as dB(A) levels:

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	Measured	B/Ground	Measured	B/Ground	B/Ground corrected
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L90	74.1	53.6	54.3	51.6	23.1
L33	75.6	54.6	55.5	51.6	22.4
L10	76.6	55.6	56.1	52.3	22.8
Average					22.8 dB(A)

If you would like further information or advice regarding the aluminium noise barriers designed and produced by Baco Contracts, their experience and specialised expertise is available to you:

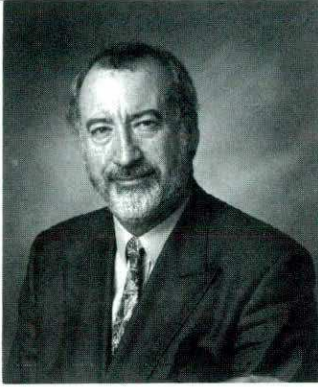


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Dear Fellow Member

This issue of the Bulletin will appear at the time of Internoise 96 in Liverpool.

In some ways it seems a long time since Internoise 93 in Leuven when we heard that the bid we had submitted to organise the event in Liverpool in 1996 had been successful. But of course the time has rushed by and a lot of hard work has been done by a lot of people since then to put the show together. To all concerned I extend my sincere gratitude. I would also like to thank the various organisations who have sponsored different aspects of the conference.

It gives me great pleasure to welcome a record number of delegates representing a record number of countries. There will also be a record number of technical papers presented both formally and in Poster sessions. We are also pleased to welcome those experts involved in meetings of various working groups of ISO, I/INCE etc which have been timed to coincide with Internoise 96.

This will be the 25th in the series of Internoise conferences and I am pleased that Professor William Lang, President of International INCE, who has been involved from the start, accepted the invitation to present the first of the Distinguished Lectures at this year's conference. I am also pleased that we are able to reprint, in this issue of the Bulletin, the text of his Lecture entitled 'A quarter century of noise control - a historical perspective'. At the conference Professor Lang will be awarded the Honorary Fellowship of the Institute.

Finally returning to the theme of strategic objectives in my first President's letter, there is a further objective which is particularly appropriate at this time.

- to develop a more co-ordinated approach to our links with overseas societies, not just in Europe but in the rest of the world.*

Recently Council agreed terms of reference for a new Vice-President with responsibility for international liaison and I am pleased to say that Professor Mark Tatbam has agreed to take on this duty.

Sincerely yours

Bernard Berry

Bernard Berry



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A QUARTER CENTURY OF NOISE CONTROL – A HISTORICAL PERSPECTIVE

William W Lang FIOA

Introduction

The twenty-fifth International Congress on Noise Control Engineering (INTER-NOISE 96) is a defining event. It marks the end of a quarter century during which a similar event has been held each year in major cities around the world. On 1972 October 04, INCE Charter President Leo Beranek in his opening remarks at the very first INTER-NOISE, said: 'Engineers know, and I'm sure that everyone in this room knows, that noise control is a complex subject. Noise emanates from many sources that constitute vital factors in our way of life. And people suffer individually from the effects of noise.' The task here is to describe what has happened during the last quarter century since the first INTER-NOISE in Washington, DC, USA. And, in particular, to describe the progress made to quiet the world in the period 1972–1996.

Setting the Stage: the Decade Before the Quarter Century

To set the stage for the developments of the quarter century just ended, attention is focused first on the preceding decade, the 1960s. Several events occurred in that decade which had a profound influence on the happenings of the quarter century that followed.

Noise Control Magazine At the end of 1961, Noise Control magazine was killed by its publisher, the Acoustical Society of America (ASA). The Society had been formed in 1929 as an offshoot of the American Physical Society '... to increase and diffuse the knowledge of acoustics and promote its practical applications.' One of the practical applications was noise control. In 1955, under the presidency of Leo Beranek, ASA began publishing Noise Control magazine which was the first publication in America to be devoted exclusively to the technical aspects of noise control. This publication was ahead of its time. It was killed not because of a lack of interest by noise control specialists; indeed, it was considered by them to be an outstanding publication, but due to a lack of enthusiasm on the part of the acousticians running the Society who were not overly concerned about noise and its effects, and did not want a small fraction of the membership to receive disproportionate benefit. During the 1960s, just under ten percent of the members of the Acoustical Society of America expressed a primary interest in noise and its control. That number is slightly above ten percent today. During its short publication life, Noise Control magazine provided a wealth of information to professionals in the emerging field of noise control. The demise of Noise Control magazine created a gap that was not to be filled for a decade.

The Fast Fourier Transform In 1965, IBM's James Cooley

and Bell Laboratories' John Tukey rediscovered the Fast Fourier Transform (FFT). Within a short time, the potential for this algorithm to revolutionize signal processing was clearly recognized, but the first software implementations were primitive and hardware implementations were several years in the future.

Computer Technology The third major development occurring in the 1960s that set the stage for the quarter century just past was the advances made during the decade in computer technology. The first large-scale digital processors were introduced in the 1950s. By the middle of the 1960s, a clock speed of 5 MHz was state-of-the-art. The personal computer (PC) was introduced at the beginning of the 1980s. By the middle of the 1980s, a desk-top PC with a 5 MHz clock speed was available. Today, a PC with a Pentium chip has a clock speed of 166 MHz, and 200 MHz machines are just around the corner. Clock speed, of course, translates approximately into processing power. In the 1970s, when the most recent quarter century began, the era of 'number crunching' in acoustics was just getting off the ground.

Structuring the Field: Noise Control Engineering Gains Recognition

As the decade of the 1970s began, there was no professional organization in the USA which was solely dedicated to the interests of the noise control engineer. Indeed, the title noise control engineer was quite new and was just being established as a recognized title for the practitioner of a specialized engineering discipline. Even with a new title, the noise control engineer was no better off professionally than during the preceding decade. But two developments were on the horizon. There was growing concern for the world around us; environmental noise was one aspect of that concern. And there was the possibility that new noise control initiatives would be introduced by the Federal government of the USA.

Workshop In 1971 January 10–12, some eighty-five noise control specialists from all over the United States and Canada participated in a Workshop on Noise Control Engineering. More than two-thirds voted to form a new organization which was chartered on 1971 June 4 in the Nation's Capital as the Institute of Noise Control Engineering of the USA. An agreement of cooperation was subsequently signed between the new organization and the Acoustical Society of America, and that agreement has been in place over the entire quarter century.

The First INTER-NOISE Congress The year 1972 witnessed the appearance of an INCE/USA newsletter,

Noise/News, in January, and the first INTER-NOISE Congress was held in October. At the INTER-NOISE 72 banquet, Professor Fritz Ingerslev announced that the INCE/USA Board had accepted the invitation from the Technical University of Denmark to host INTER-NOISE 73 in Copenhagen. The second INTER-NOISE, and the first to be held in Europe, was so successful the Board of INCE/USA recognized that its goal of creating '... an eventual federation of institutes of noise control engineering...' on a worldwide basis was close at hand. At the meeting of the INCE/USA Board on 1974 January 12, it was the consensus that every effort should be made to encourage the formation of a new international organization as quickly as possible. This new organization would take over responsibility for the INTER-NOISE series of world congresses and would help disseminate information on the rapidly expanding field of noise control engineering.

International INCE is Formed In the warm summer evening of 1974 July 28 at Bailey's Hotel in Central London, representatives of European organizations and the INCE/USA Board decided that a new organization would be established. The International Institute of Noise Control Engineering (I-INCE) was chartered according to Swiss civil law on 1974 October 1 with Professor Fritz Ingerslev as the charter President and Professor Eric Rathe as the first Secretary-General. International INCE was established to organize international congresses; and to promote international cooperation in a) research, b) the application of engineering techniques for the control of environmental noise, and c) the exchange of technical information. An announcement concerning the new institute was made at INTER-NOISE 74 which was taking place on the same date in Washington, D.C., USA. It was stated that the affairs of International INCE would be managed by its President and Secretary-General who report to its Board of Directors and General Assembly. The directors represent the six most recently-held congresses of the INTER-NOISE series, and each delegate to the General Assembly represents a member society. After initially being located in Zurich, Switzerland, the Secretariat of International INCE is located today in Leuven, Belgium.

International INCE Grows As soon as it was chartered, International INCE assumed the responsibility for sponsoring the INTER-NOISE series of world congresses. The congress in the year following the chartering was INTER-NOISE 75 in Sendai, Japan. International INCE is a consortium of member societies. The first two member societies to join the consortium were INCE/USA and the Danish Acoustical Society. From 1974 through 1996, the membership of International INCE has grown from two member societies to forty, including the world's leading professional societies concerned with acoustics and noise control. The congress in Liverpool, England, is the twenty-fifth in the INTER-NOISE series. Since 1972, these congresses have been held annually in major cities of the world, each hosted by a member society. The number of participants at a congress has ranged from 500 to 1400. Typically, more than 300 technical papers presented by

participants from over 30 different countries are published in the proceedings volumes. During the period 1975 through 1992, International INCE published a quarterly newsletter with worldwide news of noise control. In 1993, the newsletter was changed to a quarterly news magazine, Noise/News International, which is now a joint publication of International INCE and INCE/USA.

Breakthroughs of the Past Quarter Century

Consider the major technology breakthroughs of the quarter century just passed, and the important role that the INTER-NOISE series of conferences has played throughout this period. Four breakthroughs will be described in some detail. This is not intended to be a complete list, but there is unlikely to be any disagreement that the four breakthroughs selected have significantly changed the world of noise control engineering.

Sound Intensity Measurements The direct measurement of sound power flow through a unit area in a sound field, the sound intensity, has become practical for field measurements. This technique has had a major impact on noise control engineering [1].

The classical definition of sound intensity in a medium with no mean flow is the time-averaged product of the sound pressure and the particle velocity. The inventor of the sound intensity meter or acoustic wattmeter was H. Olson. His device patented in 1932 incorporated two microphones, one pressure-sensitive and the other velocity-sensitive. There were many problems in reducing the Olson device to practice. The acoustic wattmeter of T. Schultz was the first practical (analogue) implementation in the early 1950s. In the early 1970s, some forty years after the Olson patent, the fast Fourier transform had been rediscovered and high-speed general purpose computers as well as special-purpose digital instrumentation were available.

Techniques for the digital filtering of time series were developed shortly after the rediscovery of the FFT. These advances led directly to the development of two-channel methods for determining the sound intensity by digital filtering of signals proportional to sound pressure and particle velocity.

The sound power emitted by a noise source can be determined by measuring the sound intensity at specified positions on an imaginary surface enclosing the source, and then computing an approximation to the surface integral of the normal component of the intensity over the surface. With the practical realization of the acoustic wattmeter in the early 1970s, this method became feasible. Up to then, the most reliable methods for determining the sound power of a noise source involved measurements of the sound pressure alone (one-channel only) and making an assumption on the nature of the sound field which would define the relationship between the sound intensity and the sound pressure. These 'classical' methods were standardized internationally for the different environments in which they are to be carried out: reverberant, semi-reverberant and free-field [2]. The intensity method will ultimately replace the 'classical' methods because of its

inherent advantages over the older methods.

The major advantage of the sound intensity method for determining the sound power of a noise source is that the method is independent of the environment in which the measurements are made. It is not necessary to provide a special test facility such as a reverberation room or an anechoic room in order to carry out the measurements. A further advantage is that sound intensity measurements can be made in the presence of high background noise levels. The arrival on the scene of a sound intensity meter for field measurements has introduced other important improvements to the field of noise control engineering. With the enhanced computer graphics now available, it is possible to visualize a sound field by portraying it in terms of the patterns of sound intensity. This has led to a better understanding of the radiation patterns not only of simple structures, such as beams and plates, but also of complicated noise sources. The identification and localization of the individual sources of a machine with multiple sources can now be carried out with minimum effort.

The practical sound intensity meter has facilitated the measurement of the properties of noise-reducing elements, such as the transmission loss of walls and panels and the absorptive characteristics of acoustical materials. Applications involving sound intensity measurements in building acoustics have been described [3]. Sound intensity measurement is now firmly entrenched as a useful tool, and is recognized as a 'mature technology.'

Numerical Acoustics The stage was set at the beginning of the 1970s for the arrival of the 'number crunching' era. Numerical computations that up until then had been either too laborious or too time-consuming gradually became commonplace. Old methods were re-examined, and new methods were developed. Both required large amounts of computing power, much more power than had ever been previously available. Computations were made on a scale never before undertaken; in many cases, analytical results were obtained as a result of computations that had never been carried out before due to the large amount of computer storage and central processor time required. The growth of the PCs and workstations in the 1980s made it possible to do all these complex numerical calculations.

A number of techniques have been developed and refined over the past quarter century. The sound power level of a structural source can be estimated by a number of different methods in the low-frequency region where few vibrational modes of the source are excited. Experimental modal analysis (EMA) can be carried out on a prototype or model machine to determine modal shapes and modal damping. In finite element analysis (FEM), the structure is divided into a finite number of surface elements to determine the surface velocity distribution for each mode. The radiated sound power of the source can then be calculated using the Helmholtz integral equation or the Rayleigh integral equation. Or, using the boundary element method (BEM), the Helmholtz integral equation can be solved directly for the sound pressure and surface velocity.

In the high-frequency region, statistical energy analysis (SEA) [4] is available to compute the sound power level of a source by summing the powers radiated by each of the individual parts that make up the source. With the great advances in computer technology over the past quarter century, the number of acoustical problems susceptible to numerical analysis has been greatly expanded. Numerical methods will continue to evolve as processing speeds become higher and bandwidth to the desktop increases. Algorithms will be refined through a continual comparison of theory and experiment.

The Advent of the Virtual Instrument Since they first appeared on the scene at the end of the 1970s, personal computers (PCs) have developed so rapidly they threaten to replace the dedicated measurement tools of the noise control engineer [5]. Consider the sound level meter with its building blocks: input (microphone), preamplifier, frequency weighting, detector and output (display). In the decade of the 1960s, most of the instruments in use were completely analogue, with the newer instruments having digital displays to replace the moving-coil meters. During the 1970s, the building block in which analogue-to-digital conversion (ADC) occurred shifted from the output block back towards the microphone. Today, ADC is accomplished in many dedicated instruments on the signal from the microphone preamplifier. The use of digital circuitry has many advantages. In particular, the output signal can be fed directly to a PC for printing, storage and further processing.

Earlier this decade, a reasonable question to ask was the following: can the dedicated instrument (ie the specialized digital hardware for the frequency weighting, detector and output blocks of the sound level meter) be replaced by a PC which would become a Distributed Virtual Instrument (DVI)? An off-the-shelf PC could replace most of the specialized digital hardware; in today's world, the only specialized resources needed for the DVI are the input (microphone and preamplifier), the digital signal processing (DSP) function and the output. DSP is provided by application software. An example of a DVI is the Concerto which is available now on the commercial market [6].

Today, it is possible to perform real-time FFT analysis with a Pentium processor and a Windows user interface. A general-purpose PC with a microphone on an input channel, which is a miniature version of today's laptop and no larger than one of today's sound level meters, will become the measuring tool of preference for noise control engineers. Tomorrow, the noise control engineer will browse the World Wide Web, download the instrument that is desired, and then perform the analysis on the digital data from the field that has been stored as a time series in the PC. To be sure, such a scenario is still in the future. But instruments (software) will eventually be available on the Internet for downloading and users will be able to 'rent' a wide variety of analysis tools for a particular situation. The market for dedicated acoustical instruments is likely to remain active for some years, but as we move into the next millennium, it is probable that

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the role of dedicated instruments will be taken over gradually by the PCs of the future.

Active Noise and Vibration Control The field of active control of noise and vibration has grown rapidly during the last two decades. In the mid-1930s, Paul Lueg obtained the first patent on active control. In the early 1950s, Olson and May published a paper [7] which illustrated several applications of active control, but it was not until the 1970s with the advances in control systems and digital signal processing that active control became feasible.

A recent article [8] in Noise/News International summarized the many applications for active control which were described at ACTIVE 95, the 1995 International Symposium on Active Control of Sound and Vibration held in Newport Beach, California, USA on 1995 July 6-8. Most of these developments have been driven by advances in control theory and the availability of low-cost electronics for digital signal processing (DSP). Indeed, were it not for these advances, breakthroughs in active noise and vibration control would not have occurred. An earlier article also in Noise/News International [9] presented background information on active control with emphasis on signal processing requirements.

Passive noise control systems which utilize sound absorbing materials, mufflers and other techniques are generally ineffective at the lower frequencies. The primary advantage of active noise control systems is that they can provide significant noise reduction at low frequency. Destructive interference between the sound fields generated by the original primary source and that due to other secondary sources, whose acoustic outputs can be controlled, results in quieting. The most common type of secondary source is a moving coil loudspeaker whose acoustic output is controlled by an electrical signal. It is the generation and control of this electrical signal in order to reduce the acoustic field that is the signal processing task presented by active control. Active control is an emerging technology with much work in academic circles and a few practical applications. The field will develop as transducers are improved, as the costs of signal processing are reduced, and as users become more informed about the benefits and limitations of active control. The applications areas that are currently under intensive investigation include:

- Active control in ducts and pipes
- Active control in enclosures
- Active control in vehicles
- Active control of stand-alone sources
- Sound reduction by structural vibration control
- Active control of structures and vibration isolation
- Transducers for active control

The Challenges Ahead

On the twenty-fifth anniversary of the first INTER-NOISE Congress, it is appropriate to look carefully at the structure of the field of noise control engineering. A detailed study of this structure was published in the 1996

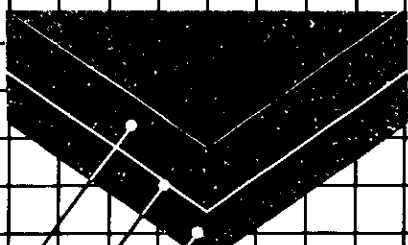
March issue of Noise/News International [10].

Consider the world of science and engineering at the turn of the last century, and then the situation today on the threshold of the next century. At the turn of the century (1900), the field of physics was neatly divided into several sub-fields (acoustics, mechanics, optics, thermodynamics, electricity and magnetism, and 'modern' physics). The American Physical Society, founded in 1899, covered all of the sub-fields of physics. The interests of engineers were represented by societies involved with five major engineering disciplines: civil, mechanical, electrical, mining and metallurgical and chemical.

During the 20th century, the field of acoustics and its practical applications gradually flowed out of the field of physics into engineering disciplines. In the USA, the Acoustical Society of America was founded in 1929, the Audio Engineering Society in 1951, acoustical divisions of the Institute of Electrical and Electronics Engineers (1949) and of the American Society of Mechanical Engineers (1981), the Institute of Noise Control Engineering (USA) in 1971. The evolution and spawning of new organizations has perhaps not ceased. Reference 10 describes some 29 national and international organizations that are involved today with the noise control aspects of acoustics. The key questions are twofold. Are the existing organizations sufficient to cover the field of noise control engineering? And are they doing a creditable job?

Consider the growth of the field of noise control engineering over the past quarter century. Twenty-five years

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ago, the profession of noise control engineer was newly established, but there were few courses offered in noise control engineering. Today, the leading universities of the world are offering such courses. As demand for environmental quiet has increased, there has been a major increase in demand for engineering services. The consulting business is flourishing. Legislatures are promulgating regulations and decrees that require noise control. The field of noise control has grown tremendously over the past twenty-five years. Consider now the *raison d'être* for the INTER-NOISE 96 Congress. Why, year after year, have large numbers of participants gathered in far-flung cities of the world to discuss the latest developments in noise control engineering? Part of the answer may be that noise control engineering is not tied to any one of the classical fields: physics, mechanical engineering or electrical engineering, but is truly inter-disciplinary. The four breakthroughs described above have required the interactions of specialists from a broad spectrum of disciplines. The reasons for participation at an INTER-NOISE Congress differ from delegate to delegate. But an engineer who is working in one of the breakthrough areas is likely to be more interested in a congress covering a broad range of subjects, which includes sessions devoted to the ultimate consumer, than a congress devoted to one field of engineering in which the interests of the consumer (eg the recipient of community noise) may not be represented. The challenges ahead are numerous, so there can

be no complacency. But the field of noise control engineering will continue to develop and flourish.

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ASPECTS OF RESEARCH ON ACOUSTICS IN THE UK

Jon Silverman MIOA

Introduction

The use of the term acoustic (ultimately from Greek meaning 'to hear') goes back to the 17th century. The first occurrence listed in the Oxford English Dictionary is dated 1605, from the writings of Bacon. Hearing and sound had historically been subsumed under the rubric of music, a subject held in high esteem. There was some earlier study of the properties of sound, but its scientific understanding can be considered to begin with Newton. Some two hundred years later, Lord Rayleigh's investigations, which were a combination of meticulous experimentation and mathematical theory, marked a further milestone in acoustics.

Today, the subject covers many overlapping facets ranging from sociological, psychological and bioacoustics through to musical acoustics and many problems in physical acoustics.

Early Development

The nature of sound was not understood until comparatively recently. In the 17th Century, Cartesian philosophy sought to explain the physical world by means of 'vortices', but Newton felt that his explanation was more in accord with reality. Newton was amongst the first of the natural philosophers to query the physical mechanism which constitutes sound. The Principia is mainly concerned with dynamics, but one section of Book 2 is concerned with wave motion and sound. Sound is ascribed to longitudinal air pressure waves, and Newton formulated an equation for the propagation of sound through a gas. He predicted the speed of sound from his equation, which was printed in the first edition of the Principia [1,2].

Newton's method of prediction was both logical and intuitive – he did not know in every detail the mechanism of sound transmission as it is today understood, yet he did have an overall appreciation of the physical basis of sound.

By the time of the second and third editions of the Principia, further speed of sound measurements had been made in France which confirmed that Newton's formula for the speed, $\sqrt{\text{pressure/density}}$, gave too low a value (by about 15%). Newton had assumed that, when air is compressed, Boyle's Law would hold, and he had even tested his theory in Neville's Court at Cambridge by timing the echo. However, and unusually for Newton, his measurements were not sufficiently accurate to show the difference between his theory and practice, and the discrepancy was only resolved when Laplace, over 120 years later, supplied the necessary modification. This is the addition of gamma (ratio of specific heats) to Newton's formula for the speed of sound.

It is difficult, with our present understanding, to appre-

ciate Newton's achievement of grappling successfully with sound propagation, and then not only arriving at a reasonable understanding from scratch but also putting that understanding into mathematical form and getting a value for the speed of sound in air. Indeed, Laplace remarked that Newton's theory, although imperfect, was a monument to his genius.

Lord Rayleigh's Work

About two hundred years after Newton's Principia Mathematica was published, Lord Rayleigh was carrying out experiments in acoustics at the family home in Terling, Essex. John William Strutt, Baron Rayleigh, published over 100 papers on acoustics and vibration between 1870 and 1919. According to his son [3], Rayleigh became interested in resonance after he was advised to read Helmholtz's book on tone-sensations in order to learn German.

His first substantial acoustics paper, published in 1870, is a detailed examination of resonance. This included, amongst other things, an explanation of the Helmholtz resonator. Rayleigh very often used musical notation in his experimental work as he had an interest in music generally. The resonances of bottles and flasks which were used to test the theory, see Figure 1, were determined by holding the container over the appropriate piano wire. The experimental apparatus at Terling is now in the process of being catalogued. He kept careful experimental records on a daily basis, and they evidence a strong commitment particularly to his preoccupation with acoustics. Rayleigh's famous treatise 'The Theory of Sound' was written while he was recuperating from rheumatic fever in Egypt and published in 1877 [4].

Aside from his scientific work, Rayleigh was asked to



Fig. 1. Helmholtz resonators at Terling (photo by kind permission of the Strutt family)

take part in many public duties. He was invited to become Chancellor of Cambridge University by the Duke of Devonshire. The idea for a National Physical Laboratory had been first mooted around 100 years ago in discussions at the British Association meetings at Ipswich (1895) and Liverpool (1896). Lord Rayleigh became chairman of a Treasury committee appointed by Lord Salisbury to consider the question. The Committee reported in favour of establishing the Laboratory, and Rayleigh was later appointed by the Royal Society as Chairman of the Management Committee of the Laboratory.

The National Physical Laboratory had responsibility for, among other things, the determination of physical constants, national measurement standards etc. and, in the present day it performs calibration checks for acoustic instrumentation such as sound level meters. It also maintains a laboratory in the Centre for Ionising Radiation and Acoustics for the determination of the Primary Standard for sound levels. The Laboratory has recently been privatised.

Horace Lamb wrote in 1920 that Rayleigh's main interest was in the unravelling of physical phenomena 'and that mathematics was to him chiefly valuable as an auxiliary. Moreover, just as in his experimental work he had recourse by preference to the simplest devices, so the mathematical apparatus whenever possible was of the most elementary nature. There was always, however, enormous mathematical power in reserve, and whenever the occasion called for it the utmost degree of skill of this kind was brought to bear.'

Recent Progress

The basic foundation for acoustics had been completed by the end of the last century, and since that time many advances have been made in the field of acoustic technology. Discussions, mainly in the United States during the first half of this century, have led to the adoption of the main noise measurement units currently in use, dB re 20 μ Pa, dB(A) etc.

If two achievements could be said to epitomise 20th century acoustics, they might well be accurate sound measurement and, more recently, the development of active noise control. But this is not to minimise the importance of acoustics in other disciplines, such as condition monitoring and medicine.

Current UK Research

There are several universities where acoustics is taught as part of a degree course, amongst the largest being Salford and Southampton. The Institute of Sound and Vibration Research at Southampton University is one of the major specialist research institutes.

Is it possible to devise a simple method to characterise structure-borne sound (vibration up to audible frequencies) in the same way as with sound power for air-borne sound? A research group at Liverpool is attempting to formulate a descriptor that will give an easy to interpret way of assessing machinery vibration. However there are some complications with structure-borne sound

in that the emission depends upon the receiver structure as well as the source, whereas in the case of air-borne sound the receiving medium is always the same. The most promising means of characterisation of a structure-borne sound source is the free source velocity, the velocity at the contact points when the machine is operating in a freely suspended state. This is an independent property of the source, and there are standard methods of measurement.

The ISVR Signal Processing Group specialises in digital signal processing with reference to acoustics, and active sound and vibration control. Signal processing research has developed from off-line computation, to advanced tools for the analysis of non-linear systems and non-stationary data. There is also an increasing emphasis on real-time computation for estimation, speech processing and control, particularly using the Texas Instruments TMS320 series processors.

Although the idea of noise cancellation was thought of many years previously, active control did not become a serious proposition until the electronic and signal processing techniques were available long after Paul Lueg's German patent in the 1930's and Olson's later work in the USA. Development of active noise and vibration control techniques is now taking place in several research groups.

Lueg's original idea also envisaged cancellation over localised areas of 3-D space, although in practice he had only considered the 1-D case of noise in a duct in detail. Some of the modern investigations into active sound cancellation took place in Chelsea College, London, where the Chelsea monopole and close-coupled monopole were developed by Leventhall and co-workers.

However, it is only with the advent of real-time digital processing techniques that active control for broad-band noise began to become a practical possibility, and the limitations of active control due to physical constraints may be reduced.

These physical limitations generally restrict the frequency range of global active control systems to below a few hundred Hz. Above this frequency it may still be possible to cancel the sound in a zone around a listener's ear and the acoustic performance of such 'local' control sys-



Fig. 2. Manikin used at ISVR for research into active noise

tems has been the subject of intensive investigation. One possible application of such systems could be in locally quieting noise near the seat headrests in a train or aircraft. Figure 2 shows a manikin at ISVR used for active noise control tests with headrest speakers.

Algorithms & Active Vibration Control

The control algorithms used to adjust the secondary sources in any of these active systems can be either feedforward or feedback. Feedforward systems rely on the measurement of a reference signal which is well correlated with the noise from the primary source, such as a tachometer signal in a propeller aircraft. Control algorithms have been developed for the rapid adaptation of such feedforward controllers even in multichannel systems where a large number of secondary loudspeakers are used to control the sound at a large number of microphones. Real-time implementation of these algorithms has been used to demonstrate the practical application of active control to the noise inside propeller aircraft, automobiles and helicopters. Feedback controllers have also been implemented for headsets and zonal control systems which are adaptive to disturbance and plant changes, and robustly stable in the face of plant uncertainty.

Research in the area of active vibration control has focused on the physical limitations of vibration isolation through multiple active mounts, and the practical application of such systems. Active elements can be combined with conventional elastomeric mounts for isolation at frequencies below a few hundred hertz. The best performance is obtained by the integrated design of the passive and active elements of the mount and by careful choice of the cost function which the control algorithm is designed to minimise.

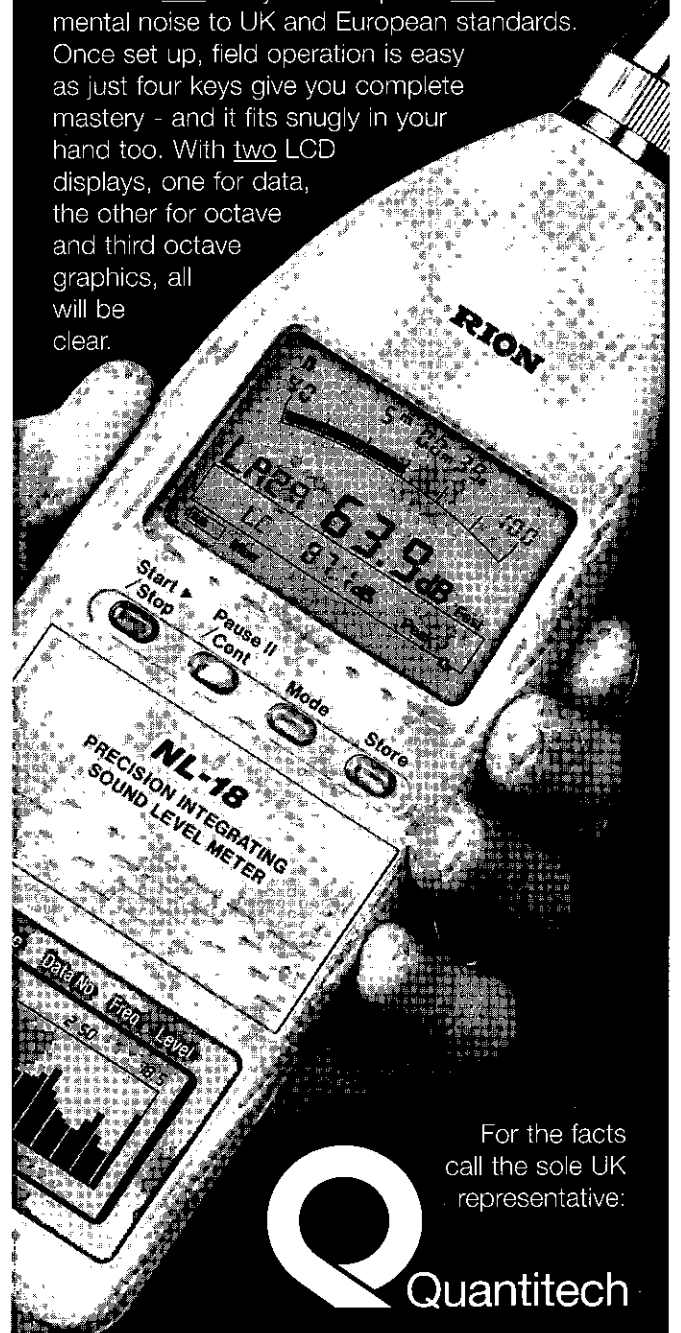
At higher frequencies it may still be possible to isolate vibration by actively controlling the propagation of structural waves in the elements which connect the vibrating source to the receiving structure. A system with three magnetostrictive actuators has been used, for example, to very effectively control the propagation of the longitudinal and two planes of flexural wave in a helicopter strut at frequencies up to several kilohertz.

Signal Processing and Analysis

Work on Mechanical Signature Analysis has mainly concentrated on satellite condition monitoring and the introduction of data from cockpit voice recorders. The condition monitoring work has involved the analysis of data from a triaxial accelerometer mounted on the Olympus Spacecraft to detect the operation of various mechanical devices and analyze the waveform of these events to monitor their condition. The analysis of cockpit voice recordings is spurred by the need to determine the cause of air accidents. The cockpit voice recorder microphones are sensitive to fuselage vibration as well as sound in the cockpit, and thus detect the response of the structure to a catastrophic event such as an explosion as well as the pressure wave. By examining the difference between the timing of these two signals an indication can

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be obtained of the position of the event within the aircraft, providing valuable information to air accident investigators. These methods have been validated by ground tests on several types of aircraft.

Some of the most rapidly growing applications of signal processing are in the field of medicine. Several methods of improving diagnostic tools using signal processing methods have been studied in conjunction with Southampton General Hospital. These include the use of time-frequency methods for the detection and classification of heart murmurs, measuring lung function using impedance measurements and measuring bone porosity using ultrasound.

Developments have been made recently in the speed and capacity of devices designed for real-time Digital Signal Processing (DSP). These developments have been used in the group to develop real-time systems for research into detection and estimation, speech processing and active control. Systems have been developed through several generations of DSP devices, particularly the TMS320 series, and currently arrays of parallel processors are being used for particularly intensive real-time tasks.

The fluid dynamics and acoustics group at ISVR is particularly concerned with acoustic phenomena caused by fluid flow. One such case, for example, which produces high levels of noise is a turbo-fan on an aircraft at take-off. The blade tips are travelling at supersonic speeds, and this produces a peculiar buzz-saw noise which has many harmonics and propagates in a non-linear way. Transform techniques have been used to look at the behaviour of the noise in the frequency domain, and simulate the behaviour of the fan at high speed with an absorbent lining.

Of importance in aeroacoustics is the noise emanating from reciprocating engine silencers, for example motor-car exhausts, or air-intakes. Attempts have been made to model, both theoretically and practically, the main acoustical phenomena in the flow chambers of these silencers, and thus to predict the potential and actual attenuation performance achieved.

Acoustics and Hearing

Acoustics is first and foremost to do with hearing, and many people are interested in exactly how hearing works. This is, of course, of great significance in understanding hearing impairment and deafness. Some groups, for example at Loughborough and Cambridge, have developed computer models of the hearing process. This approach amounts to an attempt to integrate the physiological and psychophysical bases of hearing to obtain an overall picture of the processes involved in hearing.

The vibration of the basilar membrane can be tracked using either invasive surgery or non-invasive question and answer techniques. Basilar resonance effects can be inferred based on subtly posed experiments, when subjects are questioned on the audibility of one sound in the presence of another masking sound, either tonal or broadband.

Durham University has a collaborative project between their digital signal processing group and the Music Department. Durham Music Technology group is interested in multi-microprocessor architectures for real-time sound synthesis. The 160 T800 transputer network described below is an example of this work. A more recent project involves the construction of a multi-processor T9000 network. Each of the new transputers offers an order of magnitude improvement in performance.

Parallel computer algorithms which can exploit the concurrency of the network are also being developed. In particular the recognition of signals with many harmonics by logarithmic (constant Q) transformations is looking promising. An application of this work has been extended to capture visually the complex interaction of bell sounds during the ringdown process.

Parallel Processing and Music

Since 1988, the research group has reported on issues concerning multi-transputer audio processors [5]. A prototype architecture for a transputer network was described and demonstrated in the International Computer Music Conference 90 [6]. This has been developed into an audio processor, using 160 T800 floating-point transputers interconnected as a ternary tree.

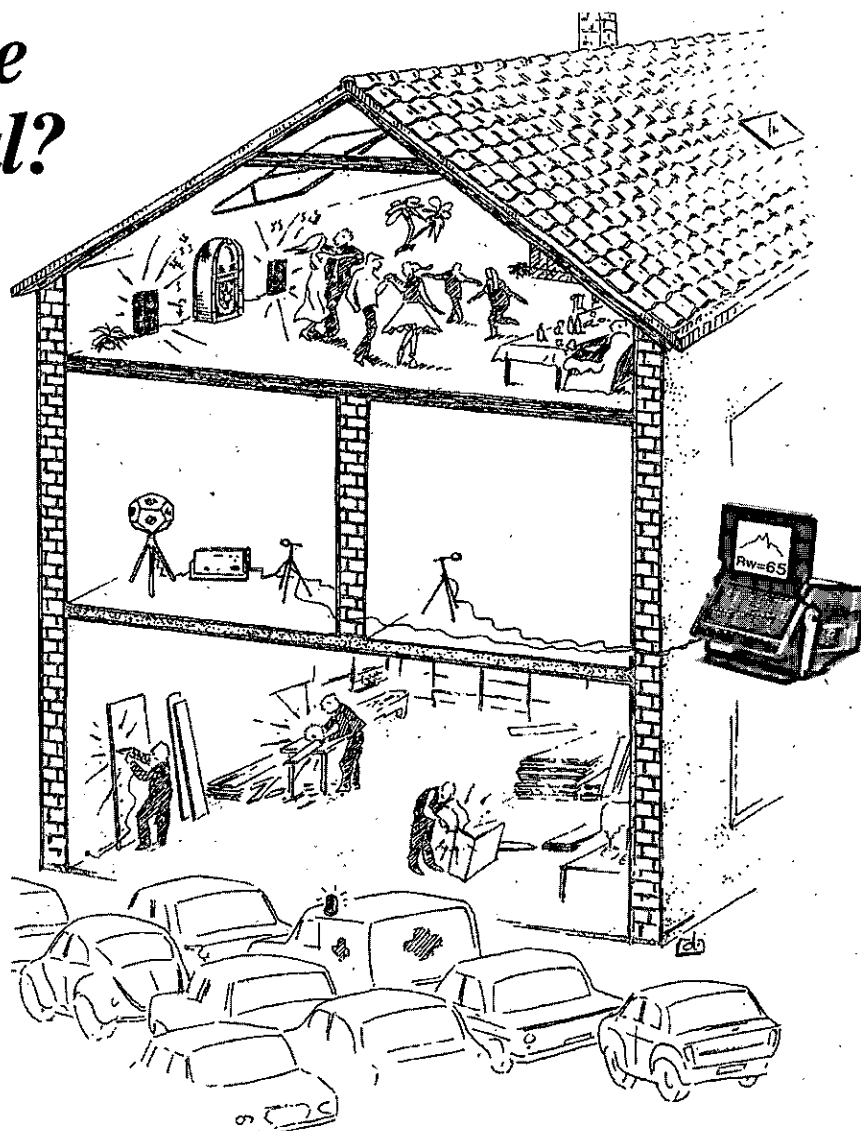
There are 16 transputers fitted onto a printed circuit board, which represents a processing power of 140 MIPS. These transputers are permanently connected, but the software configuration of the network is flexible and reprogrammable. Ten such boards form a network with a maximum processing power of 1.4 GIPS. This network has been used as a test-bed of network architecture for real-time synthesis, combined with a custom-made MIDI-to-transputer interface. Using recursive sine oscillators, an 88-note organ has been implemented in fixed note allocation and a 27-note organ with dynamic note allocation [7].

Another field of current research with many potential applications is in music analysis. A prototype system has been developed for extracting event parameters and timbral information from polyphonic music [8]. In order to satisfy the trade-off between time and frequency resolution, the system relies on a multirate analysis scheme. This is implemented in Parallel C on a Texas Instruments TMS320C40, hosted by a PC. The original data are decomposed into sinusoids, which are then recombined to form the control envelopes required for additive synthesis. The later processing stages are carried out using the PC alone, and this permits detailed graphical display of the data.

This system has immediate applications to the characterisation and automatic transcription of music, and the results so far have been encouraging. The system also offers the possibility of transforming and resynthesising the sound.

One of Durham's objectives is the production of new tools for composers of electroacoustic music. This has involved extensive field-testing and modification of the older research prototypes to ensure smooth operation and an appropriately user-friendly environment for their crea-

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tive use. Activity in this context has concentrated on the implementation of suitable synthesis algorithms on a network of 3 T800 floating-point transputers with full support facilities for studio composition. The most significant tools to have emerged to date in this context are a Parallel-C version of the MIT software synthesis programme CSOUND which incorporates dynamic scheduling routines to distribute the component synthesis tasks across the transputer network and a transputer-based phase vocoder [9].

Computers and Music

There are a number of groups which are interested in the interface between computers and music; aside from Durham, York is also in an important centre. Work in the field of Music Technology at the University of York began in the late 1960's when the Electronic Music Studio was established. The techniques of electroacoustic composition have been taught there every year since, and many now distinguished composers have worked there. Although a degree in recording engineering is not on offer, several well known recording engineers started their careers by studying Music at York. Recording Studio Techniques are taught as one of the modules in both the undergraduate and the postgraduate Music Technology courses.

The Music Technology Group has participated in the Composer's Desktop Project since its earliest days. Indeed, all of the founder members of this organisation were either Music Department graduates, members of staff or otherwise associated with the department. The CDP was founded to make computer music facilities, such as the sound synthesis language, CSound, available to individual composers. By using cheap personal computers, at a time when such facilities were generally only available on large and expensive mainframe computers, the cost was brought within the range of many. The hardware of the early Atari computer based systems was designed by the group and production engineered by the York Electronics Centre. It was also used as the basis for one of the first affordable digital audio editing systems, Audio Design's 'Sound Maestro'.

Technology plays an important role not only in the generation and recording of music, but also in the reproduction of electroacoustic music in concerts. One of the main strengths of the European electroacoustic music tradition has been the level of attention given to the diffusion of sound. Long ago systems using multiple channels and loudspeakers started to replace simple two speaker stereo. The Music Department at York has a particular expertise in a system known as Ambisonics, which is capable of reproducing three dimensional audio images. As well as its application to the diffusion of electroacoustic music, Ambisonics was used to provide sound facilities for the 1992 production of York's famed Mystery Play cycle. This was staged at the Theatre Royal, York, one of the oldest theatres in Britain. Sixteen channels of amplification were used in the 3D sound system, which was installed in addition to a full scale normal stereo PA system.

The Hard of Hearing and Deaf

The purpose of research involving the hearing impaired is to provide those with hearing disability with aspects of music which they are unable to hear. This might be by means of: a computer generated visual picture which is directly related to the music, a vibrational representation of the music by means of a device placed, for example, on the wrist or arm, or customised processing of the music prior to acoustic presentation. In the latter case, it is often of benefit to use a computer to generate the music in the first place which enables complete control over the output sound.

Work for People with Physical Disabilities is addressed towards those who have restrictions in their movements to enable them to arrange or compose music, perform music live, and create recorded performances which incorporate the player's own individual musical expression. A number of switches and other sensors are used which can be activated by hand, foot, mouth or a head wand to enable entry of musical parameters via a computer.

The acoustics of any space can be modelled mathematically and controlled by modifying the materials used to cover the walls, floor and ceiling, as well as the content of the space. Two particular issues under investigation are the problems of achieving good diffusion (spread of sound) and mode control (low frequency boom) in small rooms where physical space is limited. Analysis tools are being developed for modelling rooms, and design methods have been implemented which have resulted in diffusion structures which occupy less space than conventional ones.

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HEALTH EFFECTS OF COMMUNITY NOISE

Birgitta Berglund

Introduction by Nicole Porter MIOA

World Health Organisation Environmental Noise Criteria

Over the last couple of years there has been increasing use in this country of environmental noise criteria based on recommendations from the WHO. This has raised a number of issues and, consequently, the Environmental Noise Group is organising a workshop to be held on Wednesday 25th September 1996 at NESOT to discuss this approach.

The original 'little green document' from WHO is being updated and a final report has been presented to WHO with proposed revisions. To set the scene we are reproducing a paper presented by Professor Birgitta Berglund, who is one of the editors of the latest report, to the 15th ICA in Norway 1995, and describes the key elements of the revisions.

Principles For Assessing Health Effects

Health has been defined by the World Health Organization as 'A state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity' (Yearbook International Organizations, 1968-1969). This is a wide definition that covers noise impacts such as hearing impairment and disturbance of human activities that may result in annoyance reaction. The world community is paying increased attention not only to the environmental hazards now proven to affect the physical health of humans adversely but also to the quality of the environment as humans perceive it [1]. Since noise is usually considered to be unwanted sound, noise effects must always by definition be considered undesirable. Yet, the evaluation of critical impacts of noise is not only a scientific matter but has to conform with normative and societal concerns and decisions with respect to protection of exposed human populations. Since the strength of the association between a particular health effect and one environmental agent, such as community noise, usually is uncertain, in practice other more distinct societal goals such as economical development may easily overshadow the health concerns in environmental planning.

Although the human health effects are assessed with methods developed in physiology, psychology, sociology, epidemiology and economy, noise control is commonly formulated in terms of various limit values expressed in physical measures or indices. Such practice requires appropriate and relatively precise dose-effect relationships that are rare particularly when considering complex environmental applications as well as interindividual differences in reactions to noise. Most noise regulations are specific to the source (aircraft, industrial noise, road traffic, etc.) and subenvironments (residential areas, workplaces, schools, etc.) and it is common that exposure con-

ditions are specifically considered, for example, tonal or impulsive components, low-frequency noise, and time period of the day or night. These considerations have lead to the development diversity of acoustical noise exposure descriptors. Very few of these have been cross-validated for a particular health effect or even for real community noises. Until such confirmation exists, the various acoustical measures and indices should be used primarily for noise assessment (environmental characterization), not for health assessments (prevailing status or forecasted effects). In the present stage of knowledge it may be most appropriate to show health concern instead of using noise exposure assessments as 'proof' of no or negligible adverse effects. Particularly, it should be realized that a complex sound environment is not possible to assess in one single figure, a noise index. It is even more improbable that any of many specific health effects may be predicted from such a noise index. Moreover, since health effects appear due to immissions rather than the distant noise exposures, direct assessment of immissions (environmental characterizations) should be pursued to a larger extent than the presently practiced exposure predictions or calculations from noise source emissions.

The WHO has declared that in health protection the first aim is to protect the sensitive individuals and the second aim is to protect the general population. In the evaluation of noise effects it may be noted that at present, noise abatement is based on scientific data collected from selected or representative samples of general populations; usually adults are studied and sometimes volunteers. Some groups of people have less abilities or possibilities to cope with the impacts of noise. People at risk are, for example, those with particular diseases or medical problems, with hearing deficits, shift workers, infants and young children, the blind, and persons involved in language acquisition or complex cognitive tasks.

Specific Effects

It has been demonstrated that community noise may have a number of direct adverse effects other than hearing damage. These include interference with communication, annoyance responses, and effects on sleep, the cardiovascular and psychophysiological systems, performance and social behaviour. Below follows a presentation of adverse effects recognized in the external review draft of the forthcoming WHO Environmental Health Criteria Document on Community Noise [2]. The specific effects and proposed guideline values were agreed on in consensus among temporary advisors at a WHO Task Force Meeting in Dusseldorf in November 1992 [3].

Interference with Communication Noise tends to interfere with auditory communication in which speech is the most

important signal. Speech perception is of paramount importance in classrooms or conference rooms or where listeners with impaired hearing are involved, for example, in homes for the elderly. To ensure speech comprehension, the signal-to-noise relationship should always exceed zero dB. For a speaker-to-listener distance of about 1 m it is known that: (a) speech spoken in relaxed conversation is 100% intelligible in background noise levels of about 45 dBA and can be understood fairly well in background levels of 55 dBA; (b) speech spoken with slightly more vocal effort can be understood up to noise levels of about 65 dBA.

Speech communication is affected also by the reverberation characteristics of rooms, for example, reverberation times less than 1 s can produce loss in speech discrimination. For adequate speech intelligibility for sensitive groups, reverberation times should be below 0.6 s. For sensitive groups or when listening to complicated messages (at school, listening to foreign languages, telephone conversation), the signal-to-noise ratio should be at least 10 dB. Consequently, for sensitive groups one should strive for a low background level, perhaps 35 dBA when the message level should be at least 45 dBA.

Noise-Induced Hearing Loss Examples of high-level noise exposures of community noise are open air concerts, discotheques, motor sports, shooting ranges, and dwellings in terms of noise from loudspeakers or other leisure activities. Other important sources are music played back in headphones and impulse noise from toys and fireworks. It has also been argued that community noise exposure would be a contributing factor (socioacusis) to hearing deficits with increasing age (presbycusis). Hearing disability may be assessed in terms of difficulty in understanding speech or by audiograms (losses in dB for certain frequencies: 500, 1000, 2000, 3000, 4000 and 6000 Hz). For practical purposes hearing damage is assumed to be associated with the total energy of a particular noise exposure, that is the product of the intensity and duration. From a hearing deficit point of view, noise is described in terms of equivalent continuous sound level, L_{AeqT} , measured in dB. For occupational noise, the level is usually averaged over 8 hours of the day and night or over 40 hrs per week.

Analysis of the available data has provided a statistical basis for predicting the degree of hearing loss likely to be experienced by people exposed to steady noise during an 8-hr working day, for a period up to 40 years. The risk is by most scientists deemed negligible for less than 75 dB $L_{Aeq(8-hr)}$, but some might say below 80 dB. Above the former limit, the risk of noise-induced permanent hearing loss increases with increased sound level, although the risk increment may be difficult to demonstrate in individuals. The threshold value for damaged hearing may be even lower for noise exposure combined with ototoxic drugs, chemicals, vibration, or shiftwork.

Since the equal energy principle may be adopted, the basic criterion of 75 dB $L_{Aeq(8-hr)}$ implies that the risk would also be negligible with a 4-hr exposure to 78 dB,

a 2-hr exposure to 81 dB and a 1-hr exposure to 84 dB. Conversely, additional noise exposure outside the working hours may allow us to formulate a limit of safe exposure of 70 dB $L_{Aeq(24-hr)}$.

It is not yet clear whether or not the damage risk rules can be extended to the very short durations of impulsive noise. Evidence indicates that an increasing risk exists when impulsive sound pressure levels reach 130–150 dB peak. Addition of impulsive noise to steady noise may increase risk for damage in the range of 80–110 dB $L_{Aeq(8-hr)}$ and 100–130 dB peak.

Sleep Disturbance Effects Continuous as well as intermittent noise may produce sleep disturbance. More intense background noise gives more disturbing sleep effects. Physiological sleep effects include changes in pattern of sleep states, especially a reduction in the proportion of REM sleep (REM = rapid eye movement). Subjective effects have also been identified such as difficulties in falling asleep, subjective sleep quality, and adverse aftereffects like headache and tiredness. The sensitive groups include the elderly, shift workers, persons especially vulnerable to physical or mental disorders and other individuals with sleeping difficulties.

If negative effects on sleep should be avoided for continuous noise, the equivalent sound level should not exceed 30 dB indoors. If the noise is not continuous, the maximum level is best correlated to sleep disturbances; effects have been observed at individual exposures of 45 dBA or even less. Especially if the background level is low, noise events exceeding 45 dBA should if possible be limited. For sensitive persons an even lower limit will be preferred. Particularly it should be noted that it should be possible to sleep with a bedroom window slightly open (a reduction from outside to inside of 15 dB).

Cardiovascular and Psychophysiological Effects Many studies have shown that blood pressure is higher in noise-exposed workers and in populations living in noisy areas around airports and on noisy streets than in control populations, whereas other studies indicate no effects. The overall evidence suggests a weak association between long-term noise exposure and blood pressure elevation or hypertension. Other psychophysiological effects, such as gastrointestinal motility, are less clear.

Performance Effects There are few if any detailed studies of effects of noise on human productivity in community situations. Instead, the effect of noise on performance of tasks has been studied in research laboratories or in work situations. Depending on how meaningful the stimulus might be, noise can act as a distracting stimulus. A novel event, such as the start of an unfamiliar noise will cause distraction and interfere with many kinds of tasks. Impulsive noise may produce disruptive effects as a result of startle responses which are known to be resistant to habituation. Consistent after effects of noise on cognitive performance have been established (eg proof reading, persistence on challenging puzzles). Tasks involving motor or monotonous activities are not always degraded by noise but mental activities involving sustained attention to multiple cues are. Some accidents may be an indicator of performance deficits as well.

Persistent exposure to noise during early childhood appears to damage reading acquisition; the longer the exposure, the greater the damage. It seems clear that daycare centers and schools should not be located near major noise sources, such as highways, airports and industrial sites.

Annoyance Responses Noise annoyance may be defined as a feeling of displeasure evoked by noise. Annoyance is evoked by noise which physical characteristics include their intensity, spectral characteristics, and variation of these with time. However, annoyance reactions are sensitive to many nonacoustic factors of psychological, social or economic nature, particularly, there is a considerable difference in individual reactions to the same community noise.

Annoyance has been shown to be affected by the equivalent noise level, the highest noise level of a noise event, the number of such events and the time of the day. Community annoyance varies with activity. The threshold for annoyance for steady continuous noise is around 50 dB L_{Aeq} outdoors. If the noise levels are kept below 55 dB L_{Aeq} , few people will be seriously annoyed during daytime. Noise levels during the evening and night should be 5 to 0 dB lower than during the day. It should also be pointed out that for intermittent noise, it is necessary to consider the maximum level and number of noise events.

Effects on social behaviour For many community noises, the most important activity interference seems to be related to rest, recreation and watching television. There is fairly consistent evidence that noise above 80 dBA causes reduced helping behaviour and loud noise may also increase aggressive behaviour. Particularly, there is concern that high-level continuous noise exposures may contribute to susceptibility to helplessness in school children.

Specific Environments

Specific environments are associated with critical health effects. In dwellings, sleep disturbance, annoyance and speech interference should be considered. For schools the critical effects are speech interference, disturbance of information extraction, message communication and annoyance. In hospitals one should consider sleep disturbance, annoyance and communication interference including warning signals. In concert halls, outdoor concerts and discotheques the sound levels should be adopted that protect for hearing impairment. The same is true for sounds played back in headphones and for impulsive sounds from toys and fireworks. Finally, in certain outdoor areas that are quiet, the quietness should be preserved from noise pollution and measures should be taken to keep the signal-to-noise ratio low.

It should be realized that a noise measure based only on energy summation expressed as the conventional equivalent measure, L_{eq} , is not enough for the characterization of most noise environments. It is equally important to measure and display the maximum values of the noise fluctuations, preferably combined with a measure of the number of noise events. If the noise includes a large pro-

portion of low frequency components still lower values than the recommended guideline values proposed for specific effects will be needed. It should particularly be noted that a large proportion of low frequency components in noise, eg a 20 dB difference in dBC to dBA, may increase considerably the adverse effects.

Specifically, it should be noted that the continuous equivalent sound level may only be applied in isolation if the risk for noise induced hearing loss should be estimated. The L_{eq} may also be applied for sleep disturbance and annoyance but then it should be supplemented with other exposure information such as number of sound events and maximum level of single events. In practice, it is also important to consider the background level. This means that for most environments, that is, dwellings, schools and hospitals, as well as for areas outdoors, the assessment of continuous equivalent sound level is not enough for human health protection. Furthermore, research knowledge is lacking and, therefore, guideline values proposed in L_{eq} should be qualified with an appropriate time base before they are applied in noise protection. As a consequence, the selection of the duration for the averaging is sometimes open and, thus, presents possibilities for societies to apply more safe or more relaxed criteria.

Certain populations are at greater risk from harmful effects of noise. Young children (especially during language acquisition), the blind, shiftworkers, and perhaps in utero/fetal development are examples of such populations who primarily are of concern for noise exposure in residential areas. Since there are no firm and definite conclusions on this topic as yet, the guideline values proposed here are developed for the population at large. This means that in applying the guidelines in health protection, the consequences for potentially more vulnerable groups should be taken into account.

Acknowledgements

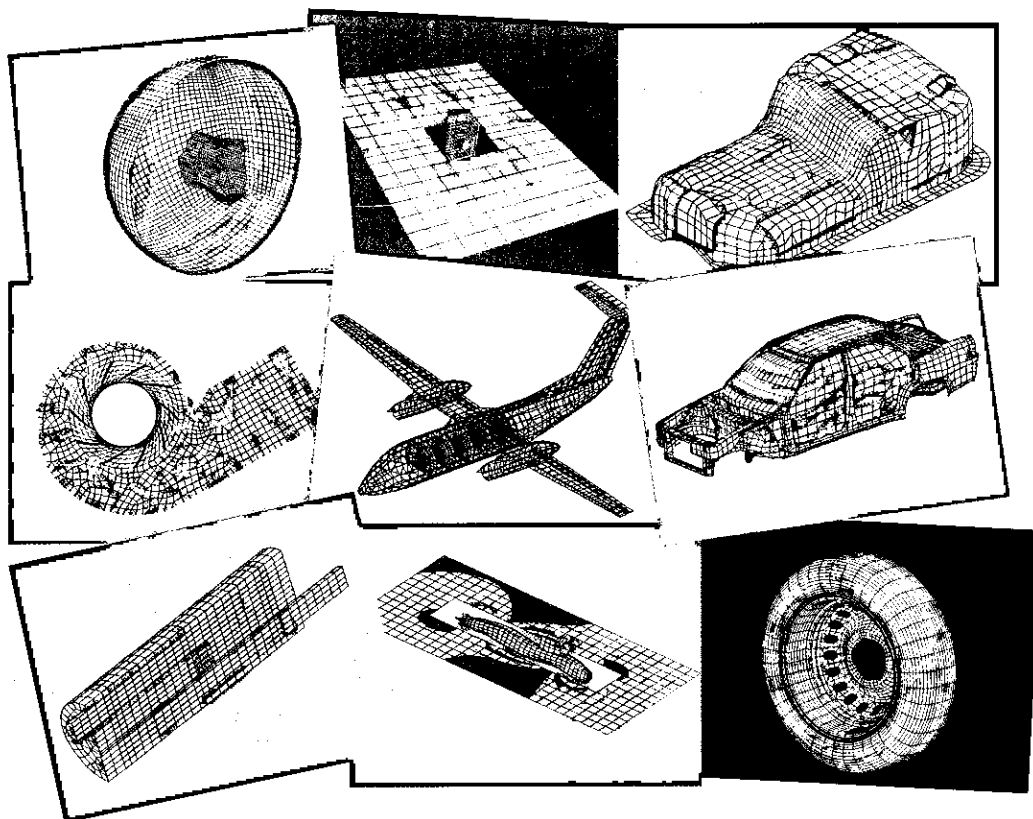
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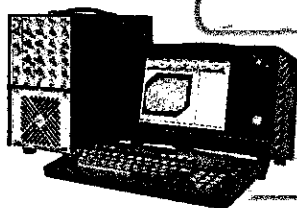
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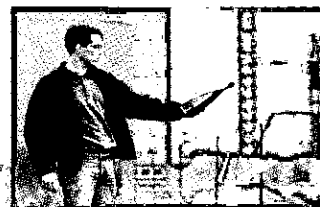
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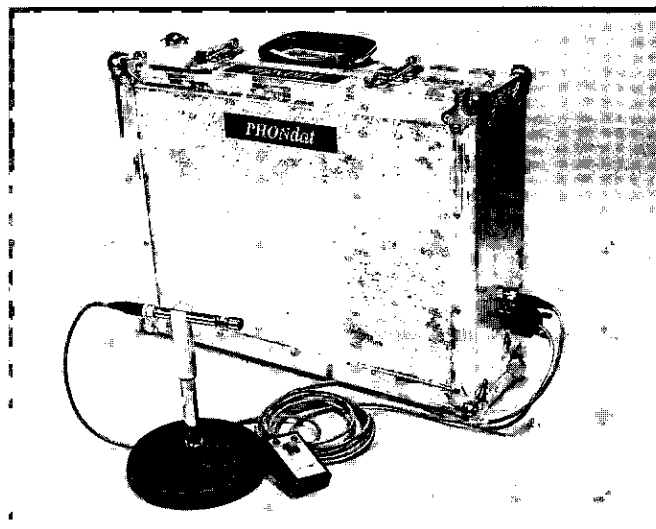
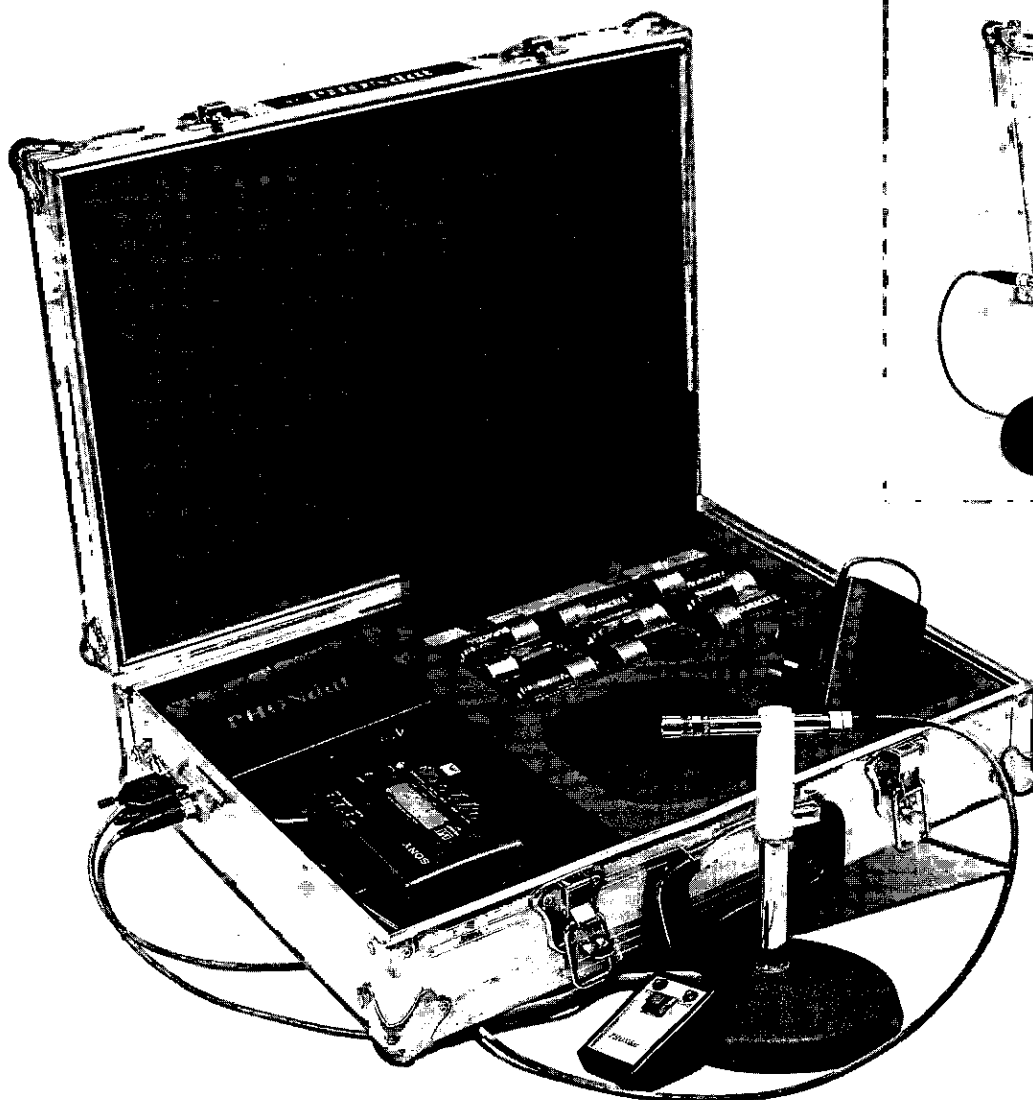
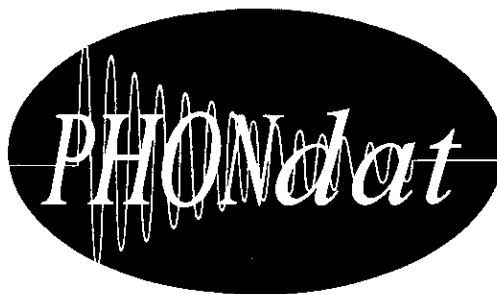
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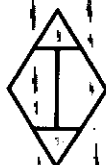
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PRACTICAL APPLICATIONS OF THE MLS TECHNIQUE TO MEASUREMENTS OF SOUND INSULATION

Ian Campbell MIOA & Svein-Arne Nordby

Summary

The theoretical basis of the Maximum Length Sequence (MLS) procedure was described in some detail by Bjor [1] along with the way in which it could be incorporated into a practical measuring instrument. The MLS technique offers a means of considerably improving the signal to noise ratio available in any given measurement location. The objective of this article is to report on the advantages that MLS offers in practical measurement situations.

The quantification of sound insulation of structures presents a number of practical problems, most of which are not apparent until the team arrives on site to commence the work. Being prepared for anything is, therefore, often a prime determinant of the ultimate cost of performing the work. Key information on the dynamic range that is available for the measurement is not readily available prior to commencing work as it is a function of the background noise level at the site, the transmission loss of the partition under test and the performance of the excitation system in the acoustic conditions found on site. The problems are compounded by the fact that the highest background noise levels are usually found in the bands where the generated levels are the lowest! Current electronics offer the ability to automate the measurements and care must be taken to ensure that they do not allow 'error' situations to be accepted into a measurement sequence due to inadequate signal to noise ratios being achieved. Careful planning of these automatic measurements is therefore needed to ensure that acceptable results are obtained.

A series of measurements has been undertaken in typical commercial situations to determine the parameters required to calculate the sound insulation of a party wall. Three series of measurements were made; the first two were performed using the conventional methods of serial and parallel measurements followed by a series using the MLS technique. The results showed that in the determination of reverberation time it was only possible to obtain the RT_{20} using the conventional methods due to the limited excitation levels available whilst MLS yielded both the RT_{20} and RT_{30} . The values for the transmission loss R'_w yielded by the series of measurements became progressively more accurate due to the improving signal to noise figures obtained using the three measurement protocols.

In all cases the time to perform the test varied. The parallel method showed the prospect of being the quickest but needed very careful setting up to avoid errors. Serial testing had the most straight forward set up procedure and produced results within the dynamic range available on the site. MLS will produce a result under almost any measurement conditions with the simple trade off being

between signal to noise requirements and measurement duration. Serial analysis methods had the lowest equipment costs followed by the parallel systems with MLS being the most expensive.

Measurement Locations

With the new ISO series of standards along with their EN counterparts [2] it is now required, in special conditions, to widen the frequency range to measure over the range 50Hz–5kHz. With current loudspeaker systems most would have problems at the lower frequencies due to the limited efficiency and high background noise levels in this range. Similarly at high frequencies the improving attenuation of the partitions results in transmitted levels that are close to the background levels. The traditional cure for these problems has been to increase the power available in the excitation system or to make the measurements at night when the background levels are lower. Both of these solutions bring their own problems and to overcome them the MLS procedure has been proposed. Tests were carried out to determine the sound transmission between a conference room and an adjacent work area. The construction was a twin leaf high transmission loss panel giving a design goal of nearly 60 dB for the R'_w . The background noise level in the receiving room was in the range of 30 to 40 dB across the frequency range. The generated level for the individual frequency bands in the source room was limited to a range of 70–90 dB due to its size and high absorption levels. Tests were carried out using a Norsonic NOR-840 Real Time Analyser, with the MLS and other building acoustics options, and a 100W power amplifier and dodecahedron loudspeaker.

Transmission Loss Measurements

Broad band noise and parallel frequency analysis The results of this approach are shown in Figure 1. The upper trace shows the source room level in channel 1 and the received level in channel 2 with the excitation on. The lower trace superimposes the background onto the levels transmitted from the source room. It is obvious that the received levels are incorrect as they are masked by the background noise. The requirement for a 10 dB difference between the received levels and the background noise is only fulfilled at the lowest frequencies. If these incorrect results had been used in a calculation of the R'_w index a result of 44 dB would have been obtained. These results confirm that broad band pink noise excitation and parallel frequency analysis can only be used in cases of low transmission loss indices or where the background noise levels are low.

Band filtered noise and serial frequency analysis Simply using a filter in the noise generator will increase the levels

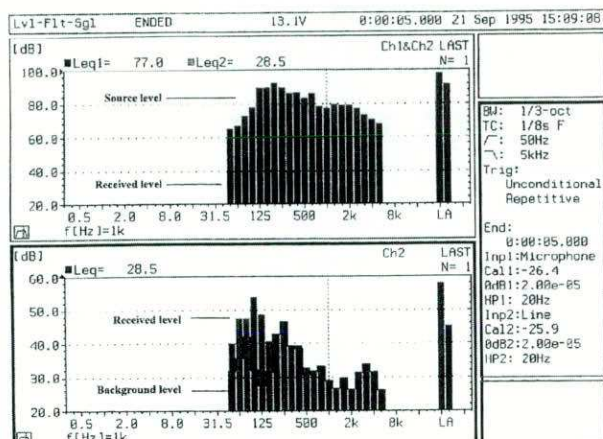


Fig. 1. L_d using Broad Band Noise and Parallel Frequency Analysis

generated in each third octave band by some 12 to 15 dB. Adding synchronous filters to the source and receive room measurement channels, brings about an improvement in the dynamic range to such an extent that the signal to noise requirement is now met for the mid frequency range. The results are shown in Figure 2 which again has the source and received levels in the top window and the received and background levels in the lower view.

Using these results the calculated R'_w would now be 52 dB, but this would still be wrong due to the signal to noise requirement not being met at all frequencies.

Broad band noise and parallel MLS frequency analysis

The results using the MLS technique are presented in Figure 3 and in this case the lower window contains a table that gives the signal to noise ratio in tabular form for both the normal and MLS methods. From this it can be seen that the requirement for a ratio of 10 dB is met over

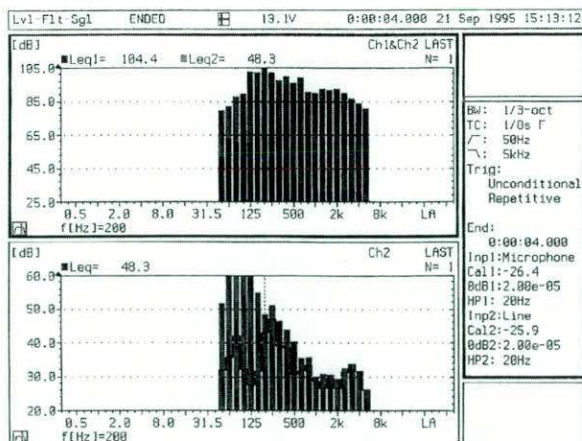


Fig. 2. L_d using Band Filtered Noise and Serial Frequency Analysis.

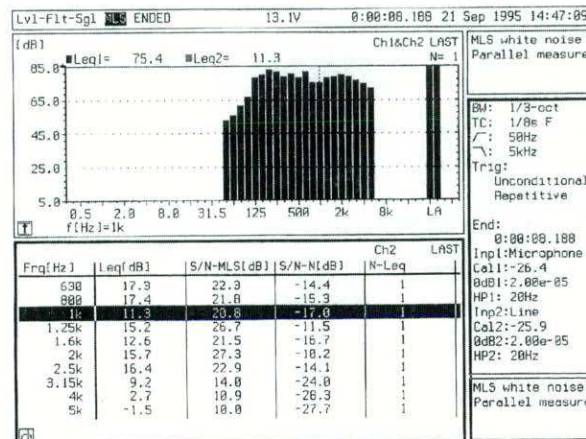


Fig. 3. L_d using broad band noise and parallel MLS frequency analysis

the full frequency range.

To achieve the required confidence figures for frequencies up to 3.15kHz it was necessary to make 58 MLS averages and this required a measurement duration of approximately 8 minutes; to extend to 5kHz a longer measurement would be necessary. The data provided by this measurement allowed an accurate calculation of the R'_w value for the structure, giving a result of 56 dB.

Reverberation Time Measurements

As the receiving room in the previous example did not present a very demanding situation a new location was chosen for this part of the project. The noise excitation equipment was relocated into a room, which due to its size and absorption gave maximum levels in the region of 70 dB with background levels of 40 to 50 dB. Figure 4 shows the detail and it can be seen that the dynamic range available is of the order of 20 to 25 dB.

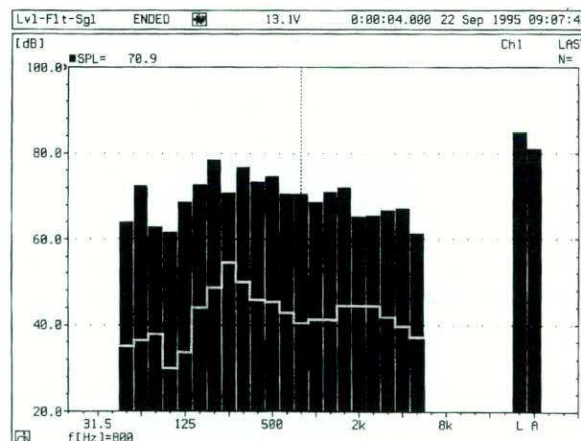


Fig. 4. Dynamic range available for the RT measurements

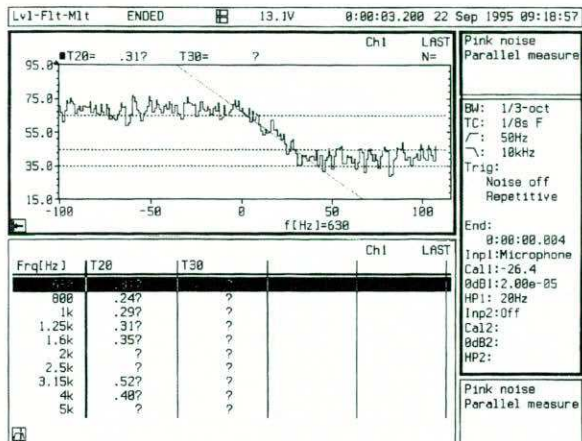


Fig. 5. RT using broad band noise and parallel frequency analysis

Broad band noise and parallel frequency analysis The problem here is the inability to achieve a high enough excitation level in all the bands simultaneously to provide the minimum decay in each. With the requirement for a 5 dB headroom and a 10 dB signal to noise ratio, using this approach it was not even possible to provide an RT_{20} . The situation is detailed in Figure 5. The upper window shows the result for the 630 Hz band where the dynamic range requirements are right on the limit of 35 dB. In the lower window the results are tabulated and it can be seen that the error warning appears against the RT_{20} results and that the RT_{30} values are suppressed.

To progress using this measurement method a significant increase in amplifier power (by a factor of 15) would be needed or the measurement programme delayed until more advantageous background noise levels persisted.

Band filtered noise and serial frequency analysis Whilst

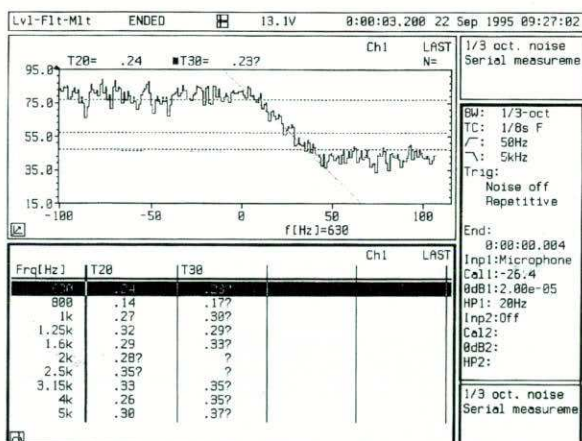


Fig. 6. RT using band filtered noise and serial frequency analysis

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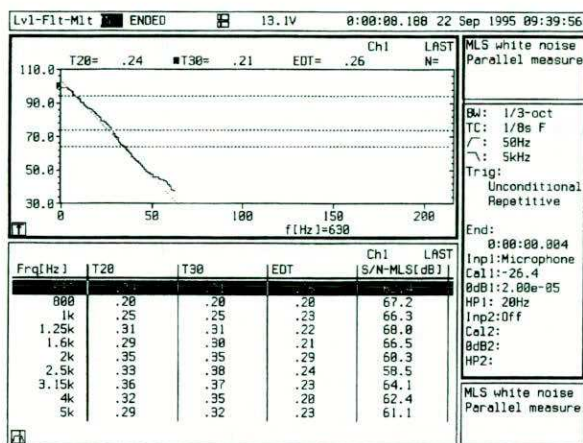


Fig. 7. RT using broad band noise and parallel MLS frequency analysis

the background noise remains at 45 dB the improvement in generated levels, referred to in the section dealing with the transmission loss measurements, provides enough amplifier power to increase the generated levels to around 80 dB. This gives sufficient dynamic range to allow for the calculation of the RT_{20} in most of the bands but there is still a significant uncertainty in respect of the RT_{30} values; the details are in Figure 6.

In this case if RT_{20} can be accepted the values provided by this method would be good enough; however it has to be accepted that even a small increase in the background noise levels would, in this case, invalidate the technique.

Broad band noise and parallel MLS frequency analysis
In order to fulfil the dynamic range requirement of 45 dB for a RT_{30} measurement it was necessary to programme the instrument for 23 MLS averages. This gives a measurement duration of around 3 minutes. In the upper window of Figure 7 the calculated backward integrated decay is shown together with a straight line indicating the

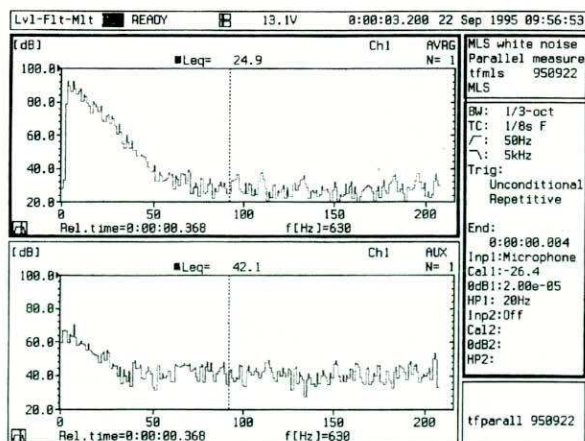


Fig. 8. Improvements in Dynamic Range obtained by using MLS

calculated RT decay for the 630 Hz band. This information is of course available for each frequency band. The table in the lower window shows that the RT_{20} and RT_{30} has been provided along with the EDT for all the bands from the one measurement sequence. This is in spite of the fact that the background noise was just as high as in the previous examples.

The dramatic effect of the MLS mode of making RT measurements can be shown by displaying the results of conventional parallel measurements with those obtained using the MLS technique. The lower curve in Figure 8 shows the conventional results where the generated levels are around 70 dB and the noise floor at 50 dB. Contrast this with a similar measurement configuration that employs MLS, shown in the upper window, and it can be seen that the generated levels have increased to around 90 dB and the noise floor has fallen to approximately 35 dB to give a significant improvement in the dynamic range.

Conclusions

As with all things it is a question of 'horses for courses'. In ideal conditions it is possible to take advantage of the speed that conventional parallel measurements provide. As more typical situations come to be considered then the balance moves in favour of sequential and MLS approaches. It is certainly true that MLS will always provide an answer, even in difficult cases such as the measurement of sound insulation between rooms above a discotheque. It is a question of trading measurement time against the signal to noise requirement; if sufficient time is available it is even possible to obtain a result under noise to signal conditions. In considering the question of measurement time we tend to think in terms of the run time for the measurement. The true time is however from arriving on site to departing again with the required results accurately logged to disc. When viewed this way, getting the equipment to the measurement location and preparing it for use is the largest single element. Add to this the necessary relocation of the microphones then the actual run time of the measurements does not seem so important. The over-riding factor must be the need to come away with the results required accurately logged to disk to avoid losing the investment made in committing to the measurement sequence in the first place. In this area MLS will always ensure a result.

References

- [1] Proc. IOA Vol. 17 Part 5 (1995) p 101-110
- [2] BS EN 20140 Measurement of the Sound Insulation in Buildings and of Building Elements

This article is based on a presentation made at the Institute's one-day meeting entitled Sound Insulation – the Law, the Science and the Practice held at the Building Research Establishment in May 1996.

Ian Campbell MIOA is with Gracey and Associates, Chelveston, Northamptonshire and Svein-Arne Nordby is with Norsonic AS, Tranby, Norway



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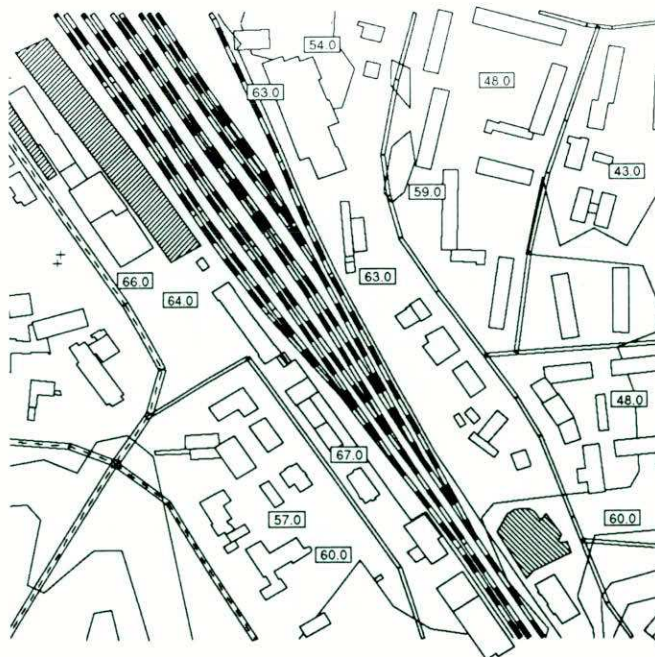
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TOWARDS A STANDARDISED DESCRIPTOR OF THE IMPULSIVE NOISE CAUSED BY LOW-ALTITUDE MILITARY AIRCRAFT

Bernard F Berry FIOA

Introduction

The noise due to a single overflight of a fast jet flying at low-altitude has a rapid onset of noise level at the start of the 'event'. The rate at which the level rises is termed 'onset-rate', and values of the order of 100 dB per second can occur in extreme cases. It is generally considered that such high onset-rates induce a startle effect on listeners which leads to a heightened annoyance response. Studies in the USA on judged annoyance due to recorded and real overflight noise have led to a proposal that a correction or penalty be added to measured levels, the value of the correction being a function of onset-rate [1]. Although no subjective studies have been conducted in the UK, there has been a considerable amount of work at NPL on carefully controlled noise measurements [2], and on prediction modelling [3]. Additional studies on source noise have been conducted at the Defence Research Agency at Pyestock [4]. Each of these three research teams uses a slightly different definition of onset-rate. This article will describe recent work to establish the implications and significance of these different definitions and consider the requirements of a standardised method.

Interest in the topic of onset-rate began in the early 1980s, in the USA, where the need to prepare environmental impact assessments during the design of military operating areas and military training routes was the driving force behind a research programme aimed at an accurate understanding of human response to noise from low-altitude flight operations. It was realised that conventional methods of assessing human annoyance response to noise, such as the method developed by Schultz, which is based on the use of the day-night average sound level L_{dn} [5], were not in themselves adequate to describe a noise environment characterised by infrequent, irregular, sudden, short and loud noise events. A review was made of the available literature to investigate the suitability of correlating L_{dn} with human annoyance for such noise events. This review resulted in the recommendation that L_{dn} could be used provided that, (a) it was based on the busiest month of the year and (b) an onset-rate adjustment was applied to the individual sound exposure

levels (SEL) used in computing L_{dn} . This adjustment was adopted by the USAF as an interim metric in 1990 [6].

Subsequently, laboratory studies using indoor and outdoor listening facilities, in which recordings of military aircraft noise events with onset-rates varying from 1.3 to 152 dB/s (decibels per second) were presented to participants, have resulted in a refined form of the adjustment, where the value varies from 0 dB for onset-rates below 30 dB/s to 11 dB for rates above 150 dB/s [1].

More recently a 'rented-home' experiment has been completed [7]. Here the social setting and presentation of sound stimuli were said to be more normal than in the laboratory experiments. The results of this experiment have confirmed the appropriateness of the onset-rate adjustment. The form of the adjustment is shown in Figure 1 and is almost the same as that found in the laboratory experiment, except that the onset-rate at which the adjustment first becomes non-zero is reduced to 15 dB/s.

The form of the adjustment shown here is to be adopted for official use by the USAF, and is under consideration by ANSI Working Group S12-15 Environmental noise measurement and assessment [8].

Current Definitions of Onset-Rate

USAF Method In the study, published in 1987, which first proposed the interim metric, onset-rate is initially referred to in a footnote (reference 6; page 18) as follows:

'Onset-rate, nominally equal to the average rate of change of level during the onset of the noise event, is

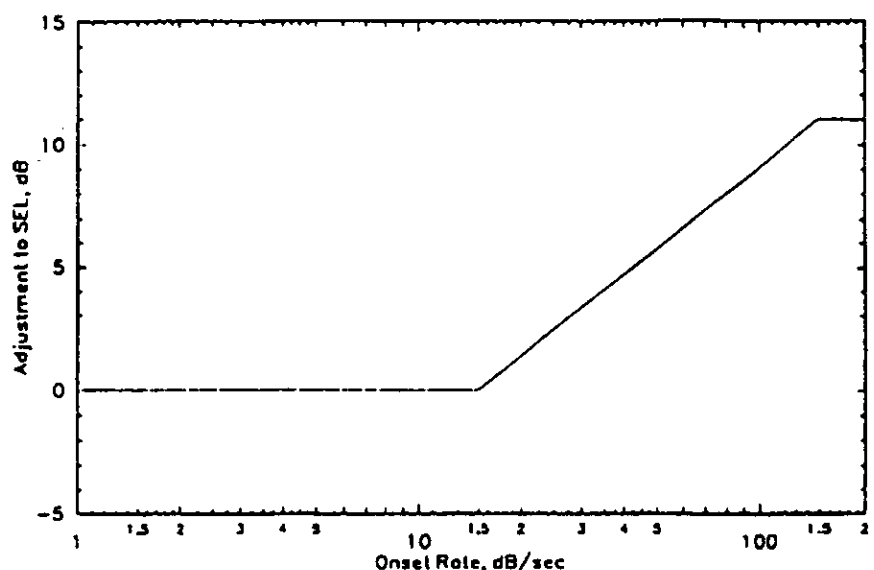
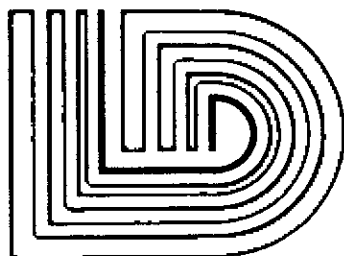


Fig. 1. Onset-rate adjustment from rented home experiment

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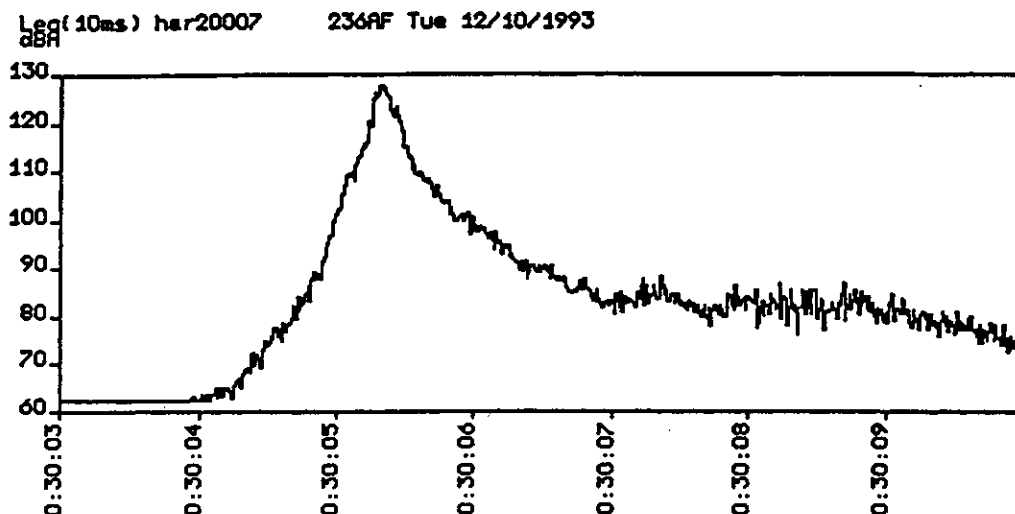


Fig. 2. Time-history of $L_{aeq,10\text{ ms}}$ for Harrier event H at Exercise Luce Belle

defined more precisely at the end of this section.' The definition which follows, on page 23 of the report reads, 'the rate of change in decibels per second, of the A-weighted fast sound level, L_{AF} , of the overflight signal between the time the signal first exceeds the ambient level by 5 dB, and the time the signal first exceeds a level 5 dB below its maximum value.'

Note that no specific method of averaging the rate of change of level was ever defined. In effect an 'eyeball' average is said to have been used. Thus it is not simply a case of calculating a level difference and a time difference and dividing one by the other. It is understood that this straightforward calculation was applied to cases where the rate of change of level was reasonably constant over the onset phase of the noise event, but that where, as is often the case, the onset is at first gradual and then increases, the estimate of onset-rate was made using the portion of the level-time history closer to the maximum level.

The situation is complicated even further by the fact that close examination of the technical reports [1,7] describing the laboratory experiment and the rented home experiment actually make no reference to the above 'definition', but refer to two different methods of determining onset-rates. To quote from the reports:

'The original rates given in Table 2 were obtained by an algorithm employing the highest 20 dB of digitized levels. The digitization analysis system included a fast (0.125 second) detector for all sounds. The rates shown in Table 3 were based on measurements of slopes on a level recorder chart using a wider range than just the highest 20 dB. When determining the slopes the paper speed and writing speed of the level recorder were adjusted so that the measured slopes represented the signal and not the time constant of the detector'. Note that the wider range referred to is unspecified.

This lack of a precise definition, even for the USAF method, leads of course to uncertainties in applying the method, but for completeness, and to illustrate the prob-

lem in the calculations which follow, two values of onset-rate are given,

- one derived directly from calculation of the level and time differences over the range from 5 dB above ambient to 5 dB below the maximum level and,
- one which derives from that part of the level-time history, with a reasonably constant slope, leading up to the point at 5 dB below the maximum level.

NPL Method

The National Physical Laboratory first became involved with this topic in 1990 when, as part of the continuous programme of development of AIRNOISE, a mathematical model for computing military aircraft noise contours, we were asked to extend it to include low-altitude operations. This work resulted in the prediction model FLYBY [3]. To provide data with which to validate and refine the prediction model, a special joint NPL/RAF IHMT trial – Exercise Luce Belle – was conducted in which a number of different aircraft types were flown straight and level at heights between about 100 and 250 feet above ground level, at various speeds and engine power settings. The results of the trial were published in two NPL reports [2]. The method of quantifying onset-rate which arose during the course of this work was simply to measure the rate of change of level, using Fast time-weighting, over the 40 dB leading up to the maximum level.

DRA method

The principal interest of the Noise Research Section at the Defence Research Agency at Pyestock is in the modelling of source noise [4]. In the course of work on the prediction of time-histories of noise from the Tornado aircraft, an attempt was made to follow the general principles of the USAF method, but of course in the predictive case, there was no measured background level as a reference point. It was felt that the 'maximum local rise rate' was the most indicative of the aircraft flight

condition. The method which developed out of this work, and which can be implemented readily on a spreadsheet, can be summarised as follows:

1. Whatever the original integration time used to measure a time-history, a smoothing is applied with a 0.5 second running average to remove irregularities due to atmospheric propagation effects etc.
2. Then a series of effective local rise rates are produced by taking successive differences of adjacent values in the time-history, and dividing by the appropriate time interval.
3. Finally a curve is fitted through the values in the above series in order to indicate the general trend in the rise rate over the noise event. It is suggested that a cubic fit offers the best approach.

Comparison of Methods

In the initial study presented here, the three methods discussed above have been applied to the noise of four particular Harrier overflights. These correspond to events D, G, H and C p.m. in the NPL reports on Exercise Luce Belle [2]. In the limited space of this short article the general problem can be illustrated by considering event H (aircraft height 92 feet, speed 484 knots). A time-history of $L_{Aeq,10ms}$ derived from recordings taken directly underneath the flight track is shown in Figure 2. To approximate to the Fast time-weighting required for the NPL and USAF methods, the above basic time-series of $L_{Aeq,10ms}$ has then been concatenated to the closest integration time to 125 ms which is itself a multiple of 10 ms, ie 130 ms. Figure 3 (a) shows the time history for Event H.

USAF Method

The maximum value is 125.9 dB(A) and the nearest value to 5 dB below this is 122.0 dB. The point at which the level first exceeds the ambient by 5 dB is a level of 69.1 dB(A). This produces a level difference of 52.9 dB(A), over a time period of 910 ms, giving a calculated onset-rate of 58.1 dB/s. It is however clear from the time-history, particularly as shown in Figure 2 where the integration time is 10 ms, that there are two distinct slopes. If we take the portion over the top 40 dB(A), this leads to a value for the onset rate of 71.5 dB/s.

NPL Method

The nearest value to 40 dB below the maximum is 88.7 dB(A). This gives a

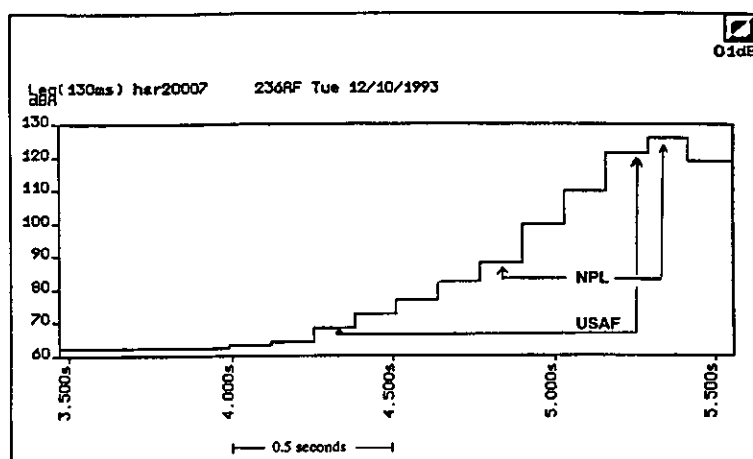
level difference of 37.2 dB and a time difference of 520 ms, leading to a calculated onset-rate of 71.5 dB/s.

DRA Method

Figure 3(b) shows the plot of the level, the local rise rates and the cubic fit. A maximum onset-rate of 65.1 dB/s is indicated.

In this particular case, the application of the USAF method is not straightforward because the time-history of the level shows two distinct phases. The section within about 40 dB of the maximum is different from that nearer the ambient level. If allowance is made for this, and the method is applied as it is believed was originally intended, then there is no difference between the USAF and NPL methods. Examination of the time-series of the local rise rates involved in the DRA method (Figure 3(b)) shows the sharp increase in slope at about half way between the ambient and the maximum level. Because this

3(a) USAF and NPL methods



3(b) DRA method

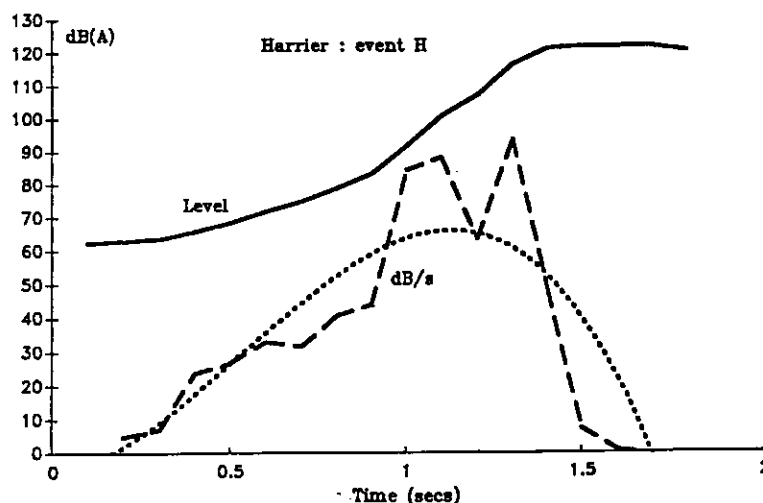


Fig. 3. Onset-rate methods applied to event H

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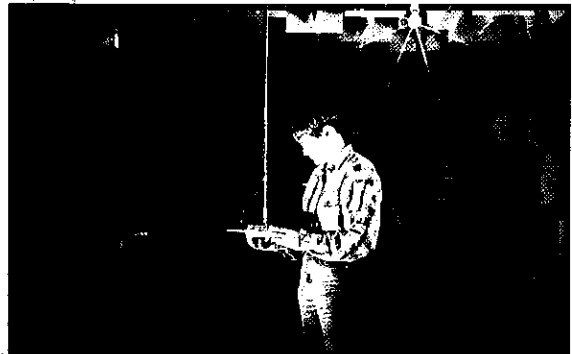
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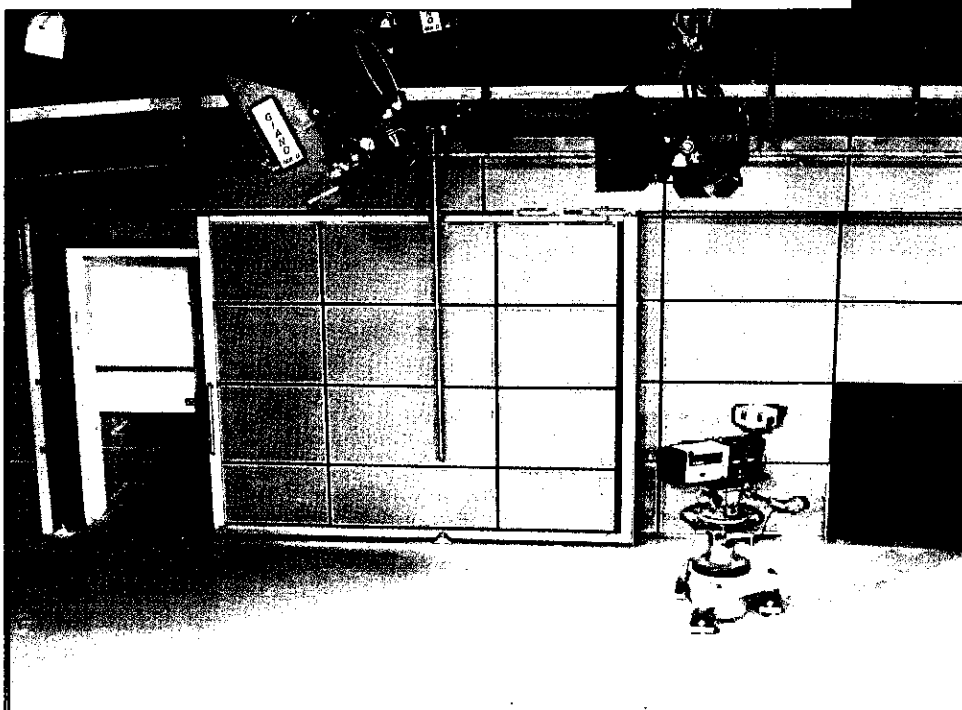
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method in effect takes into account the whole of the onset phase, the resulting value is less than that generated by the NPL method, which emphasises the more rapidly changing section near the maximum value.

The general picture which emerges from this comparison of methods applied to four aircraft overflight noise events with onset-rates, in decibels per second, varying from the high 20's to the high 70's, is that where the onset-rate is at the lower end of this range, and the initial slope is relatively constant, then the results from the application of the USAF method and the NPL method are very similar, and the DRA method gives values which are 3 to 4 dB/s higher. Where the onset-rates are higher, and this is normally associated with noise events which have more complex onsets, with marked changes in slope, then, on the assumption that our interpretation of the way the USAF method would be applied in practice is correct, since both the USAF and NPL methods then concentrate on the top 40 dB of the time-history, they are essentially the same. However, even here there can be large numerical differences in calculated values because of the relatively coarse steps in the time-history. For those noise events with faster, more complex onsets, the DRA method, which takes into account more of the time-history, results in values for onset-rate of the order of 20 dB/s lower than the other methods.

The DRA method has some distinct advantages over the USAF method in that the process of averaging over the noise event is defined in physical terms. It is not certain however that the exact form of the averaging is yet optimised. Should it for instance place more emphasis on the top 30 to 40 dB of the time-history, rather than be influenced by the whole onset phase? Perhaps the optimum method would, like the NPL method, use that part of the time-history nearer the maximum level, but like the DRA method, use the approach of a running average and smoothed differences to establish a value of the slope, rather than a simple division of level-difference by time-difference.

Conclusions

Three physical methods of quantifying onset-rate - the USAF, NPL and DRA methods - have been investigated. Uncertainties can arise over the practical implementation of the USAF method, due to the lack of an objective definition of the process of averaging the rate of change of level.

The application of the methods to four noise events has been examined in detail. In the two examples where onset-rates were in the order of 30 to 40 dB/s, and the initial slope of the time-history was relatively constant, results from the USAF and NPL methods were very similar, whilst the DRA method gave values 3 to 4 dB/s higher. Where the onset-rates are higher, and this is normally associated with noise events which have more complex onsets, with marked changes in slope, since both the USAF and NPL methods then concentrate on the top 40 dB of the time-history, they are essentially the same. However, even here there can be large numerical differences in calculated values because of the relatively coarse

steps in the time-history. For these noise events with faster, more complex onsets, the DRA method, which takes into account more of the time-history, results in values for onset-rate of the order of 20 dB/s lower than the other methods.

The DRA method, although more complex in nature, has some advantages, in that the process of averaging is defined in physical terms. The exact form of the averaging could be further optimised. With the aim of agreeing a standardised method, work is in progress to examine the methods further, using a larger number of examples, and to apply the principles of averaging to the USAF and NPL methods. In collaboration with the USAF Armstrong Laboratory and Wyle Laboratories, this work will include the re-analysis, by the various methods, of military aircraft noise events used to establish the relationship between onset-rate and the adjustment to SEL shown in Figure 1 of this article.

Acknowledgements

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ELECTROMAGNETIC COMPATIBILITY & CE MARKING OF ACOUSTIC INSTRUMENTATION – WHAT DOES IT ALL MEAN?

Richard Tyler FIOA

Introduction

On 1 January 1996, the European Union Directive 89/336/EEC 'on the approximation of the laws of the Member States to electromagnetic compatibility' became compulsory. In practice this means that all electronic equipment manufactured on or after this date must be tested in accordance with the Directive, and if it complies with the Directive, it must be marked with the CE mark before it can be legally offered for sale anywhere within the European Union. Any product not complying cannot be legally offered for sale and can be refused entry to any EU country.

This Directive has caused considerable concern amongst almost all electronic equipment manufacturers wishing to sell in Europe, as it applies irrespective of the manufacturing origin of the product. The word 'approximation' in the original title is well placed, because at the time of writing, many of the Standards relating to Electromagnetic Compatibility are still being prepared, revised, or in many cases have yet to be written.

So what is the position with regard to electroacoustic instrumentation and what does it mean for the supplier and the user?

Electromagnetic Compatibility Requirements

The Directive has many sections, but in general these fall into three categories.

- First, the instrumentation must not emit more than certain permitted levels of electromagnetic radiation, to avoid causing interference to other electronic equipment, often referred to as the Emissions from the instrument.
- Second, the instrument must not alter its performance beyond defined characteristics when in the presence of standardised electromagnetic fields, often referred to as the Immunity of the instrument.
- Third, the instrument must survive, in a defined manner, discharges of static voltages of standardised magnitudes on to any part of the unit.

Many Standards now exist within the International Electrotechnical Commission (IEC), CENELEC and other related bodies, that attempt to define the exact requirements, while many more are still in preparation.

Given that this law is now in force, what does it mean? For most of the equipment normally encountered in the acoustic measurement field, the Standards EN 50081 [1] and EN 50082 [2], both of which are in 2 parts, give the generic, or basic, requirements, whilst the IEC 1000 series [3], which is currently in 56 parts (and still growing) give more specific requirements and tests.

The EN standards are divided into two parts, depending on the expected location of the instrument, which may be either Residential, Commercial and Light Industry, or Industrial. The requirements for the two types of location are similar but significant differences do exist in the severity of the testing.

What Effects Does Electromagnetic Radiation have on Acoustic Instruments & the Outside World?

There is no single answer to this – the effects can be almost anything. Dealing with the emissions first, an often encountered problem is operating equipment such as sound level meters near radio receivers. Old all-analogue meters were fine, but with the modern inclusion of a microprocessor, this has all changed so that many meters will now interfere with the radio. The EMC standards do not actually stop this, but will limit the size of the effect and over what distance it occurs.

Immunity is another matter entirely. Operate the same sound level meter near a source of radio-frequency (RF) emission and what will the readings do? If the meter is not sufficiently well screened internally from these RF sources, at some particular frequency (or frequencies) there is every likelihood that the readings of sound pressure level will change significantly.

The most telling RF source today is rapidly becoming the mobile telephone. Try operating the phone in a steady sound field with the sound level meter just 0.5 m away from the phone's aerial (about the distance of the phone in use while the user is also holding a sound level meter). If the meter is susceptible (ie not immune), readings could easily change ± 10 to 20 dB! Change the sound level meter for a dosimeter with its microphone on a cable around the users body, and these numbers might reach 30 or 40 dB!

These are some of the reasons why Electromagnetic Compatibility was thought to be required and to be a good idea. Later work has shown just how complex a subject it can be. The current situation is outlined in the next three sections.

Emissions

This requirement is probably the best defined at present. Basically, it requires the airborne radiation from the instrument to be measured at a fixed distance and that it shall not be more than a certain field strength. As an example: for equipment containing microprocessors in a Residential environment, the frequency range that must be measured is 30 – 1000 MHz at a distance of 10 m,

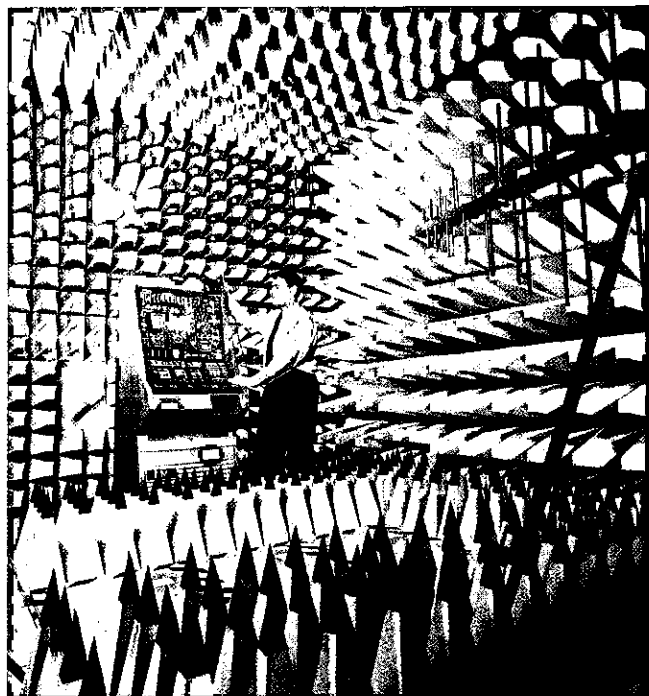


Fig. 1. RF Anechoic Chamber in Use. Photograph by courtesy of ERA Technology Ltd, Leatherhead, Surrey

and the permitted field strengths are 30 dB(μ V/m) up to 230 MHz and 37 dB(μ V/m) at all higher frequencies considered.

If the instrument is powered by a mains supply, then additional tests are performed on the emissions found on the power cable to ensure that interference is not transmitted to the supply, and typically cover the frequency range 0 – 30 MHz with a variety of limits. If the instrument can be fitted with any external cables, or connected to another piece of apparatus that in itself is not CE marked, then the tests must be carried out with all these cables and assemblies connected. In theory a separate test should be made for each configuration, but evidence supporting similarity between systems reduces the amount of testing required.

Testing is carried out in an area known to be free from RF signals and several interesting places have been tried, including caverns in deep underground mines. An RF anechoic chamber is most often used, as shown in Figure 1. A calibrated receiving antenna is placed at a known distance from the equipment under test and all measured signals are checked for field strength. This may mean operating the equipment in a typical sequence of functions to check that no emissions exceed the limits.

Immunity

This subject is undoubtedly the most problematic at present as the generic standards define only the electromagnetic environments into which the instrument is to be placed. They say nothing about what should happen to it, which is supposed to be the province of Product Standards, the vast majority of which do not as yet exist.

There are no product standards in existence for most of the commonly encountered electroacoustical instruments such as sound level meters, calibrators etc, although some are in preparation by a new Working Group within TC29 of the IEC. This was formally established in October 1995 and the author is a member.

In order to satisfy the CE marking criteria today, manufacturers must at present define their own criteria for passing or failing this test, with no legal requirement to divulge these criteria unless specifically asked to do so! It could be argued that unscrupulous sources might define a very simple-to-pass test and qualify for the CE mark on an instrument that perhaps produces huge errors, whilst others struggle to eliminate every effect from their instrument. Only a defined set of tests for a given product will close this loophole.

The type and frequency range of these tests is diverse, and are specified in EN 50082. Broadly speaking, the instrument is subjected to a radiated field of 3 V/m or 10 V/m over the range 80 – 1000 MHz, cabling and power supply cords to frequencies from 0.15 – 80 MHz, with a test for all at 50 Hz. In addition, for mains powered equipment, a variety of voltage surges, dips, fast transients and interruptions must be induced on the supply for the instrument to withstand in some fashion. Although it is by no means easy to ensure immunity to all of these fields, criticism has been levelled at the radiated field strength for being too low.

Testing can be performed either by placing the unit under test in an RF anechoic chamber, or in a special horn-shaped GTEM Cell (Gigahertz Transverse Electromagnetic Cell), see Figure 2. The advantages of a GTEM Cell are its small size and the low power required to radiate the RF field over an instrument. However, the instrument must be small enough for there not to be significant variations in field strength over its volume. Closed circuit TV is often necessary to read displays on instruments inside the cell. Several antennae may be required to radi-

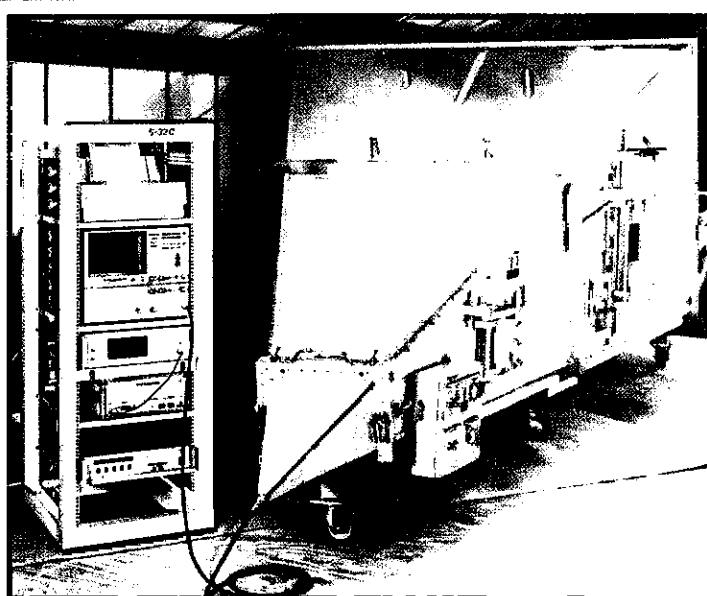


Fig. 2. GTEM Cell. Photograph by courtesy of Electro-Metrics Ltd, Sheffield, Bedfordshire

ate the required energy and give the specified field strength over all frequencies at the instrument position. For acoustic instruments, some acoustic noise is fed into the microphone, often via a plastic duct from outside the cell, and any change in the display level as the test proceeds will be noted. At present, suggested allowable changes are ± 1 dB for Type 1 sound level meters and ± 2 dB for Type 2.

In the USA, the ANSI Committee looking into the same effects has drawn a parallel with their Standard on permissible exposure of humans to electromagnetic fields and suggested that all instruments used by humans should withstand the same levels. In similar terms to EN 50082, this would give field strengths of 63V/m! Very few test sites are able to generate this size of field at present.

Electrostatic Discharge

This test consists of two parts:

- Static discharges are made directly in contact with any exposed surface of the instrument, usually up to ± 4 kVolts.
- Attempts are made to discharge in the air to any point up to ± 8 kVolts.

Three grades of performance are quoted in the generic standards, ranging from no effect at all to stopping the instrument working. After being stopped by such a test, the instrument must be capable of being restored to full working order by means of its own controls without loss or corruption of any stored data.

Unlike the tests for Emissions and Immunity, this test is carried out with no cables connected, so that any sockets are exposed. However, the contact discharge is not expected to be actually pushed into any of the sockets.

Testing is usually performed manually with apparatus capable of discharging the appropriate voltage pulse (see Figure 3). Pulse energy is applied to any exposed part of the instrument while the test engineer observes the effect and reports problems. All instruments are tested over a ground plane, and air discharges will be made to occur as the instrument's design permits.

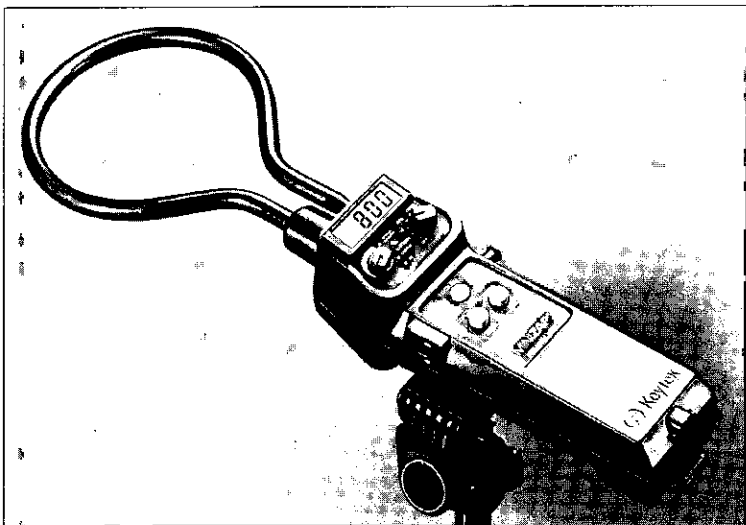


Fig. 3. Electrostatic Discharge Apparatus. Photograph by courtesy of Comtest, Fleet, Hampshire

Acoustic Instrument Product Standards

As stated in the section on Immunity, at present there are no Product Standards for most types of Acoustic Instrumentation. In an attempt to standardise the testing performance limits for most well known product types, Addenda that define acceptable performance are being prepared for each of the Instrument Standards. Unfortunately to date, there has been little time for the Working Group to meet and use available test data to formulate limits that could be deemed reasonable.

Meanwhile, almost every manufacturer in the field appears to have experienced significant problems in defining and passing tests that give correlation with the tolerances of measurement accuracy defined for the instrument type.

As an example: a draft text for Sound Level Meters complying with IEC 651 has been written which proposes that all meters shall be tested in a sound field of 74 dB. When exposed to the electromagnetic field at any RF frequency, the reading on the meter shall be the same as that when no e.m. field is present within ± 1.0 dB for Type 0 & 1 meters, and within ± 2.0 dB for Type 2 & 3 meters. Manufacturers may test to lower levels than 74 dB and claim superior immunity if all readings from 74 dB down to the claimed level are within these tolerances.

It remains to be seen whether this will find general agreement, but is at least a step towards a level playing field on which users will be able to compare the performance of different manufacturers' offerings.

As soon as a Product Standard is published, it takes precedence over any other EMC Standard, so compliance should become uniform soon after publication.

CE Mark Certification of Instruments

There are two basic means of complying with the CE marking requirements. These are usually referred to as the Technical Construction File and the Standards Route often known as Self Certification.

For the first route, the designer and manufacturer must define every parameter of the instrument, specify its construction down to the last item, and then submit the file to an appointed 'Competent Body' for approval that all aspects of EMC are covered. Competent Bodies are established by each Country in the EU as test laboratories with sufficient expertise in EMC that are allowed to certify the Technical Construction File as acceptable. A probability factor is usually included (around 85%) which in practice means that on any random sample of the product leaving a manufacturer's premises, there is an 85% probability that the unit meets the EMC requirements in full. Note that the actual product does not necessarily have to be tested to comply with this method, although test results will often be included to support the claims.

For the Standards route, the manufacturer will compile a file of relevant information on the product identifying which Standards are being claimed, and identify a 'Responsible Person' authorised to make the declaration of conformance with these

Standards. In most cases, this is supported by test results from an approved EMC testing laboratory to show that a sample of the product has been subjected to all tests relevant to the claimed Standards and that the defined tolerances and performance comply with those Standards. Note that the laboratory does not actually certify the product by this route; the certification is made by the manufacturer or his appointed representative.

Failure to comply with the CE marking regulations has a variety of effects, depending on the country in which the offence occurs. If the product is being imported, Customs Officers can refuse entry, while any customer is at liberty to refuse delivery of unmarked products and various local officials may also become involved.

Declarations of Conformity may be challenged by anyone with reasonable grounds for so doing. In the UK, Trading Standards Officers will be responsible for ascertaining whether or not the Declaration of Conformance is valid or not. In most EU countries, a false declaration or evidence showing that the product does not conform can lead to a fine, but in the UK a conviction with a jail sentence up to three months is also possible. A Prohibition of Sale notice may be issued and these may be published Europe-wide.

The costs and time scales for ensuring compliance are not insignificant. Test laboratories in the UK are charging in the region of £750 per day and most products take several days to test in all aspects fully. Test results must be presented for each product in all of the permutations offered to the market-place. On top of this come the manufacturer's paperwork and record keeping aspects, assuming that the product sails through the tests first time. Where the self certification and test method is used (which seems to be the majority route for existing design products) it is not uncommon for several visits to be made to the test laboratory before the products are redesigned to comply completely. This will probably be reduced as design engineers become more familiar with the requirements of EMC and new designs with EMC in mind start to appear.

What does the Mark mean to the User?

At this point in time, it is impossible to give a precise answer to this question. It should mean that all products carrying a CE mark have known limits of emissions so that the risk of interference between two items of electronic equipment may have been reduced, and is certainly at a uniform standard. It should also mean that electrostatic discharges do not cause irreparable harm – which is highly likely to have been the case before these regulations were enforced anyway.

The CE Mark guarantees nothing for the immunity of a product unless there is a Product Standard in force, which it is fervently to be hoped will happen fairly soon for electroacoustic instrumentation. Once implemented, it will ensure that all instruments meet a certain base level of performance, and the evidence is that this will improve the immunity of the instrument in question significantly if the evidence of the recent alterations to designs that have

been made by most manufacturers is significant. It is also likely to have an impact on the cost of producing the item, which may or may not be passed on to the purchaser, but will certainly influence new designs that may carry additional costs to ensure compliance.

It can only be speculated whether this additional immunity is actually needed by the user, as the author is not aware of any significant number of complaints about existing designs, even though many of these are being found wanting in some areas of recent EMC testing.

The manufacturer has no choice but to comply with the legislation by some means while the user has no choice but to take CE marked products. The consequence of all this appears to be that many of the instruments on sale at the end of 1995 had disappeared from the catalogues by January 1996. It has proved expensive or difficult to gain compliance for many designs and products, so that it has not proved worthwhile to get many long established items or products nearing the end of their marketable life certified. This may well result in customer frustration at being unable to re-order a product of which they already have some units and familiarity, but appears unavoidable. (Of course the old non-compliant product can continue in use for as long as it remains serviceable).

Conclusions

It is a little difficult at the present time to get very enthusiastic about the benefits of the CE marking of electroacoustical instrumentation for EMC purposes. Until the Product Standards are introduced and complied with by all manufacturers, there is no easy way for the user to ascertain the advantages of one product offering over another, and it may well be that for the uses to which most instruments are put, the status quo of today is adequate. However, as time progresses, the uniformity of all apparatus to meet the same objectives, and the increasing use of electronics in all aspects of daily life, mean that the improvements that will result in the future will be of benefit to all, and the ability to recognise superior performance will be available.

The clock had to be started somewhere, as older equipment already in use will be around for many years to come. This has now happened, and it will be interesting to see what effects it has on other types of electronic equipment. For the acoustician, the work in hand should ensure a guaranteed standard for the future.

References

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- [2] EN 50082-1:1992 & EN 50082-2:1995. 'European Standard - Electromagnetic compatibility - Generic immunity standard'.
- [3] IEC 1000. 'A series of standards from the International Electrotechnical Commission on all aspects of EMC'. For full listing consult latest Standards Bodies.

Richard Tyler FIOA is Manager of Advanced Engineering at CEL Instruments Ltd, Hitchin, Herts SG5 1RT ❖

HIGH-SIDED VEHICLES AND ROAD TRAFFIC NOISE BARRIERS

David C Hothersall FIOA & S A Tomlinson

Introduction

Many countries have well developed methods of predicting the noise from road traffic for use in road design and planning, and for assessments for compensation. The effects of noise barriers are usually calculated by a path difference approach [1]. The path difference between the direct ray from source to receiver and the ray via the top of the barrier is maximised by placing the barrier as close to either source or receiver as is practicable. This is expected to give the greatest efficiency of attenuation for a barrier of given height. As a result of this consideration and also because of the increasing use of noise barriers in urban situations where site restrictions can occur, noise barriers are often situated very close to the edge of the road. However in these conditions the effect of multiple scattering between the barrier and the vehicle can cause a degradation of performance. The effect has been discussed by several authors (eg [2]) but detailed quantitative information is scarce. In this article results are reported for the modelling of these conditions using a boundary integral equation method. The effects of the proximity and the height of the vehicle on the performance of a plane wall barrier are reported. The use of absorbing screens to overcome the problem is considered.

Numerical Model

The system modelled is shown in Figure 1. The vehicle is represented as a rectangle with the source offset by 0.3 m horizontally from a bottom corner. This is a two-dimensional model which in three dimensions is equivalent to an infinite coherent line source and an infinitely long barrier and vehicle parallel to the source and of uniform cross-section and surface covering along their length. A reformulation of the Helmholtz equation as an integral equation in which the integral is taken over the surfaces of the barrier and vehicle is solved by a bound-

dary element approach [3]. Virtually any shape and distribution of surface acoustic properties over the section can be considered. The Insertion Loss is calculated, defined by

$$IL = 20 \log_{10} (P_g / P_b) \text{ dB},$$

where P_g is the acoustic pressure at the receiver when source, vehicle and ground are present and P_b is the pressure for the same conditions with the barrier included. All absorbent surfaces in the model are assumed to be locally reacting and are specified according to the equations of Delany and Bazley [4]. The flat ground on the side of the barrier away from the road is assumed to be grassland, having a flow resistivity of 200,000 Nsm⁻⁴ and a layer depth of 0.1 m. Where the use of absorbing material is specified on a barrier it has a flow resistivity of 20,000 Nsm⁻⁴ and a layer depth of 0.1 m. This results in a surface impedance similar to that of a layer of mineral wool or a similar strong absorber. The implementation of the model assumes that the barrier cross-section is polygonal and the corners of the barrier and surface treatment of each part are input as data for the model. The standard barrier used throughout the investigation is 0.2 m in width and 2 m in height.

The pressure is calculated at third-octave centre frequencies between 63 Hz and 3.15 kHz for nine receiver positions at heights of 0, 1.5 and 3 m above the ground and at distances of 20, 50, and 100 m from the centre line of the barrier. The Insertion Loss for a broad-band noise source with a spectrum representative of A-weighted road traffic noise [5] is obtained at each of the receiver positions by combining the calculated results at third-octave centre frequencies for propagation with and without the presence of the barrier. The arithmetic mean of the Insertion Loss values over the six receiver positions above the ground can be considered as a measure of the efficiency of the barrier system and this figure is defined as the Mean Insertion Loss.

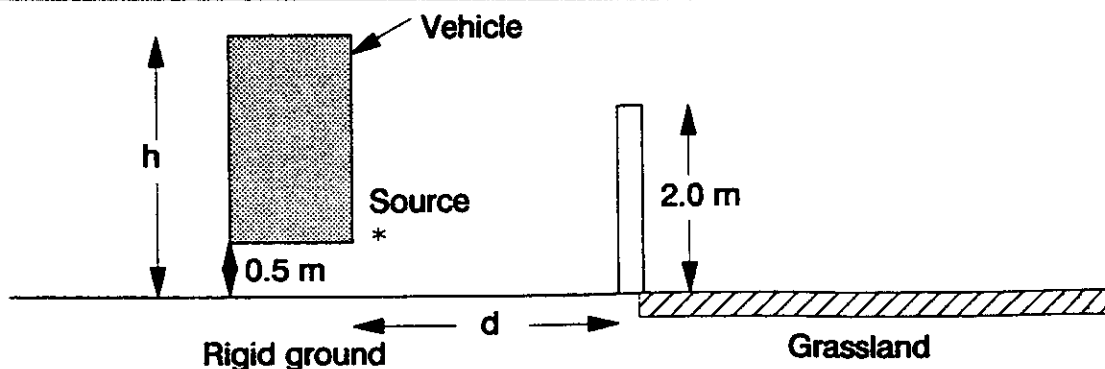


Fig. 1. Configuration of the two-dimensional model

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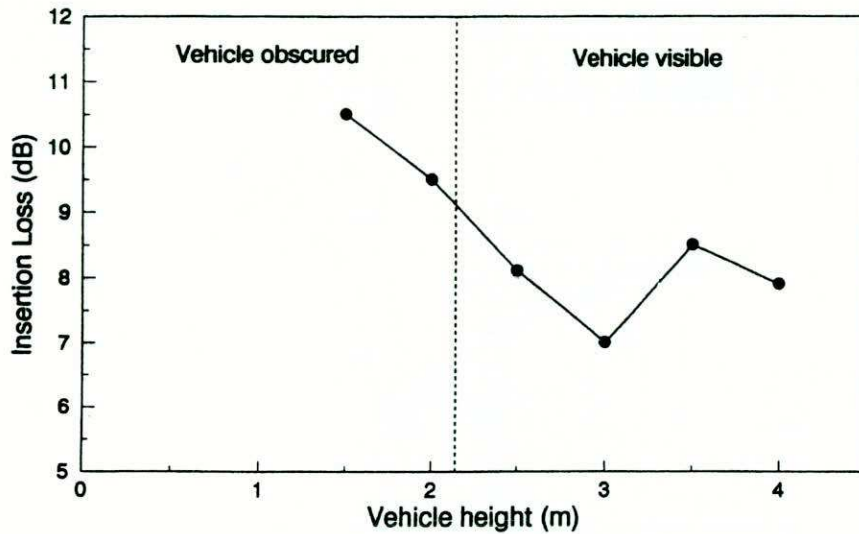


Fig. 2. Broad band insertion loss at 20 m behind the barrier and 1.5 m above the ground

Results

The broad band Insertion Loss calculated at a receiver position 20 m behind the barrier and 1.5 m above ground is plotted in Figure 2 as a function of the height of the vehicle, h . The barrier has rigid surfaces. The distance from the barrier to the side of the vehicle, d was 5.5 m. From this receiver position the vehicle becomes visible over the barrier at a height of 2.2 m. A continuous reduction in Insertion Loss is observed as the height increases from 1.5 to 2.5 m. Above this height the Insertion loss remains approximately constant.

Figure 3 shows the Mean Insertion Loss over six receiver positions plotted as a function of vehicle height. The solid line is for a barrier with rigid surfaces. When $h = 0.5$ m the result is for the source without the presence of the vehicle. As the height is increased the Mean Insertion

Loss reduces. The result for $h = 1.5$ m is representative of a stream of automobiles. The vehicle becomes visible at the various receiver positions at heights of between approximately 1.7 and 2.2 m. A serious degradation of performance of the screen of about 5 dB is observed at the greater vehicle heights.

Maintaining the vehicle height at 4.0 m and changing the distance from the barrier produced little change in the Mean Insertion Loss. For $d = 2, 5.5, 18.5$ and 22.0 m the Mean Insertion Losses were 4.6, 4.6, 4.2 and 4.0 dB. These small changes may be a result of the geometrical accuracy of the model. In practice the finite length of the vehicles and the departure of the vehicles and barrier from being exactly parallel may reduce the predicted deterioration in performance at the greater distances.

Figure 4 shows spectra of Insertion Loss for a specific

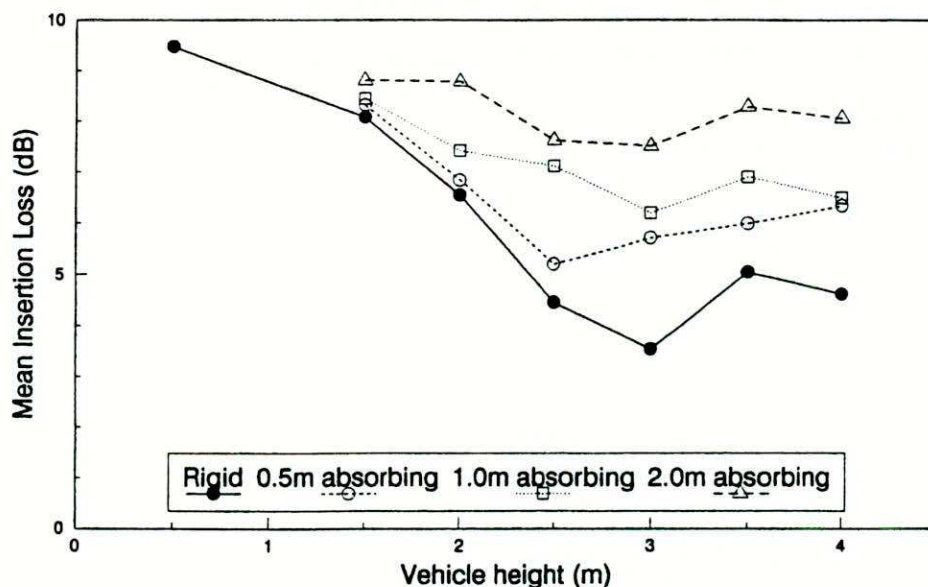


Fig. 3. Mean insertion loss for various surface treatments of the road facing side of the barrier

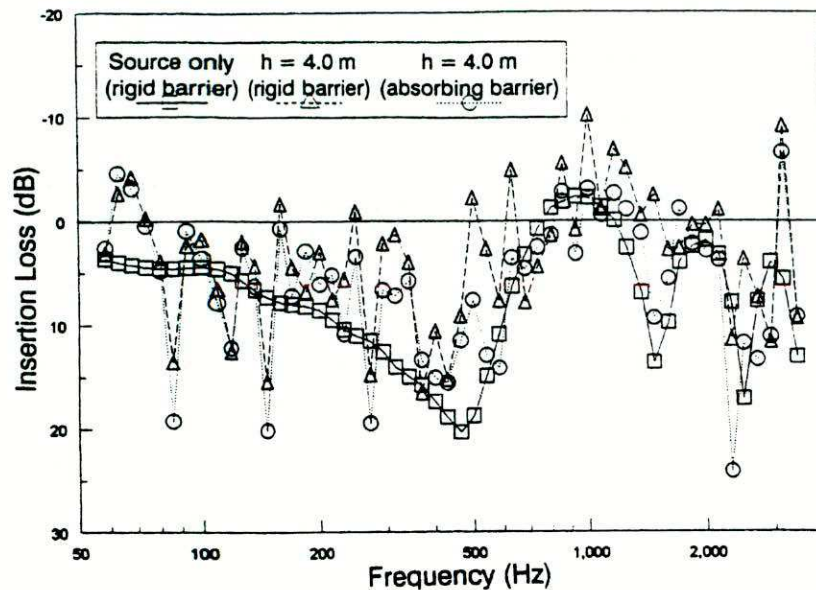


Fig. 4. Insertion loss spectra for various combinations of vehicle and barrier

receiver position. This is 50 m behind the rigid barrier and in the ground surface. The solid line is for the source at 5.2 m from the barrier without the presence of the vehicle body. The dips are associated with interference between the direct and ground reflected rays on the source and receiver sides of the barrier. The dashed line is for the same conditions but with a 4.0 m high vehicle present. The oscillations in the spectrum are due to multiple reflections between the vehicle side and the barrier. The dotted line shows the result when the traffic facing side of the barrier is absorbing. At higher frequencies the peaks of the oscillations are substantially reduced.

Conclusion

The two-dimensional formulation of the model means that the results translate into three-dimensions as an infinite coherent line source with the barrier and the vehicle side extending for an infinite distance along the road. In terms of the vehicle this is not realistic and the results probably represent a worst case condition. The model is more realistic for the case of railway trains with a barrier near the track and the results could be related to these conditions.

For the configurations considered, multiple reflections significantly degrade the performance of a barrier, particularly when the vehicle is higher than the barrier. The reduction in efficiency did not appear to be sensitive to the separation of the vehicle and barrier up to 22 m. Use of an absorbing surface on the source side of the barrier restores the attenuation and provided that the source is in the position used in the model (ie well below the upper edge of the barrier) the performance can be almost completely restored even when the vehicle side projects above the barrier. A progressive improvement is observed with an increase in area of the absorber. The model assumes a still, homogeneous atmosphere and it is possible that atmospheric effects, such as scattering due to air turbulence could be significant in site conditions.

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This article is based upon a paper originally presented at Inter-Noise 95, Newport Beach, CA, USA, July 1995.

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FINITE ELEMENT MODELLING OF DISSIPATIVE SILENCERS

Keith S Peat MIOA & K L Rathi

Introduction

This article presents results obtained from a finite element formulation for the acoustic analysis of a general dissipative silencer chamber [1]. The situation under consideration is the case of a uniform flow duct which is surrounded by a volume of arbitrary shape, which may be filled with anisotropic absorbent material of non-uniform density. Previous finite element formulations [2-5] of the analysis of dissipative silencers have been extended to include the effects of mean flow within both the central flow duct and the surrounding absorptive material. It has been shown in the past that the steady flow in the central flow duct induces a small, but acoustically significant, mean flow in the absorbent material [6-7]. The finite element formulation begins with the nonlinear analysis of the induced steady flow field in the absorbent region and is followed by the coupled analysis of the convected acoustic wave motion in the flow duct and dissipative regions, the latter also being nonlinear. The coupling occurs through implementation of conditions of continuity of particle displacement and pressure on the common boundary of the two regions.

Results are presented which illustrate the effect of the induced steady flow upon the effectiveness of a silencer and the benefits obtained from detailed modelling of the induced velocity field. Earlier results of this nature [8] were obtained on the basis of simplified linear modelling

of the steady flow. The model is used to investigate the effects of nonhomogeneous packing of the absorbent material, bearing in mind that any nonhomogeneity affects the induced velocity field in the absorbent as well as the direct acoustic properties. Indeed any induced flow is sufficient to make the acoustic properties of the absorbent anisotropic, even if the material itself is isotropic.

The equations and finite element formulations are for the most general case of arbitrary three-dimensional geometry and non-homogeneous, anisotropic absorbent material. Results are given for axisymmetric absorption silencers packed with non-homogeneous, isotropic material. Modelling of flow-induced acoustic inhomogeneity and anisotropy is included in these results.

Analysis

The analysis considers convected acoustic wave motion through a duct and a surrounding silencer volume which is packed with porous material, see Figure 1. The duct, region R_1 , is taken to be of arbitrary but constant cross-section and to have its axis in the x_1 -direction of an orthogonal coordinate system $x \equiv (x_1, x_2, x_3)$. The steady convective flow is assumed to have uniform axial velocity U within the duct and to be of low Mach number M , such that the steady flow may be regarded as incompressible. The absorption silencer, region R_2 , is a volume of arbitrary shape which is packed with porous material which may be inhomogeneous and anisotropic. The axial pres-

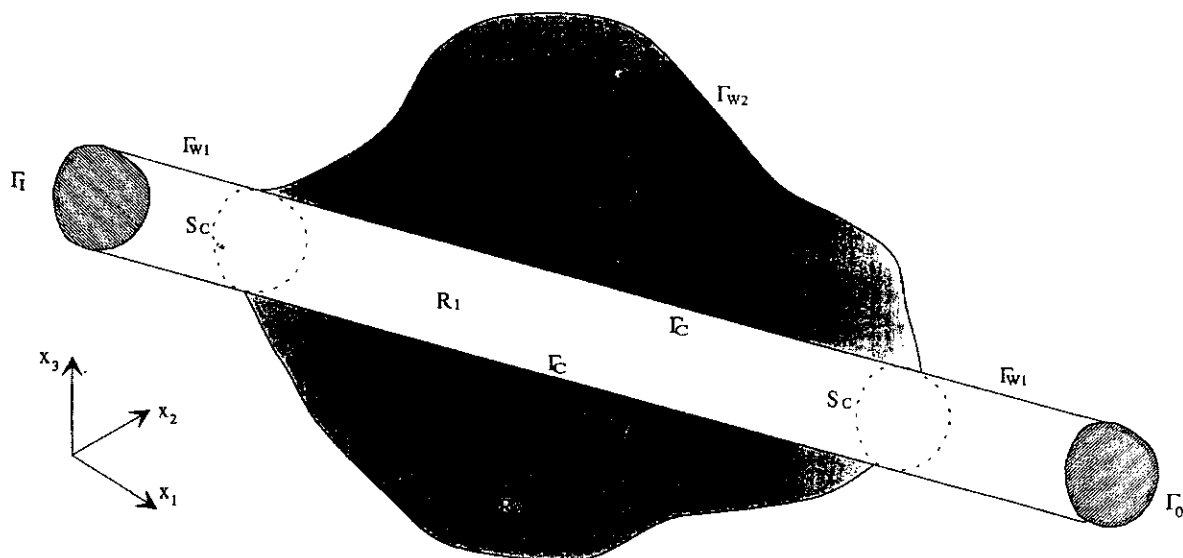


Fig. 1. General silencer geometry

sure gradient of the steady flow in the duct induces a steady flow field within the porous material of region R_2 which can have significant acoustic effect [6,7]. The magnitude of the velocities of the induced flow are very small, typically $O[10^{-3} U]$, such that the cross-flow between regions R_1 and R_2 does not seriously compromise the assumption of uniform flow in region R_1 .

The outer walls of regions R_1 and R_2 are assumed to be rigid and impervious, hence of infinite impedance, and are denoted by Γ_{W1} and Γ_{W2} respectively, or collectively by $\Gamma_W (= \Gamma_{W1} + \Gamma_{W2})$. The duct is taken to extend sufficiently far upstream and downstream of the silencer volume such that plane-wave conditions may be implemented on the inflow and outflow boundaries of region R_1 , which are denoted by Γ_1 and Γ_0 respectively. The frequency of analysis is thus restricted to be below the cut-on frequency of higher-order modes in the central duct. Regions R_1 and R_2 share a common boundary Γ_c within the silencer volume. In many practical situations a perforated screen separates these two regions, the purposes of which are to keep the porous material in place and to guide the mean flow, in order to keep the back-pressure to a minimum. Generally the porosity of such a screen is so large that its acoustic effect is negligible and its effect is ignored in the following analysis.

Acoustic equation in the low duct For harmonic time variation $e^{i\omega t}$ the linearised acoustic wave equation with uniform mean flow convection of Mach number M in the

x_1 direction can be written as

$$\nabla^2 p'_1 + \left(k - iM \frac{\partial}{\partial x_1} \right)^2 p'_1 = 0 \quad (1)$$

where

p'_1 is the acoustic pressure in region R_1 and $k = \omega/c_0$ is the wavenumber.

Steady flow equations in the absorbent region The steady flow through the anisotropic porous material in region R_2 is governed by the Ergun or Forcheimer equation

$$\nabla \bar{p}_2 = -[S] \bar{q}_2 \quad (2)$$

where $\bar{p}_2$ and $\bar{q}_2$ are the steady-flow pressure and velocity in region R_2 . $[S]$ is a diagonal matrix whose j th element is $(\sigma_{vj} + \sigma_{ij} \bar{q}_{2j})$ where σ_{vj} , σ_{ij} are the viscous and inertial flow resistive coefficients respectively, in direction x_j . These coefficients can be determined experimentally from steady flow tests of a given material [6]. The continuity equation together with equation (2) implies

$$\nabla \cdot [S]^{-1} \nabla \bar{p}_2 = 0 \quad (3)$$

Since the elements of $[S]$ are dependent upon $|\bar{q}_2|$, equations (2) and (3) must be solved iteratively [1] subject to the following boundary conditions: the normal component of velocity and hence pressure gradient is zero on



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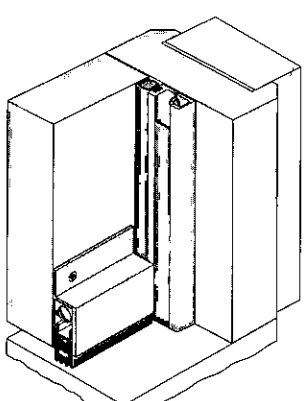
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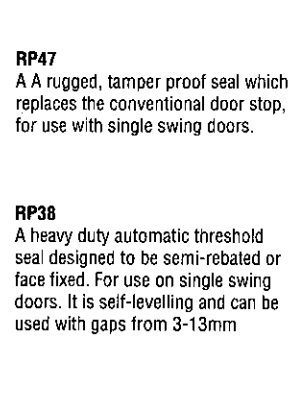
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A call for papers will be issued in summer 1996; the deadline for submission of abstracts will be 1 December 1996.

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CALL FOR PAPERS

International Conference

NUMERICAL/ANALYTICAL METHODS FOR FLUID-STRUCTURE INTERACTION PROBLEMS

(Organised by the Underwater Acoustics Group)

Strelley Hall, PAFEC Limited, Nottingham, UK

16-18 December 1996

Computer based analytical methods have been covered at many Institute of Acoustics conferences, primarily for frequency domain applications. The current meeting aims to extend the scope of the discussion by covering both time domain as well as frequency based phenomena. Applications will include transducer design, signature reduction and vulnerability studies as well as entrained fluid problems such as test tank design or inkjet printing. It is intended that both linear and non-linear aspects be covered for fluid and structural responses. Techniques discussed may include finite elements, boundary elements, finite difference, statistical energy analysis and transmission line modelling.

- Radiation
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Prospective authors are invited to submit a 200 word abstract as soon as possible. Successful authors will be notified by early September. Complete manuscripts may be up to 10 pages long including diagrams and must be in the hands of the conference organiser by 1 November 1996. The conference proceedings will be published in Volume 18 of the Proceedings of the Institute of Acoustics and copies will be available at the start of the conference.

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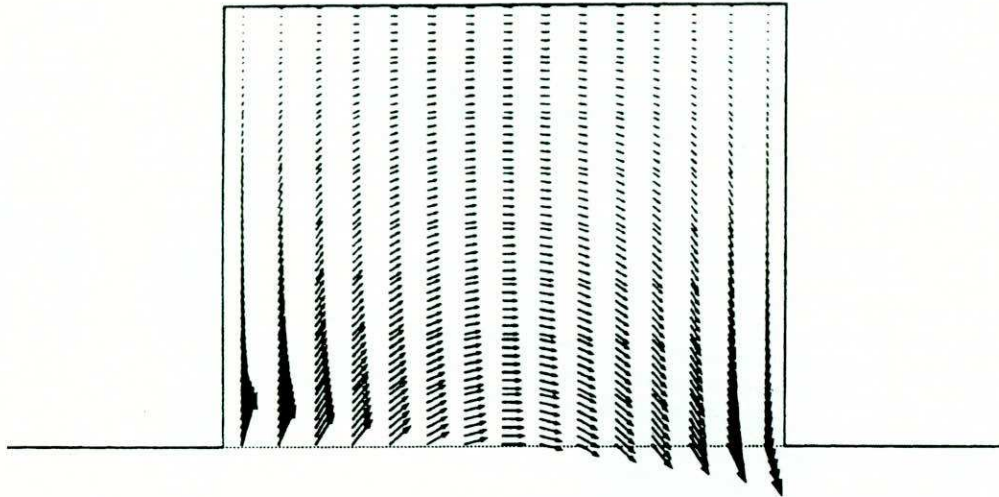


Fig 2. Steady flow velocity field in the absorbent

the hard-wall boundary of region R_2 , namely Γ_{w2} ; the axial steady flow pressure gradient $\partial \bar{p}_2 / \partial x_1$ on the common boundary Γ_c is the same as the axial pressure gradient throughout region R_1 , $\partial \bar{p}_1 / \partial x_1$ and is assumed to be known from experiment.

Acoustic equations in the absorbent region The linearised equations of continuity and momentum in the porous material of region R_2 , for harmonic time variation $e^{i\omega t}$, combine to give the wave equation in the porous material

$$\rho_0 \omega^2 \Omega X p'_2 + \nabla \cdot [R] \nabla \bar{p}_2 = 0 \quad (4)$$

where $\bar{p}_2$ is the acoustic pressure in region R_2 , Ω is the volume porosity and X is the compressibility, which is frequency-dependent and complex. $[R]$ is a diagonal matrix whose j th element is ρ_0 / ρ_{aj} where ρ_{aj} is the effective, complex, mean fluid density in the pores of the material for motion in direction j , namely

$$\rho_{aj} = (\rho_0 m_j / \Omega) (1 - i \Omega \sigma_j / \omega \rho_0 m_j) \quad (5)$$

where, m_j is the structure factor and s_j is the flow resistivity. The flow resistivity and hence effective density are dependent upon the steady flow through the porous material. The flow resistivity can be written as (6)

$$\sigma_j = \sigma_{0j} + \sigma_{ij} \left[|\bar{q}_2| + (\bar{q}_2 \cdot \bar{q}_2) \bar{q}_{2j} / \bar{q}_{2j} \right] \quad (6)$$

where $\sigma_{0j}(\omega)$ is the complex acoustic flow resistivity in direction j , and as $\omega \rightarrow 0$, $\sigma_{0j}(\omega) \rightarrow \sigma_{vj}$. It is seen, from equation (6), that the acoustic properties depend upon the acoustic velocity field in addition to the steady flow velocity field and hence the acoustic problem is non-linear. A rapidly convergent iterative scheme for this problem has been found [1].

Delaney and Bazley [9] formulae have been used to represent the zero flow characteristic specific impedance

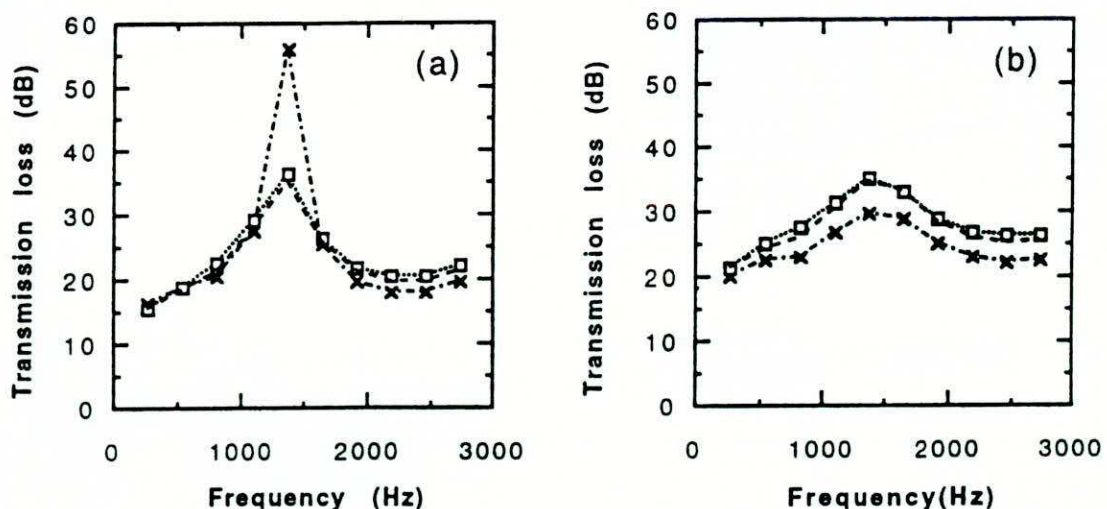


Fig. 3. Effect of induced flow in the absorbent. (a) $M = 0$. (b) $M = 0.196$ Without induced flow — x — With induced flow --- With uniform axial induced flow ...□...

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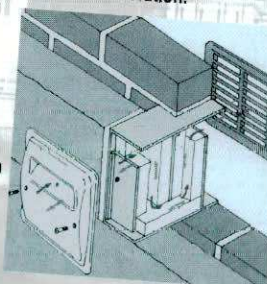
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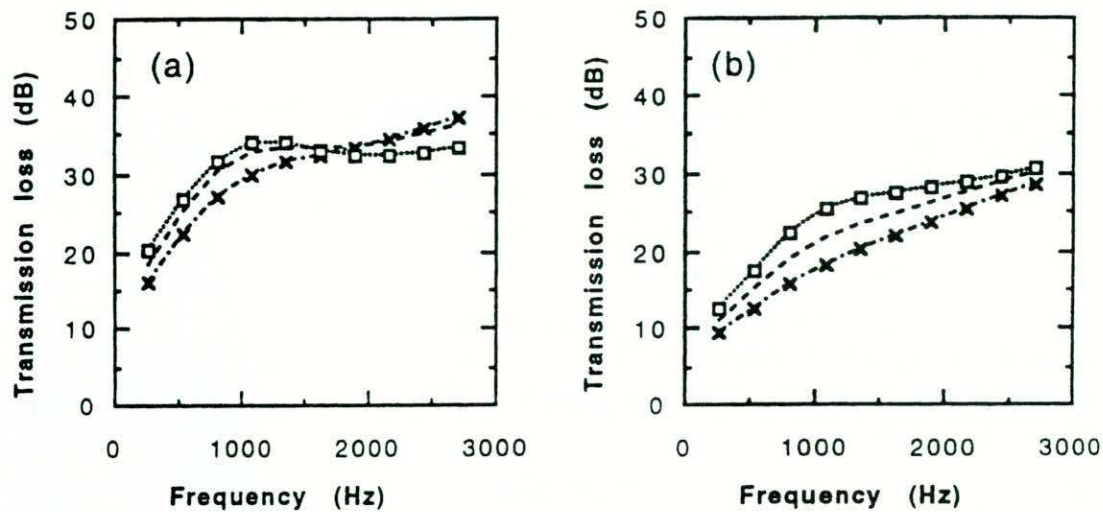


Fig. 4. Effect of radial variation of the density of basalt wool (a) $M = 0$ (b) $M = 0.196$. Density decreasing with radius - x - Uniform density - - - - Density increasing with radius ..□...

z_{0j} and propagation coefficient γ_{0j} of a given absorbent material and then the general characteristic specific impedance z_j and propagation coefficient γ_j follow as

$$z_j^2 - z_{0j}^2 = (-iz_{0j} / \rho_0 \omega \gamma_{0j}) (\sigma_j - \sigma_{0j}) \quad (7a,b)$$

$$\gamma_j^2 - \gamma_{0j}^2 = (-i\gamma_{0j} / \rho_0 \omega z_{0j}) (\sigma_j - \sigma_{0j})$$

Finally

$$c_0^2 \Omega X \rho_{aj} = \gamma_j^2 \quad \text{and} \quad \rho_{aj} / \rho_0 = z_j \gamma_j \quad (8a,b)$$

Acoustic boundary conditions The component of acoustic velocity normal to the hard walls of boundary Γ_w is assumed to be zero for both regions R_1 and R_2 . On the common boundary Γ_c , there is continuity of pressure and the normal component of displacement. It is assumed that sufficient length of inlet and outlet duct is modelled such that plane-wave conditions apply on the inlet and outlet

flow boundaries Γ_1 and Γ_0 of region R_1 . In particular, the four-pole parameters and hence transmission loss of the overall system can be evaluated from two separate solutions of the entire problem with different inflow and outflow boundary conditions [10].

Finite element formulation The first task is to determine the pressure and hence velocity field of the steady flow in the absorbent, region R_2 . The steady flow velocity field is required in order to determine the acoustic properties of the absorbent material, for use in the coupled acoustic analysis of regions R_1 and R_2 . The weak Galerkin finite element formulations for the steady flow field and the coupled acoustic fields are detailed in Peat and Rathie [1].

Results

Results are shown for axisymmetric silencers only. In the first

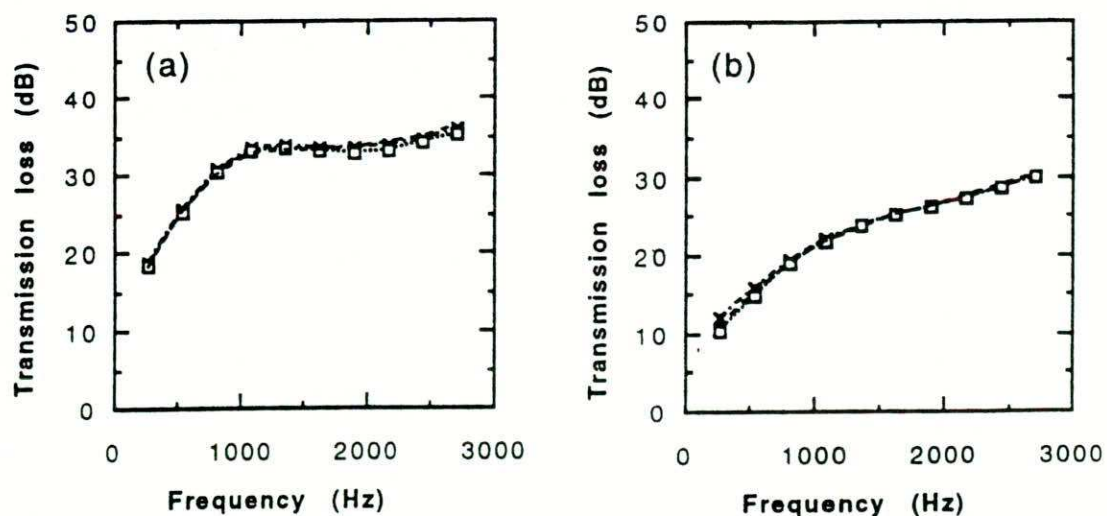


Fig. 5. Effect of axial variation of the density of basalt wool (a) $M = 0$ (b) $M = 0.196$. Density decreasing with distance - x - Uniform density - - - - Density increasing with distance ..□...

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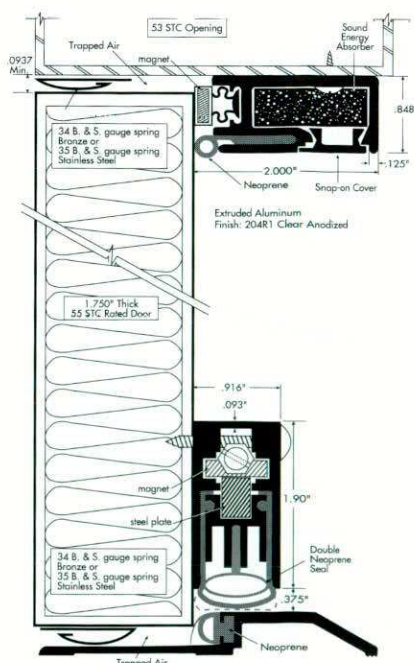
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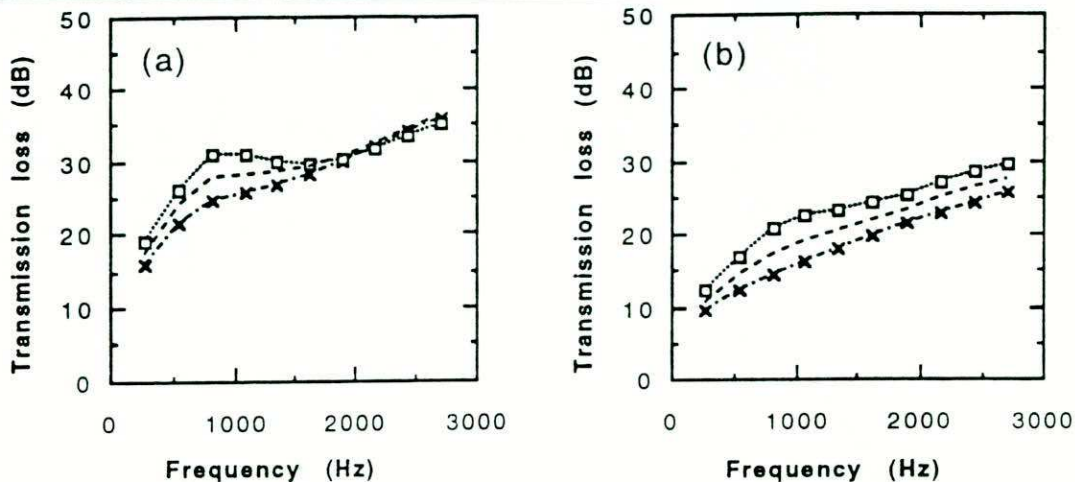


Fig. 6. Effect of radial variation of the density of 'E' glass (a) $M = 0$ (b) $M = 0.196$. Density decreasing with radius - $\square$ - - Uniform density - $\cdots$ - Density increasing with radius - $\times$ -

instance, an expansion box silencer of length 150 mm, radius 100 mm, filled with homogeneous, isotropic foam is considered. The central flow duct has a radius of 19.8 mm. The silencer is shown in cross-section in Figure 2, together with the calculated induced steady flow velocity vectors due to a uniform flow in the central duct of Mach number 0.196. It is seen that the steady flow has large variation in both magnitude and direction. Figures 3(a) and 3(b) show the transmission loss of this silencer for flow convection in both senses (positive Mach number implies flow in the same direction as the initial acoustic wave motion).

It is observed that, while there are significant differences between the calculations with and without induced steady flow effects within the absorbent region, there is very little difference between results obtained with the assumption of uniform, axial steady flow in the absorbent and those obtained on the basis of the actual non-uniform, three-dimensional calculated velocity field.

Figures 4 and 5 indicate the effects of radial and axial variation, respectively, of the packing density of basalt wool absorbent in the same silencer geometry as considered previously. The variation of packing density is between 88 and 164 kg m⁻³.

Figure 4 shows that significant performance gains or losses can result from radial variation of the packing density, as compared to uniform packing of the same total mass of absorbent material. Figure 5 shows that axial variation of the packing density has no significant effect and this observation remains true for longer silencers.

Finally Figure 6 shows results for radial variation similar to Figure 4, except that the absorbent material here is 'E' glass. While results are similar, there is no longer a significant cross-over effect with frequency in the $M = 0$ case.

Conclusions

Finite element formulations have been developed which can determine the non-uniform induced velocity field in an absorbent region and account for its affect upon the acoustic performance of a general dissipative silencer. In practice, it has been found that, while induced flow effects are important, there is little need to calculate accurately the

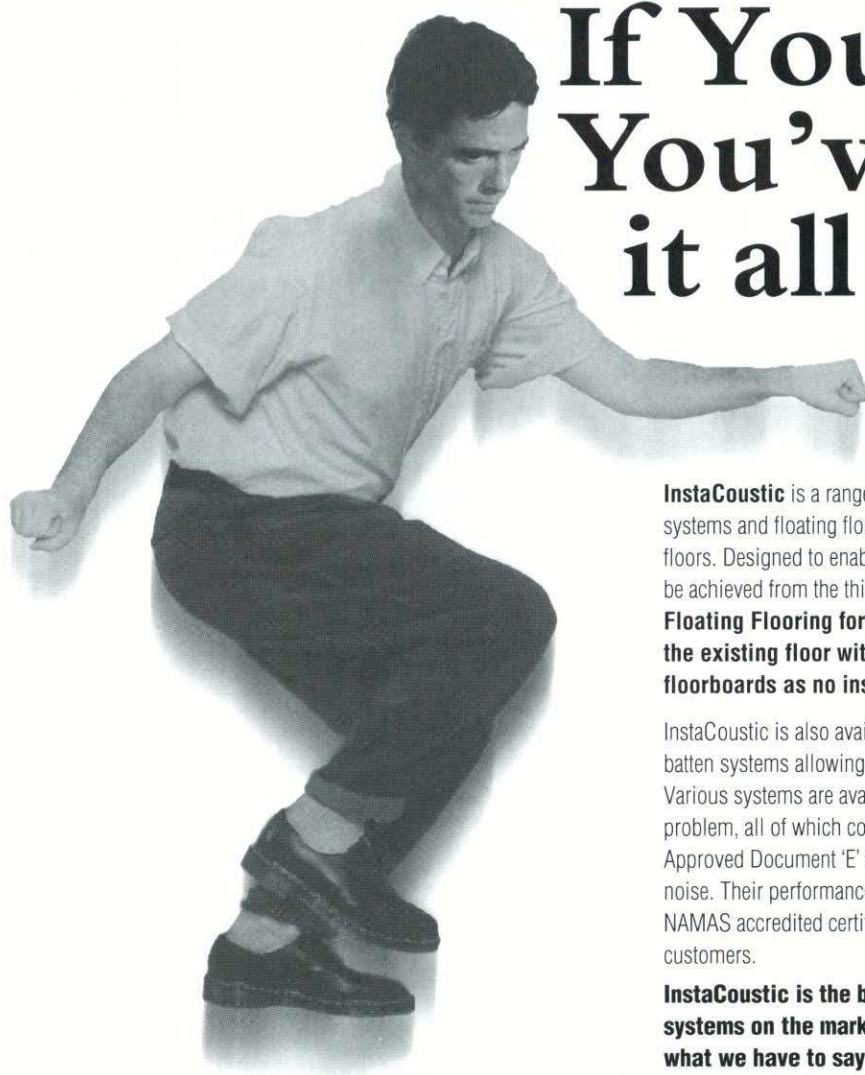
induced flow field. The finite element model has been used to study the effects of non-uniform packing of absorbent material. It has been shown that radial variation of the packing density can have significant effects, but axial variation causes insignificant changes. The effect upon acoustic performance of radial variation of the packing density is dependent upon frequency, mean flow speed and the absorbent material.

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SOUND INTENSITY MEASUREMENTS FOR BUILDING ACOUSTICS

Carl P Hopkins AMIOA & Tina A Emmanuel MIOA

Introduction

It is commonly accepted that sound intensity measurement offers a potentially powerful diagnostic tool in the field of building acoustics. However, despite the continual improvement in measurement instrumentation, there has been a lack of guidance and procedural information available for transmission loss measurements. This will be partly rectified by the publication of the revised ISO 140-5 which concerns 'Field measurements of airborne sound insulation of facade elements and facades'. Annex E describes a sound intensity measurement method for the determination of the sound reduction index for a building element which is to be used when flanking transmission affects the accuracy of the traditional method or when the intensity method is deemed to be preferable.

This article looks at the practicalities of sound intensity measurements in typical rooms in dwellings and for facade elements with reference to the revised ISO 140-5. An extension of this approach to sound power measurement for separating and flanking elements is also described to allow sound power rank ordering.

Intensity Measurements in Reverberant Fields

The ability to accurately measure sound intensity in enclosed spaces is affected by the reactivity of the sound field. This is described by the pressure-intensity indicator or field indicator F which is defined as 'the difference between the time and surface averaged sound pressure level, L_p , and the normal sound intensity level, L_i on the measurement surface'. Reverberation times can be simply related [1] to an average value of the field indicator F , to give an indication of problems obtaining accurate intensity measurements in a reverberant room.

$$F = 9 + 10 \log_{10} \left(\frac{S}{A} \right) = 9 + 10 \log_{10} \left(\frac{ST}{0.16V} \right)$$

where S is the element surface area (m^2)

A is the absorption area of the receiving room (m^2)

V is the room volume (m^3)

T is the reverberation time (s)

In the above expression it is assumed that there is a doubling of mean square pressure approximately 150 mm from the radiating surface where the intensity probe is commonly placed. Waterhouse [2] quotes the increase in the sound pressure level at a perfectly reflecting surface to be 2.2 dB in a reverberant field hence the assumption used in the above equation gives worst case values. (NB The rule of thumb quoted in the revised ISO 140-5 to achieve $F < 10$ dB with $S/A < 1.25$ is inferred from the above equation.)

The draft European Standard describing a survey method for field measurements of sound insulation (also referred to as the 'short test method') [3] contains average reverberation times in octave bands (125 Hz – 2 kHz) for common room constructions using European measurement data. These data can be used to indicate when the average field indicator F is likely to exceed 10 dB in typical rooms in dwellings, leading to potential intensity measurement problems. Average values of field indicator F are shown in Table 1 assuming an average room dimension of 3.5 m perpendicular to the separating wall for measurement of the sound power radiated by the separating wall. The data indicate that unfurnished rooms are likely to present measurement problems in the building acoustics frequency range without the introduction of absorbent material into the room. In furnished rooms, accurate measurements without additional absorbent are more likely to be feasible. The average reverberation times all have values greater than or equal to 0.4 s whereas a value of 0.3 s which is common in many furnished living rooms in the UK would give an average field indicator of 6.2 dB.

Waterhouse Correction

The energy density in enclosed spaces is not uniformly distributed as assumed in the diffuse field model. At the boundaries of a room, the phase relationships between waves at a single point are no longer random which causes an increase in the energy density near the boundaries. Waterhouse [2] introduced a correction term for sound pressure measurements made in the central region of a reverberant room to calculate the total sound energy in the room. Use of the Waterhouse correction must be considered whenever sound pressure measurements made in the centre of a reverberant room are to be related to radiated sound power. The Waterhouse correction W in dB is defined as

$$W = 10 \log_{10} \left(1 + \frac{S_T \lambda}{8V} \right)$$

where

S_T is the total area of all the boundary surfaces in the receiving room (m^2)

V is the receiving room volume (m^3)

λ is the wavelength of sound in air (m)

Waterhouse corrections are shown in Figure 1 for 15 m^3 and 35 m^3 rectangular rooms assuming an average room dimension of 3.5 m perpendicular to the separating wall with a room height of 2.3 m. The size of the correction term for rooms in typical dwellings is found to be greater than 0.5 dB below 1 kHz.

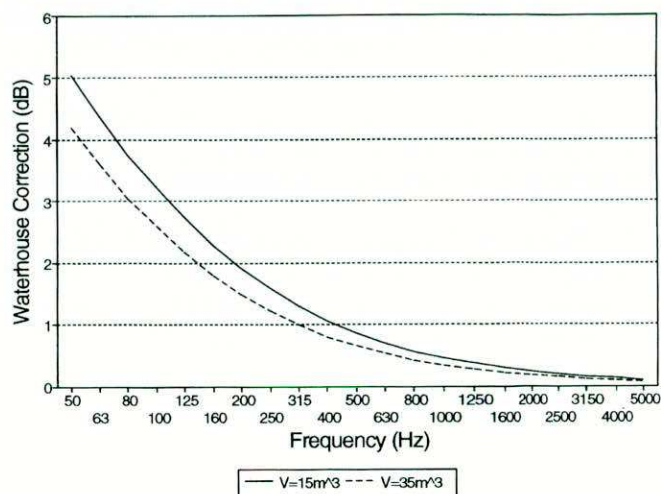


Fig. 1. Waterhouse correction for typical rooms of volume V (m^3)

Field Measurement of the Sound Reduction Index of Facade and Facade Elements

The principle of measuring the sound insulation of a building element is to measure the sound power transmitted through the element and compare it with the sound power incident on the element. With traditional methods

of measuring sound insulation, both the incident and transmitted sound power are obtained indirectly from sound pressure level measurements. With the intensity method the incident sound power is obtained indirectly from sound pressure level measurements as before, but the transmitted sound power is obtained directly by measuring the sound intensity radiated by the element.

The use of sound intensity measurements to measure the sound reduction index of facades and facade elements in the field has several advantages. The intensity measurements can be made on the inside or the outside of a facade, depending on whether it is more suitable to place the sound source indoors or outdoors. (A disadvantage is that a steady sound source is required and therefore traffic noise is not suitable as a source). Another advantage is that the sound reduction index of a facade element (such as a window) can be measured, even when there is significant sound transmission through other parts of the facade.

Requirements of ISO 140-5 Annex E in revised ISO 140-5 sets out the test procedure that should be followed, including some recommendations and requirements on how the intensity measurements should be carried out. The most important of these are as follows:

- The measurement surface must totally enclose the test element. This means that if the test element is not in a niche, the measurement surface must be box-shaped to enclose it.
- The time and space integrated sound intensity level shall

Volume (m^3)	15					35				
Octave Bands (Hz)	125	250	500	1000	2000	125	250	500	1000	2000
<i>Furnished Rooms</i>										
Kitchens	8.5	8.5	8.5	8.5	8.5	8.5	9.0	8.5	8.5	8.5
Bathrooms	9.5	9.5	8.5	8.5	8.0	10.0	10.0	9.0	9.0	8.5
Others	8.5	8.5	8.0	8.0	7.5	8.5	8.5	8.5	8.5	8.0
<i>Unfurnished Rooms</i>										
Type a	8.5	9.5	9.5	9.5	8.5	9.5	10.0	10.0	9.5	9.0
Type b	9.5	11.0	11.5	11.0	10.5	9.5	11.5	12.0	11.5	11.0
Type c	8.5	11.0	12.0	12.5	12.5	9.5	11.5	12.5	13.0	12.5
Type d	8.5	11.0	11.5	12.5	12.5	9.5	11.5	12.0	13.0	12.5
Type e	12.0	12.0	12.0	12.0	10.0	12.0	12.5	12.5	12.5	10.5
Type f	13.0	13.0	13.0	12.0	11.0	13.0	13.0	13.0	12.5	11.5
Type g	12.0	12.5	13.0	13.5	13.5	12.5	13.5	13.5	13.5	13.5
Type h	12.5	13.0	13.5	13.5	13.0	13.0	14.0	14.0	14.0	13.5
Mixed type a+e	10.5	11.0	11.0	11.0	9.5	11.0	11.5	11.5	11.0	10.0
Mixed type b+f	11.5	12.0	12.5	11.5	11.0	11.5	12.5	12.5	12.0	11.5
Mixed type c+g	10.5	12.0	12.5	13.0	13.0	11.0	13.0	13.0	13.5	13.0
Mixed type d+h	10.5	12.0	12.5	13.0	13.0	11.5	13.0	13.0	13.5	13.0

Unfurnished	Soft floor covering		Hard floor covering	
Floor type	Light	Heavy	Light	Heavy
Light walls/ceiling	a	b	c	d
Heavy walls/ceiling	e	f	g	h

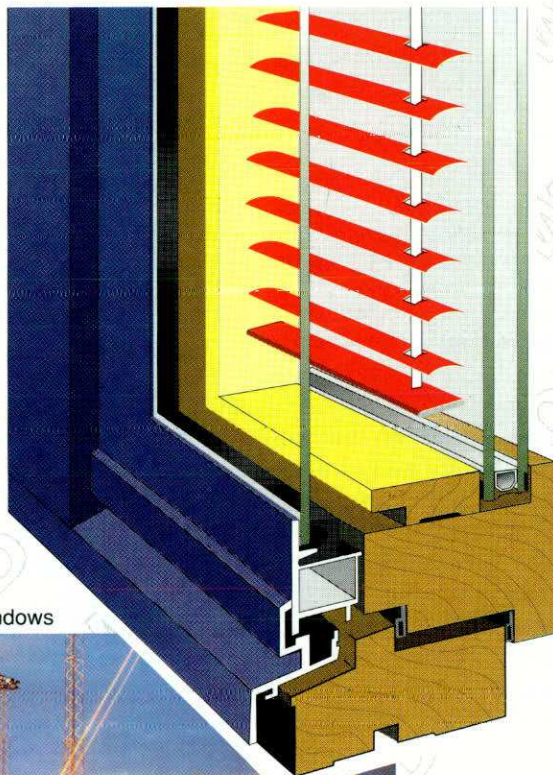
Table 1 Calculated average field indicator values for typical rooms using European measurement data for average reverberation times. Also shown is the key to the symbols representing construction type

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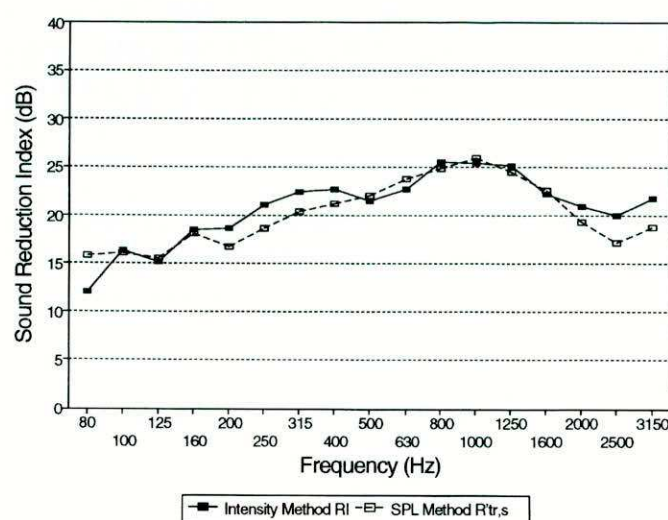


Fig. 2. Comparison of facade element SRI using intensity measurement to complete facade using traditional sound pressure measurement.

be measured by scanning the intensity probe across the measurement surface with a scanning pattern of parallel lines. The arithmetic average of two scans should be taken; one carried out horizontally and one vertically. The difference between the two measurements should be less than 1.0 dB for every frequency band. The results may still be used if the requirement cannot be met, having attempted to change the scanning pattern or sound field, but the deviation from the standard must be stated in the test report.

- The field indicator F shall be no greater than 10 dB.

Practical considerations for scanning sound intensity measurements Small facade elements, such as windows mounted in a niche, can often be treated as a single area and scanned with a single sweep of the intensity probe across the surface defined by the niche opening. However, due to the large surface area of most walls, or in cases where a box-shaped surface is used, it is generally more convenient and practical to split the wall surface into sub areas to be scanned individually. (Scanning a large area requires physical repositioning of the operator and probe during the scan, which increases the chance of operator movement noise causing negatively signed intensity or overload.)

The disadvantage of using sub areas is due to the fact that the field indicator F is defined for the complete measurement surface. If a single scan area is used for the whole surface, a straightforward check on the measurement validity can be made by ensuring that $F < 10$ dB for each scan. If F is too high, attempts can then be made to reduce it by increasing the distance of the probe from the wall surface, or adding extra absorbent to the room and repeating the scans. If multiple sub areas are used, the field indicator, which is calculated from all sub area measurements, is not instantly available to be checked in the field unless the measurement equipment is computer controlled. This means that a judgement has to be made, on the basis of individual sub area measurements,

whether attempts need to be made to reduce F . In the field, the time available on site effectively sets the limit on the amount of repeat data that can be gathered to try and improve the field indicator.

Time constraints in the field also restrict the ability to meet the requirement of achieving less than 1.0 dB difference between the horizontal and vertical scans. In the field it is often difficult to satisfy this requirement, especially at the upper and lower limits of the building acoustics frequency range. To be certain of meeting the requirement, scans must be compared as the measurements are carried out, so that repeat scans can be made until the requirement is satisfied. This is too time-consuming in the field, and it has been found that a practical solution is to carry out two horizontal scans and two vertical scans for each sub area and take the average of the horizontal and vertical scans with the smallest difference in each frequency band [4].

Example field measurement The intensity technique was used to measure the sound reduction index of a single glazed, wooden-framed window, set in a 230 mm thick solid brick facade facing a residential road.

To avoid disturbing the neighbours, the noise source was placed inside the room and the sound intensity measurements were made on the outside of the facade. The measurement surface was a box-shape enclosing the window. The main surface of the box was parallel to the window and approximately 150 mm in front of it. The measurement surface was divided into sub areas, the main surface being divided into eight sub areas, and each side of the box being a separate sub area. (It was necessary to make the sub areas quite small in order to reduce the measurement time for the individual scans. Noise from traffic on the residential road affected the intensity measurements, which therefore had to be made in the quiet periods when no vehicles were passing).

Each sub area was scanned four times (twice horizontally and twice vertically) and the mean intensity level for each sub area was obtained from these measurements as described above. The time and space averaged sound intensity level over the whole measurement surface (L_I) was then calculated, taking account of the different sizes of the various sub areas.

The sound pressure level in the source room (L_p) was obtained from measurements at six positions in the centre of the room, and the sound reduction index of the window was calculated using the following equation:

$$R_I = L_p - 6 - \left(L_I + 10 \log_{10} \left\{ \frac{S_m}{S} \right\} + 10 \log_{10} \left\{ 1 + \frac{S_T \lambda}{8V} \right\} \right)$$

where

L_p is the average sound pressure level in the source room (dB re 20 μ Pa)

L_I is the average normal intensity for a measurement surface enclosing the window (dB re 10^{-12} Wm $^{-2}$)

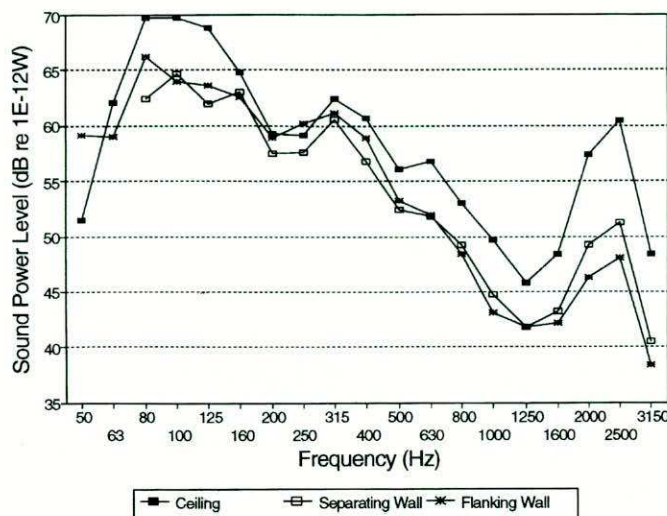


Fig. 3. Sound pressure measurements

S_m is the area of the measurement surface (m^2)

S is the area of the window (m^2)

Figure 2 shows the sound reduction index of the window as measured using the intensity technique and compares it with the sound insulation of the whole facade, as obtained by the traditional sound pressure measurement method (with road traffic as the source). An initial comparison of the sound intensity levels radiated by the window and the wall of the facade had suggested that the sound insulation of the facade would be dominated by the window, so it would be expected that the two measurements give similar results. It can be seen that on the whole the agreement between the two sets of results is good. The weighted sound reduction indices obtained with the intensity technique and the traditional method were 23 dB and 22 dB respectively.

Measurement of Sound Transmission Between Dwellings

Example measurement analysis and discussion Intensity measurements made in the BRE flanking laboratory can be used to illustrate measurement analysis in a situation where sound is radiated by two flanking surfaces and a separating surface. A wide band noise source was placed in one of the first floor rooms with intensity measurements taken in the adjacent first floor room. The two flanking surfaces included a 100 mm aerated concrete flanking wall leaf (70 kgm^{-2}) and a 12.5 mm plasterboard ceiling (10 kgm^{-2}) supported by a wooden lattice. The separating surface was a 100 mm concrete separating wall leaf (166 kgm^{-2}). Radiation into the receiving room was dominated by the plasterboard ceiling with a predicted critical frequency in the 2.5 kHz third octave band. Below the critical frequency, non-resonant transmission across the

plasterboard between the room and roof void is dominant, whereas above the critical frequency, resonant transmission between room and plasterboard as well as roof void and plasterboard dominates.

Measured sound power levels for each of the three surfaces are shown in Figure 3. The primary check on this data is made using the field indicator values for each measurement surface shown in Figure 4. The field indicator is dependent upon the position of the probe in the sound field and is non-zero if the sound field is not that of a plane progressive wave or inter-channel phase mismatch exists. The normalised error due to phase mismatch can be quantified using the difference between the residual pressure-intensity index and the measurement field indicator. ISO 140-5 specifies that the residual pressure-intensity index is greater than $(F+10)$ dB so that the maximum error in the intensity measurement due to phase mismatch is less than 0.45 dB. Assuming that the phase mis-

match is known to be negligible compared to the actual phase difference that exists in the sound field, the field indicator for a measurement made in a reverberant field can only indicate that the sound intensity value may not be accurate because it is not a progressive plane wave field. The revised ISO 140-5 requires that $F < 10$ dB which in this example is only satisfied for all surfaces between 400 Hz and 1.25 kHz although the separating and flanking walls had field indicators below 10 dB between 160 Hz and 1.6 kHz. The reason for higher field indicator values with the ceiling measurements is partly due to the difficulty in damping the room modes between the ceiling and the floor without the operator standing on absorbent material whilst scanning the ceiling. Intensity measurements on walls are simplified by the fact that absorbent material can be stacked behind the operator to

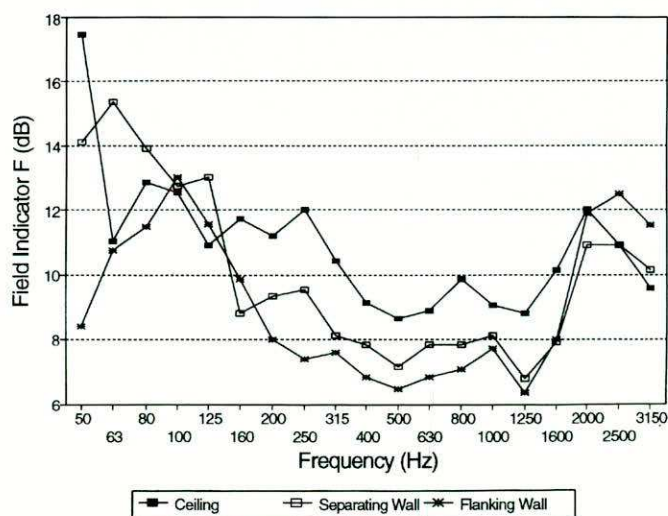
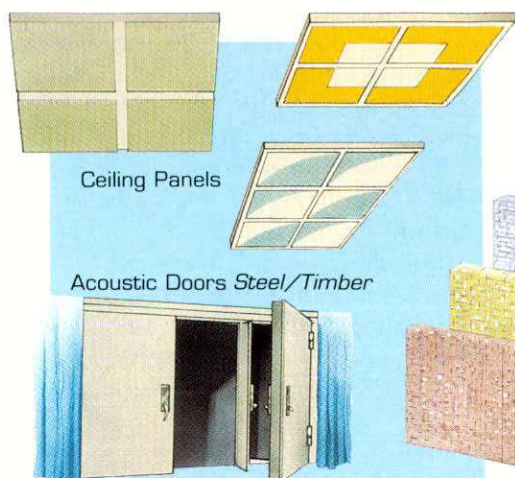


Fig. 4. Field indicator F for each measurement surface

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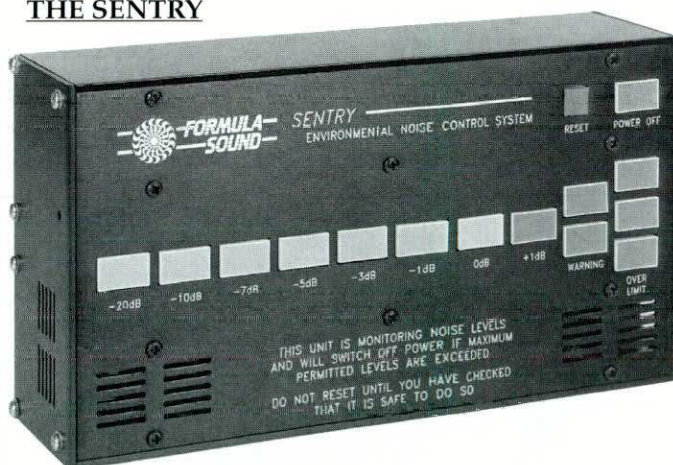
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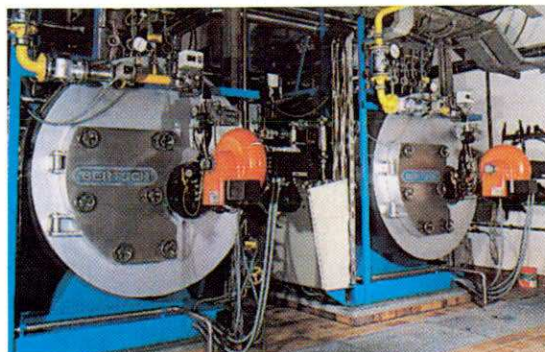
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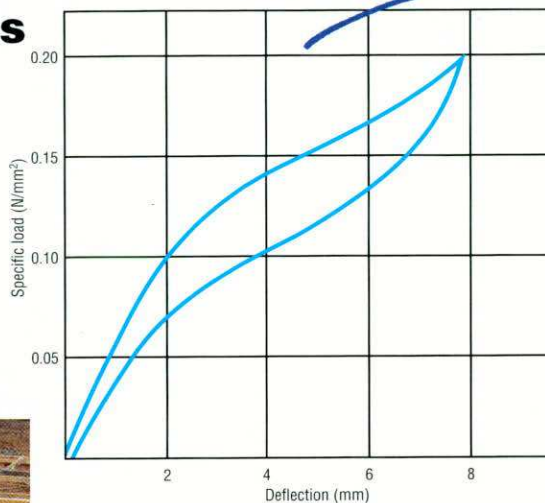
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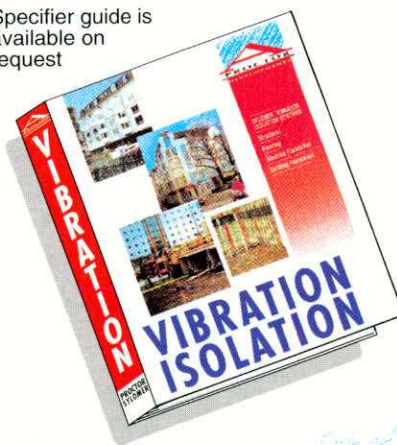


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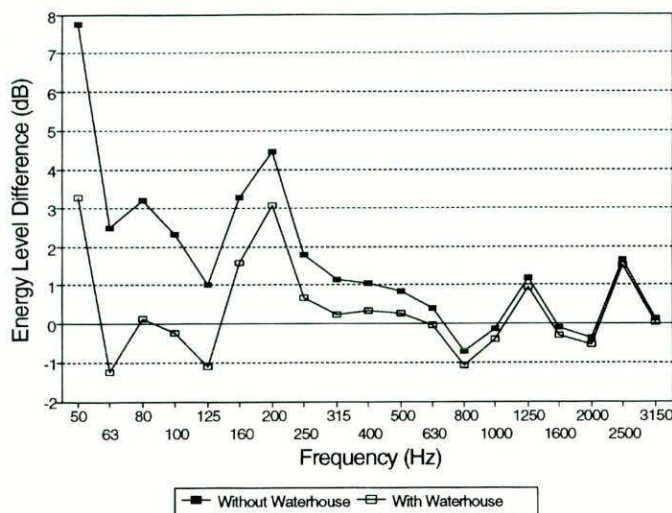


Fig. 5. Energy level difference ΔE

damp the room modes at each measurement position. (NB Measurement problems are also encountered when scanning a floor surface where it is awkward to hang absorbent material above the operator and operator movement noise must be avoided.)

If field indicator values greater than 10 dB cannot be resolved on site, a secondary check should be made to ensure that the measured receiving room sound energy corresponds to the predicted sound energy from the intensity measurements using all the significant radiating surfaces in the receiving room. The measured receiving room sound energy is found from sound pressure measurements in the centre of the room with the addition of the Waterhouse correction. The difference between the calculated energy from the intensity measurements and the measured energy using sound pressure is calculated as shown in the equation below.

$$\Delta E = 10 \log_{10} \left(\sum 10^{L_{wi}/10} \right) + 10 \log_{10} \left(\frac{4}{A} \right) - L_p - 10 \log_{10} \left(1 + \frac{S_T \lambda}{8V} \right)$$

where

L_{wi} are the measured sound power levels for each of the i radiating surfaces

L_p is the average sound pressure level in the receiving room (dB re 20 μ Pa)

Zero values for ΔE indicate the inclusion of all significant radiating surfaces and accurate sound intensity measurements for the dominant radiating surfaces. The use of intensity measurements with $F \geq 10$ dB in rank ordering of the sound power rating for different surfaces can with caution be justified by referring to values of ΔE .

Figure 5 shows the energy level difference ΔE using measured receiving room sound energy with and without the Waterhouse correction. The receiving room volume V was 51.2 m³ with a total surface area S_T of 87.6 m². These room parameters give rise to Waterhouse correc-

tions that cause a significant increase in the accuracy of the receiving room sound energy at low frequencies. Between 400 Hz and 1.25 kHz where $F < 10$ dB for all three surfaces, ΔE is seen to be less than 1.1 dB.

Vibration Measurements for Sound Power Estimation

As an alternative to sound intensity measurements, surface vibration measurements combined with predicted radiation efficiencies can be used to estimate the sound power radiated by each surface. However, this approach can be impractical and inaccurate for the following reasons. Prediction of the radiation efficiency at and below the critical frequency is often inaccurate. Above the critical frequency, the radiation efficiency tends to unity and the results are more reliable. At present, the preference of the construction industry appears to be a move away from wet trades like plastering towards the use of dry finishes such as plasterboard lin-

ings. These linings are commonly 12.5 mm thick with critical frequencies in the 2.5 kHz or 3.5 kHz third octave bands, therefore, this approach will be of negligible use due to the restricted frequency range where the assumption of unity for the radiation efficiency is valid. It should also be noted that lightweight materials excited by a sound field will have measurable vibration below the critical frequency which is due to non-resonant transmission, hence the vibration levels measured at these frequencies are not appropriate for use with predicted radiation efficiencies. Measurement of wall vibration also requires that sufficient measurement positions are used to account for the spatial variation in vibration.

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This article is based on a presentation made at the Institute's one-day meeting entitled Sound Insulation - the Law, the Science and the Practice held at the Building Research Establishment in May 1996.

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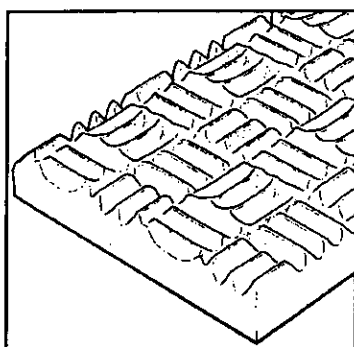
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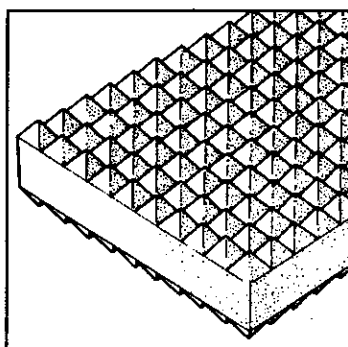
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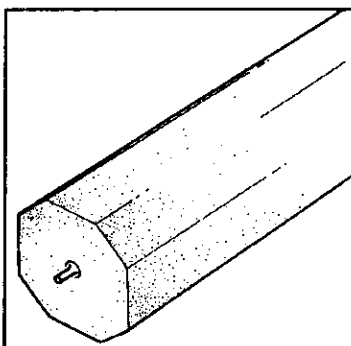
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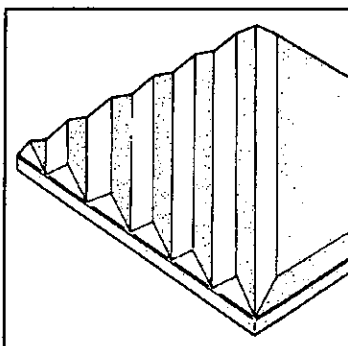
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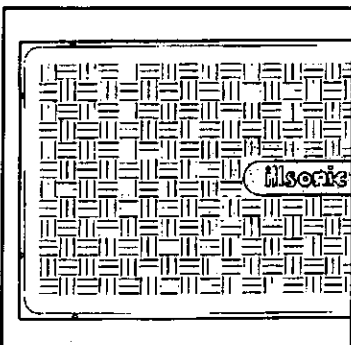
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THE NEW MANCHESTER CONCERT HALL: THE BRIDGEWATER HALL

Rob Harris FIOA

In conjunction with Inter-Noise 96, a technical visit is being arranged to the new Bridgewater Hall, in Manchester, which will open in September 1996. This article reviews the key facts behind the construction of the hall.

The architects were Renton Howard Wood Levin (RHWL) and the building engineers were Ove Arup & Partners.

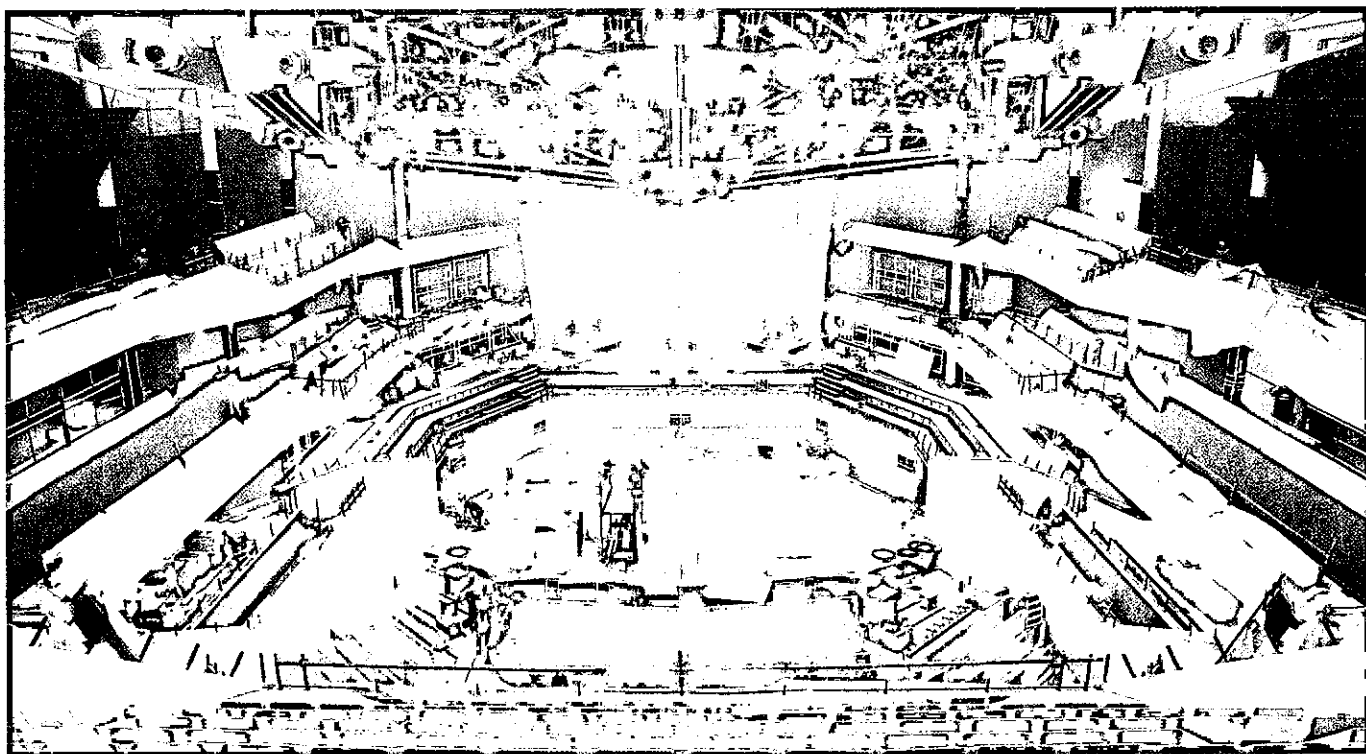
The hall was designed without compromise to be excellent for the performance of classical, symphonic, choral and organ music. Other performance types will utilise the high quality sound reinforcement systems installed.

The geometry of the auditorium, conceived and refined jointly by Arup Acoustics and RHWL, is a synthesis of two concert hall geometries known to provide excellent symphonic sound: the 'shoebox' and 'vineyard' forms. The result is a hall with exceptional visual and acoustical intimacy. The volume of the auditorium, 24000 m³, was determined by the reverberation time criterion of around 2 s at mid-frequencies. The finishes of the hall provide the appropriate reflections and diffusion of sound. The seats were developed by the design team and tested acoustically to provide the appropriate degree of sound absorption, ensuring that the acoustic of the hall in rehearsal conditions is close to that during performance.

In addition to our listening experience in concert halls worldwide, we utilised both an acoustic scale model and a computer model to predict and refine the design of the auditorium. The programme of acoustic testing and tuning within the hall includes test rehearsals by the Halle and BBC Philharmonic Orchestras and the Manchester Camerata, as well as complex analytical measurement studies. The final selection of the grand piano was made within the auditorium, to match the instrument sound to the auditorium acoustic.

The entire concert hall building, weighing over 25,000 tons, is supported on 280 steel springs to prevent disturbance from the Metrolink trains which run past the site. Airborne noise, from traffic and aircraft, is excluded by wrapping the ancillary accommodation around the auditorium. Where the auditorium rises above these buffer zones there are massive twin wall and roof structures to exclude noise. To avoid disturbance from building services noise, the ventilation systems have been designed to meet stringent limits (Preferred Noise Criterion PNC 15); elements such as the concert lighting and house lighting have been tested to ensure that they will not produce any measurable noise.

Rob Harris is with Arup Acoustics



Manchester Concert Hall Site, May 1996

NOISE IN A HYDRO-ELECTRIC POWER STATION

Philip Dunbavin MIOA

It is not every day that we are asked to investigate a noise problem inside a Welsh mountain, however, this article will describe just that occurrence. PDA were asked to investigate a tonal noise problem inside a planning office at Dinorwig Power Station. Although this was not a problem in terms of the Noise at Work Regulations, it represented a serious problem. The impact of this noise problem was being felt, literally, in terms of fatigue, loss of concentration and significantly reduced productivity.

Firstly, let us look at the general situation. Dinorwig Power Station is situated in Llanberis, Gwynedd and is in effect a large capacitor. Water is stored in a reservoir on top of a mountain. At times of high demand, when people are putting the kettle on in the mornings or after Coronation Street, water pours through pipework inside the mountain, spins the turbines and is deposited in a second reservoir at the bottom of the mountain. The electricity this generates is sold at a premium rate to the National Grid, as it is supplied at times when it most needs it. Then, at night, the water is pumped back up the mountain to the top reservoir, using electricity bought from the National Grid at a much lower off-peak rate.

The scale of engineering of the site is breathtaking. The mountain contains a tunnel network so big one is given a map upon entering. The tunnels are large enough for two medium sized lorries to pass side-by-side. The machine hall inside the mountain is some 25m high and is known as the 'concert hall'. The station has eight floors, six turbines and even has a theatre for tourist visits, all deep inside the mountain.

Faced with this engineering, it was somewhat daunting to be examining a problem that had foxed many other engineers previously asked to provide a solution. The office in question is situated on a level three stories above the turbines and one of the walls of the office is the mountain itself. Our initial reaction when hearing about this problem was the same as other engineers who had visited the office, that structure-borne vibration was finding its way into the office and manifesting itself as airborne noise through lightly supported structures, and to solve the problem would involve some quite tricky vibration isolation of the office structure.

Our site visit was timed to coincide with the morning peak generating times. It had been noted by users of the office that the problem worsened when Turbine No. 6 was active. Upon hearing the tone

generated when Turbine No. 6 started spinning it was immediately obvious why working in the office was so tiring. Apart from the high level of the tone, it was very difficult to localise any source. Walking around the office, the level of the tone varied but it was still extremely difficult to localise any source of the tone. As can be seen from Figure 1, a third octave band spectrum of the noise at the desk revealed no information about the problem at all, the tone was narrow enough not to contribute significantly to a third octave band.

However, by switching to narrow band analysis the problem is instantly visible as shown in Figure 2, with a tone some 25 dB above the background noise level. We had now established and quantified the problem, and were left with the simple task of finding and eliminating the source. This was made tricky by the inability to localise any source of noise. However, at least now we knew what we were looking for.

Our first tactic was to examine vibration in all surfaces inside the office, especially all lightly supported systems such as filing cabinets and plasterboard partitions. This was done in one-third octave bands and narrow bands (0.1 Hz.) to track down the source of our tone. It was found that vibration in all the structures was so low that one third octave band analysis was simply of no value. Switching to our narrow band analyser we saw that, although a small amount of tonal vibration was present, calculations revealed that the levels were nowhere near high enough to produce the airborne tonal noise measured at 52 dB. It had to be concluded that the

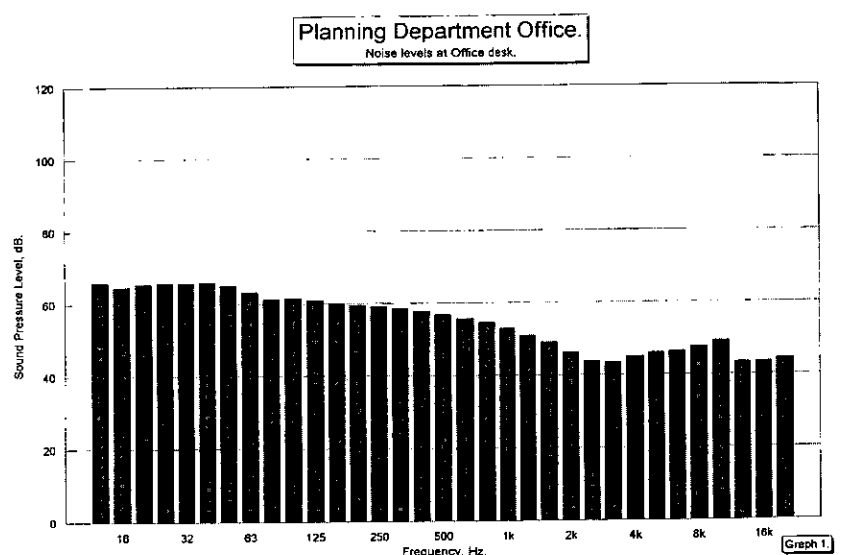
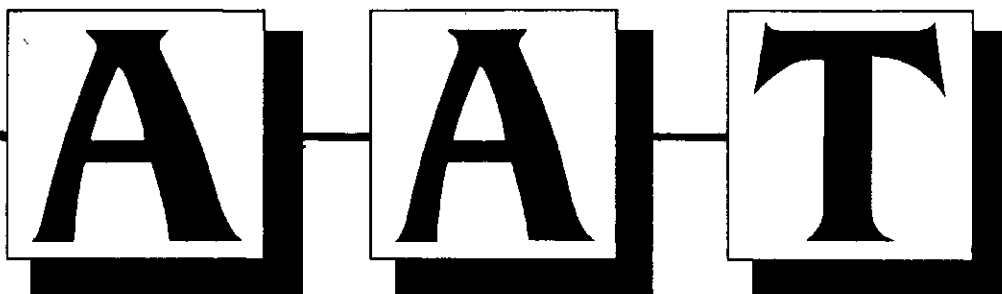


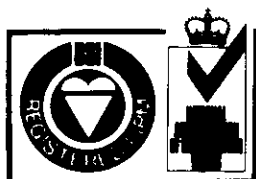
Fig. 1. 1/3 octave band frequency analysis of the noise in the Planning Department Office



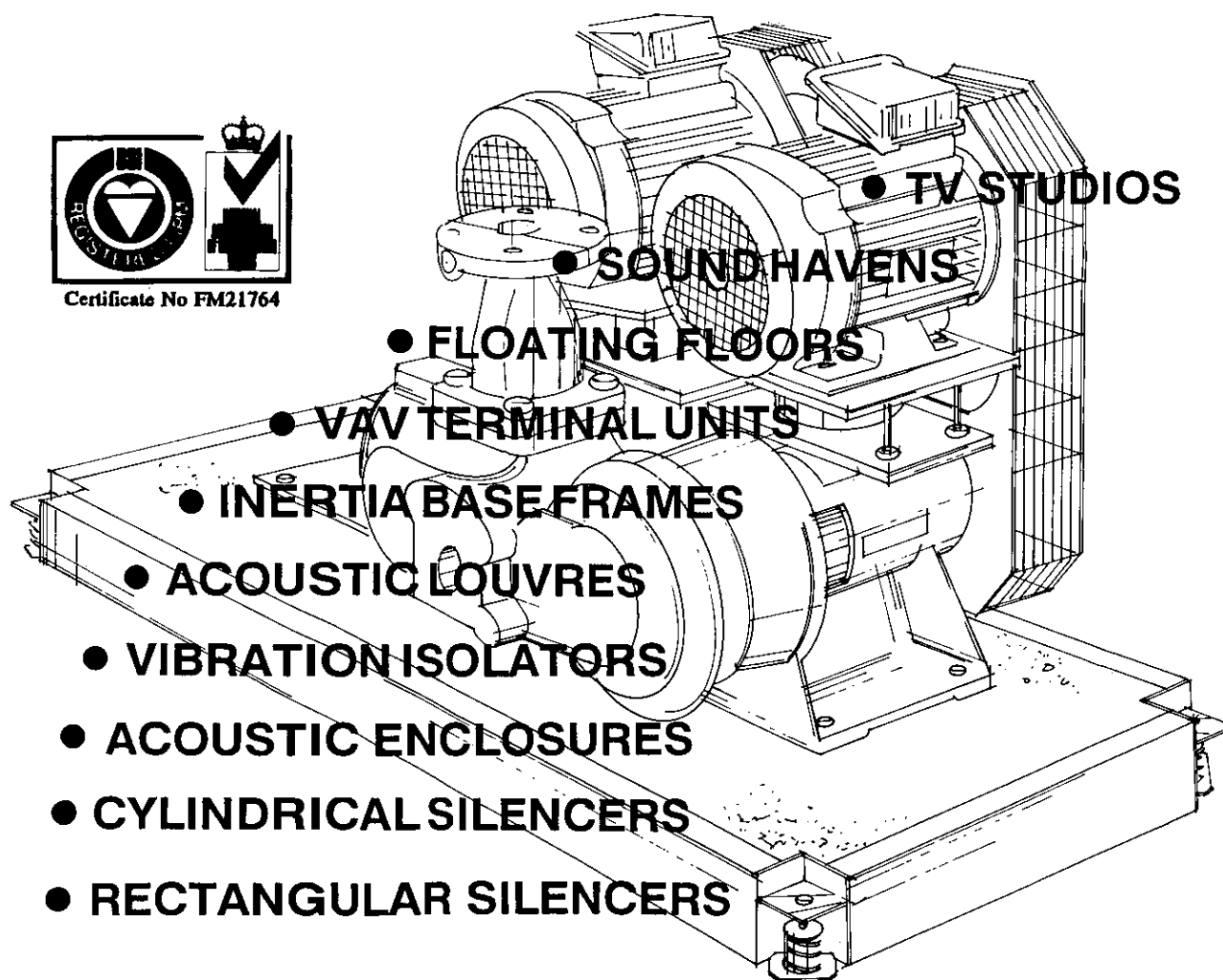
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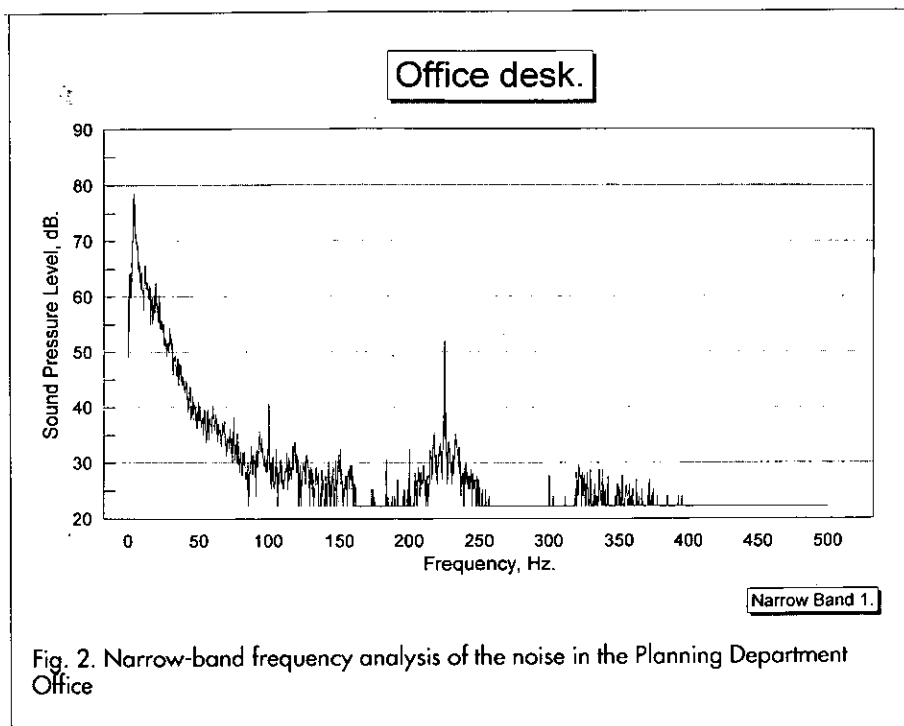


Fig. 2. Narrow-band frequency analysis of the noise in the Planning Department Office

source of noise was not vibration in the structure.

Taking a leaf from Sherlock Holmes, after having eliminated all possibilities, we were left with the truth, no matter how impossible it seemed. The tonal noise must be airborne, thus travelling up three flights of stairs, through various doors and entering the office as airborne noise. Opening the office door onto the outside stairwell, the level of the tone grew higher. The second narrow band presented here in Figure 3 shows the noise in the stairwell, our 225 Hz tone is now some 18 dB higher. Again, there was very little vibration in the building structure, leading us further to the idea that the noise problem was airborne rather than structure borne. Descending down the stairs the tone was getting louder and louder until we reached the turbine level. Making a measurement one metre away from Turbine No. 6 revealed our tone some 38 dB higher than we were measuring in the office.

Further investigation throughout the remainder of the station showed that vibration was indeed a problem in certain areas, and the 225 Hz. tone was causing resonance in all manner of structure. A wall of lockers had enormous amounts of vibration in them and were all behaving as loudspeaker cones, as were many office windows, air conditioning ducts and desks which were located nearer to the turbines. In effect, the turbines were generating airborne noise and vibration energy which was being amplified by a multitude of sources throughout the rest of the station.

With this huge amount of noise

sources, it was not appropriate to use our normal approach of noise control at source. Back inside the office, various field level differences were measured. It was deduced that the tone was breaking in through the main office door and a door connecting the office to a neighbouring workshop. These doors simply needed replacing with acoustic doors, attenuating the tone by some 20 dB.

Another source of the tone was the air supply system. This needed treating by installing two straight through silencers, one for each of the two supply ducts serving two grilles near the office desk we were investigating. For such a complex noise source the eventuality was quite a simple solution. It was also a method exercise in using the most important piece of equipment every acoustician is supplied with, their ears. By aurally tracking the source down it

was possible to solve quite a complex problem and provide an easy solution, whereas some theoretical solutions which had been previously offered such as floating floors and walls would have been very expensive and most importantly of all, not worked.

As was stated at the start of this article, tackling a noise problem inside a mountain is not the sort of thing we do every day, so our thanks go to Dinorwig Power Station for providing us with such a brain-teaser and also allowing us to write about it further.

Philip Dunbavin MIOA is Director of Philip Dunbavin Acoustics Ltd, Warrington, Cheshire

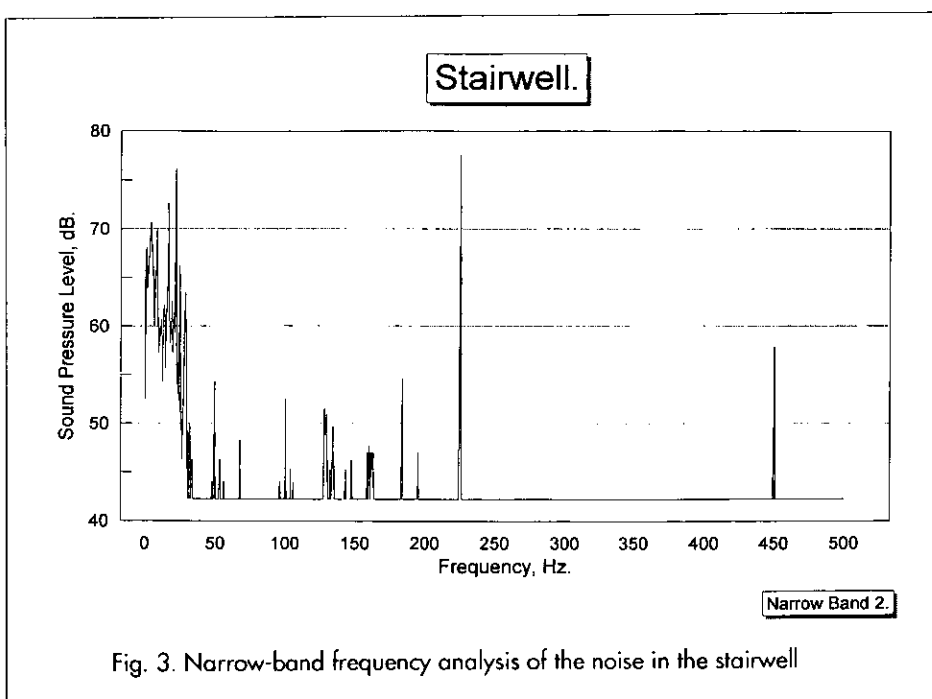
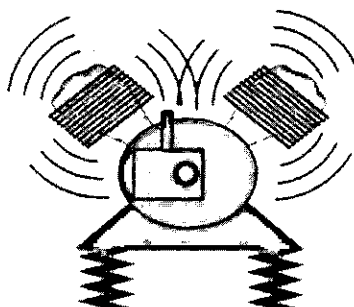


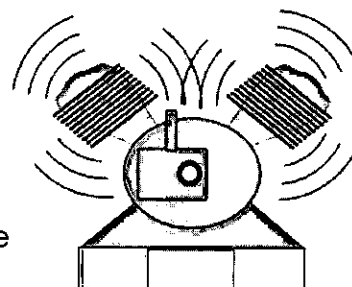
Fig. 3. Narrow-band frequency analysis of the noise in the stairwell

A New Solution for Controlling Structural Vibration



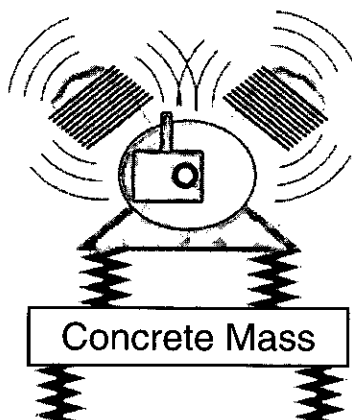
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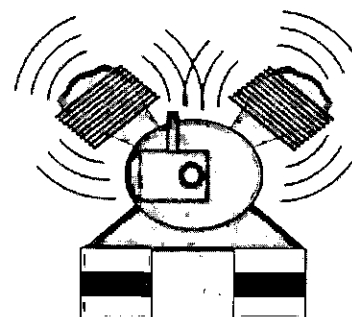
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ACOUSTIC PERFORMANCE – EXPLODING THE MYTH

Philip E Jones MIOA

The development of lightweight structural partition systems has begun to explode the myth that effective sound insulation can only be achieved with the use of heavy masonry construction. The resurgence of the cinema industry, and the growth in multiple screen complexes, has provided a wealth of technical performance data which support the laboratory tests conducted on lightweight high performance partition systems. It is now widely accepted that with a good design, a metal framed plasterboard wall weighing no more than 50kg/m² is capable of providing sound insulation of a sufficient performance to effectively separate two cinema auditoria.

However, recent reductions in the weight of the plasterboard linings of these partitions, whilst improving the fixing and handling benefits of the boards, has cast some doubt on the sound insulation performance of the framed structure. As a pre-emptive measure plasterboard manufacturers have introduced 'acoustic' boards to combat this concern. The case against these weight reductions remains 'unproven' and must be judged in the context of each application. For instance the use of 'acoustic' boards may offer little improvement in overall performance when the sound insulation between auditoria is dominated by flanking transmission.

By examining two typical construction methods for building and refurbishing cinemas, the problems of identifying the sound transmission route and appropriate means of sound isolation can be seen.

In a conversion situation, problems often occur where a masonry wall forms a continuous bridge across the end of a lightweight division element. In this situation, the sound insulation performance of the partition system is compromised by flanking transmission leaking into the auditoria. This can be resolved by the installation of an independent plasterboard wall lining in front of the masonry which then isolates the element.

Within the new multi-screen developments, flanking transmission is often associated with the continuous steel decked roof, which forms a core element of the building. The transmission path can usually be reduced with the installation of suspended ceilings.

In addition, several other elements can have an impact on the sound insula-

tion performance, notably where the wall is penetrated by structural steelwork, and air leakage at junctions and masonry end walls. In all the above areas, flanking transmission can impair the overall performance of the system.

There is a significant economic case for using lightweight construction, which offers both the contractor and client major advantages in terms of speed of construction and material costs. Wall foundations are minimised with a twin-framed high performance partition offering a consequent reduction in time, material and labour costs. Additionally, the system gives the potential to construct a wall 15 metres high but only 300 mm wide. To address the impact of new lower board weights, laboratory evaluations of two well established cinema dividing walls have recently been undertaken. Both were lined with wallboard to the outer faces of an independent twin metal stud framework and mineral wool insulation was hung in the cavity.

The first wall utilised a basic construction, comprising a double layer of 15 mm (Figure 1) plasterboard, the second was a more sophisticated construction with one layer of 19 mm plasterboard (Figure 2) plank and two layers of 12.5 mm plasterboard. For the more complex

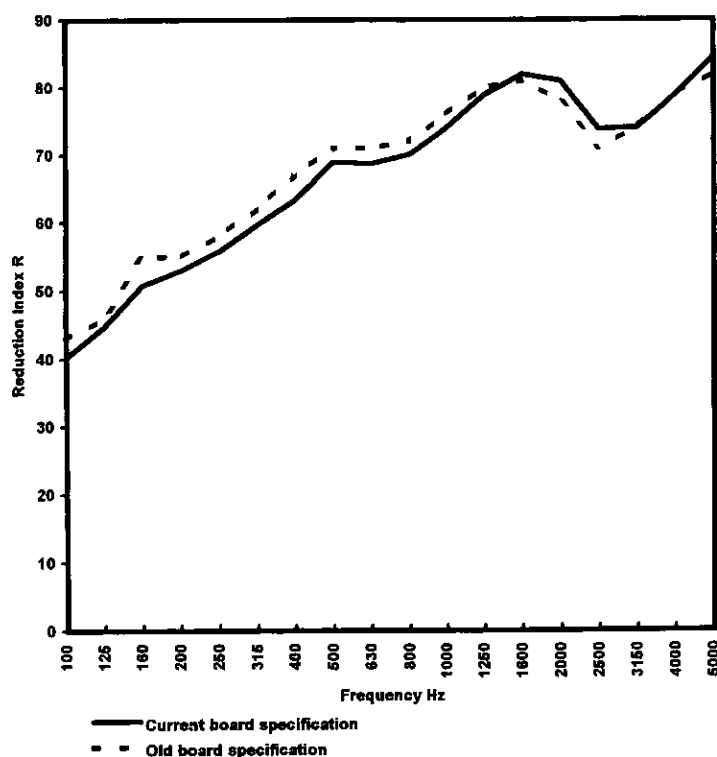


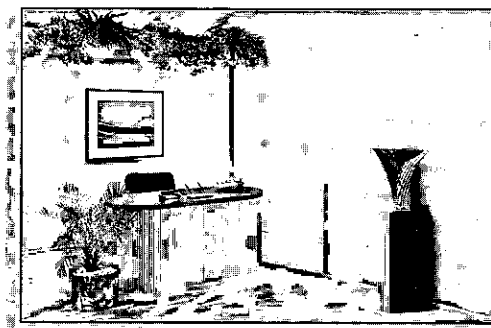
Fig. 1. Auditoria wall comparison (double layer 15mm Gyproc wallboard)

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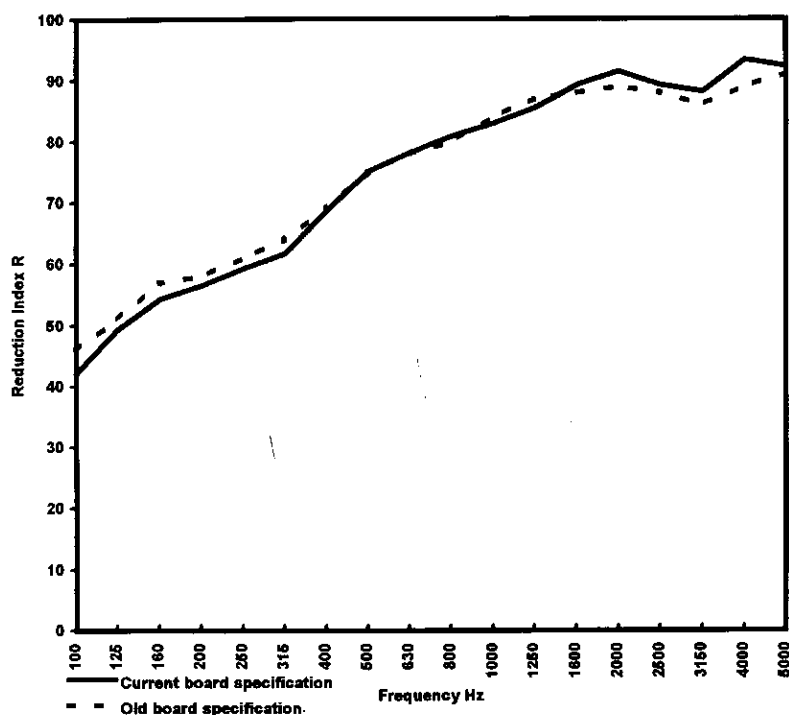


Fig. 2. Auditoria wall comparison (single layer 19mm Gyproc plank and double layer 12.5mm Gyproc wallboard)

construction, additional sound insulation was achieved from the increased mass of the elements and the minimisation of resonance and critical frequency effects of specific board thicknesses. Test results on both walls indicated a loss of 2 dB in the weighted sound reduction index for a 20% reduction in overall board weight. For the basic wall this resulted in a rating of 67 dB against a recorded 69 dB for the second wall.

However, on site the controlling factors will probably prove to be the major flanking elements of the steel deck roof and adjoining walls. Given that construction quality is monitored, especially in the sealing of the wall, and the flanking details have been optimised, the nominal requirements of 60 dB and 65 dB for the shell and fit-out stages respectively should be achieved using the reduced weight plasterboard.

Conducting tests on a single layer metal stud partition, the same 20% weight reduction results in a 3 dB reduction in performance (Figure 3). In these tests the increased stiffness of the lighter board also has a negative contribution to the performance by decreasing the isolation between the partition linings. In these cases the test data indicate that the application of 'acoustic' boards will be necessary to maximise the benefit of the metal framework.

One benefit of the increased stiffness of the lighter boards may be identified where the plasterboard is fixed to masonry with plaster dabs. In this instance the increased stiffness may reduce the 'pumping effect' of the air trapped in the cavity between the lining and the wall. This par-

ticular effect remains largely untested and is therefore the subject of further evaluation.

Given the evidence of both laboratory and site test data, the conclusion regarding reduced board weights and the consequent effect on sound insulation performance can be summarised as follows. Although decreases in board weight reduced the sound insulation of the building element, it is likely that flanking transmission will play a large part in the final sound insulation rating for many site cases. So, in practical terms, the weight reduction of the board will have less significance in the overall performance.

A rudimentary guideline for the selection and specification of plasterboard will be that where information is available relating to the performance of low weight plasterboard this should be used to design a solution. It is worthy of note that irrespective of plasterboard weight, it should be possible to find a solution to meet most sound insulation needs. In the situation where test data relate to plasterboard weights in excess of current levels, it will be necessary to specify the 'acoustic' boards to meet the requirement.

In all cases careful consideration should be given to all the elements of the composite construction in order to achieve the required performance at the optimum cost.

Philip Jones MIOA is a consultant in drywall construction, building acoustics and fire protection ❖

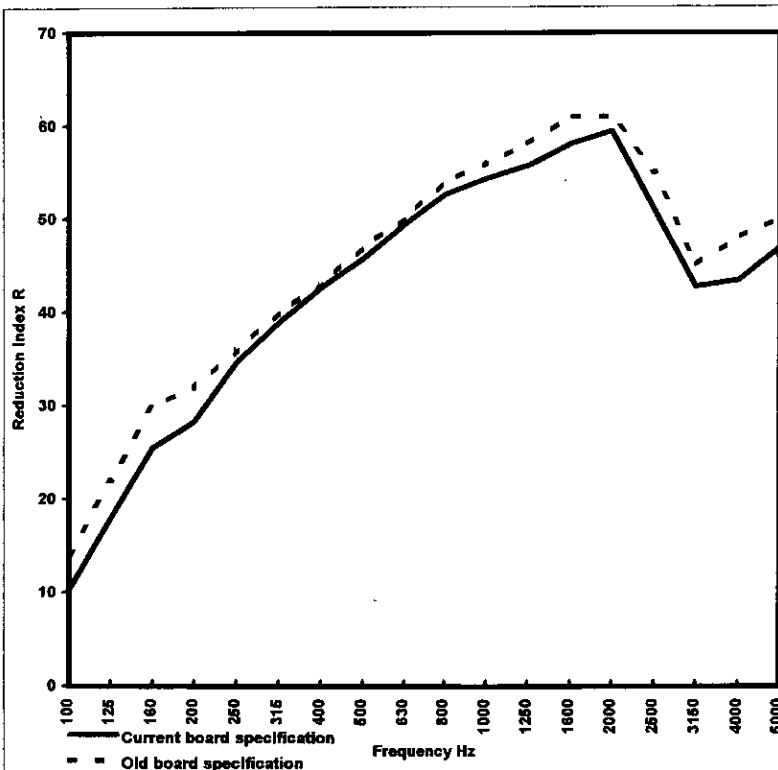


Fig. 3. Single layer metal stud partition comparison

WHAT'S GOING ON IN THE ENGINEERING COUNCIL

Mike Heath CB CBE CEng

A key aim of the new partnership between the Engineering Council and the engineering institutions is to deliver an effective engineering voice on issues of principal concern to the country and engineers as a whole. We therefore have to build upon the co-operative mechanism identified in the New Relationship proposals.

We have agreed to set up Institution Working Groups (IWGs), with a finite life, to address specific issues and areas of national interest. IWGs will normally be set up under the auspices of either the Board for the Engineering Profession (BEP) or the Board for Engineers' Regulation (BER), using the central Executive Board to provide co-ordination.

The BEP has set up the following IWGs:

Regional Affairs – Proposals are being made for a new regional structure and for joint ventures on regional public relations, Neighbourhood Engineers and the Year of Engineering Success (YES). Subject to BEP approval, policies will then emerge for implementation based on a pan-institutional model.

Industry – A pan-institutional scheme is being explored for increasing the number of Industry Affiliates without undermining existing schemes. We believe it is essential to involve industry more effectively in our thinking.

The '20-20 Vision Programme' – Joint ventures between participating institutions, covering transport, energy, the environment and telecommunications, will cover about 18 months. The energy group is being led by the Institution of Mechanical Engineers and the outcome will be a learned society report. The group on the environment is being led by the Institution of Chemical Engineers. Early indications are that it will produce a project-based illustration of the beneficial approach engineers bring to environmental problems. On telecommunications, which is being led by the Institution of Electrical Engineers, four leading edge seminars are initially being arranged. The transportation group is being led by the Institution of Civil Engineers. The working format has yet to emerge, but is likely to involve a radical approach.

The Council's involvement in future activities is predominantly co-ordination and facilitating, but a number of activities funded by sponsorship are continuing. These are the Neighbourhood Engineers' programme, the Young Engineers for Britain competition (now conducted jointly with the Standing Conference on Schools' Science and Technology), the Environment Award, the Women Into Science and Engineering (WISE) campaign, the Times Educational Supplement 'School of the Year' Award, and the Technology Enhancement Programme which is sponsored by the Gatsby Charitable Foundation.

One of the most important series of events for 1997

will be the Year for Engineering Success. The campaign will be formally launched on 2 September 1996. The Engineering Conference, which the Council will hold once a year, will be combined in 1996 with the YES campaign launch.

The Department of Trade and Industry sponsored initiative, Action for Engineering and its associated six working groups, have identified a number of future tasks, some of which will fall to the Council and the Engineering Employers' Federation (EEF) from the middle of 1996. How these will be managed in the future and the resources required to do so are being examined.

Unlike the BEP, which works under a largely discretionary framework, the BER has specific functions and duties to carry out.

The BER has set up two IWGs to cover the revision of our registration 'bible' (SARTOR) and Quality Assurance for our nominated bodies. Much work had already been done on the revision of SARTOR following the issue of the consultative document, 'Competence and Commitment'. The IWG has established the need for a new approach to its structure. Lasting principles, showing concepts, aspirations and a general regulatory framework will form Part One, while Part Two will be a set of documents which are the equivalent of implementing regulations. This will provide a document which is flexible and can respond to ongoing changes in education, training and employment, while avoiding the need frequently to revisit the basics.

Directly connected with work on SARTOR is the need to ensure that the requirements of industry, now and in the future, are reflected in registration at the CEng, IEng and EngTech levels.

The Quality Assurance IWG aims to produce a system that ensures a high level of quality assurance in the systems used by the Council's nominated bodies to bring forward individuals for registration while keeping bureaucratic procedures to a minimum.

These are only the highlights of a formidable programme of work which is taking us rapidly towards a future in which engineering will play a much larger part in our national scene.

Mike Heath is Director General of the Council



NEW CHARTERED ENGINEER

John Steel first became interested in acoustics while studying for the Degree of Building Engineering at Heriot Watt University, Edinburgh which he was awarded with first class honours in 1985. After a brief period working for Miller Construction on pre-contract planning he decided to return to Heriot Watt to carry out research into noise in buildings. His work was mainly in the field of structure borne sound transmission which resulted in the award of an Msc in 1987.

He was awarded the degree of Doctor of Philosophy for investigation into the application of Statistical Energy Analysis to noise transmission in framed buildings in 1990.

In 1991 he took up a post as lecturer in the Department of Mechanical Engineering at Heriot Watt University where his work has extended into studies of sound transmission on motor vehicles and marine structures and has received industrial and funding council support. He also began work on condition monitoring of rotating machines

through the application and development of Acoustic Emission sensors.

Consulting work which he has carried out over the last ten years has included studies of noise transmission in railway vehicles, environmental noise studies and investigations into road traffic accidents. In 1994 he carried out work on noise transmission in

buildings for the National Research Council, Canada, at their home laboratories in Ottawa.



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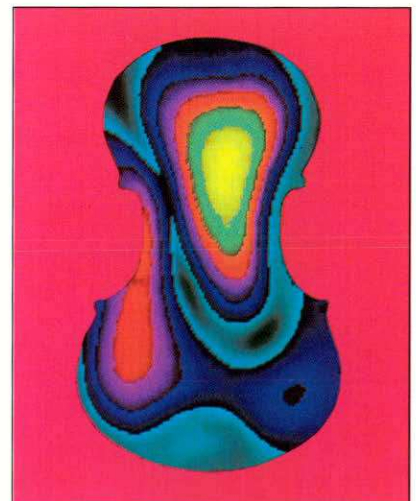
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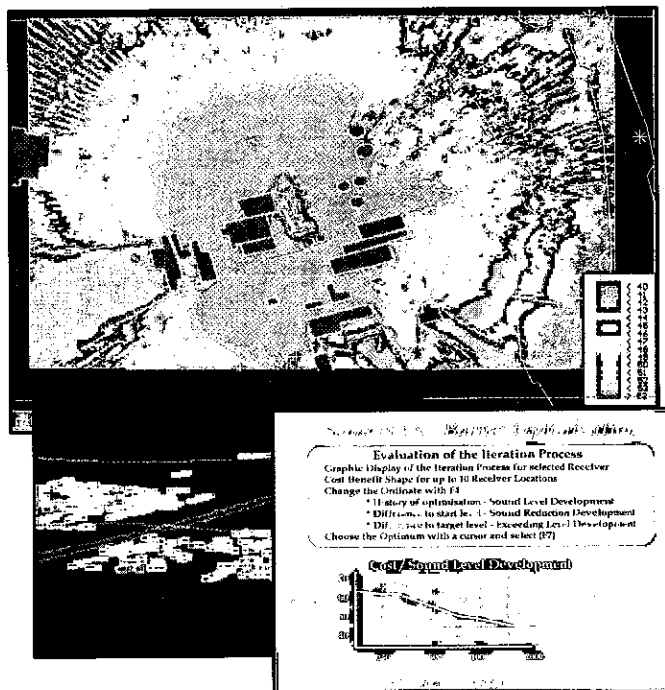
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CPD

Continuing Professional Development

Since January this year, 206 people or 9% of the membership, have joined the CPD Scheme. It is early days yet, but the Scheme seems to be operating fairly smoothly with few problems. A meeting of the CPD Committee and the Regional Representatives was held on 20 June, to discuss the operation of the Scheme.

A few points of information arising from regional reports were:-

- The IOA CPD Scheme is not mandatory, but it is hoped that all members will see the value in joining the scheme.
- The initial £17.50 charge is made up of a £12.50 joining fee and an annual charge of £5.00.
- Regional evening meetings count for 2 hours CPD. Other conferences and seminars count for hours present. All IOA meetings now provide CPD certificates to participate.
- Members can count time at other organisations' meetings if relevant, and each member should identify CPD activities relevant to them. These will be different for each individual depending on their age and circumstances. (See Scheme notes for further information).
- Meetings can be counted as CPD for than one institute, if relevant.
- We're now half way through the year. CPD records will be checked in January 1997.

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As there was not much to report from the regions, those present gave some thought to how they wanted the Scheme to develop, and how they really saw the benefits to IOA members. The following points were made.

- CPD should not just be a matter of assessing hours to fit a total, but should give individuals an opportunity to make some sort of career development plan, and work towards specific goals. This may be something they wish to do along with their employers, or perhaps individually.
- It was seen to be especially important that younger members should begin their careers with CPD as an integral part.
- Members may find that a mentor would be useful. A mentor would probably be someone with more experience than the individual and from somewhere other than that individual's workplace. The mentor could give impartial advice or information on work in the acoustics field which may be of relevance to the member's CPD.
- The support of employers would be a great advantage to any member's CPD plans.
- Guidance on self study, which could appear in the Bulletin, would be very useful to some members.

The CPD Scheme is a pilot scheme, and the committee and representatives need your views on whether it is working and how it could be improved. If you have any comments on the points raised above, please let the Institute (or Sue Bird) know.

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SOUND INSULATION – THE LAW, THE SCIENCE AND THE PRACTICE

29 May 1996, Watford

The Building Acoustics Group organised a highly successful one-day meeting at the Building Research Establishment in Garston, Watford on the 29 May 1996. The meeting was well attended, with 125 delegates representing a wide spectrum of professions. The papers covered sound insulation issues of regulation, analytical methods of assessment, site difficulties and practical issues, in depth and breadth.

Les Fothergill of the Department of the Environment Building Regulations Division introduced the meeting, and chaired the first session.

Bob Craik of Heriot-Watt University started the presentations with a paper jointly co-authored with Archie MacPherson, describing the take-up of post-construction testing of sound insulation between dwellings in Scotland. He concluded that, for a price, post-construction testing leads to an improvement in the overall performance of the housing stock. Paul Goring of AIRO examined the concept of 'reasonable' in relation to Approved Document E of the Building Regulations, and detailed a case history where there had been some dispute. Garry Seal of the London Borough of Waltham Forest provided the concluding presentation to the first session giving a paper describing ratings using Sound Reduction Index R and Level difference D and the accuracy of individual measurements.

John Seller of the Building Research Establishment chaired the second session, first introducing colleague Carl Hopkins who presented a paper written jointly with Tina Emmanuel. Carl described the practicalities of the use of sound intensity measurements in the field, looking at both facade measurements and measurements between internal spaces. Building on previously published work Robin Mackenzie detailed developments in the application of certain foams for impact sound reduction in floors, in a joint paper with Robin Hall. The properties of new reconstituted open-cell polymer foams were examined and compared with other foams. Ian Campbell presented the final paper of the second session, written with Svein-Arne Nordby. The paper and presentation describing MLS (maximum length sequence) in practice.

Tony Jones of AIRO chaired the penultimate session of the meeting. David Oldham started with a joint paper with M A Rowell describing investigations into the sound reduction index of factory cladding panels. The effect of non-diffuse incident sound field on the SRI was examined and found, for the cases measured not to have a significant effect. Robin Wilson followed with a joint paper with Alan Cummings. A theoretical model providing an exact solution of radiation from a plate into a porous medium was given, and compared with measured data. The results indicate that radiation into porous media is

greater than that into air, and for certain elements this radiation damping can be significant in increasing the total loss factor. It was surmised that in buildings this effect may be less noticable. Y Lam concluded the third session, building on previous work on single skin metal cladding systems detailing the theory to allow the prediction of the SRI of double skin cladding systems. This prediction method was reported to accurately predict the SRI for common cladding systems.

The final session was chaired by Nick Antonio of the Building Research Establishment. Nick Tinsdeall presented a paper produced jointly with Colin Grimwood and John Seller. The paper provided an overview of field tests carried out over the last three years on party wall constructions given in Approved Document E of the Building Regulations. In comparison with previous work the figures indicate the mean $D_{nT,w}$ has increased for certain similar wall constructions. Steve Wray and Ian Scarr both presented their work looking at the practical problems involved with sound insulation tests; difficulties that arose over a number of tests were detailed and some advice on how to overcome these were given. Peter Clark presented a joint paper written with R C Chanaud, detailing a specific measurement system. Paul Wornell of Housing Association Property Mutual gave the concluding paper on the problems encountered on site. Included in the presentation were various percentage failures in workmanship and construction of elements to meet the requirements of the Approved Documents to the Building Regulations. These figures were derived from a very large sample. Instructive slides illustrating common defects in both design and construction were shown.

After this very full day of papers and discussion, the meeting concluded with a visit to the BRE Acoustic facilities.

Nick Antonio MIOA ❖

Members of the Institute may purchase copies of the proceedings from the Institute, price £20.

The papers by Hopkins/Emmanuel and Campbell/Nordby are reproduced in full in this issue of Acoustics Bulletin.

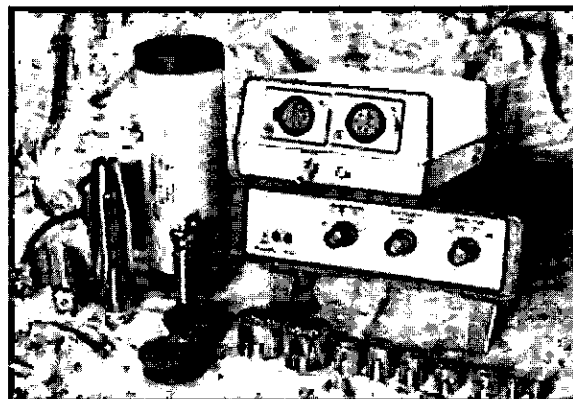


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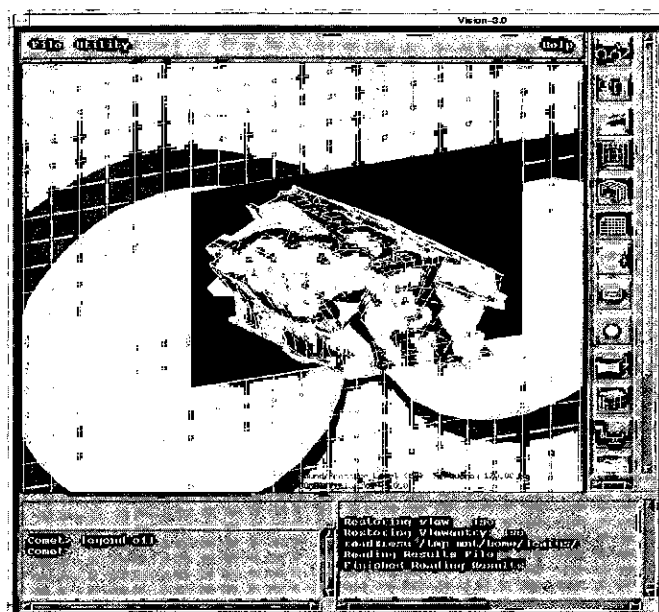


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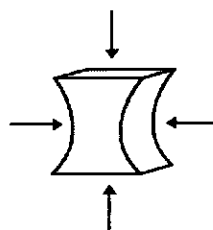
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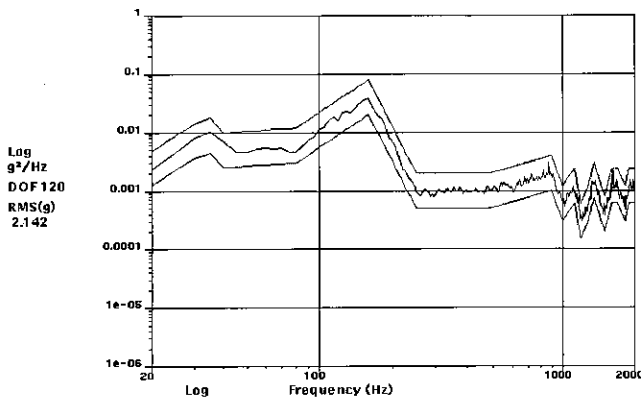
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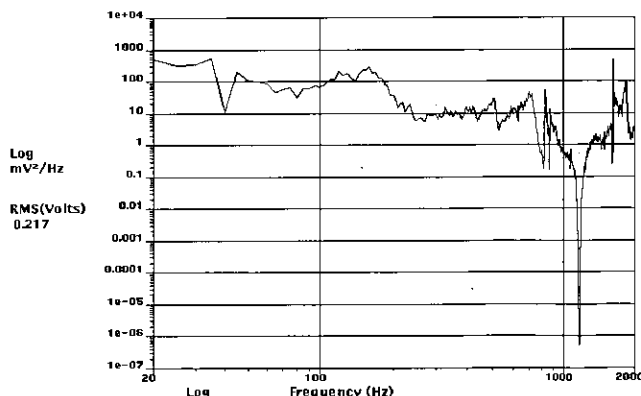
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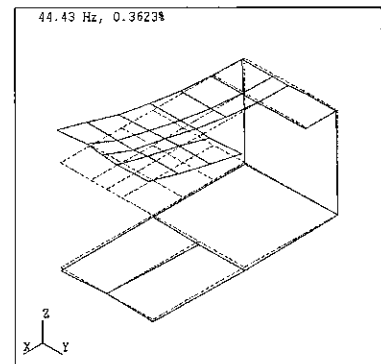
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News from BSI

BS EN Publications

The following are British Standard implementations of the English language versions of European Standards (ENs). BSI has an obligation to publish all ENs and to withdraw any conflicting British Standards (BSs) or parts of BSs. This has led to a series of standards (BS ENs) using the EN number.

BS EN ISO 7235: 1966: Acoustics - Measurement procedures for ducted silencers - Insertion loss, flow noise and total pressure loss.

Sets out requirements for determining the insertion loss, in frequency bands, of silencers with and without air flows; the sound power level, in frequency bands, of the flow noise generated by silencers; and the total pressure loss of silencers with air flow. Not applicable to reactive silencers used for motor vehicles. No current standard is superseded.

Draft British Standards for Public Comment

95/717445 DC

Determination of sound power levels of fan coil units, unit heaters and unit coolers using reverberation rooms.

96/101064 DC Revision of BS 5228 Noise and vibration control on construction and open sites. Part 1: Code of practice for basic information and procedures for noise and vibration control.

Note: Special price £22.50 (non-members £45.00) (157 pages)

96/101065 DC Revision of BS 5228 Noise and vibration control on construction and open sites. Part 2: Guide to noise and vibration control legislation for construction and demolition including road construction and maintenance.

96/101066 DC Revision of BS 5228 Noise and vibration control on construction and open sites. Part 3: Code of practice applicable to surface coal extraction by opencast methods.

96/704435 DC ISO 5347-21 Methods for the calibration of vibration and shock pick-ups - Part 21: Shock calibration using laser doppler velocimeter (ISO 5347-21)

96/561513 DC BS EN ISO 140-12 Acoustics - Measurements of sound insulation in buildings and of building elements - Part 12: Laboratory measurement of room-to-room airborne and impact sound insulation of an access floor (ISO/DIS 140-12) (prEN ISO 140-12)

96/103804 DC EN 12354 Building acoustics - Estimation of acoustic performance of buildings from the performance of products - Part 1: Airborne sound insulation between rooms (prEN 12354)

NOTE: Special price £9.75 (Non-members £19.50) (72 pages)

96/103500 EN 12354-2 Building acoustics - Estimation of acoustic performance of buildings from the

performance of products - Part 2: Impact sound insulation between rooms (prEN 12354-2)

British Standard Implementations

BS ISO 9207: 1995 Manually portable chain-saws with internal combustion engine - Determination of sound power levels - Engineering method (grade 2)

No current standard is superseded

BS ISO 10884: 1995 Manually portable brush-cutters and grass-trimmers with internal combustion engine - Determination of sound power levels - Engineering method (grade 2)

No current standard is superseded.

BS ISO 9568: 1993 Cinematography - Background acoustic noise levels in theatres, review rooms and dubbing rooms.

Specifies measurement methods and maximum ratings.

No current standard is superseded.

British Standards Reviewed and Confirmed

BS 6840:Part 16:1989 Guide to the 'RASTI' method for the objective rating of speech intelligibility in auditoria.

British Standards Withdrawn

BS 6864: - Laboratory tests on noise emission from appliances and equipment intended for use in water supply installations.

BS 6864:Part 2:1987 Method for mounting and operating draw-off taps

Superseded by BS EN ISO 3822-2: 1996

ISO Standards

ISO 3746: - Acoustics - Determination of sound power levels of noise sources - Survey method.

Technical Corrigendum 1: 1995 to ISO 3746: 1979

Will be incorporated into BS EN ISO 3746 which will replace BS 4196: Part 6: 1981 (1986)

ISO 3822-2: 1995 (Edition 2) Acoustics - Laboratory tests on noise emission from appliances and equipment used in water supply installations - Part 2: Mounting and operating conditions for draw-off taps and mixing valves. Will be implemented as BS EN ISO 3822-2 when ratified by CEN, to supersede BS 6864:Part 2: 1987

EN ISOs

The following International Standards have been adopted as ENs. These documents have been approved by CEN/CENELEC.

EN ISO 11200: 1995 (ISO 11200: 1995) Acoustics - Noise emitted by machinery and equipment - Guidelines for the use of basic standards for the determination of emission sound pressure levels at work station and at other specified positions (ISO 11200: 1995)

EN ISO 11201: 1995 (ISO 11201: 1995) Acoustics - Noise emitted by machinery and equipment - Measurement of emission sound pressure levels at a work station and at other specified positions - Engineering method in an essentially free field over a reflecting plane (ISO 11201: 1995)

EN ISO 11202: 1995 (ISO 11202: 1995) Acoustics - Noise emitted by machinery and equipment - Measurement of emission sound pressure levels at a work station and at other specified positions - Survey method in situ (ISO 11202: 1995)

EN ISO 11203: 1995 (ISO 11203: 1995) Acoustics - Noise emitted by machinery and equipment - Determination of emission sound pressure levels at a work station and at other specified positions from the sound power level (ISO 11203: 1995)

EN ISO 11204: 1995 (ISO 11204: 1995) Acoustics - Noise emitted by machinery and equipment - Measurement of emission sound pressure levels at a work station and at other specified positions - Method requiring environmental corrections (ISO 11204: 1995)

EN ISO 11546:- (ISO 11546:-) Acoustics - Determination of sound insulation performances of enclosures

EN ISO 11546-1: 1995 (ISO 11546-1: 1995) Measurements under laboratory conditions (for declaration purposes) ISO 11546-1: 1995

EN ISO 11546-2:1995 (ISO 11546-2: 1995) Measurements in situ (for acceptance and verification purposes) ISO 11546-2: 1995

This information, provided by John Tyler, was announced in the January-June 1996 issues of BSI Update ♦

Book Reviews

Waves and Distributions

Thordur Jonsson and Jakob Yngvason
World Scientific 1995, 186pp hardback
ISBN 981-02-0974-6 £35

You would probably ignore this volume in a bookshop. There are no sleeve notes, the preface is short and sharp, and there is no introduction. Even the title is misleading if you are not up to date in mathematical terminology. In short, there are few clues to what it contains.

But you would be making a mistake. It actually provides a rigorous and comprehensive, yet concise treatment of the mathematics needed to deal with acoustics and wave phenomena in general. The language is terse and mathematical, and assumes a background in calculus of many variables and linear algebra, as well as a grasp of mechanics and electricity and magnetism. However, the arguments are clear and logical. Derivations and theorems can be followed without the frustrating hunt through earlier sections for the meaning of symbols and terminology found in so many books. Furthermore, there are none of the unexplained and unfathomable jumps that are so commonly prefaced by phrases like 'it may be shown that...', 'we leave it to the reader...', or just 'obviously...'. The book starts with a self-contained introduction to fluid mechanics and the theory of elasticity, leading to derivations from first principles of the wave equations for sound waves in fluids and elastic waves in solids. This includes a useful explanation of the often taken for

granted linearity approximations and their consequences. A brief second chapter follows on electromagnetic wave equations. The third chapter then moves on to plane waves, stressing the importance of harmonic waves, and introduces boundaries, reflection and refraction.

The fourth chapter introduces the theory of distributions. This is the potentially misleading part of the title. The term 'distributions' here does not have the statistical meaning most of us would assume, but refers to the class of generalised functions that can be used in just the same way as normal functions. The Dirac delta is given as an example. By developing the theory of mathematical operations in spaces of distributions, the reader is lead via convolution to Fourier analysis in a way that does not require the usual fudging around various problem areas like functions that are continuous 'almost' everywhere.

This treatment is expanded in Chapter 5, probably the most important part of the book, to general solutions of wave equations in homogeneous media and spherical waves in particular. Initial values are introduced, Huygens' principle is explained, and cavities and waveguides are dealt with. Chapter 6 then concludes with a discussion of dispersion. It is a shame there is not also a chapter on diffraction.

There is no conclusion, and the book finishes with a short list of 56 mostly mathematical references and a skimpy index. A page of 16 errata came with the review copy and there are a few fairly obvious typos in the text, but this is neither better nor worse than most technical books.

In summary, then, this is a useful book on the mathematics of wave phenomena, covering almost all aspects of the subject. It would be particularly useful as a complement to one of the many good acoustics books that are unfortunately a bit too fluffy in their mathematics. It would be even more useful, and probably sell better, with some padding in the way of a meaningful introduction, an expanded bibliography, and a more comprehensive index.

Peter F Dobbins FIOA ♦

Artificial neural networks for speech analysis/synthesis

M G Rahim

Chapman & Hall, 1994 pp
ISBN 0-412-56370-3 £35

This book is one of the very few publications available that systematically study the use of artificial neural networks (ANNs) in the very challenging field of speech analysis & synthesis. The book contains nine chapters that can be vaguely grouped into an introductory and reviewing section (Chapters 1-4); a research section dedicated to the use of ANNs to achieve articulatory model based speech analysis & synthesis (Chapters 5-8); and a summary and concluding section (Chapter 9). The introductory and reviewing section firstly provides a brief history of the art of speech synthesis and a short review of the human speech production process as well as various digital synthesis techniques in this field. It then introduces the reader to some common ANN models as well as their learning techniques with the emphasis being placed on

the multi-layer perceptron (MLP) model and the back propagation algorithm. This is followed by a review of ANN aided speech analysis techniques and several case studies illustrating the potential of using ANNs in speech analysis & synthesis. The second section of the book specialises in the area of articulatory speech synthesis. It covers articulatory modelling, the use of ANNs to achieve the required acoustic/geometric vector mapping, the techniques for establishing an appropriate training data set, and the use of the dynamic programming technique to select an optimal sequence of articulatory geometric parameters so that the inherent ambiguity of the non-unique acoustic-to-articulatory parameter mapping can be accommodated. The final section gives a summary of the book contents together with two suggested future research directions for ANN based articulatory speech synthesis.

The book places emphasis on bringing together prior background material and recent research results on the use of ANNs for speech analysis & synthesis. It therefore can be an informative introductory and referencing source for diverse readers who happen to have a prior basic knowledge, up to graduate level, in speech processing and are interested in using ANNs for speech analysis and synthesis. Given the complexity involved in achieving high quality speech synthesis and the fierce commercial competition in trying to pioneer a low-bit rate product among top international giants, it should hardly be surprising that the book is more likely to be enjoyed by scientific researchers, and the price of the book, £35, just reflects it.

Nongji Chen ❖

Surface Acoustic Waves in Inhomogeneous Media
S V Biryukov, Yu V Gulyaev, V V Krylov and V P Plessky
Springer Series on Wave Phenomena, Volume 20
ISBN 3 540 58460 9 £69

For many physicists and engineers, surface waves are a mathematical curiosity, first encountered during initial studies of wave motion, and subsequently forgotten as of little practical importance. This book is a timely reminder that surface waves actually have many practical applications, a fact which is given a prominent place both in the introduction and throughout the text. Acoustic surface waves are specifically considered in this book and their interactions with inhomogeneities in the medium are treated both theoretically, as well as from the point of view of the practical applications to which these can be put. Many of these applications are to solid state electronic devices, and so surface waves, as a phenomenon that has long had a theoretical base, have in a sense recently come of age.

This book, a translation of an existing Russian text, is really a collection of papers on individual topics. The first chapter gives a fairly brief treatment of basics for the main types of surface waves, while the next fourteen chapters all deal with fairly specialised questions. Initially there is a good deal of emphasis on the interaction between surface acoustic waves and electrons in the material leading to various acousto-electronic effects,

including amplification and charge transfer. Piezoelectrics and various types of layered media also come in for discussion, together with surface waves at interfaces.

An overriding theme of the book, as might be expected from its title, is the effect of spatial inhomogeneities on the surface with surface acoustic waves. These surface irregularities include specific shapes such as apertures, wedges and edges, as well as arrays of features like lines or grooves of different cross-sections. Scattering by random inhomogeneities is also treated. The presentation achieves a good balance between mathematical detail and explanations in terms of physics. Page after page of equations can often be discouraging for the reader who wishes to obtain some initial insight into an unfamiliar subject and this book wisely avoids this pitfall. There is an abundance of useful illustrations and frequent discussions of applications. There is a very full collection of references for each chapter as well as a large bibliography for ten specific topics. Taken together, these provide a useful guide to the latest progress in the subject.

This book is a useful addition to the Springer Series on Wave Phenomena. It will be welcomed by all who wish to gain some insight into the behaviour of surface acoustic waves and the numerous applications that they have found.

B J Uscinski ❖

Detailing for Acoustics (Third Edition)
Peter Lord and Duncan Templeton
E & F N Spon, 1995 200 pp.
ISBN 0-419-20210-2 £37.50

This is the 3rd Edition of the book, and I hoped as a user of the 2nd Edition that this update would be an improved version. I was pleasantly surprised as the most annoying aspects of the 2nd Edition have been addressed and almost eradicated.

The stated objective of the book is to provide a practical reference manual for Architects, Students, Structural and Services Engineers and Interior Designers. I suspect that the average Architect, Engineer or Designer would not use the book to its potential. The user of this type of book needs to know about the basics in order to make good use of it. It does provide a wealth of information, in respect to comparing performances of various components which is extremely useful for the practising Acoustician.

It includes a compendium of information which saves the need to continuously keep a bookshelf handy. The main section includes data on the sound insulation performance of building components and is very informative and quite expansive with numerous third octave sound insulation test data.

There is a section on sound absorbing and reflecting materials. Again it includes useful data based on test results.

The other section covers plant and services noise. It includes a diverse range of topics, with some quite unusual information.

Any comprehensive book on the subject range will have difficulty in slotting the data in the appropriate sec-

tion. This book is quite logical in that respect and is provided with a reasonable index.

The numerous drawings and tables are generally quite clear, though sometimes an important bit of information appears to be missing. In this respect, the 3rd Edition is much clearer and includes improved and updated information as compared to its predecessor.

The book has a paperback cover which does not do it justice. It could really do with a long lasting hardback cover. At £37.50 it provides good value for money.

R Peliza ❖

Sound Transmission through Buildings using Statistical Energy Analysis

Robert JM Craik

Gower, 1996

ISBN 0-566-07572-5,

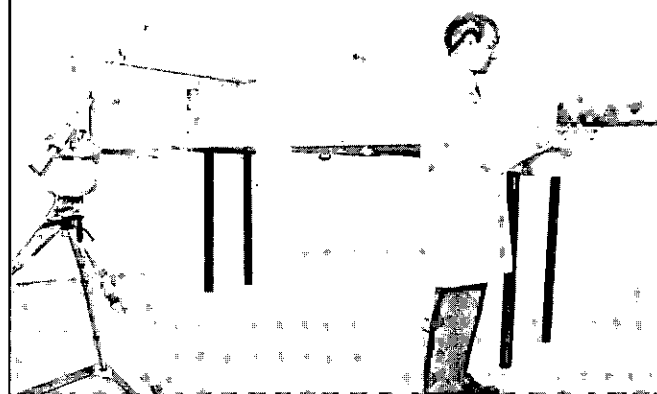
This book by Professor R.J.M Craik is suited to those with a working knowledge of acoustics who are interested in both the general application of Statistical Energy Analysis (SEA) and the more specific modelling scenarios that are encountered when dealing with structure-borne sound transmission in buildings. The layout of the book is such that the reader can logically progress through the book from cover to cover or delve into chapters for specific information. A short tutorial introduction uses a simple direct transmission problem to illustrate to the new user, relationships between the theories and parameters of classical acoustics with those of SEA before proceeding to deal with SEA in greater detail. The subjects covered include:

- SEA models in terms of system and subsystem definitions
- Subsystem properties
- Coupling loss factor definitions for radiation and structural coupling
- Calculation of structural coupling loss factors using a wave approach
- Calculation of system performance using both path and matrix analysis
- Applications of SEA modelling to direct and flanking transmission in building acoustics

The applications chapters build on the work of the previous sections to show measured and SEA predicted data which along with modelling and analysis information, provide the reader with an insight into significant transmission paths for various building constructions. Among the constructions considered in these chapters are double walls (masonry and lightweight), lined masonry walls, and single masonry walls in a complete building. Tabulated structural transmission coefficient data and information on prediction accuracy with particular reference to the uncertainties and errors involved with real building constructions also make this a useful reference text. Implementation of SEA in a specific application area requires that informed decisions are made at both the modelling and analysis stages. This book provides the reader with an engineering approach to the application of SEA for sound transmission in buildings and a basis on which those decisions can be made.

J W Sargent MIOA ❖

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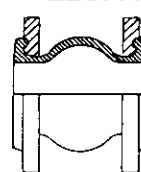
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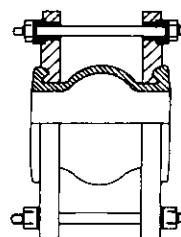


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Active Control of Noise and Vibration

C B Hansen, Department of Mechanical Engineering, University of Adelaide, Australia

Written for all those involved in the active control of noise and vibration, both in industry and academia. In the first half of the book, the authors explain the fundamental concepts underlying the various sub-disciplines of active noise and vibration control. They then apply these concepts to practical systems. This book is the first to treat the active control of both sound and vibration in a unified way, and contains the most up-to-date developments and research.

234x156mm approx. 1300 pages 520 line illus
September 1996 Hardback: 0-419-19390-1 approx. £150.00

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F J Fahy, Institute of Sound and Vibration Research, University of Southampton, UK

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Detailing for Acoustics

3rd edition

P Lord, University of Salford and **D Templeton**
BDP Acoustics Ltd

● an at-a-glance manual of construction details

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Oros's UK distributor is Diagnostic Instruments.

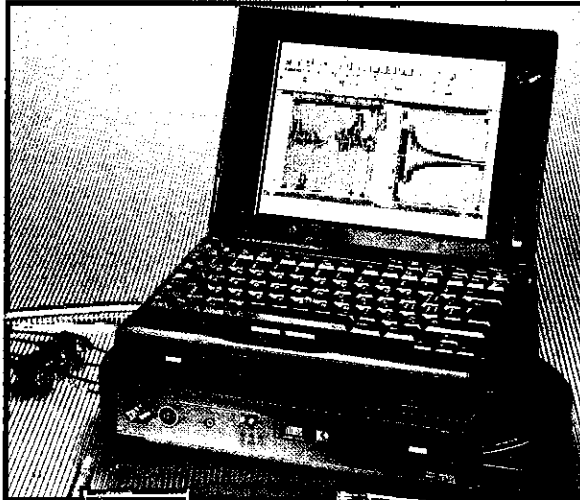
For more information contact Sylvie Souchon, OROS 13 chemin des Prés, ZIRST 4403, 38944 MEYLAN Cedex. Tel: (00 33) 76 90 62 36; Fax: (00 33) 76 90 51 37.

VSI CLUBLIFE

New sound ceiling

A new sound system is claimed to eliminate many of the noise problems associated with discos, nightclubs and other entertainment venues.

Loud music can fall foul of Environmental Health Departments because of noise nuisance and staff



can experience noise induced hearing loss through extended exposure to high sound levels.

VSI Clublife Ltd, a specialist sound and lighting supplier, now claim to be able to eliminate most of these noise problems with their new 'sound ceiling'. The system, designed by JBN of Sweden, consists of nine acoustic tiles set in an unobtrusive 3m square frame which is suspended from the ceiling directly over the centre of the dancefloor.

The tiles (600 mm x 600 mm) are constructed of sound proofing materials to minimise any noise or vibration problems passing to the floor above and eight loudspeakers are set into each one. The loudspeakers are pointed downwards which makes the overall sound very directional. This, say VSI, reduces the levels by 80% (10dB) within one to one

and a half metres of the dance floor.

VSI use a CEL-269 sound level meter to test and demonstrate the effectiveness of the sound system. The simple to use meter clearly shows the difference between the levels on and off the dancefloor. John Stevens of VSI said 'Although the audible difference in levels is very noticeable the meter visibly demonstrates just how important this reduction is in real terms. This is a significant factor in the system's success.'

The reduction is so dramatic that it is possible for bar staff and customers to talk at normal conversational levels when they are just a short distance from the dance floor. The system also means that the expenditure and difficulty associated with other more conventional sound proofing measures, like double glazing and baffling, are no longer necessary.

Each of the tiles can be supplied with a variety of coloured surfaces to match the venue's decorative style. These include an ultra-violet finish which appears white in daylight but changes colour depending on the light source.

There is also a choice of power output for the loudspeakers to suit the various sizes of venue.

The 'sound ceiling', which featured on BBC's 'Tomorrow's World', has already been installed in many nightclubs, community centres, hotels, fun pubs, caravan parks and restaurants.

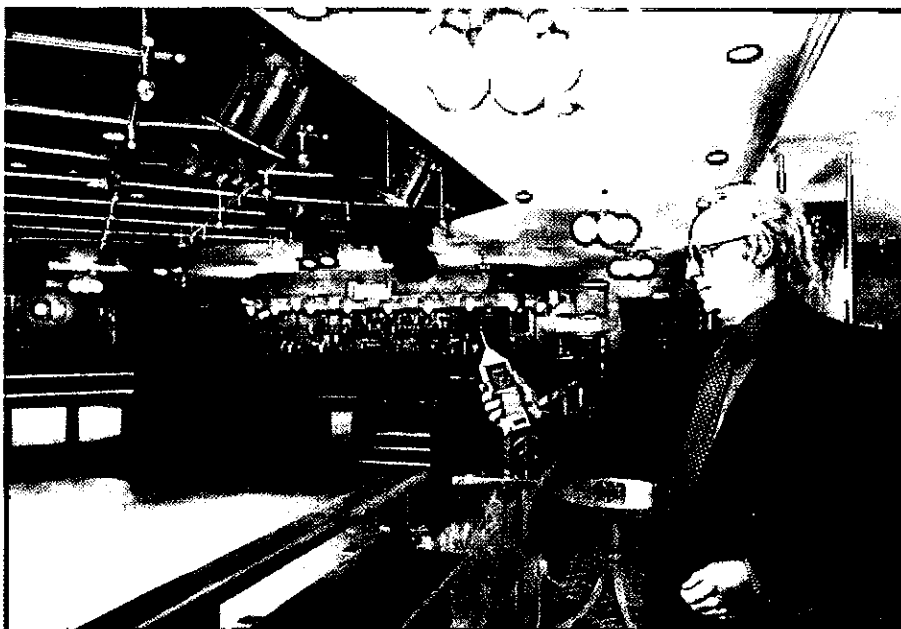
For information on sound level meters contact CEL Instruments Ltd., 35-37 Bury Mead Road, Hitchin, Herts SG5 1RT Tel: 01462.422411 Fax: 01462.422511

For information on sound ceilings contact VSI Clublife Ltd, 75 Gloucester Road, Croydon, CRO 2DL Tel: 07000-883131 Fax: 0181 665 5288.

QUANTITECH

RION NL-18 Integrating sound level meter

A new, dual display, Type 1 Precision Integrating Sound Level Meter, designed for measuring both Workplace and Environmental Noise to



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FOR A HIGHER QUALITY LIFE



inter-noise 97

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BUDAPEST - HUNGARY
1997 AUGUST 25-27

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FIRST ANNOUNCEMENT

INTER-NOISE 97, the 1997 International Congress on Noise Control Engineering, will be held at the Technical University of Budapest, in the capital of Hungary from 1997 August 25 to 27. The Congress is sponsored by the International Institute of Noise Control Engineering, and is being organized by the Acoustical Commission of the Hungarian Academy of Sciences and the Hungarian Scientific Society for Optics, Acoustics, Motion Pictures and Theatre Technology.

INTER-NOISE 97 will be the twenty-sixth in a series of international congresses on noise control engineering that have been held all over the world since 1972. The theme of INTER-NOISE 97 is: HELP QUIET THE WORLD FOR A HIGHER QUALITY LIFE.

Technical papers in all areas of noise control engineering will be considered for presentation at the congress and for publication in the Congress Proceedings.

An Announcement and Call for Papers will be issued shortly; copies will be available from the Conference Secretariat at the address given below.

A major acoustical equipment, materials and instrument exhibition will be held in conjunction with INTER-NOISE 97. The exhibition will include materials and devices for noise control as well as instruments such as sound level meters, acoustical signal processing systems, and equipment for active noise control.

Programs for "accompanying persons" and social activities for all delegates will be organized.

Further information on the Congress and the Exhibition may be obtained from the INTER-NOISE Conference Secretariat

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Please return this coupon if you are interested in being added to the mailing list for INTER-NOISE 97.

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☐ My company may be interested in participating in equipment exhibition

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British and European standards has been introduced by RION of Japan.

The RION NL-18 is much easier to use than most meters as it has only four operating buttons. The extensive set up keys and programming controls are recessed and covered to prevent tampering or accidental resetting during use, and the set up parameters will be retained even after the instrument is switched off.

This new meter is instantly recognisable by its TWO LCD displays - one presents measurement data in both digital and analogue forms, the other a graphic display of instantaneous sound level, and both graphic and numeric presentation of octave and third octave spectra. Two frequency- and two time-weighted measurements can be made and, unusually for an instrument of this type, displayed simultaneously, as well as Leq, SEL, Lmax, Lmin and 5 percentile levels. Ln can be displayed (n=1-99%) for preset measurement periods of 1 second to 24 hours. The instrument's memory will store 100,000 instantaneous sound levels, Leq, Lmax and Ln data of 7200 periods and up to 100 octave and third octave spectra. Battery life in continuous operation is 24 hours. Further details from Quantitech Ltd, Unit 3 Old Wolverton Road, Old Wolverton, Milton Kynes, MK12 5NP Tel: 01908 227722. Fax: 01908 227733.

AcSoft Ltd

SVAN 912 sound and vibration analyzer

Sound and vibration measurement specialist AcSoft is distributing Svan-tek's SVAN 912 handheld sound and vibration analyzer.

This new analyzer provides not only a wide range of sound measurement features but also comprehensive vibration analysis func-

tions. With microphone, charge, ICP and direct inputs, the SVAN 912 offers outstanding flexibility for on-the-spot analysis in industrial applications such as noise control, occupational health and safety at work, machinery health monitoring, industrial quality assurance and research & development.

The SVAN 912 is a dedicated sound and vibration Type 1 meter providing measurement of SPL, Leq, SEL, acceleration, velocity, displacement, voltage level, and statistical analysis. Users can select from built-in linear, A, C, 'human response to vibration' weighting filters, and a G infra sound filter, and there is a choice of time constants. A time history of up to 32000 results can be measured in parallel with octave- and third-octave realtime digital filter analysis.

Analysis functions also include FFT analysis of acceleration, velocity, and displacement, as well as noise. The choice of windows, frequency resolution, zoom, averaging, and spectrum manipulation functions is spectacular for a handheld instrument, with the large 128 x 128 pixel backlit LCD providing a wide variety of display options.

Control of the SVAN 912 is menu-based for ease of operation. PC connectivity is provided via an RS232C/Centronics interface, and AcSoft can supply a versatile software package for set-up and downloading results.

The SVAN 912 is powered by internal battery, providing a full day's operation, or through an AC power adaptor. The standard 256kbytes non-volatile memory can store up to 350 100-line FFT spectra, 1280 octave spectra, or 760 third-octave spectra. The memory can be expanded to 1Mbyte.

Head Acoustics' system

Head Acoustics' HEAD Measurement

System is now available in the UK from AcSoft.

Head Acoustics' state-of-the-art technology, based on many years' experience in artificial head binaural recording technology, provides aurally accurate, fully reproducible recordings of sound signatures. Applications include noise diagnosis and analysis, product development including automotive development, quality control, communications measurements and architectural acoustics.

The HMS II Artificial HEAD Measurement System precisely replicates the human anatomical and auditory system. It is compatible with modern measurement technology, allowing new standards to be achieved in binaural sound recording, analysis and playback. Features of the artificial head system which extend its applicability include capabilities for calibration, remote control, field operation, and DAT recording. Measurement parameters such as range and equalisation settings, filters, rpm, date and time are stored within the system to be accessed as required.

Head-Acoustics' modular range of support equipment for the artificial head provides for digital storage and archiving, aurally equivalent analysis and post-processing, and faithful reproduction using the HEADphone Playback System. Analysis options include binaural and multichannel systems, while a communications analysis system is designed for use in tandem with a dedicated version of the artificial head adapted for send and receive testing of telephone terminal equipment and echo cancellers. Other variations adapt the system to specialised applications. The head and shoulder simulation can be separated from the electronics for easier deployment. A binaural microphone



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allows a person, for example the driver of a car, to assume acoustic functions similar to the artificial head. A binaural filtering system allows manipulation of right and left channels in the frequency domain for identification of annoying noise components.

For further information contact: John Shelton, AcSoft Ltd., 6 Church Lane Cheddington, Leighton Buzzard. LU7 ORU. Tel: 01296 662852. Fax: 01296 661400.

News Items

BITS & PIECES

Website sound effects track listings

BITS & PIECES has launched a website, giving full track listings of all 12 currently released Sound Effects CD's and custom sound effects service. The website also has information on BITS & PIECES acoustic and audio engineering consultancy services.

Clients of BITS & PIECES include the BBC, the Royal Opera House and the Royal National Theatre, who have all used both sound effects and consultancy services on prestige projects such as the recently refurbished BBC Radio Theatre. Recent consultancy work includes noise assessments of musicians to comply with the Noise at Work Regulations. For more information visit the website at

<http://www.users.dircon.co.uk/~bits/>
or contact: BITS & PIECES 105, Chariton Church Lane, London SE7 7AB
Tel: 0181 858 9738. Fax: 0181 488 0846. E-mail: all@bits-and-pieces.co.uk

FERGUSON AND TIMPSON

Acoustic test chamber at Internoise 96

An acoustic test chamber able to provide 24 dB(A) background noise level will be featured at Internoise 96 in Liverpool on the Ferguson and Timpson Ltd stand (No.28). When developing the design for this Acoustic Test Chamber, the brief was to provide a test environment, incorporating a sound absorbent lining, to achieve a cut-off frequency of 300Hz. The target internal ambient noise level in the 1.75m³ chamber was 25dB(A). Independent tests gave a result of 24dB(A).

This design of chamber is not intended to be within ISO requirements for anechoic rooms but it does provide a cost effective, controlled acoustic environment which can be used for both quality assurance and development applications. Orders for four of these chambers have been received from manufacturers in the computer peripherals and automotive components markets.

Ferguson and Timpson will also be including on their stand, information on their design and manufacturing capability for acoustic enclosures as well as details of their range of materials for noise control and vibration/shock absorption.

For further information contact Peter Timpson, Tel: 0141 882 4691.

LARSON-DAVIS

Catalogue and Internet home page

The new catalogue from Larson-Davis enables readers to quickly seek and find an environmental noise monitoring system configuration ideally suited to a wide variety of applications.

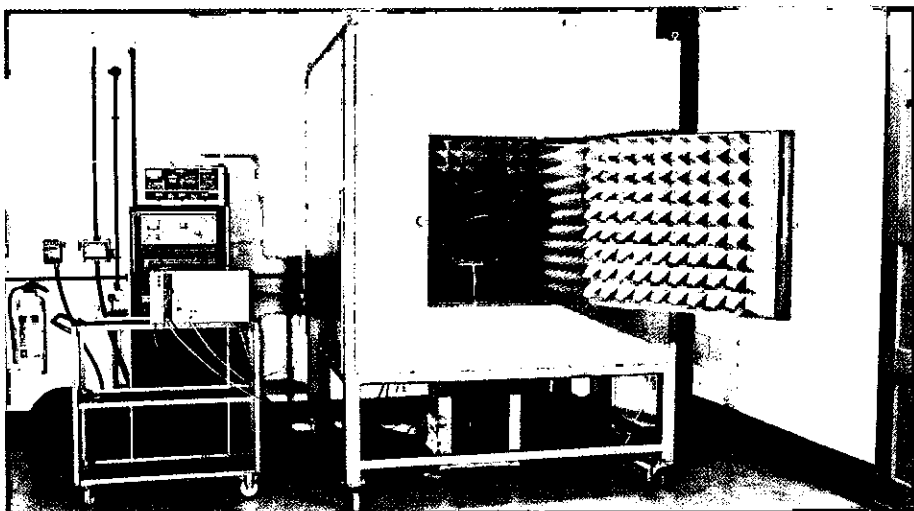
Configurations include the 'Feather-weight', 'Light weight', 'Light-heavy-weight', and 'Heavy-weight' portable systems plus the 'Permanent Outdoor Monitoring System' similar to the L.D system used at Heathrow, Gatwick and Stansted airports.

The catalogue contains technical information including descriptions of each configuration with photographs and schematic diagrams.

Five different computer software packages give further choice and control to the customer. Software includes modules from simple download into a standard spreadsheet package, to more sophisticated products for automatic calibration and remote set-up though direct line and cellular modem communication.

Sensors for windspeed, direction, temperature, humidity, barometric pressure and rain gauge are clearly described so pricing can be quickly determined to keep overall control of purchase well within the customers grasp.

Provo, UTAH-Larson Davis Incorporated (Nasdaq Symbol 'LDII') have also announced the release of their 'Superior Sound and Vibration



Instrumentation' home page at "http://www.lardav.com".

Larson Davis' initial entry to the Internet includes full text and graphics for its product specification sheets; a calendar of upcoming shows featuring Larson Davis booths; an overview to the Larson Davis service and support policy; an e-mail link to the Larson Davis Marketing Department for additional product and pricing information; and a comprehensive international directory of Larson Davis sales representatives including phone and fax numbers, e-mail address and related links.

The catalogue and more information about the home page are available from Alan Boyer at Larson Davis Ltd, Redcar Station Business Centre, Station Road, Cleveland, TS10 2RD or by telephone on 01642 491565.

NPD ASSOCIATES

Dairy at peace with the neighbours – thanks to new British Aluminium noise barrier

Northern Dairies in Manchester



needed to re-direct incoming milk delivery tankers to reduce the amount of on-site manoeuvring. The new traffic system involved planning (change of use) permission, and as the dairy site is next door to a residential area, a potential noise pollution problem had to be anticipated.

Advice was obtained from Andy Turnbull from the University of Salford's Department of Applied Acous-

tics, and a specification determined for a noise barrier to be erected around part of the perimeter of the dairy site.

Baco Contracts, a member of the British Aluminium group, was selected to supply and install their recently-developed absorbent noise barrier 120 metres in length, 5.4 metres high, constructed from maintenance-free aluminium.

The new barrier is of an absor-

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- simple front-panel operation
- up to 20 dB gain, AC coupling and ICP power, all switchable
- single-channel version available

The Kemo VBF18 provides two channels of true one-third octave bandpass filter in a compact 1.75-inch high box. The 3-digit resolution of cutoff frequencies means that all standard centre frequencies in the audio band can be set. A complementary band elimination mode adds greatly to its versatility.

Each response is sharper and more accurate than one made up from lowpass and highpass filters, and requires only one channel instead of two. A rear-panel parallel input allows for simple remote frequency switching, and computer interfaces can also be supplied. ® Registered Trade Mark.

Kemo Ltd., 12 Goodwood Parade, Elmers End, Beckenham, Kent BR3 3QZ.
Tel: 0181 658 3838. Fax: 0181 658 4084.

bent type, constructed from modular (600mm x 4 metres) aluminium panels containing sound absorbent and sound insulating materials. British designed, made and tested, the Baco noise barrier features profiled perforated aluminium on the noise pollution facing side, whilst the reverse side is profiled aluminium sheet (a variety of colours are available for both sides of the Baco barrier and depending on application, different finishes are available on the reverse side). Prefabricated and modular panel construction allowed the installation team to make rapid progress thereby containing labour costs and time.

Independent tests conducted on site, after installation, have proved that the new noise barrier provides an average insertion loss of 22.8 dB(A) using a typical HGV vehicle noise source – a performance which is addressing the envisaged noise pollution problem.

For further information, contact Stuart McCallum at NPD Associates

01782-717292 Tel: or Julian Crabb at Baco Contracts Tel: 01753-233466.

WIMTEC ENVIRONMENTAL LTD

Management acquires Wimpey Environmental

Wimpey Environmental Limited a subsidiary of George Wimpey plc, has been acquired by the management. The new company will trade as Wimtec Environmental Limited and will retain the skill base, experienced staff, quality accredited laboratories and other facilities of the long-established technology business. It will also continue to operate from the existing head office at Hayes, Greater London, and regional offices in Cardiff, Birmingham, Warrington and Edinburgh.

Wimtec Environmental will continue to provide technical support to the Wimpey Group and aim to further develop site investigation, environmental measurement and consultancy, and laboratory services in

order to continue to satisfy client requirements and concerns over environmental issues and legislation, property and land liabilities and development opportunities.

Under the terms of the management buy out, Wimtec Environmental acquires the existing and diverse capabilities of the company, ranging from site investigation and geotechnical engineering, to measurement and assessment of the natural and built environments. The company has developed specialist skills and experience associated with construction, property, housing and mineral activities. These services are supported by an extensive holding of analytical instrumentation, plant and equipment and laboratory facilities for soils, chemical, microbiological and asbestos testing.

The acquisition of Wimpey Environmental Limited also includes its subsidiary company WIMLAS Limited, a Government approved certification body for European Technical Approvals under the

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Construction Products Directive. WIMLAS Limited will continue to operate under its established and successful format and present name.

The acquisition does not include the oceanographic consultancy business, based in Swindon, which was sold to Fugro Holdings in June. For further information, contact Phil Ellis, Business Development Director, Wimtec Environmental Limited on: 0181 573 7744.

METROLOGY FOR WORLD CLASS MANUFACTURING AWARDS 1996

Building on the successful launch of the Metrology for World Manufacturing Awards in 1995, the metrology industry now proudly claim a credible platform which recognises achievement, excellence and the value added contribution of metrology products, systems and technology.

'This award scheme represents a

key step forward in the promotion of metrology as a critical component of future manufacturing success.' - Tim Eggar, Minister for Trade and Energy.

The four Award categories recognise the continuum that exists in metrology, from scientific research through to applications in manufacturing industry.

The Metrology for World Class Manufacturing Awards are presented annually at a Gala Awards Dinner Ceremony, which, in 1996, will take place on Tuesday 26 November at the Metropole Hotel, Birmingham, UK during Manufacturing Week exhibitions.

Winners will receive a specially commissioned trophy and, in categories which incorporate the NPL Awards for Measurement, financial reward. More importantly, they will receive due recognition, and encouragement to aspire to greater levels of excellence, innovation and success.

Nominations are sought from individuals and organisations who

can give evidence of new ideas, of real added value, of innovation and product system excellence, that ultimately contribute towards World Class Manufacturing in the UK.

Judges will take into account the added value contribution in terms of degree of innovation, of cost reduction, increased performance, quality standards, product development, speed to market and efficiency, depending on the category.

Data and testimonial evidence will be welcomed by the judging panel as will examples of supplier input into end product development.

All entrants will be acknowledged and shortlisted entrants may be invited to present their case to a judging panel

Eligibility

Category 1. All university staff and students, industrial and government researchers - employed in the UK. University applications must be endorsed by a Head of Department

Category 2. Industrial organisations involved in manufacturing,

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with or without the collaboration of universities, technical colleges or government research organisations.

Category 3. Companies which have benefited from the case studies. Case studies may not necessarily have been prepared by the applicant itself.

Category 4. Nominated individuals in private or public employment. Self nomination, particularly in the publicity and media category, will be considered provided suitable referees are given.

Award Categories

1. Frontier Science and Measurement – innovation in metrology and measurement standards for industry and research.

2. Innovative Metrology – applications of measurement technology in manufacturing.

3. Measurement for manufacturing excellence – proven applications of metrology which have contributed to wealth creation in the UK manufacturing scene. Entrants are asked to describe the market sector – ie Construction – Electronics – Energy – Process Industries – IT/Communications etc.

4. Champions of Metrology – individuals or organisations raising the profile of metrology for manufacturing excellence in the UK, through Training and Education in Metrology, Publicity and Media, Promotion of UK industry metrology interests at a National, European or International level within and through government structures and organisations.

For further information, contact Bernard Berry, NPL. Tel: 0181 943 6215. Fax: 0181 943 6217.

CEL INSTRUMENTS LTD

New analyser cuts product noise testing time

A new analyser has cut product noise testing time at Brush Electrical Machines from six man hours to just one half hour.

The Loughborough company carry out regular acoustic emission tests on their range of machines which range from 65 kW units to giants providing 120MW and weighing over 120 tons.

Measurements (conforming to BS 4999 part 109 1987) are taken at various points around and over each machine to enable a report to be produced to meet their customers' requirements.

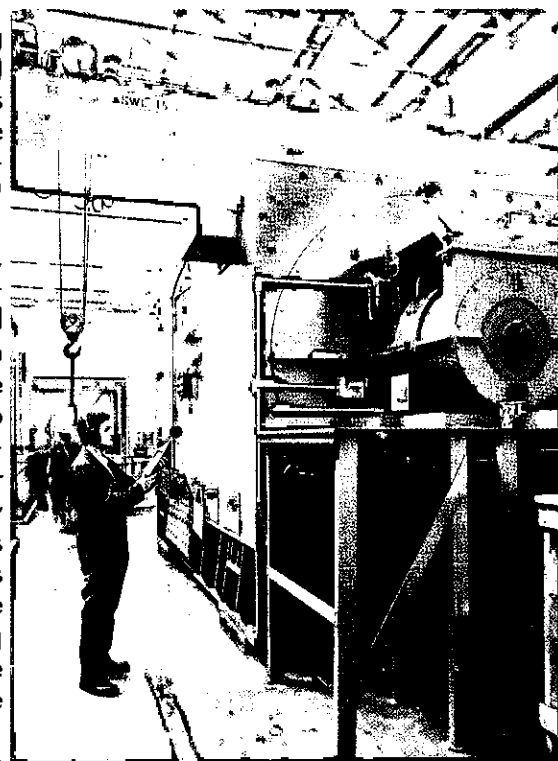
With earlier equipment, offering only sequential measurements, one engineer would take a measurement for each frequency band and shout the answer to his companion to record on paper. This procedure had to be repeated for each of the nine frequency bands at each location. This was a problematic process as the high noise levels from the machines can make hearing difficult. One ambient noise level reading would also be taken.

When the test was over the results would be typed into a spreadsheet to produce the report. For the largest machines there could be up to 350 readings to enter. The total procedure took over six man hours to complete.

Since March 1996 Brush Electrical Machines have used a CEL real-time sound level analyser which eliminates nearly all of the manual and repetitive work by simultaneously measuring all of the octave bands and automatically storing the data to memory. This makes it possible for one engineer to carry out a full analysis at each measurement point in a few minutes which is not only more cost effective but reduces the engineer's exposure to noise to the minimum. Because of this operational speed background noise readings are now taken at each measurement point to ensure that the external noise from other operations in the factory do not affect the actual machine emissions.

The stored data from both the Ambient and machine noise measurements is downloaded directly into the computer using the CEL Sound-track dB1 software and then exported to a Lotus 1-2-3 spreadsheet software package.

A macro then loads both sets of data into the appropriate positions



in the spreadsheet, performs the calculations to BS 4999 part 109 (to produce the sound power level for the all of the required bandwidths) and prints a report incorporating text, data and graphical information.

A detailed application note on the advantages of using the CEL Real-time sound level analyser for product noise testing is available free of charge from CEL Instruments. For a copy of the application note and for information on CEL sound level meters: CEL Instruments Ltd., 35-37 Bury Mead Road, Hitchin, Herts SG5 1RT Tel: 01462 422411 Fax: 01 462 422411

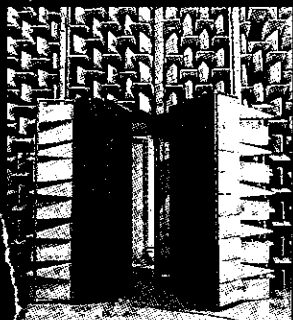
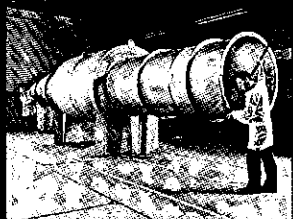
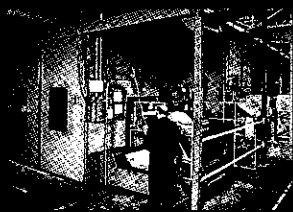
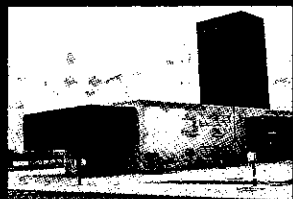
News of Members

Professor John Ffowcs Williams FIOA who is at present Rank Professor of Engineering (Acoustics) in the University of Cambridge, has been elected to be the next Master of Emmanuel College, Cambridge. He will take up the new post on October to succeed the present Master, Lord St John of Fawley.



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OPTIONS
13:25:14 BATT=8.8 V
CONTRAST m/sec²
REF TONE CALIBRATE
SET CLOCK DELETE MEM
DOWNLOAD **PRINT**
TO SELECT

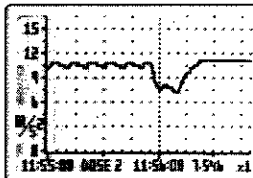
Clear and concise menu screen allows for easy set up & use.

00:08:13 LIN RUN
RANGE 0.01-30 m/sec²
A =0.000 ALEG=4.337
AMAX=29.41 AMIN=0.000
PROFILE ON
DOSE OFF STORED 0

Comprehensive display of all measurement parameters both in memory and while collecting data.

DOSE 2 RUN 4 LIN
RANGE 0.003-10 m/sec²
BEG 11:55:08
AMAX=11.10 AMIN=6.987
ACTUAL DUR 00:01:59
DOSE(8HR) = 0.661
BEG DUR 04:01:59
DOSE(8HR) = 7.383

99 user runs - each can contain 7 dose set ups for various machines.



Full profile capability of every dose.

DOSE(m/sec²) RUN10
1 ✓ 2.244
2 ✓ 0.725
3 ✓ 1.257
4 ✓ 1.922 DAILY DOSE (8HR)
5 ✓ 1.959 4.700
6 ✓ 0.806
7 ✓ 2.683

The result 'A 8' daily dose displayed on screen.



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