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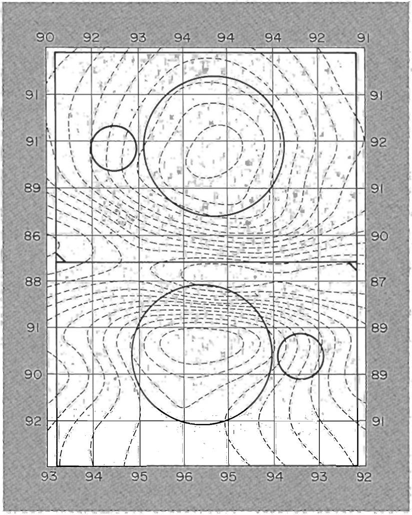

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The DEADLINE for receipt of news items, reports and advertising copy will be **25 SEPTEMBER 1991.** (see opposite page for the editorial staff to contact).

Acoustics Australia

Vol 19 No 2 August 1991

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COVER ... Acoustic intensity map for two loudspeakers (see article by JCS Lai).

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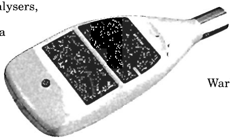

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Standards for Medical Ultrasound and Transducer Calibration At the National Measurement Laboratory

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ABSTRACT: Ultrasound is used widely in medicine for diagnostic, therapeutic and surgical purposes. Mechanisms by which ultrasound can affect biological tissue are briefly reviewed. From these mechanisms it is possible to identify some of the acoustical parameters that should form the basis of exposure measurements. The principle methods of measuring these parameters are described with particular reference to the facilities presently available at the National Measurement Laboratory, CSIRO.

1. INTRODUCTION

Ultrasound is used in various medical diagnostic, therapeutic and surgical applications. When used diagnostically, especially in obstetrics, the received exposure to ultrasound must not have adverse biological effects. However, in physiotherapy, the exposure must be large enough for the ultrasonic vibration to affect the tissues. In surgical applications, high power ultrasonic waves are focused onto regions of tissue for destructive purposes. For example, in lithotripsy, kidney stones are shattered by highly focused ultrasonic shock waves.

Since ultrasound interacts with biological tissue, it is essential to know the ultrasound exposure level in order that an assessment may be made of any possible hazard to a patient during an application. International organisations have drawn up safety standards for both diagnostic and therapeutic equipment [1-5]. These standards require that the ultrasound output power, the intensity and the beam parameters must be specified. Furthermore, some of these performance standards [1,2] can be used as guidelines of quality assurance for manufacturers.

In this paper, a brief review of the biological effects of exposure to ultrasound is given. Other papers that consider some of the issues discussed here are available in the literature [6-8]. This discussion will identify the important parameters related to issues of safety and potential risks. Methods of measuring these parameters are discussed, and the facilities at the National Measurement Laboratory (NML) designed to fulfil these measurement standards are described.

2. MECHANISMS FOR BIOEFFECTS OF ULTRASOUND

2.1 Thermal mechanism

In an absorbing biological tissue, sonic heat production is a significant mechanism for bioeffects of ultrasound. The heating can easily bring about temperature elevations sufficient to alter biological structures and/or processes. As a rough guide, it can be shown [7] that for an ultrasound beam of effective average intensity (total power/effective radiating area) 1 $\mathrm{Wcm^{-2}}$ (typical of a physiotherapy system) incident on soft tissue, the temperature rise is approximately $0.014°\mathrm{Cs^{-1}}$. It is common (and recommended) practice to move the transducer during therapy treatment so that the temperature does not become excessive in any given location, and to minimise the establishment of standing waves that inhibit the cooling effect of blood flow. Since heat production is a result of absorption mechanisms which depend on the ultrasound intensity, intensity is an important parameter for characterising the heating effect of ultrasound. The production of heat by ultrasound absorption in tissue forms the basis of hyperthermia treatment of some cancers.

2.2 Nonthermal mechanisms

A number of non-thermal mechanisms have been discussed in the bioeffect literature [6-9]. In many situations where ultrasound produces bioeffects and significant temperature elevation is not involved, the cause of change is considered to be related to the mechanical aspects of the sound field, e.g. pressure, shearing stress etc. In medical pulse-echo diagnostic ultrasound, the ultrasonic waves generated are often of sufficiently large amplitude that the elastic response of the biological medium is non-linear. The linear analysis which assumes that the waves are of infinitesimal amplitude and that the change in density of the medium is directly proportional to the change in pressure, is not adequate to describe the non-linear acoustic field. The ultrasonic wave is then said to be of finite (as distinct from infinitesimal) amplitude. A number of distinct phenomena, not observed in low-amplitude acoustic fields, become apparent as the wave amplitude is increased. The amplitude at which non-linear effects are observable depends on the elastic properties of the propagation medium and on the sensitivity of the observation mechanism.

2.2.1 Finite amplitude distortion and generation of harmonics

As an ultrasonic disturbance of finite amplitude propagates through a medium, energy is transferred from an initially monochromatic wave to its harmonics. This phenomenon complicates characterisation of the field of medical devices [10] and has important ramifications for sound absorption. As the beam propagates through tissue, the original monochromatic form of the wave takes on a spectral character, until eventually the waveform becomes stabilised (saturated) at a distance from the source where the time rate of energy input to the harmonics equals the time rate of energy dissipated through absorption.

In typical medical beams, the highest amplitudes are usually found on-axis, so saturation effects are first observed in this region. Thus, as the source amplitude is increased, the peak amplitude of the fundamental component on-axis reaches a maximum value and all of the additional energy is transferred to higher frequency harmonics, while off-axis the fundamental continues to increase in amplitude. The beam pattern, therefore, becomes dependent on source amplitude and axial position. Finite amplitude distortion will generate high frequency components more rapidly in the relatively low loss fluid volumes within the human body. In particular, transmission through urine and amniotic fluid may result in shock discontinuity formation under some circumstances [11]. The high-frequency content in a shock pulse will lead to a high deposition of energy in the initial layers of lossy tissues behind such fluid paths.

2.2.2 Cavitation

Of the range of non-thermal bioeffect mechanisms the one which is of greatest interest is that of cavitation. Cavitation phenomena are produced in a liquid medium subjected to an acoustic disturbance when the acoustic pressure during rarefaction reduces the hydrostatic pressure below some "threshold" value. At higher pressure amplitudes, microbubbles can act as nucleation sites for the generation of cavities which may collapse abruptly following the rarefaction half cycle. Such collapse cavitation can have associated large local temperature rises. For this reason the threshold pressures for collapse cavitation in vivo and in aqueous materials (e.g. blood) are of particular interest. The threshold varies with local conditions and increases with frequency [12]. As a rough guide, the threshold value in the low MHz range is about 1 MPa [12] in a solution of sodium iodide.

In the observation of both cavitation and finite-amplitude effects, the acoustic parameter primarily controlling their occurrence is not intensity but pressure. It is thus important to measure the pulse pressure waveform, and in particular the maximum rarefaction (or peak negative pressure) amplitude. The cavitation threshold also depends on the pulse repetition frequency (PRF). This can be explained if one postulates that the bubble fragments from a previously collapsed cavity may act as nucleation sites for subsequent cavitation action [9]. Other properties of the wave such as its frequency and pulse character, are also important.

2.2.3 Radiation force and radiation torque

If structures possessing acoustic properties different from those of an embedding medium are subjected to acoustic radiation, steady or unidirectional radiation forces are exerted on them. The radiation force on an object, which arises from a non-zero time-averaged pressure $<p>$ associated with the acoustic field, is a non-linear effect of the field but there is still some controversy concerning its origin. (There is some variation in the usage of the term "radiation pressure", see reference [13] for further discussion.) The use of a radiation force balance to determine the total acoustic power in a transducer beam is discussed in the next section.

Analogous to the radiation force, which may cause translational motion, is another quantity "radiation torque", which tends to produce rotary motion. Sonically produced twisting and spinning of cells occurs when the local sound field is highly non-uniform on a microscopic scale. Micro-scale non-uniformity of the ultrasound field exists in tissues because of the inhomogeneities presented to the ultrasound by vessel walls, cell walls, and especially by any gas-filled spaces that may be present. Radiation torque acts on the medium and, in a fluid, can give rise to steady circulatory flow, i.e. acoustic streaming. The streaming can be of a relatively large scale, such as associated with an ultrasonic beam in a water tank. On the other hand, near surfaces where acoustic boundary layers are set up, it can be of very small scale (of the order of microns) and is called "micro-streaming". Micro-streaming is an important topic in connection with the bioeffects of ultrasound. When micro-streaming is present, the high velocity gradients and associated shearing stresses which exist in boundary layers can cause damage to biological cells and macromolecules. While the potential relevance of these mechanisms is clear, the determination of their significance is largely limited by our relatively poor understanding of the acoustical microstructure of tissue [14].

2.3 Assessment of bioeffects in humans

In general, assessment of the effect of ultrasound in humans is more complicated than in many other animals. Assessment of safety for a given exposure from a particular device would require monitoring investigations over many years, particularly when one is looking for long-term effects: latent periods could be as long as 20 years in the case of cancer development, or the effect may not be seen for another generation. Thus, looking at exposure is only a first prudent step in investigating human effects. At the moment, no well documented direct risks of the use of ultrasound at recommended levels have been established [6] and the benefits of ultrasound in medicine far outweigh the presently perceived potential risks. However, it is still recommended that the intensity and power used should be as low as reasonably achievable in clinical applications.

3. MEASUREMENT OF ULTRASONIC FIELD PARAMETERS

There is a large variety of ultrasound transducer types in medical use [15], but with few exceptions they employ the thickness vibration of a piezoelectric ceramic plate, constructed of poled lead zirconate titanate (PZT) or lead titanate (PT), to generate and/or detect the ultrasonic fields. The transducers used are usually resonant devices, but for diagnostic imaging applications the thickness resonance is normally heavily damped by a well acoustically matched absorbing backing in order that short, broad-band pulses can be easily obtained. Very short ultrasound pulses are desirable in diagnostic applications in order that reflections from closely spaced objects can be more easily differentiated (to maximise longitudinal resolution). Either electronically controlled transducer arrays, or single transducers that are mechanically rotated or oscillated, are used to scan a volume of tissue for imaging purposes. Transducers for Doppler applications (see the paper by Wilson, last issue) may be designed for use only in Doppler mode, or may be used also as an imaging transducer in a so-called "duplex" scanner. In physiotherapy and surgery, transducers are designed to deliver relatively large amounts of energy to the tissue for therapeutic or destructive purposes. The ultrasound frequencies used in most medical applications are in the range 0.5 to 15 MHz, corresponding to approximate wavelengths in soft tissue of 3 to 0.1 mm.

The wide range of techniques for the measurement of ultrasonic fields described in the literature is summarised in a number of review articles [8,16,17]. The properties that can be measured directly with relative ease are acoustic pressure and acoustic power. Pressure is measured using a hydrophone, while acoustic power can be measured using a radiation force balance. Another parameter, the particle displacement, can be measured by a more complex interferometric method [18], and can provide absolute standards for hydrophone calibration [19]. The principles of the techniques and their implementation at NML are described in the following sections.

3.1 Measurement of acoustic pressure using hydrophones

A hydrophone is a device which produces an electrical signal in response to an applied acoustic field. The sensitive element

Figure 1: Needle (left) and membrane hydrophones. The active elements of both consist of the piezoelectric polymer PVDF. The element of the needle hydrophone is mounted at the end of the needle, perpendicular to the needle axis, and is approximately 0.5 mm in diameter. The active element of the membrane hydrophone is a poled spot approximately 0.5 mm in diameter at the centre of the membrane.

of the hydrophone is usually a small piezoelectric element and the electrical voltage developed is proportional to the acoustic pressure at the element. A hydrophone can be used to determine the spatial distribution of the field amplitude, i.e. the beam pattern or beam profile, if the size of its active element is comparable to, or smaller than, the acoustic wavelength. The temporal variation of the field, i.e. the pulse waveform, can also be determined providing the device has a known (preferably flat) frequency response. Two commonly used hydrophone types are shown in Figure 1. On the left is a needle hydrophone [20] with a PVDF (polyvinylidene fluoride, a piezoelectric polymer [21]) element mounted at the probe tip, while that on the right consists of a sheet of PVDF stretched across a support ring, and only a small central region of the sheet is poled (a membrane hydrophone [22,23]). As hydrophones are not absolute devices, they must be calibrated, and three of the techniques which may be used are planar scanning [24], reciprocity [25] and optical interferometry [19].

The choice of size of hydrophone depends upon considerations of spatial resolution and of directional response. Presently, the smallest commercially available PVDF hydrophones have an element diameter of 0.5 mm, which is larger than the ultrasonic wavelength in water for frequencies above 3 MHz. Thus many hydrophone measurements actually give a result which is an average of the acoustic pressure over the active element. This can cause an underestimate of the spatial-peak acoustic pressure level [26].

PVDF hydrophones, however, have some disadvantages, particularly for the measurement of high intensity fields. Firstly, they are susceptible to damage in high power ultrasound beams, such as those generated by lithotripter and hyperthermia transducers. Secondly, it is difficult to electrically shield PVDF hydrophones sufficiently to prevent significant interference between electrical pickup and the acoustically generated signal in continuous wave applications. A fibre-optic hydrophone developed at NML [27,28] is an attempt to overcome some of the problems associated with the use of PVDF hydrophones. The optical fibre is expected to be more rugged than PVDF films in its ability to withstand high power ultrasound and its output is immune to electromagnetic interference. Furthermore, as it is the cladding diameter of the fibre (approx. 80 μm) that determines the ultimate spatial resolution, the fibre hydrophone can provide very good spatial resolution for beam profile measurements. However, the fibre is a line sensor whose output is proportional to the line integral of the acoustic pressure along the fibre length, so a tomographic technique has to be used to reconstruct the spatial pressure profile.

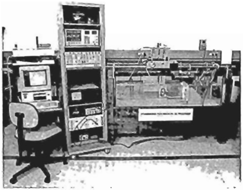

Figure 2: The beam plotting facility at NML. The water tank contains a relatively large transducer array consisting of six individual transducers focused at a common point. A membrane hydrophone can be seen in the centre of the tank, mounted on the x-y-z scanning stage.

To use a hydrophone to characterise a transducer field, a suitable water tank and adequate coordinate positioning system are required. The beam plotting facility at NML is shown in Figure 2. The tank is lined with absorbing materials to eliminate reflection, and deionised, degassed water is used. The transducer is mounted on a manually controlled five-axis micromanipulator and the hydrophone is mounted on a computer-controlled X-Y-Z translation stage. The resolution of the scanning system is 8.75 μm. In characterising a transducer, the location of the peak acoustic pressure is found by scanning the hydrophone throughout the acoustic field until the largest peak positive or negative signal is observed. If this maximum is located in the far-field of the transducer where a plane wave approximation is valid [29], the peak acoustic pressure p(t) can be converted to instantaneous intensity I using:

$$I = p^2(t)/\rho c \qquad (1)$$

where ρ and c are the density and velocity of sound in the medium. This intensity corresponds to the spatial-peak temporal-peak (I_{sptp}) intensity. After the peak pressure position is located, it is usual to scan across the plane P_f, the focal plane for a focused transducer, passing through this point and normal to the acoustic beam-axis, to obtain a diametric beam plot. If the beam is not cylindrically symmetric, a two dimensional scan in the plane P_f is required. Figure 3a shows a plot of a two-dimensional scan of a transducer with hexagonal symmetry and Figure 3b is a contour plot of the same two-dimensional scan which displays the pressure distribution of the ultrasonic beam. With reference to appropriate standards [3,4], other acoustic parameters can then be derived from the scanning results.

3.2 Measurement of total acoustic power using radiation force balances

A radiation force balance aims to measure the force produced on a target intercepting the whole ultrasound beam [13,30]. The radiation force was introduced in Section 2, and is related to the rate of change of momentum in the ultrasound beam. It acts in the direction of propagation of the ultrasound.

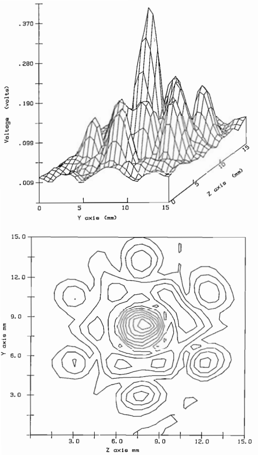

Figure 3: Beam profile of a transducer array with hexagonal symmetry in a plane through the focus of the transducer array and perpendicular to the hexagonal axis.
(a) A three-dimensional plot of the hydrophone output voltage.
(b) A contour plot of the data shown in (a). The contour interval is 10% of the maximum voltage.

The measured force F on a highly reflecting target in water may be related to the incident acoustic power W by

$$W = Fc \tag{2}$$

where c is the velocity of sound in water. If the force is vertical it is equivalent to a mass m, where

$$m = W/gc \tag{3}$$

and g is the acceleration due to gravity. Therefore, an ultrasonic beam of 1 W total power will produce a force at temperature of 20°C of approximately 68 mg.

At NML, a float densitometer, originally designed to measure changes in the density of water [31], has been modified for use as a radiation force balance [32] (Figure 4). A highly reflecting target is mounted on a float which contains a magnet. The vertical position of the float is optically sensed and a servo loop holds it submerged in a fixed position by controlling the current in a coil, whose resultant magnetic field interacts with the magnet in the float. The system is computer controlled.

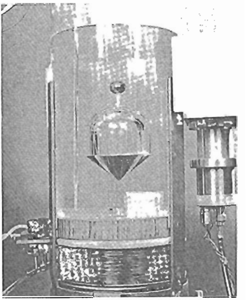

Figure 4: The magnetic float radiation force balance developed at NML. The float (centre) is suspended by a combination of buoyancy, gravity and the magnetic force provided by the coil that can be seen at the base of the water bath and a small permanent magnet inside the float. The transducer to be calibrated can be seen protruding into the bottom of the water bath, and the ultrasound is reflected laterally by the conical stainless steel base of the float and absorbed by a rubber lining (not shown in photograph). The bulb at the top of the float intercepts a horizontal light beam to provide the position control signal.

The current in the coil is a measure of the radiation force, and the apparatus can be calibrated using known weights. This balance can be used to measure power output of diagnostic transducers, which have typical output powers from 1 mW to 100 mW.

Three other radiation force balances are also available at NML for total power measurement:

1. A tethered float radiometer designed and built at the National Physical Laboratory (NPL) in the UK [33], which can be used for the output power range 150 mW to 9 W. It is used mainly for therapy transducers.
2. An electronic balance (Mettler H51) modified and equipped with reflecting and absorbing targets, which can be used to measure power output levels greater than 15 mW. The advantage of this balance is that it is easier to operate than the two balances mentioned above.
3. A portable digital power meter which can be used in field work (e.g. in hospital or clinics), which has a range of 1 mW to 30 W.

3.3 Hydrophone calibration

At NML, hydrophone calibration can be carried out using several methods:

3.3.1 Planar scanning method

Planar scanning provides a technique for the calibration of a hydrophone using a transducer of known total power output W. The transducer used can be a standard power source such as those supplied and calibrated at the NIST (formerly NBS) in USA, or a transducer calibrated using the radiation force balance at NML. The output voltage of the hydrophone is

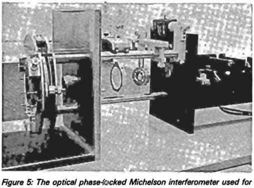

Figure 5: The optical phase-locked Michelson interferometer used for hydrophone calibration at NML. On the left of the picture is an adjustable mounting for the acoustically transparent membrane. The main optical components of the interferometer are on the right, and optical components to enable the beam to be shifted and focused onto a particular point on the membrane are in the centre.

measured as the hydrophone is scanned over a plane in the far field of the calibrated transducer. The output voltage V_0 at the hydrophone is measured as a function of position, and the square of the voltage is then integrated over the area of the ultrasonic beam. The end-of-cable loaded sensitivity M_L of the hydrophone can be determined by dividing the integral of the square of the hydrophone output voltage by the total power of the beam [24]:

$$M_L = \{ \int\int V_0^2 \, dy\, dz) / (2\varrho c W \}^{1/2} \qquad (4)$$

3.3.2 Calibration of hydrophones using optical interferometry

Optical interferometry is used to directly measure the ultrasonic displacements in a transducer beam, by focusing one beam of a Michelson interferometer onto a thin, optically reflecting but acoustically transparent membrane immersed in water in an ultrasonic beam. In principle this membrane could be a membrane hydrophone, but in practice a thinner (3 μm) film than the thinnest available PVDF film is used. As long as the membrane is in the focal region or the far field of the ultrasonic transducer, the pressure is proportional to the displacement, and a hydrophone can be calibrated by substituting it for the membrane and measuring the output signal.

An optical interferometer similar to the primary standard used at NPL [19] in the UK has been installed at NML (Figure 5). This interferometer was developed by the Harwell Laboratory, UK [34]. The major difficulty of measuring ultrasonic displacements in the MHz frequency range is that they are very small ($\approx 10^{-8}$ to 10^{-10} m), and in general much smaller than those associated with low frequency background vibrations. The Harwell interferometer [34] compensates for the effect of low frequency vibrations by shifting the phase of the reference beam with a Pockels cell controlled by a signal fed back from the interferometer output. This constitutes an optical phase-locked loop, and it ensures that the interferometer is insensitive to displacements at frequencies less than about 100 kHz and has maximum sensitivity at frequencies in the MHz range. This interferometer is capable of resolving dynamic displacements as small as 10^{-11} m in a bandwidth of about 300 kHz in the low MHz range. This is an extraordinary capability.

3.3.3 Direct comparison

Calibration factors of hydrophones can be found by direct comparison with a secondary standard. The secondary standard can be a PVDF hydrophone calibrated using the optical interferometer at NML. PVDF hydrophones with calibration provided by NPL in the UK are also available and can be used in the comparison.

4. CONCLUDING COMMENTS

International standards governing the use of ultrasound in medicine are still evolving as a result of the intensive research activity of recent years. The ability to make accurate quantitative measurements of the ultrasonic output of transducers is an essential prerequisite not only to evaluating the medical effects of ultrasound exposure, but also for effective and reliable use of ultrasound for diagnostic or other purposes. In the past three years, the medical ultrasound standards and calibration project at NML has gone through the developmental stage and most of the equipment is now ready to be used in providing ultrasound power measurements and hydrophone calibrations. Measurement services can now be provided at the request of companies, hospitals and other organisations wishing to evaluate their medical ultrasonic equipment. It is expected that the laboratory will participate in international intercomparisons of ultrasonic standards with institutions in other countries in the near future.

ACKNOWLEDGEMENT

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Ultrasonics—A Useful Tool in Biophysical And Biomedical Research

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ABSTRACT: Ultrasonic absorption and velocity measurements in biological fluids can shed light on the underlying biophysics. We discuss here research on the deformability of human red blood cells and the compressibility of plant cells, and preliminary work on protein coagulation.

1. INTRODUCTION

Therapeutic and diagnostic applications of ultrasound are now of major importance in medicine. Ultrasonic imaging techniques are part of the modern medical arsenal for non-invasive diagnosis, and Doppler measurements of blood flow, ultrasonic physiotherapy and tissue characterisation are commonplace. Here I will discuss several areas of biophysical and medical research where ultrasonics provides unique and useful information about the underlying physics.

Most of the above applications involve the propagation of sound in inhomogeneous media and it should be recognised at the outset that our understanding of the underlying physics is far from complete. The physics is difficult because one is confronted with multiple scattering from particles or occlusions which are randomly distributed and which vary in size and shape. In suspensions, the attenuation of sound from viscous effects or relaxation processes are frequently more significant than the scattering contribution.

We are collaborating with colleagues at the University of Surrey in modelling the attenuation of sound in mineral and biological suspensions. Biological suspensions have been treated as spheres of viscoelastic fluid (cells) surrounded by a viscoelastic shell (the membrane) in a viscous fluid medium [1]. The inter- and intracellular fluids will support the propagation of longitudinal waves only, whereas both longitudinal and shear waves can propagate in the membrane. The differing thermodynamic properties in the three media can also generate thermal waves at the boundaries of the media and introduce a thermal contribution to the attenuation of sound. The disadvantage of the model lies in the large number of variables required to describe the various processes in the three media. Fortunately, there are experimental data for many of these, such as viscosity, thermal conductivity, velocity of sound etc, or good estimates can be made.

An initial test of the model in dilute biological suspensions of HeLa, hybridoma and BHK cells, in which only single, rather than multiple, scattering processes were important, proved satisfactory [2] although the experimental uncertainty precluded placing too much confidence in the model.

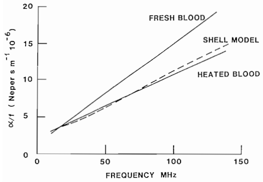

Figure 1: Multiple scattering calculations for 2.75 μm radius cell — compared with experimental data for fresh and heated blood.

2. HUMAN RED BLOOD CELLS

The concentration of red blood cells (RBC) in human blood is of the order of 40 to 50 volume percent, so that multiple scattering can be expected to be significant. In Figure 1, estimates from the multiple scattering shell model for shell radii of 2.75 μm are compared with experimental sound absorption data for fresh and heated human blood containing 43 vol.% RBC. The agreement between the prediction of the model and experimental results for heated blood is quite good, whereas the fresh blood data show significantly greater absorption. Fresh RBC at rest are not spherical but biconcave discoid as seen in Figure 2. The radius is approximately 4 μm and the

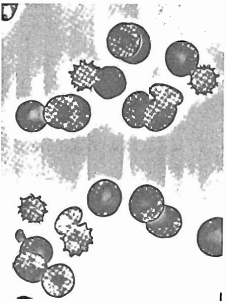

Figure 2: An electron micrograph of normal and echinocytic RBC.

thickness varies from 1 μm at the centre to over 2 μm at the thickest point. The radius of an equivalent volume sphere is 2.75 μm. Also shown in Figure 2 are echinocytic RBC, commonly known as "prickly pears" or simply as spherocytes. RBC will adopt this shape when subjected to heating to 50°C, prolonged storage, ionic imbalance, depletion of adenosine triphosphate (an important energy providing component of the cell), or as a consequence of some diseases and infections.

The question arises as to whether the difference in sound absorption between fresh and heated human blood is due to the change in shape or to some other mechanism. We know, from many comparative measurements on normal blood and that of sufferers of genetic diseases which impair RBC deformability, but may or may not alter the cell shape, that the shape effect is relatively unimportant. However, the cell deformability adds significantly to the absorption of sound, at least at some frequencies. The remarkable ability of RBC to deform is demonstrated in Figure 3, an electron micrograph of a human RBC flowing through a capillary with a diameter of 2 to 3 μm, that is, considerably smaller than that of the cell. This ability is vital to cell function, especially to the primary purpose of the RBC, which is to convey oxygen from the lungs to tissue. Oxygen exchange occurs largely in the capillaries and flowrate in the capillaries is primarily determined by RBC deformability. Deformability also determines the survival rate of RBC following transfusion, and in haemolytic anaemias where the RBC are more fragile, less deformable than normal. In such anaemias, the production of new RBC in the bone marrow, which goes on throughout life, cannot keep pace with the destruction during circulation, resulting in RBC volume fractions and haemoglobin concentrations in the blood that are reduced to perhaps half of normal. The passage of an RBC through a capillary smaller than itself or through gaps in the spleen of the order of half a micron requires a reversible structural change in the phospholipid network of the cell membrane and in the underlying protein cytoskeleton. We postulated that these were relaxation processes that might be characterised by sound absorption [3]. Physicists and chemists have used this means of studying liquid relaxation phenomena such as ionic equilibria, structural isomerism and critical points [4]. Such relaxation processes provide an energy sink, provided that the appropriate insonation frequency is used, and therefore increase the absorption of sound. Where there is a single or dominant thermal relaxation process, the sound absorption takes the form shown in Figure 4a, which conforms to

$$\alpha/f^2 = A + B/[1 + (f/f_c)^2] \qquad (1)$$

where α is the sound absorption coefficient, f is the frequency, f_c is the characteristic frequency for the relaxation process and A and B are constants.

Sound absorption is measured directly as the energy lost in passing through a specific length of fluid. The sound absorption coefficient is expressed as energy loss (in Nepers or dB) per cm of fluid. The distance between a matched pair of axially mounted transducers in a pulse chamber is varied, and measured precisely, to match the energy loss for some ten steps on a precision attenuator. Care must be taken to optimise the impedance matching of the input and output sides, especially at higher frequencies. Stirring is essential if blood or other sedimenting fluid mixtures are studied. The actual pulse chamber is shown in Figure 5a and a block diagram of the measurement system in Figure 5b.

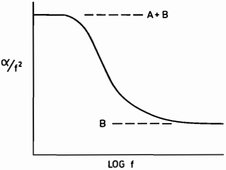

Figure 4a: α/f^2 versus log f for a single relaxation process.

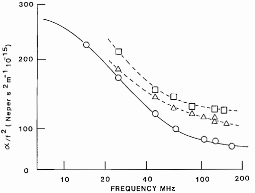

Figure 4b: α/f^2 versus f. Experimental data for ○ haemoglobin solution ☐ fresh blood △ heated blood — Equation (1).

We see in Figure 4b that the sound absorption of human haemoglobin in native plasma at a concentration of 139 g/ℓ conforms to Equation (1) with a characteristic frequency of 25 MHz. Presumably, this is related to structural relaxation of the haemoglobin molecule. However, normal fresh blood of the same haemoglobin content can not be fitted by Equation (1) and there is an additional contribution to the absorption of sound. This we have attributed to membrane deformability [3].

Figure 3: An RBC flowing through a nutritive capillary.

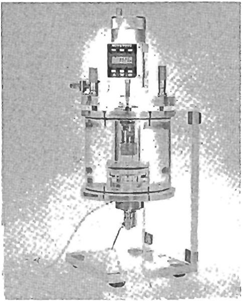

Figure 5a: The pulse chamber.

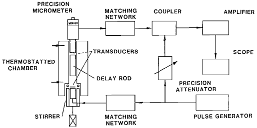

Figure 5b: Block diagram of the sound absorption measurement system.

If the same fresh blood is heated to 50°C for several minutes to stiffen the RBC, the sound absorption is reduced but is still higher than the equivalent solution where the haemoglobin is not "packaged" in cells. Since RBC are known to lose their deformability with storage, even under blood bank conditions, we measured the 37°C sound absorption coefficient of normal whole blood as a function of the period of storage at 4°C. The results are shown in Figure 6 in the form α/f versus f, which is essentially linear over the frequency range 10 to 100 MHz.

The data show a consistent fall in sound absorption, both in the value of α/f and the slope, at frequencies in excess of approximately 20 MHz. If this change in sound absorption can be attributed to the decrease in RBC deformability, then we have a means of monitoring the quality of stored blood and the likelihood of the RBC surviving transfusion.

The development of sound absorption measurement as a quality control monitor in blood banking remains our prime concern, but we have used this method in several clinical studies in collaboration with haematologists at St Vincent's, Royal North Shore and Prince of Wales Hospitals in Sydney. An immediate and significant application was to confirm the potential survival rate of irradiated blood after transfusion. Although α-irradiation is known to cause chemical damage to the RBC membrane [5], its effect on RBC physical properties had not been investigated. Blood is x- or α-irradiated prior to transfusion to leukemia patients undergoing chemotherapy. The patient's blood-making function is disrupted and, in conjunction with bone marrow transplants, chemotherapy can so impair the immunological system that it can be attacked by the transfused blood in what is known as graft-versus-host disease. Irradiation destroys the activity of the lymphocytes and prevents maturation of the stem cells. We were therefore able to show that irradiated blood cells, subjected to the normal dose of irradiation, 25 Gy of cobalt 60, whether fresh or stored for two weeks, were still capable of surviving the rigours of circulation [6].

Another spin-off from the above work has proved of value in sports medicine. As already discussed, capillary perfusion and oxygen transfer are related to RBC deformability, and, to a lesser extent, plasma viscosity. This led us to propose [7] that successful endurance athletes, whose performance level is a function of their ability to use oxygen, would have higher cell deformability and lower plasma viscosity than untrained individuals. Sound absorption measurements on the blood of a group of long distance runners confirmed this hypothesis and prompted conjecture on haemorheological adaptation with aerobic training [7]. Similar measurements have been made on the blood of sheep exercising on a treadmill at elevated temperatures. They form part of a major experiment headed by Dr Bob Hales of CSIRO Animal Production which seeks to elucidate the cardiovascular mechanism in heat stress. Internal body temperatures may reach 42°C in heat stress, particularly with exercise-induced heat exhaustion, sufficient to cause "sphering" of the RBC and to facilitate microthrombus formation.

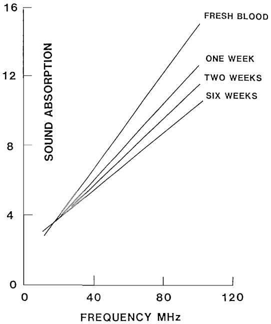

Figure 6: α/f versus f in whole blood as a function of storage time.

3. PLANT CELLS

Plant cells are very different to blood cells. They are nucleated, enclosed in rigid cases, do not move through a circulatory system nor need to deform. Useful biophysical information about these cells can be obtained via the velocity of sound as opposed to the absorption of sound.

The velocity of sound in a fluid is given by

$$c = (\beta_s \varrho)^{-1/2} \tag{2}$$

where β_s is the adiabatic compressibility and ϱ is the density of the fluid. The velocity of sound can be measured in the same pulse chamber used in sound absorption measurements, operating as a wave interferometer at odd harmonic frequencies of the transmitting crystal. In this method, a block diagram of which is given in Figure 7, the wavelength is measured directly by counting up to 200 maxima and minima in the amplifier output as the distance between the crystals is varied by the micrometer.

With Kim Ritman and John Milburn of the University of New England Botany Department, we have tried to relate the compressibility of plant cells to the cell turgor, the hydrostatic pressure developed within the cells as a result of the asmetic interaction between the contents and the environment [8]. While this was unsuccessful, we found an interesting parallel between the compressibility of isolated asparagus strengeri cells and the onset of plasmolysis with increasing osmotic potential in calcium chloride and glycerol suspensions. This is shown in Figure 8. When plasmolysis occurs, the more flexible cytoplasm shrinks away from the rigid outer cell wall (comparable to the bladder of a football shrinking away from the leather casing with deflation). Hence, the suspension of plant cells becomes more compressible. The combination of precise velocity of sound and density measurements for the cell suspension yields the suspension compressibility via Equation (2). The compressibility of the cells was determined from

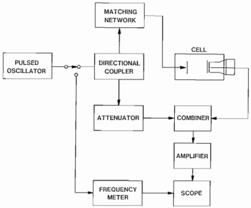

Figure 7: Block diagram of the velocity of sound measurement system.

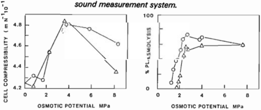

Figure 8: Cell compressibility and % plasmolysis in calcium chloride O and glycerol suspensions △ versus osmotic potential.

$$\beta_{susp} = \beta_{solv}(1 - x) + \beta_{cell}x \tag{3}$$

where x is the volume fraction of cells in the suspension and the subscripts refer to the suspension, solvent and cell respectively.

Equation (3) has been shown to provide a good fit of the velocity of sound in fresh blood as a function of the RBC content. Extrapolation to 100% RBC provided an estimate of the adiabatic compressibility of the human RBC which agreed closely with a reported value for equine RBC [9]. These data and those for the temperature dependence of the velocity of sound in human blood and blood components are shown in Figures 9 and 10. The velocity and absorption of sound in a wide range of human haemoglobin solutions in native plasma up to a concentration of 320 g/ℓ, compared with the physiological cell value of 340 g/ℓ, have also been measured [10].

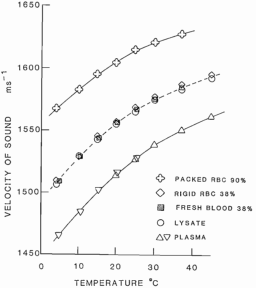

Figure 9: The velocity of sound as a function of temperature in blood components.

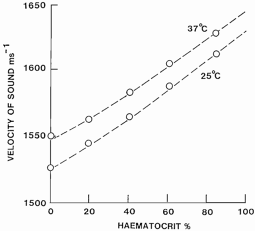

Figure 10: The velocity of sound in fresh blood as a function of cell volume fraction — fitted values using Equations (2) and (3).

4. PROTEIN COAGULATION

The velocity and absorption of sound have also been studied in homogenised milk and reconstituted powdered milk in 20% suspensions at frequencies ranging from 15 to 185 MHz. While the data are of scientific interest, in as much as they are aqueous emulsions with a significant protein content, we should remember that reconstituted milk is an important export particularly to South-East Asia. The reconstituted milk must be sterilised at 120°C but care must be taken to avoid protein coagulation. The scientific problem lies in defining and understanding the coagulation point and the industrial problem is in quality control. The onset of coagulation and the qualitative nature of the coagulum vary considerably (some would say from cow to cow on the one farm), and even small variations in protein and fat concentrations produce significant changes in the coagulation process. Bovine milk contains 87% water with milk fat, lactose casein, lactalbumin and other proteins the other constituents. Prior to homogenisation, the globules in the emulsion range from less than 1 μm to 20 μm in diameter, but homogenisation produces a relatively uniform globular distribution averaging 1 μm diameter. In Figure 11, we see that homogenised milk and 20% reconstituted milk have different absorption spectra, especially in the low frequency (less than 25 MHz) range. We are currently modifying our apparatus to investigate these lower frequencies, which seem to highlight the differences in proteins and may provide the key to understanding the coagulation process in milk.

Jelly, the familiar edible gelatin, is typical of protein coagulation, which sets up a three-dimensional, reticulated network or polymer lattice. In addition to the above research on milk, we have done similar work on jelly (which is preferable to work with for many reasons) and we believe that ultrasonic techniques are well suited to resolve some of the physics. The RBC deformability which has been our principal research interest relies on a similar protein reorganisation, the major protein species of the cytoskeleton being spectrin and actin. A recent discussion [11] of cells that crawl, a group that includes some white blood cells, amoeba and slime moulds, explains the membrane deformability in terms of alternating gelation and disassembly of Actin protein chains. The biochemistry underlying these processes is quite complex, involving calcium ions and other proteins which promote the gelation, stabilisation and solution of the actin filaments. Actin, together with myosin, is involved in muscle contractibility, a process which has much in common with what we have discussed. Another important area of blood rheology research is the clotting process, in which the plasma protein, fibrinogen, mediated by calcium ion and a protein enzyme called thrombin forms a three-dimensional fibrin network. We have just commenced looking at this process. While applications of ultrasonics in biophysical and biomedical research have been stressed here, much remains to be done in characterising and metering mineral suspensions. Slurry engineering and hydraulic transport are vitally important to the Australian mineral industry. Ultrasonics will play a variety of roles in multi-phase flow measurement and in the control of sedimentation and flotation processes. These are applications which must be underpinned by fundamental studies of scattering, the topic with which we commenced this discussion.

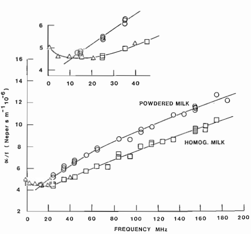

Figure 11: α/f versus f in homogenised milk and 20% reconstituted powdered milk. △ Ref. [12].

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DR WILSON REPRINTS

In the last issue (April 1991) of Acoustics Australia, Fig 2(a) of the article "Recent Developments in Medical Diagnostic Ultrasound" by Dr L S Wilson did not reproduce with sufficent detail. This has been corrected in the reprints which are available on request from Dr Wilson at the Ultrasonics Laboratory, CSIRO Division of Radiophysics, 126 Greville St, CHATSWOOD 2067.

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Some Applications of the Sound Intensity Technique

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ABSTRACT: Almost a decade has elapsed since commercial sound intensity measurement systems became available. The sound intensity technique has found increasing applications. In this paper, examples are given in which sound intensity measurements are used for determination of sound power, noise source location and field sound transmission loss.

1. INTRODUCTION

Although the first device for sound intensity measurements was patented by Olson [1] in 1932, it was not until 1977, when Fahy [2] and Chung [3] independently applied digital signal processing techniques to the sound intensity theory, that commercial systems became available. The increased interest in the sound intensity technique is reflected in Figure 1 which shows the distribution of papers published on the subject in English language journals since 1973. A breakdown of a total number of 139 papers into two general areas, theory and application, reveals the general trend expected in any research field that the number of "applications" papers increases as a better understanding of the theory is obtained. Recently a whole issue of Acoustics Australia was devoted to a coverage of the technique and the experience of using it for various applications [4]. Although at present, there are no International Standards on using the sound intensity technique, they are being drafted and it is expected that an International Standard on measurements of the sound power using the sound intensity technique will be finished some time in 1991 [5]. The sound intensity technique enables sound power measurements to be made directly instead of by traditional methods conducted in controlled acoustic environments (such as anechoic, semi-anechoic or reverberant rooms) via sound pressure level measurements. It also offers other advantages such as external noise suppression capability, noise source identification and noise ranking.

In this paper, some applications of the sound intensity technique undertaken at the Acoustics & Vibration Centre in the Australian Defence Force Academy will be described to illustrate the range of problems that can be tackled with the new technique.

2. THEORY

As the theory of the sound intensity technique has been described in detail in the literature (see for example, Fahy [6]), it will only be briefly outlined here to highlight some of its capability and limitations.

Unlike sound pressure which is a scalar quantity, sound intensity or sound energy flux density (i.e., the rate of energy flow per unit area) is a vector quantity. The time-averaged intensity vector $\tilde{I}$ is defined as

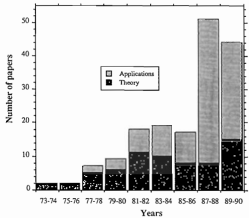

Figure 1: Distribution of sound intensity papers published in English language journals since 1973.

$$\tilde{I} = (1/T) \int_0^T p\, \tilde{u}\, dt \qquad (1)$$

where p is the sound pressure
$\tilde{u}$ is the particle velocity vector.

The component I_r of the intensity vector $\tilde{I}$ along a direction r can, therefore, be determined if the particle velocity u_r can be measured. In the absence of a mean flow and turbulence in the medium, the particle velocity component u_r in the r direction is related to the pressure gradient by the Euler's equation (2):

$$\rho\,(\partial u_r/\partial t) = -(\partial p/\partial r) \qquad (2)$$

where ρ is the density of the medium.

The pressure gradient may be approximated by finite differencing so that in practice, this can be determined from the pressure difference ($p_A - p_B$) detected by two microphones closely spaced at a distance $\triangle r$ along the direction r. The pressure p in equation (1) can be obtained from the average of the two microphone signals. Integration of equation (2) yields the particle velocity u_r:

$$u_r = -(1/\varrho \triangle r) \int (p_B - p_A)\, dt \qquad (3)$$

By substituting equation (3) into equation (1) and taking the Fourier Transform, it can be shown [6] that the active intensity spectrum $I_r(\omega)$ in the r direction is related to the imaginary part of the cross-power spectrum G_{AB} between the microphone signals:

$$I_r = -(1/\omega \varrho \triangle r)\, \mathrm{Im}(G_{AB}) \qquad (4)$$

where ω = circular frequency (rad/sec).

Since $\mathrm{Im}(G_{AB})$ is related to the phase change of the sound field over the distance $\triangle r$ separating the two microphones, a typical sound intensity measuring system comprises a sound intensity probe made up of a pair of phase-matched microphones and a dual channel signal analyser which could be either based on fast Fourier Transform (FFT) or on digital filtering techniques. Usually, the two microphones are mounted in a "face-to-face" configuration separated by a distance $\triangle r$. The response of a sound intensity probe follows approximately a "cosine" law (that is, maximum along the axis of the probe and minimum normal to the axis of the probe). Hence a sound intensity probe basically indicates the magnitude and direction of the net intensity along the axis of the probe. For sound incident to the probe axis at angles less than 90 degrees, a net positive intensity would be measured whereas at incident angles greater than 90 degrees, a net negative intensity would be indicated. This directional property is often used as a quick check of the operation of a sound intensity measuring system when doing field measurements.

2.1 Error considerations

Possible sources of error in applying the sound intensity technique have been described by Gade [7]. Basically they are mainly related to the phase mismatching between the two microphone channels, which determines the low frequency limit and the finite difference approximation in measuring the particle velocity u_r, which determines the high frequency limit.

It can be shown (see [7]) that for an accuracy to within 1 dB, the phase change of the sound field over the microphone separation distance $\triangle r$ has to be greater than 5 times the phase mismatch and the wavelength of the highest frequency of interest has to be greater than $6\triangle r$.

2.2 Pressure-intensity index and dynamic capability

The pressure-intensity index L_K is defined as the difference between the sound pressure level L_P and the sound intensity level L_I and is related to the phase change Φ over the spacer distance $\triangle r$ for a given wavelength. L_K gives an indication of the type of sound field in which the measurements are made. For example, the more diffuse the sound field or the larger the angle between the probe axis and the intensity vector, the larger the value of L_K.

Owing to the phase-mismatch between the two channels, the intensity measured is not zero even if the two channels receive an identical signal and the pressure-intensity index measured under this condition is known as the residual pressure-intensity index L_{KO}. The error L_e due to phase mismatch between the two channels can be expressed (see [7]) in terms of L_K and L_{KO} as:

$$L_e = 10 \log_{10}[1 \pm 10^{0.1(L_K - L_{KO})}] \qquad (5)$$

It can be seen from equation (5) that for an accuracy to within 1 dB, L_K has to be 7 dB less than L_{KO}. The dynamic capability L_D of a sound intensity measuring system can, therefore, be defined as ($L_{KO} - 7$) dB. Hence, it is important to monitor L_K during measurements to ensure that it does not exceed L_D.

3. APPLICATIONS

In all the measurements described here, the sound intensity measuring system comprises a Bruel & Kjaer (hereinafter referred to as B&K) 2032 dual channel FFT analyser and a sound intensity probe made up of a pair of B&K 4181 phase-matched 0.5 inch microphones mounted in a face-to-face configuration. Most of the measurements were made with the microphones separated at a distance of 12 mm, covering a frequency range from 125 to 5000 Hz. There has been considerable debate in the literature regarding discrepancies between measurements obtained at discrete points and those obtained by the scanning technique. Our experience indicates that as long as scanning is performed properly, the difference between the two techniques is insignificant. All measurements described here have been obtained by scanning the sound intensity probe over a number of small segments. The narrow band sound intensity data were processed and synthesised into 1/3 or 1/1 octave bands with a Hewlett-Packard series 300 microcomputer.

3.1 Sound power

The sound power W of a sound source is related to the component I_r of the intensity vector normal to a hypothetical surface S enclosing the source:

$$W = \int_S I_r\, dS \qquad (6)$$

Traditionally, the sound power of a noise source is determined by measuring the sound pressure level in particular acoustic environments (such as anechoic or reverberant rooms) because under such conditions, the sound intensity level can be inferred from the measured sound pressure level. The international standards ISO 3741-3746 [8] cover methods in this category.

According to Gauss' theorem, if there is no source or sink within a measurement volume, then the sound power W as given in equation (6) is zero. This property offers a significant advantage in using the sound intensity technique for sound power determination as external noise will not contribute to the sound power of the noise source under test provided that the external noise is stationary and there is no absorption within the measurement volume. Thus "in situ" sound power measurements with high accuracy can theoretically be achieved. In practice, the accuracy is limited by the dynamic capability of the system as discussed in section 2.2 above.

Sound power spectra were obtained for a B&K 4205 reference sound power source by using two methods, namely, measurements in an anechoic room and sound intensity measurements. The B&K 4205 sound power source was set to produce a sound power level of 80 dB in octave band noise (centred from 125 Hz to 8 kHz) and wide band noise (covering 100 Hz to 10 kHz). Sound pressure level measurements in an anechoic room (with a lower cut-off frequency of 150 Hz) were made over a hypothetical hemisphere of radius 1 m using a B&K 2231 modular sound level meter (with filter set 1625) with the sound power source placed on a reflecting plane made of 3.5 mm thick aluminium sheet. The procedure used was according to International Standard ISO 3745 [8]. The sound intensity measurements were made in a room with a volume of 85 m³, a reverberation time of 0.8 s at 500 Hz and a background noise level of about 55 dB(A). The hypothetical measurement volume was

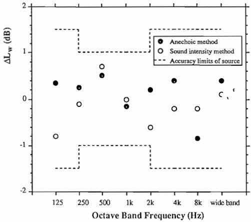

Figure 2: Deviation ΔL_W of measured sound power level from the set value for a reference sound power source.

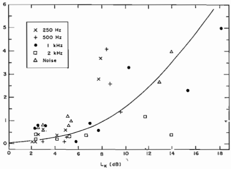

Figure 3: Variation of ΔL_W with the pressure-intensity index L_K.

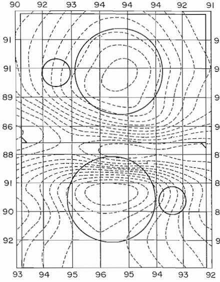

Figure 4: Intensity map (in dB) for two loudspeakers (numbers around the grid indicate overall intensity in dB for contours).

rectangular (0.2 × 0.25 × 0.2 m). Only 5 faces are measurement faces as the bottom surface coincides with the reflecting plane on which the noise source is placed. The intensity probe was swept over each measurement face (that is, scanning technique) to obtain a spatial-averaged intensity for that face. Figure 2 shows the deviation ΔL_W of the measured sound power level from the set level of 80 dB for the octave band noises and wide band noise. The accuracy limits of the reference source B&K 4205, as specified by the manufacturer, are also plotted in Figure 2 for comparisons. The results indicate that the sound intensity measurements agree with the anechoic room measurements to within 1 dB and both sets of measurements fall within the accuracy limits of the reference source, thus supporting the use of the sound intensity technique for "in-situ" sound power measurements.

In order to assess systematically the effects of background noise on sound power measurements, a loudspeaker was placed at 0.5 m from one measurement face to produce external noise. Measurements were made with the B&K 4205 source producing 250 Hz, 500 Hz, 1 kHz and 2 kHz octave band noise, and wide band noise, each of which was set at three different sound power levels, namely, 65, 75 and 85 dB. Corresponding to these noises under test, the loudspeaker was made to produce pure tones of 250 Hz, 500 Hz, 1 kHz and 2 kHz, and white noise respectively, each of which was set at three different power levels, namely, approximately 70, 80 and 90 dB. Figure 3 shows the variation of the deviation ΔL_w of the measured sound power level from the set level for the B&K 4205 source with the pressure-intensity index L_K. Although there is a considerable scatter in the data especially for large L_K, a curve of best fit subject to the constraint that $\Delta L_w = 0$ for $L_K = 0$ has been obtained:

$$\Delta L_W = 10 \log_{10} (0.948 + 10^{0.1(L_K - A)}) \quad (7)$$

where A = 12.86 dB.

Here A can be interpreted as the external noise sound power suppression level. Considering an accuracy of ±1 dB in setting the sound power level with the B&K 4205, the data in Figure 3 indicates that for measurements with an unknown source using this system, the sound power measured would be accurate to within ±1 dB for L_K less than 8 dB. It must be pointed out that an attempt to use equation (7) as a universal correction curve could be erroneous; it merely indicates the range of L_K for which one can establish the confidence limits for a particular system and is, in fact, related to the dynamic capability of the measuring system, thus indicating the importance of knowing the dynamic capability of one's sound intensity measuring system.

3.2 Location of a noise source

Owing to the directional response of a sound intensity probe as described in section 2.0, the sound intensity technique has often been used to locate a noise source by the "null-search" method; that is, the intensity probe is swept in a direction parallel to its axis past a suspected noise source, the location of the noise source being indicated by the reversal of the sign of the intensity spectrum as the probe passes the source. The sound intensity technique can be quite useful in identifying airborne noise transmission paths, particularly in building acoustics as demonstrated by Lai [9]. In such applications, the sound intensity probe is pointed towards the suspected partition and if the sound intensity spectrum is positive, then it can be inferred that the dominant noise is propagating through this partition. However, great care must be taken in monitoring the pressure-intensity index L_K in such applications because if the sound field is diffuse, then measurements may approach or even exceed the dynamic capability of the system, thus invalidating the use of the technique under such conditions.

Another method of locating a source is to perform an intensity mapping. Figure 4 shows one such application in

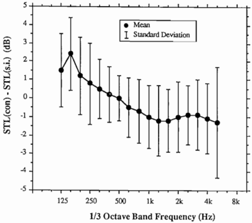

Figure 5: Comparisons between STL obtained by conventional and sound intensity methods.

which contours of overall sound intensity (in the frequency range 100 Hz to 6.4 kHz) have been obtained for two loudspeakers, one on top of the other with the bottom one standing on a reflective plane. The measurement grid, located at about 150 mm from the loudspeakers, is also shown and indicates that a total of 80 measurements have been made. The location of each loudspeaker is indicated by a large circle and each loudspeaker has a small circular port. The intensity contours clearly reveal the locations of the loudspeakers and the greater influence of the reflecting plane on the bottom loudspeaker than the top loudspeaker can be discerned. However, since only overall intensity contours have been plotted and the resolution of the measurement grid is not sufficiently fine, the effect of the circular ports has not been revealed in Figure 4.

3.3 Sound transmission loss measurements

In terms of the sound power W_s incident on the partition and the sound power W_r transmitted through and radiated by the partition, the Sound Transmission Loss (STL) is defined as:

$$STL = 10 \log_{10}(W_s/W_r) \qquad (8)$$

Traditionally, a test partition is installed in between two reverberant rooms and the STL is determined from the averaged sound pressure levels measured in the source and receiving rooms.

Expressed in terms of the space-averaged sound pressure level, L_{pi}, in the source room and the transmitted sound intensity level, L_{it}, using the relationship for a diffuse sound field and the normal values for the density of air and the speed of sound, equation (8) becomes

$$STL = (L_{pi} - 6) - L_{it} \qquad (9)$$

Hence, the sound transmission loss of a test partition can be obtained by measuring the averaged sound pressure level in the source room and the intensity transmitted through the partition into the receiving room. There has been considerable research conducted in establishing the accuracy of sound transmission loss measurements using the sound intensity technique in conventional laboratory facilities which consist of a source room and a receiving room. Absorption is normally introduced into the receiving room to reduce its diffusivity so that sound intensity measurements can be made within the dynamic capability of the measuring system. Lai et al [10] has surveyed and analysed over 40 tests reported in the literature. The difference in measured STL between the conventional sound pressure method and the sound intensity method is shown in Figure 5 in 1/3 octave frequency bands. It can be seen that with the exception of 160 Hz,the agreement between the two methods is within 1.5 dB. The STL values determined using the sound intensity technique are lower at the low frequencies and higher at the high frequencies than those determined using the conventional technique. It has been suggested that the discrepancies at low frequencies relate to the increase in energy density at the surfaces and junctions in the room because of the interference between the incident and reflected waves. A correction, known as "Waterhouse correction" (see [11] as given in expression 10), can be applied to both the source and receiving rooms for the conventional method and to the source room for the sound intensity method:

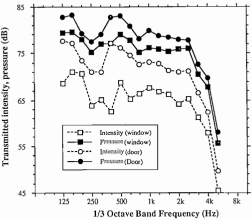

Figure 6: Comparisons between sound transmission through door and window.

$$10 \log_{10}(1 + S\lambda/8V) \qquad (10)$$

where λ is the wavelength of sound at the centre frequency of the filter band

S is the total surface area of the room

and V is the volume of the room.

With the application of the "Waterhouse correction", the agreement at low frequencies between the conventional and sound intensity methods is generally improved. The standard deviation of the agreement between the two methods for the test results surveyed by Lai et al [10] is also shown in Figure 5 and is about 2 dB. The variation of the agreement from tests to tests depends, to a certain extent, on how the sound intensity technique is used and on whether "Waterhouse correction" is applied. The general trend seems to indicate that with increased understanding of the sound intensity technique and improved experimental procedure, an agreement better than 1 dB is achievable between the conventional and sound intensity methods.

The real advantage of the sound intensity technique lies in field transmission loss measurements where transmission loss of elements such as doors and windows in composite partitions can be determined, thereby revealing the weakest link in composite partitions. Conventional sound pressure methods can only determine the sound reduction of a composite partition as a whole. As an example, Figure 6 shows the sound intensity transmitted through a 35 mm thick plywood door (2100 × 820 mm) and through a 6 mm thick glass (810 × 600 mm) built into the door. While sound pressure measurements do indicate in this particular case that the wooden door is the weaker link, the difference between the sound insulation of the wooden door and the glass is highlighted by the intensity measurements.

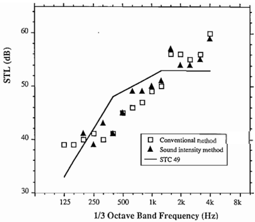

Figure 7: Comparisons between STL measurements for a 200 mm thick heavy block work.

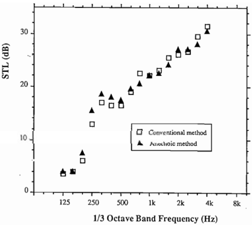

Figure 8: Comparisons between STL measurements for a hardboard panel.

The application of the sound intensity technique to field transmission loss measurements of elements of composite partitions is quite promising, as reported by Lai & Burgess [12]; however, in such applications, the success of the technique still very much depends on the expertise of the people using the technique and in understanding whether the measurements made are valid or not.

The sound intensity technique is particularly useful for the building industry as transmission loss measurements of heavy block work can be determined fairly quickly on the building site. An example is to build a source room on the site where the four walls can be made up of four different types of block work to be tested and the surroundings of the room are "open air". The averaged sound pressure level in the source room and the intensity transmitted through each wall can be measured. The STL of each wall can then be determined from equation (9). The results obtained by this technique for a 200 mm block work agree very well with standard laboratory tests made for the same block work, as shown in Figure 7. It should be noted that for this particular test, no data are provided for the STL at frequencies below 160 Hz because the pressure-intensity index L_K during measurements approached or even exceeded the dynamic capability of the measuring system. Sound intensity measurements in "open air" are subjected to two major sources of error, namely, background noise and wind conditions. As sound intensity measurements are made within 200 mm of a wall, the influence of background noise in "open air" is often not significant. As pointed out in section 2 above, commercial sound intensity measuring systems assume no mean flow and turbulence in the medium; thus, substantial errors can result from making outdoor sound intensity measurements under windy conditions. To a certain extent, this error can be reduced by using movable sound absorbing panels to shield the sound intensity probe from wind during measurements.

A novel technique for measuring acoustical properties (i.e., sound transmission loss and absorption coefficients) of lightweight panels using the sound intensity technique inside an anechoic room has been developed and studied by Lai et al [13]. Basically, the procedure involves (i) measuring the incident sound intensity I_i generated from a sound source at a plane where the tested panel is to be mounted, (ii) measuring the net sound intensity $(I_i - I_r)$ in front of the panel, where I_r is the intensity reflected from the panel, and (iii) measuring the sound intensity I_t transmitted through the panel. Since the tests are conducted in an anechoic room, it can be assumed that there are no reflections from the walls of the room. From these three measurements, the sound absorption coefficient and sound transmission loss of the test panel can be deduced. Figure 8 shows the sound transmission loss result of a 5 mm thick hardboard panel, which compares favourably with standard laboratory two-room test. This is a normal incidence testing method, which can also be extended to oblique incidence. The limitations of this technique are basically determined by the diffraction effects around the edges of the panel and will be discussed in more detail by Lai et al [13].

3.4 Other applications

Apart from the applications mentioned above, the sound intensity technique can be used to determine the impedance of materials and radiation efficiency of structures. One area currently under active research is the application of the sound intensity technique to measurements in flow ducts and active noise control [6].

4. CONCLUSIONS

Commercial sound intensity measuring systems have been available for almost a decade. A literature survey has revealed that the sound intensity technique has found increasing applications and is gaining acceptance while International Standards are being drafted to incorporate this technique. Examples given here show that provided the limitations of the sound intensity technique are understood, the technique can be used with good success for the determination of sound power "in situ", the location of noise sources and identification of airborne noise propagation path and field measurements of transmission loss of elements of composite partitions. With the improvement in hardware and software, accompanied perhaps by reduction in price, sound intensity measurements will certainly be more extensively used and the limits of applications will lie mainly on the ingenuity of the users.

ACKNOWLEDGEMENTS

Much of the work reported here has been conducted in collaboration with Marion Burgess, Andrew Dombek, Ken Mikl and P. Narang, to whom I am grateful for their assistance and stimulating discussions. The work described here has been supported in part by the University College Rector's Special Research Grant and in part by the University of New South Wales/CSIRO Collaborative Research Grant.

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REPORT

EXCELLENCE IN ACOUSTICS AWARDS 1990 NSW DIVISION

In November 1990 the NSW Division of the Acoustical Society held its second Excellence in Acoustics Awards presentation night in the elegant surroundings of Bilson's Restauramt nestled in the harbourside atmosphere of Circular Quay West in Sydney.

The first Awards night was held in December 1988 the year in which it had been conceived as a Bicentennial Project with the aim of recognising, promoting and stimulating the pursuit of excellence by individuals and organizations in the variety of fields under the acoustics (and vibration) umbrella.

Norm Carter, Chairman of the NSW Divisional Committee, made a brief official welcome thus setting the tone for an evening short on speeches and long on laughter and lively conversation.

There were many familiar faces amongst the guests and their partners, representing the broad gamut of members of the Society. Some new faces (on the NSW scene!) included Gary Woods, recently arrived from Perth to head up the NSW Public Works Department Acoustics Group, and Society President, Stephen Samuels, having made the move from Melbourne to work with environmental consultants Mitchell McCotter.

Representatives were also present from the three sponsors without whose generous financial support the 1990 Awards would not have been possible. These included CSR Hebel's John Klune, David Linaker and Peter Cummins; Bradford Insulation's, Clyde Parsons and Keith Davis and, from Newcastle, Michael Johnson and John Russell of Hudson Pacific, a construction firm specialising in noise control.

Especially noteworthy were guests representing the lay judge on each adjudicating panel for the two Awards categories. There was Jeff Dobell, executive officer of the Sydney Division of the Institution of Engineers, Australia, standing in for national chief executive, Bill Rourke and Peter Walsh, Director of the Standards Association of Australia, standing in for Chief Executive, Stewart Horwood. Also at hand to observe and report on this occasion was Robert Jackson, a journalist with the Institution of Engineers national publication Engineers Australia. Robert subsequently reported on the Awards in Engineers Australia's national 1990 Awards of Engineering Excellence.

Not forgetting the entrants and the Awards themselves, when it came time to announce the winners Tony Hewett, Chairman of the Excellence in Acoustics Awards Committee, made a concise and information-packed speech. In **Category One**, Architecture, Manufacturing or Research and Development, the winner was Sydney based acoustical consulting firm **Peter Knowland & Associates** for its acoustical design of the Main Auditorium of the Aotea Centre in Auckland, New Zealand. This 2300-seat hall is designed as a multi-purpose auditorium catering for events ranging from opera and ballet to chamber music, from symphony orchestral performances to popular concerts. A clearly elated Peter Knowland was present to receive an elegantly framed certificate on behalf of his firm. The judges noted that "Peter's entry involved the resolution of difficult problems by unusual and innovative techniques with the attainment of a high quality outcome".

Also **highly commended** in this category were the entries of **Robert Fitzell Acoustics** for the Architectural Acoustic Design of Brisbane Airport Domestic Terminal, involving innovative design solutions for external and internal noise control and sound reproduction, and **Renzo Tonin & Associates** (the 1988 Awards winner in this category) for its work on Noise and Vibration Design associated with the construction and operation of the Perisher Ski Tube rack-rail transit system. The adjudicating panel in this category consisted of Richard Heggie and Dick Godson, principals with Richard Heggie Associates, Barry Murray, principal of Wilkinson Murray Griffiths, Bill Rourke, chief executive of The Institution of Engineers Australia and Tony Hewett, Chairman of the Excellence in Acoustics Awards 1990.

The winner of **Category Two**, Engineering Reports, Procedures and Systems was **Dr. Qunli Wu** a project engineer with Vipac, for his treatise, on the Determination of the Size and Location of an Object in a Rectangular Cavity by Eigen Frequency Shifts, arising from doctoral research carried out in Architectural Science Department of Sydney University. An obviously proud Dr. Wu was at hand to accept his framed award certificate. In this case the judges noted that "... the research is novel and advances acoustic knowledge ... the ideas presented clearly work...". **Highly commended** in this category was **Robert Fitzell Acoustics** for their report on the Elements and Applications of Integrated Systems for Noise and Vibration Level Monitoring and Data Collection. In this Awards category the adjudicating panel consisted of Dr. John Dunlop, Senior Lecturer with the Department of Applied Physics at the University of NSW (and also an Assisting Editor for Acoustics Australia), Dr. Renzo Tonin & Associates, Stewart Horwood, chief executive of the Standards Association of Australia, and Tony Hewett, Chairman of the Awards Committee.

With the formal part of the evening over the conversation returned to its previous cocktail party level, it was certainly clear the 1990 Awards had been a successful event representing a bright spot in this time of economic downturn.

Once again the Excellence in Acoustics Awards Committee would like to extend its congratulations to the winners and its thanks to all who participated in the success of the 1990 Awards. Hopefully the 1991 Excellence Awards will continue and improve upon the success of its predecessors. In time it is hoped, in the spirit of excellence, the Awards will evolve to include a broader range of judging categories and will attract a wider range of entrants possibly including individuals and organisations from the community at large.

Andrew Zelnik

Acoustic Impedance Calculation From Impedance Tube Data

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ABSTRACT: The expressions for R_s and X_s, the real and imaginary components of the specific normal acoustic impedance Z_s of the surface of a material, as given in Australian Standard AS1935 are incorrect. Correct expressions are developed in this paper. The chart Figure 3 of AS1935, which purports to represent the expressions given, is in fact correct. However, since experimental results are now normally based on computation rather than charts, it is important that the correct expressions be used. The errors are significant.

1. INTRODUCTION

The acoustic impedance tube (or standing wave apparatus) has a long history of use for determination of acoustic absorption properties of materials. It was referred to at least as early as 1902 and a commercial version has been available since 1955 [2].

The impedance tube in its usual form enables the experimental determination of absorption coefficient and acoustic impedance of a material for sound waves at normal incidence. Often the acoustic properties are required for some form of random incidence, in order to simulate wave behaviour in enclosed spaces. This is done by reverberation chamber tests; refer, for example, to AS1045 [3]. However, the impedance tube method is much faster and cheaper and is often used, especially for comparing many materials quickly, in basic research and in pre-selection of arrangements for more extensive study.

The impedance tube apparatus, its limitations, the experimental technique and data reduction are described thoroughly in ASTM C384 [4] and AS1935 [1].

In AS1935, expressions are given (p. 9) for the components of impedance, R_s and X_s. These expressions are wrong. The correct expressions are developed and given in this work.

2. STATEMENT OF EXPRESSIONS

For notation see Appendix 1.

The expressions given in AS1935-1976 (p. 9) are:

$$\frac{R_s}{\varrho c} = \frac{10^{L_o/20}[1 + \tan^2 2\pi(d_1/\lambda - 0.25)]}{1 + 10^{L_o/20}\tan^2 2\pi(d_1/\lambda - 0.25)} \qquad (1)$$

$$\frac{X_s}{\varrho c} = \frac{[10^{L_o/20} - 1]\tan 2\pi(d_1/\lambda - 0.25)}{1 + 10^{L_o/10}\tan^2 2\pi(d_1/\lambda - 0.25)} \qquad (2)$$

The correct expressions are:

$$\frac{R_s}{\varrho c} = \frac{10^{L_o/20}[1 + \tan^2 2\pi(d_1/\lambda - 0.25)]}{1 + 10^{L_o/10}\tan^2 2\pi(d_1/\lambda - 0.25)} \qquad (3)$$

$$\frac{X_s}{\varrho c} = \frac{[10^{L_o/10} - 1]\tan 2\pi(d_1/\lambda - 0.25)}{1 + 10^{L_o/10}\tan^2 2\pi(d_1/\lambda - 0.25)} \qquad (4)$$

Figure 3 in AS1935 is a chart which is stated to be a computational chart for enabling $R_s/\varrho c$ and $X_s/\varrho c$ as given by Equations (1) and (2) to be read directly. In fact, the chart represents Equations (3) and (4) and thus will give the correct values for $R_s/\varrho c$ and $X_s/\varrho c$, whereas Equations (1) and (2) will not.

3. DEVELOPMENT OF CORRECT EXPRESSIONS

Consider incident and reflected waves represented as follows (see Appendix 1 for notation).

Incident wave $\quad p_i = Ae^{i(\omega t + kx)}$

$$p_r = Be^{i(\omega t - kx + \theta)}$$

Acoustic pressure at surface $= p = p_i + p_r$

Particle velocity at surface $= u = u_i + u_r = (1/\varrho c)(-p_i + p_r)$

Normal surface impedance $Z_s = -p/u$ (since surface velocity is taken as positive in the negative x direction)

$$\therefore \frac{Z_s}{\varrho c} = \frac{(p_i + p_r)}{(p_i - p_r)} = \frac{Ae^{ikx} + Be^{-i(kx+\theta)}}{Ae^{ikx} - Be^{-i(kx+\theta)}}$$

$$= \frac{A + Be^{i\theta}}{A - Be^{i\theta}}$$

$$= \frac{A + B(\cos\theta + i\sin\theta)}{A - B(\cos\theta + i\sin\theta)}$$

Rationalising, and substituting $Z_s = R_s + iX_s$,

$$\frac{R_s}{\varrho c} = \frac{A^2 - B^2}{A^2 + B^2 - 2AB\cos\theta} = \frac{1 - (B/A)^2}{1 + (B/A)^2 - 2(B/A)\cos\theta}$$

$$\frac{X_s}{\varrho c} = \frac{2AB\sin\theta}{A^2 + B^2 - 2AB\cos\theta} = \frac{2(B/A)\sin\theta}{1 + (B/A)^2 - 2(B/A)\cos\theta}$$

Reflection coefficient $\alpha_r = (B/A)^2 = (S-1)^2/(S+1)^2$, where standing wave ratio $S = (A+B)/(A-B)$.

Substituting and simplifying, and noting that $(1-\cos\theta)/(1+\cos\theta) = \tan^2(\theta/2)$,

$$\frac{R_s}{\varrho c} = \frac{S(1 + \tan^2(\theta/2))}{1 + S^2\tan^2(\theta/2)} \tag{5}$$

$$\frac{X_s}{\varrho c} = \frac{(S^2-1)\tan(\theta/2)}{1 + S^2\tan^2(\theta/2)} \tag{6}$$

Standing wave ratio is the ratio of maximum and minimum pressures in tube. If the level difference between maximum and minimum is L_o (decibels), then

$$L_o = 20 \log S,$$
$$S = 10^{L_o/20} \tag{7}$$

If d_1 is distance from specimen face to first minimum pressure, then from the expansion of $|p_i + p_r|$,

$$d_1 = (\lambda/4)(1-\theta/\pi)$$
$$\theta/2 = 2\pi(d_1/\lambda - 0.25) \tag{8}$$

Substituting (7) and (8) in (5) and (6) gives (3) and (4).

Table 1 — VALUES OF $R_s/\varrho c$

d_1/λ θ deg	0 180	0.0625 135	0.125 90	0.1875 45	0.25 0
$L_o =$ 0dB	1.0	1.0	1.0	1.0	1.0
5	0.562	0.625	0.854	1.351	1.778
10	0.316	0.364	0.575	1.364	3.162
15	0.178	0.207	0.345	1.025	5.623
20	0.100	0.117	0.198	0.645	10.0

For $0.25 < d_1/\lambda < 0.5$, use $(0.5 - d_1/\lambda)$ and attach − sign to θ

4. ERRORS AND CHECK VALUES

The errors which arise from use of the incorrect equations can be large. For example, if $L_o = 20$ dB and $\theta = 0$, the result given by Equation (1) is 10 times the correct value, and the result from Equation (2) is less than 0.1 times the correct value.

For checking programs or for obtaining a rapid estimate from L_o and d_1 values, a tabulation of R_s and X_s is given in Tables 1 and 2. Comparison of these tables with Figure 3 of AS1935 will show that Figure 3 is correct.

5. CONCLUSION

From the above development and from independent calculations based on other sources it is considered that the equations for specific normal acoustic resistance and specific normal acoustic reactance as given in AS1935-1976 are incorrect. Amendment is necessary.

ACKNOWLEDGEMENT

The contributions to this work by S. Dias-Jayasinha and J. de Jongh are gratefully acknowledged.

SUPPLEMENTARY NOTE

Since submitting this article a private communication has indicated that the errors were typographical. It is also understood that corrections to the Standard are in progress.

Appendix 1 — NOTATION

Z_s	specific normal acoustic impedance
R_s	specific normal acoustic resistance
X_s	specific normal acoustic reactance
ϱc	characteristic impedance of air
L_o	true value of difference in decibels between maximum and minimum sound pressure levels in the standing wave pattern
d_1	distance from face of specimen to nearest minimum in standing wave pattern
λ	wavelength of sound at test frequency
p_i, p_r	sound pressure of incident and reflected waves
A, B	amplitudes of p_i and p_r
θ	phase angle by which reflected wave leads incident wave at face of specimen
ω	$2\pi f$, where f = test frequency
k	$2\pi/\lambda$
t	time
x	distance $x = 0$ at face of specimen Standing wave pattern exists in the region $x \geqslant 0$.

Table 2 — VALUES OF $X_s/\varrho c$

d_1/λ θ deg	0 180	0.0625 135	0.125 90	0.1875 45	0.25 0
$L_o =$ 0dB	0	0	0	0	0
5	0	−0.269	−0.519	−0.581	0
10	0	−0.367	−0.818	−1.373	0
15	0	−0.399	−0.939	−1.974	0
20	0	−0.409	−0.980	−2.258	0

For $0.25 < d_1/\lambda < 0.5$, use $(0.5 - d_1/\lambda)$ and attach − sign to θ and + sign to $X_s/\varrho c$

REFERENCES

1 Australian Standard 1935-1976. Method for the Measurement of Normal Incidence Sound Absorption Coefficient and Specific Normal Acoustic Impedance of Acoustic Materials by the Tube Method. Standards Association of Australia, Sydney, 1976.

2 P.V. Bruel. The Standing Wave Apparatus. Bruel & Kjaer Technical Review, No. 1, 1955, pp. 2-20.

3 Australian Standard 1045-1988. Method of Measurement of Absorption Coefficients in a Reverberation Room. Standards Association of Australia, Sydney, 1988.

4 A.S.T.M. C384-88. Standard Test Method for Impedance and Absorption of Acoustical Materials by the Impedance Tube Method. Amer. Soc. for Testing and Materials, 1988, vol. 04-06, pp. 95-105.

NEWS NEWS NEWS NEWS

NSW

April Technical Meetings

On 3 April a Symposium was held on "The Need for a Code of Ethics" with **Dr Peter Miller**, Chairman of the Institution of Engineers Standing Committee on Liability, as guest speaker. **John Goldberg**, **Anita Lawrence** and **Richard Heggie** were the other speakers. Dr Miller stressed the importance of ethical behaviour for all the professions, especially because of the necessity for judgement and interpretation of data, a feature of professional work which is sometimes not fully appreciated by the layman. He also discussed the importance of a code of ethics in forming the foundation and holding together a professional Society. The other speakers spoke in favour of a formal code of ethics although there was some doubt that this, in itself, would achieve anything. The meeting favoured the formulation of a Code of Ethics which all new members would be required to sign agreement.

On 17 April **John Whitlock** (CSIRO Division of Building Construction and Engineering) spoke on "Noise Control versus Fire Protection in Buildings". John pointed out that building regulations sometimes require quite different and sometimes conflicting solutions to requirements for sound transmission loss and sound absorption. In these circumstances, acousticians should be alert to the fire properties of the materials they use and also consider the acoustical problems which may arise from special fire walls etc.

May Technical Meeting

Graduate students from the Dept of Architectural and Design Science at the University of Sydney discussed their projects on 29 May. **John Wilson** explained his study of the correlation between laboratory and field tests for the sound transmission loss of brick walls and the possibility that field tests may be preferable. **Jin Leon** described his experiments on the relation between pitch and intensity to the perception of the duration of sounds. **John Wendoloski** reported on the effect of the termination on the sound radiation from pipes. His measurements of the velocity distribution across the mouth of the pipe have confirmed Raleigh's assumptions and using computer modelling he has obtained a variational solution to the equations governing sound radiation from pipes. **Chan Hoon Haan** explained his studies of the acoustical properties of auditoria and how the data would be used to guide the development of design rules for auditoria. **Steve Cooper** compared various criteria for helicopter noise designed to minimise adverse community response.

Norm Carter

ACT

April Technical Meeting

Since the late 1980s the responsibilities for planning to maintain the unique environment in the ACT has changed. The aim of a meeting on "Noise Control and Planning in the ACT", held on 17 April, was to provide a forum for discussion of relevant issues.

Ian Lawrence, from the Environmental Planning and Assessment Section of the ACT Planning Authority, explained the approach to the establishment of Guidelines in the ACT and identified the major noise issues which are being considered. Representatives from other agencies with some responsibilities for noise issues provide brief comments before the general discussion. These were:**Tim Kahn**, from the Air, Noise and Nuclear Section, Environmental Protection Division of DASETT, **Anne Lyons-Wright**, from the Environmental Planning Branch of the NCPA, **Jake Kasinathan**, from the the Environmental Protection Section of the ACT Government and **Bill Knight**, from the NSW SPCC office in Queanbeyan.

Marion Burgess

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SOUTH AUSTRALIA

April Technical Meeting

A site visit to the Adelaide Entertainment Centre was held on 3 April. The representatives from the local consulting firm, Bassett PGD, discussed both the problems of containment and rejection of unwanted noise and the acoustic problems due to the wide variety of uses for the Centre. Following the visit a "Thai Night" dinner was enjoyed at a nearby hotel.

May Technical Meeting

Peter Maddern and **Peter Messer** talked about noise control for a popular disco at Glenelg. Solutions to the low frequency noise problem involved double glazing of windows, provision of a concrete roof and extensive treatment of the disco venue. A novel and effective treatment of the source allows programmable suppression of the particular portions of the spectrum annoying the neighbours. Selective suppression of the annoying portions by up to 10 dB has been achieved without detection by those in the venue.

David Bies Prize

In recognition of the contributions of David Bies to the science, practice and education in acoustics, the South Australian Branch has established a prize to recognise outstanding contributions in this area. The prize will be available each year and may be awarded to an acoustical practitioner based in SA or to persons who have made meritorious contribution to the discipline in SA.

David Bies

WEST AUSTRALIA

March Technical Meeting

A visit to WA by Federal secretary **Ray Piesse** was the catalyst for a meeting on 21 March, attended by about 35 people, on "Common-Law Claims for Industrial Deafness - Is WA Next?". Ray's long experience in NSW was complemented by the legal expertise of local solicitor **John Gordon**. Following a discussion on some NSW experience, John Gordon's description of the quirks of the Statute of Limitations goes some way to explaining why there have not yet been any cases in WA.

May Technical Meeting

World-leading research by a team at the UWA Physiology Dept provided the theme for a fascinating meeting on "The Ear as an Acoustic transducer" on 16 May. Dr **Graeme Yates** explained the remarkable transduction "technology" of the inner ear to about 15 members. One aspect was the frequency discrimination of the inner hair cells, which is enhanced by the outer hair cells "bouncing" on the tympanic membrane creating a "positive feedback" loop. The loop gain is carefully set at just below 1. The loss of just a few percent of the outer hair cells reduces this loop gain slightly, causing a large drop in overall system gain, ie hearing acuity.

John Macpherson

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OBITUARY

Reg McLeod

It is with deep regret that the Victoria Division informs Australian Acoustical Society members of the recent death of Reg McLeod, who served as treasurer of the Division during the 1970's.

Reg worked with the State Electricity Commission of Victoria as an Engineer practically all his working life, until his retirement in 1987. In his early days with the SECV, Reg was concerned with balancing work for rotating machines. In the 1980's he was a key man with the Commission on technical information and research on the "Environmental Effects Statement" for the Newport Power Station. Towards the end of his career, Reg was mainly concerned with acoustical design of control rooms for SECV personnel, training noise officers and setting up various training courses in acoustics.

To his friends, Reg was known as an avid hobbyist and keen golfer (he built his own golf buggy). His mild manner, modesty, eye for detail and very deep and subtle understanding of acoustics were some of his excellent qualities. We wish to convey to his widow and family, on behalf of the Australian Acoustical Society, our deepest sympathies and appreciation for Reg's contribution to the Victoria Division.

G Benke

STANDARDS

Standards Australia has revised its register of those standards which are referred to in Commonwealth, State and Territory legislation. The new Handbook, HB4, recognises the need to provide a comprehensive up-to-date reference for all those who need to determine compliance requirements under legislation in Australia. The handbook deals predominantly with formal references to Standards in Acts, Regulations, By laws and Ordinances.

A draft Australian Standard, **DR 91095**, on "Ground transmitted vibration from airblast explosions, part 1" is available for comment. The standard proposes maximum levels permissible to avoid human discomfort and structural damage to residential and industrial buildings.

Those Standards which are available through the Standards Secretariat of the Acoustical Society of America, are listed in a new catalogue 10-1991. An **American Standard** on "Audible emergency evacuation signals" has recently been released. The Standard specifies the procedures for determination of the spectrum and the pattern on "on" and "off" times. *Further information from ASA Standards Secretariat, 335 East 45th St, New York 10017, USA*

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CONFERENCES

• WESTPRAC IV

Westprac IV is the official Conference of the Western Pacific Regional Acoustics Commission. It will be held in Brisbane from 26 - 28 November 1991 (the week prior to INTERNOISE 91) and the aims are:

- to provide a meeting ground for personal contact with fellow acousticians from Western Pacific region
- to promote greater interchange between member countries, associations and individuals
- to consult, discuss and exchange technical information within the theme - Progress in Acoustics

The keynote speakers will be **Prof Toshino Sone** (Japan), **Prof Wann Yu** (Korea), **Prof Ji Qing Wang** (China) and **Prof Yuan Ling Ma** (China). A total of 127 papers will be presented during the conference. *Further information from: Conference Convenor, Westprac IV, P.O. Box 155, North Quay, Queensland 4002. Tel (07) 227 6802, (07) 227 6422 Fax (07) 227 7677*

NOISE WORKSHOP

The aim of this workshop is to achieve a practical understanding and application of basic noise control principles and practices. It is sponsored by the World Health Organisation Noise Reference Centre for the Western Pacific Region and the Department of Environment and Heritage, Queensland. The five day workshop, from 18 to 22 November 1991, is designed for personnel involved in environmental noise monitoring and control. The course will be held in Brisbane and the cost will be $650. *Further information: Greg Lee Manwar Tel (07) 227 6436 Fax (07) 227 7677*

• INTERNOISE 91

I am pleased to report that there has been an outstanding response to the Call for Papers for INTERNOISE 91, to be held in Sydney from Dec 2 to 4 1991. The 2nd Circular - Invitation to participate - has been distributed and lists the titles of some 460 abstracts (about 80 from Australian authors).

The Circular includes details of the various associated activities. Technical tours include visits to BHP Colliery and Steel Works at Port Kembla, National Acoustics Laboratory and National Measurement Laboratory in Sydney, BHP Mini Steel Mill at Rooty Hill, noise monitoring system at Sydney Airport and the Sydney Opera House. Most of these tours have been generously subsidised and as places are limited, early registration is recommended.

Registered accompanying persons (fee $A35) may take part in a number of special tours including a complementary 2-hour harbour cruise. One full-day tour is to the Blue Mountains and Australian Wildlife Park and the other is a city tour. Half-day tours include city sightseeing, visits to the Art Gallery and Australian Museum or a walking tour in the historic Rocks area of Sydney.

The social programme includes the Opening Ceremony which will be addressed by a prominent Australian and include musical entertainment, a Happy Hour, a conference banquet and a farewell party. A Trade Exhibition is also being organised. Block bookings have been made at special conference rates at a range of hotels, motels and University Colleges.

I am sure that those of you who were fortunate to participate in the 10th ICA in 1980 will remember the many opportunities they had, not only to discover the latest research and development work being carried out in acoustics in many parts of the world but also to form and renew friendships with acousticians from many different countries. INTERNOISE 91 promises to be an equally interesting and exciting event - albeit concentrating more on the area of noise control engineering. I encourage everyone who possibly can to join in - remember it is likely to be the last major international acoustics event in Australia in the 20th Century!

Further information: Christine Bourke, Conference Secretariat, IPACE Institute, University NSW, PO Box 1, Kensington, NSW 2033, Australia

Anita Lawrence

Internoise Brochure Correction

p11 "..(1 night/bed).." should read "..(1 night/room).."
and "Savoy apartments consist of a double bedroom with a convertible double bed in the living room. Extra child beds, kitchen and laundry facilities are available. Suitable for families. $110/night"

Air- and Structure-Borne Sound and Vibration

The Australian Acoustical Society has been invited to be a cooperating society for the Second International Congress on Recent Developments in Air and Structure-Borne Sound and Vibration to be held March 4-6, 1992. The Congress is being sponsored by Auburn University in cooperation with the Acoustical Society of America and the Institute of Noise Control Engineering. The announcement and call for papers has recently been distributed.
Further information: Congress Secretariat, Dept Mech Eng, 210 Ross Hall, Auburn university, AL 36849-3541, USA.

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Overseas Exchanges

The Australian Academy of Science supports a number of scientific exchange programs which offer financial assistance for Australian researchers to spend some time in other countries on appropriate projects. Some countries which are part of the exchange program are Japan, United Kingdom and China. *Further information: International Exchanges, Australian Academy of Science, GPO Box 783, Canberra ACT 2601 Tel (06) 247 3966*

Various other international fellowships and scholarships are available and information on these schemes can be obtained from: *Department of Employment, Education and Training, PO Box 9880, Canberra ACT 2601 Tel (06) 2767708*

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Bradford Insulation has introduced a technical service via a 008 number (not available in WA or NT) for immediate information on all design and specification queries - Tel 008 011 301

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Singaporean manufacturer **Acoustical Services** (1989) is seeking distributors for its range of ultrasonic flaw detectors and thickness gauges. The Echope series range from basic units for universal applications to units with varied range of functions for special applications. *Further information: C S Chong, Acoustical Services (1989) Pty Ltd, 209-212 Innovation Centre, Nanyang Crescent, Singapore 2263, Tel 2660242, Fax (65) 2660665*

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Reinforced Earth Pty Ltd have a new address PO Box 742, Gosford 2250 - Tel 043 72 1566 Fax 043 72 1590. Marketing Manager - Mr Gary Power

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REQUEST FOR INFORMATION

Would any former students, research associates or friends of the late Dr R W B Stephens please send a brief summary regarding their joint activity with Dr Stephens to:

Dr R C Chivers, University of Surrey, Guildford
Surrey GU2 5XH UK

who is making a collection of papers relating to Dr Stephen's activities.

PEOPLE

Peter Griffiths left Wilkinson, Murray, Griffiths in May, to take up a permanent position with Arup Acoustics in London. Apart from his many years of work in the acoustical consulting scene, Peter has been a consistent and active member of the NSW Divisional Committee over recent years.

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In late November 1990, **Donald Woolford** left the Australian Broadcasting Corporation, for whom he had been an engineer and consultant in acoustics for many years, first in SA and later in NSW. Parting from the ABC has enabled a career change but his interests will still include psychoacoustics, music and hearing problems among symphony musicians. Don is an active supporter of the Society, having been a Federal Councillor, member of the SA Divisional Committee and is currently a member of the NSW Committee.

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It is with pleasure that we welcome **Environmental Noise Control Pty Ltd** as a sustaining member of the Society

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New Members

• Interim Admissions

We have pleasure in welcoming the following who have been admitted to the grade of Subscriber while awaiting grading by the Council Standing Committee on Membership.

New South Wales
Mr T Markiewicz

Victoria
Mr K A Eaglesome

Western Australia
Mr P R Baster, Ms P Gabriels, Mr T S Saw

• Graded

We welcome the following new members whose gradings have now been approved.

Student

New South Wales
Mr T Cain

Victoria
Mr D E P Lawrence, Mr A J Rogers, Mrs K Terts (TAS)

Subscriber
New South Wales
Mr G J Kasinathan (ACT), Dr H M Williamson (ACT)

Member
New South Wales
Mr P Karantonis, Mr J L Tai (Malaysia)
Queensland
Mr B D Borgeaud, Mr R H Palmer
Western Australia
Mrs R J MacMillan, Mr R I Sutherland

BOOK REVIEWS

SOUND ANALYSIS AND NOISE CONTROL

John E K Foreman

Van Nostrand Reinhold, 1990, pp 461, Hard Cover ISBN 0 442 31949 5
Australian Distributor: Thomas Nelson Aust, 102 Dodds St, South Melbourne Vic 3205 Price $139.95

The preface of this book states that it provides the link between the understanding of the fundamentals of sound and the application of those fundamentals. The range of topics covered certainly attempt to provide the bridge between the two aspects.

As for any book with sound and noise in the title, the first chapters cover the basics of sound and of hearing. The following chapter on instrumentation starts with the construction of the microphone and ends with sound intensity instrumentation. The inclusion of photographs, as opposed to block and line diagrams, makes this chapter particularly interesting for the person just embarking on the study of sound measurement.

The next chapters on sound fields, absorption and transmission loss and vibration control bring together material from a wide range of other books. In any compilation some things must be left out, for example the STC system is explained but the table of typical sound transmission loss values only gives octave data and does not list the STC for each construction. The chapter on noise criteria and regulations relate primarily to American criteria but some reference is made to ISO standards.

The last two chapters, on general review of noise control, practical examples and noise source diagnosis comprise almost half of the book. There are many diagrams and examples which would of great benefit to students and those new to the field. A large portion of one of the chapters is a reproduction of the Bruel & Kjaer publication "Noise Control Principles and Practice" which I have found to be a good source for examples to use for classes or discussions. The chapter on case studies provides more technical details. The final pages of the book give useful information including other general reference books, lists of American and International Standards and guides for products and instrumentation suppliers in America.

The book certainly does attempt to provide the bridge as indicated in the preface, and would be a useful reference book for libraries and for those learning about the various approaches to noise and vibration control.

Marion Burgess

Marion Burgess is research officer at the Acoustics and Vibration Centre of the Australian Defence Force Academy. She has been, and still is, involved with teaching acoustics to both undergraduate and postgraduate students.

MUSIC, SOUND AND TECHNOLOGY

John M Eargle

Van Nostrand Reinhold, 1990, pp 290,
Hard Cover, ISBN 0442 31851 0
Australian Distributor: Thomas Nelson Aust,
102 Dodds St, South Melbourne Vic 3205,
Price $99.95

With this new book, dealing with musical acoustics at a semi-technical but non-mathematical level, the interested reader now has a selection of at least five volumes of this type published within the past ten years, together with several earlier classics, from which to choose. Each of these books has merits, and their continuing appearance is evidence for growing interest in the field. With this variety from which to choose, it is appropriate to look for distinguishing features by way of content or treatment.

Eargle, so the publishers notes inform us, holds degrees in music and electrical engineering, has worked as a recording engineer, and is now head of an audio consulting firm in the US. This background is reflected in his choice of emphasis for the book, about half of which is devoted to concert-hall acoustics, orchestral seating arrangements, microphone and loudspeaker placement, and related topics. The acoustics of musical instruments occupies another 30 percent of the contents, with emphasis on spectra, power range and playing technique rather than on mechanistic details, and there are short but adequate sections on physical and psychological acoustics. This balance of material does not duplicate that in any other book of which I am aware.

The book is clearly and pleasantly written, and is an easy read for someone with a background in physics, engineering or acoustics. It would also be useful at senior high school level for students taking an option in this subject area. Even for those quite familiar with the material, there are some useful insights to be gained, and the book would provide useful background for those interested in sound reinforcement or recording - a field in which Eargle has also written an engineering handbook. There are only a few equations, and those mostly for things like reverberation time, and the text is well illustrated with line drawings and a few photographs. A few musical examples are quoted but, as with the mathematics, these need not put off the unequipped reader. Each chapter has a short bibliography, mostly listing other books at a similar level. The text is almost completely free from typos, except for one table in which the pit dimensions and track spacings in a CD are all given as millimetres, when micrometres are required!

I can recommend this book for school and community libraries, and for the general reader at university or professional level. My only reservation is the price, which seems rather high for a non-specialist book of only moderate length.

Neville Fletcher

Neville Fletcher is a Chief Research Scientist with CSIRO. He has written widely on musical acoustics, among other things, and has recently published a (rather mathematical!) book "The Physics of Musical Instruments" (with T.D. Rossing) which will be reviewed in the near future.

HANDBOOK OF HUMAN VIBRATION

Michael J Griffin

Academic Press Ltd, 1990, Hard Cover,
ISBN 0 12 303040 4
Australian Distributor: Harcourt Brace
Jovanovich, Australia, Locked Bag 16,
Marrickville NSW 2204 Price: $346.50

This 1000 page work is a milestone in its field. Nowhere else have I seen such a comprehensive and authoritative coverage of this important topic. The field of human vibration has been defined as the study of the effect of mechanical vibration on the human body. The book attempts to explain the way in which the various influential factors, including the vibration itself, combine to produce the human response. In many areas, our knowledge of human vibrations is quite limited and Griffin presents a well referenced summary of what is known plus a discussion of the limitations of existing studies. As a leading researcher in human vibrations at the Institute of Sound and Vibration Research, University of Southampton, Michael Griffin must be one of the foremost experts in this field. His years of work and standing in human vibrations is obvious from the quality and extent of this handbook.

From the outset it is clear that this is not a field for the narrow disciplinary specialist. The study of human vibrations is multi-disciplinary in the extreme involving physics, physiology, psychology, mathematics, engineering, medicine and statistics. Since only a few luminaries can claim sufficient knowledge in all of these areas, the handbook provides an extensive glossary with definitions of terms such as cross-spectral density, cutaneous sensory system, damped natural frequency, monosynaptic and double-blind testing. It would be a rare person who could claim familiarity with the full range of human vibration terminology.

As with most discussions of human vibration, the topic is divided up into the areas of whole-body vibration and hand-transmitted vibration. Chapters on whole-body vibration cover the topics of vibration discomfort, activity interference caused by vibration, health effects, vibration perception, building vibrations, motion sickness, biodynamics, seating dynamics, vibration standards and measurement techniques. The chapters on hand transmitted vibrations cover vascular and other disorders, dose-effect relationships, preventative measures, vibration standards and measurement techniques.

The discussions of vibration standards are most useful since they include explanations of some of the rationale behind the standards as well as reference to relevant research. Also, Griffin does not hesitate to criticise the standards or point out inadequacies in their coverage. This criticism is most helpful to the practicioner who may have to utilise standards and needs to know more about their limitations.

With a recommended retail price of $346.50 the Handbook of Human Vibration is very expensive, however in my opinion it is good value for money. It makes an excellent starting point for the beginner, it is an authoritative reference book for the researcher and it serves as an invaluable guide to the practicioner. The book would be a most useful addition to the personal library of medical doctors, engineers, lawyers, scientists, trade union officials and administrators who work in human vibrations. It is also a book that should be found in any well stocked university or technical library.

Hugh Williamson

Hugh Williamson is a Senior Lecturer in the Department of Mechanical Engineering at the Australian Defence Force Academy. As well as lecturing in design, materials, logistics and vibrations, he is an active member of the Acoustics and Vibration Centre carrying out research and consulting in machinery vibrations and noise.

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OCCUPATIONAL NOISE INDUCED HEARING LOSS:

Prevention and Rehabilitation

WORKSAFE AUST and UNIVERSITY OF NEW ENGLAND

Nat. Occupational Health and Safety
Commission, Sydney; University of New
England, Armidale, 1991, pp 110, Soft Cover
ISBN 0 85834 925 6
Distributor: Worksafe Aust, GPO Box 58,
Sydney 2001. Price $A35

During November 1990, a series of one day seminars was presented in various centres throughout Australia on "Occupational Noise" Induced Hearing Loss: Prevention and Rehabilitation". Speakers in the seminars were Professors Raymond Hetu and Louise Getty from the University of Montreal, Prof William Noble from University of New England and Richard Waugh from Worksafe Australia.

The seminars featured the public health oriented approach to rehabilitation and prevention developed at the University of Montreal, and the implications of that approach for research and practice; the history and politics of noise induced hearing loss; an overview of the Australian scene regarding noise exposure, hearing impairment, compensation and rehabilitation; and the Worksafe Aust national strategy for the prevention of occupational noise induced hearing loss. The Proceedings of the Seminars include the texts of the presentations and a paper discussing the issues raised in the seminar discussions.

NEW PRODUCTS

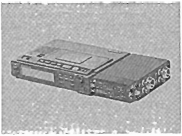
NORSONIC

Sound Analyser

The Norsonic Integrating Sound Analyser, type **110**, combines the features of an integrating sound level meter, environmental noise analyser, frequency analyser, graphic level recorder and reverberation time analyser in a single portable instrument. The 110 conforms to requirements for type 0 performance and can simultaneously measure Lp, Lmax and Lmin with Fast, Slow and Impulse time constants, Leq, Leqt, SEL and wave form +Peak and -Peak followed by amplitude distribution statistics. Serial 1/1, 1/3, 1/6 and 1/12 octave frequency analysis can be undertaken and the current and stored data can be seen numerically or graphically on a built-in LCD screen. The RS 232 interfaces allow simultaneous printing and down loading of data.

DAT Front End

DAT recorders do not normally support microphone inputs. The Norsonic front end, type **112**, is designed to be mounted on a Sony Pro Dat recorder so that the two act as one unit with a common shoulder strap. It has two microphone and two line inputs and input amplifiers.



Further information: RTA Technology Pty Ltd, 1st Flr, 160 Castlereagh St, Sydney, NSW 2000 Tel: (02) 267 5939, Fax: (02) 261 8294

CIRRUS

Data Logging Sound Level Meter

The **CRL 236** Data Logging Sound Level Meter takes a series of integrated measurements truly representing the actual energy during the integration period of either 1/8, 1 or 10 sec. The CRL 236 has its own data store, for eventual copying to an MS-DOS compatible computer and then any of the statistical indices over any period can be separately determined. It can be supplied in a waterproof outdoor measurement case and can be left in situ to log the noise climate. For continuous monitoring situations, remote control operation can be used over telephone lines.

Integrating Sound Level Meter

The **CRL 254**, based on the successful CRL 222, has been developed to meet the exacting requirements of the United Kingdom Armed Services for checking compliance with the European Community Directives for noise in the Leq and Slow response sound level plus both dB(A) and dB(C), to allow selection of the best ear defenders should the levels be too high.

Screening Audiometer

The **CRL 602** is an easy-to-use, Binaural Screening Audiometer fully complying with the IEC 645 Specification for Class 4 units. It provides a simple means of establishing hearing levels at an employee's initial medical check and thereafter easy routine screening to ensure early detection of any hearing loss.

Further information: Davidson, 17 Roberna St, Moorabbin, Vic 3189, Tel: (03) 555 7277 Fax: (03) 555 7956

BRUEL & KJAER

Noise Dose Meter

The noise dose meter, type **4436**, protects the microphone within the casing. A rubber tube attached close to the user's ear acts as a "wave-guide" and ensures accurate measurements. The meter conforms with international standards, can be used as a type 2 integrating meter and has large data storage capacity.

Hydrophone Calibrator

The Hydrophone Calibrator, type **4229**, is a compact, battery operated, high precision sound source and comes complete with three couplers and an adaptor, for calibration in air. The level at (nominally) 250 Hz is high enough to allow calibrations to take place even in noisy surroundings.

Portable Sound Intensity Analyser

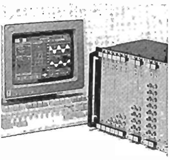
The type **4437**, portable sound intensity analyser measures sound intensity, sound pressure and particle velocity levels simultaneously and calculates the pressure-intensity index. The memory saves up to 4200 measurements in 140 positions. The probe, type **3547**, has been specially developed for use with the 4437 and includes a remote control handle.

Reverberation Processor Module

The type **BZ 7108** module, is used with the sound level meter, type 2231, to calculate reverberation times using the impulse-response method. Either an ordinary starting pistol or the sound source, type 4224, can be used with the module.

Machine Monitoring System

COMPASS - Computerised Prediction Analysis and Safety System - is a totally new machine monitoring system which exploits the latest advances in industry driven progressive technologies. COMPASS is an individually configured system using standard, off-the-shelf building blocks. These are connected to a central Unix workstation via Ethernet to slave terminals and monitoring racks distributed around the plant. Digital Signal Processing is used in monitoring and analysis modules. Adaptive Monitoring Strategy is used to automatically select an optimum monitoring technique for actual machine operating condition.



Further information: B&K, PO Box 177, Terrey Hills NSW 2084 Tel: (02) 450 2066 Fax: (02) 450 2379

SENSIMETRICS

Speech Synthesiser Package

KLSYN88 is a speech synthesiser developed at M.I.T. and is now available to researchers in the speech community and related fields. The principle software package for VAX C has been adapted to allow it to run on IBM and Macintosh personal computers and on a SUN workstation.

Further information: Sensimetrics, 1 Kendall Square, Building 100, Cambridge, Massachusetts 02139, USA

CSR GYPROCK

Acoustic Design Manual

CSR Gyprock have recently launched their Acoustic Design Manual which gives test results, or predictions of likely performance, for over 180 different plasterboard wall and ceiling systems. Each system is accompanied by an illustration and brief description of the various components, along with the test report details. The data shows that high values of sound transmission class can be obtained with partitions comprising Gyprock, for example an STC of 58 can be achieved with a staggered stud wall system incorporating a cavity infill.

Further information: CSR Gyprock on (02) 609 9633, (03) 688 7422, (07) 277 3422, (08) 348 1400 or (09) 351 4444

TELEX

Ear Protection for Musicians

It is well established that some musicians, both in the pop and orchestral fields, do suffer loss of hearing sensitivity. It is essential that ear protection worn by musicians does not affect their ability to hear the musical qualities of the sound produced by their own playing and that of their colleagues. Two new earplug models, from Etymotic Research, have been designed to provide musicians with balanced ear protection. The **ER15** uses a diaphragm similar to a passive speaker cone fitted to a soft, individually moulded earplug sealing deeply in the second bend of the ear canal. The **EAR HiFi** uses a tuned resonator and acoustic resistor.

Further information: Telex (Australiasia) Pty Ltd, GPO Box 1099 Blacktown, NSW 2148, Tel (02) 831 2666, Fax (02) 831 3029

DIARY

• Indicates an Australian Activity

CONFERENCES and SEMINARS

1991

September 22-25, MIAMI
13TH ASMA CONFERENCE ON MECHANICAL VIBRATION AND NOISE
Details: Prof T.C. Huang, Dept Engineering Mevchanics, University of Wisconsin, 1415 Johnson Drive, Madison, WI 53706, USA..

October 8-10, THE HAGUE
3rd INTERNATIONAL SYMPOSIUM ON SHIPBOARD ACOUSTICS
Details: Ms Meinardi, TNO Corporate Communications Dept, P.O. Box 297, 2501 BD The Hague, The Netherlands.

November 4-8, HOUSTON
MEETING OF ACOUSTICAL SOCIETY OF AMERICA
Details: Acoustical Society of America, 500 Sunnyside Blvd, Woodbury, NY 11797, USA.

• November 25-29, MELBOURNE
ASIA - PACIFIC VIBRATION CONFERENCE 91
Details: Conference Convenor, Centre for Machine Condition Monitoring, Monash University, Clayton, Victoria 3168

• November 26-28, BRISBANE
WESTERN PACIFIC REGIONAL ACOUSTICS CONFERENCE IV
Details: Conference Convenor, P.O. Box 155, North Quay, Queensland 4002.

• December 2-4, SYDNEY
INTER-NOISE 91
Details: IPACE, P.O. Box 1, Kensington, NSW 2033

December 9-13, HONG KONG
POLMET 91
Details: Conference Secretary, Hong Kong Institution of Engineers, Room 1001 10/F1, Island Centre, 1 Great George St, Causeway Bay, Hong Kong

• December 10-12, GOLD COAST
9th BIENNIAL CONFERENCE ON MODELLING AND SIMULATION
Details: David Mayer, Biometry Branch Dept Industries, PO Box 46, Brisbane, Q 4001

1992

March 4-6, AUBURN
2nd INTERNATIONAL CONFERENCE ON RECENT DEVELOPMENTS IN AIR- & STRUCTURE-BORNE SOUND AND VIBRATION
Details: Congress Secretariat, Dept Mech Eng, 201 Ross Hall, Auburn University, Alabama 36849-3541, USA.

May 11-15, SALT LAKE CITY
MEETING OF ACOUSTICAL SOCIETY OF AMERICA
Details: Acoustical Society of America, 500 Sunnyside Blvd, Woodbury, NY 11797, USA.

May 25-29, GANSK
5th SPRING SCHOOL ON ACOUSTO-OPTICS AND ITS APPICATIONS
Details: A.Sliwinski, Institute of Experimentl Physics, University of Gdansk, Wita Stwosza 57, 80-952 Gdansk, Poland.

September 3-10, BEIJING
14th ICA
Details: 14 th ICA Secretariat, Institute of Acoustics, P.O. Box 2712, Beijing 100080, China

October 12-16, ALBERTA
1992 INTERNATIONAL CONFERENCE ON SPOKEN LANGUAGE PROCESSING
Details: ICSLP-92, Catering and Conference Services, University of Alberta, 103 Lister Hall, Edmonton, Alberta, Canada T6G 2H6

• December 14-18, HOBART
11th AUSTRALIASIAN FLUID MECHANICS CONFERENCE
Details: 11 AFMC Secretariat, Dept Civil & Mech Eng, University of Tasmania, GPO Box 252C, Hobart 7001

COURSES

The demand for a special listing of the courses in the area of acoustics has arisen from the increased recognition of the importance of continuing education. Details of an Australian course, in the standard format, will be included at no cost. Additional details can be included in an advertisement at the normal advertising rates.

1991

October 28-31, CANBERRA
Basics of Noise and Vibration Control
Details: M. Burgess, Acoustics and Vibration Centre, Australian Defence Force Academy, Campbell ACT 2600 Tel (06) 268 8241 Fax (06) 268 8276

November 18-22, BRISBANE
Noise Workshop
Details: G Lee Manwar, Dept Environment & Heritage, PO Box 155, North Quay, 4002 Tel (07_ 227 6436, Fax (07) 227 7677

December 5-6, MELBOURNE
Sound Intensity Course
Details: Dr L.L. Koss, Mechanical Engineering Dept, Monash University, Clayton, Vic, 3168 Tel (03) 565 3551 Fax (03) 565 3558

December 9-12, ADELAIDE
Active Control of Noise and Vibration
Details: M Heslop, Dept Mech Eng, University Adelaide, GPO Box 498, Adelaide, SA 5001 Tel (08) 228 5459

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JOURNALS RECEIVED

Applied Acoustics V 32 No 4 1991
V 33 Nos 1,2 1991
Canadian Acoustics V 19 No 2 1991
Chinese J Acoustics V 10 No 2 1991
J Catgut Acous Soc V 1 (II) No 7 1991
New Zealand Acoustics V 4 Nos 1,2 1991
Shock & Vibration Digest V 23 Nos 4-7 1991
STL-QPSR (Stockholm) 4/1990
Dept Speech Communication & Music Acoustics, KTH (Stockholm), Annual Report 1990

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Information and Applications regarding membership should be directed to the appropriate State Division Secretary

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SOCIETY SUBSCRIPTION RATES

From 1 APRIL 1991 membership subscriptions will be as follows:

Fellow and Member	$85
Affiliate and Subscriber	$68
Student	$50

ANNUAL CONFERENCE

Copies of past conference proceedings may be ordered from:

Publications Officer
Australian Acoustical Society
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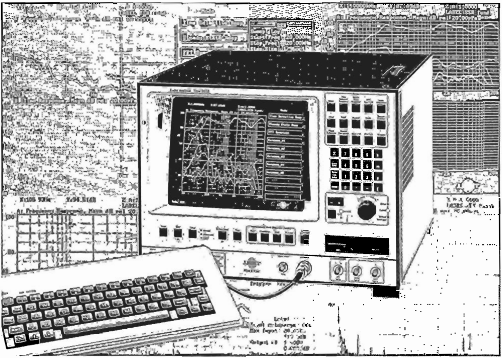

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The 2012 is designed to help you in your work. You can create autosequenced measurement routines, which run your measurements automatically, saving you time and effort during repetitive measurement tasks. And the 2012's multi-tasking design means that you can be performing new measurements while processing previous data, and printing results, all at the same time.

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