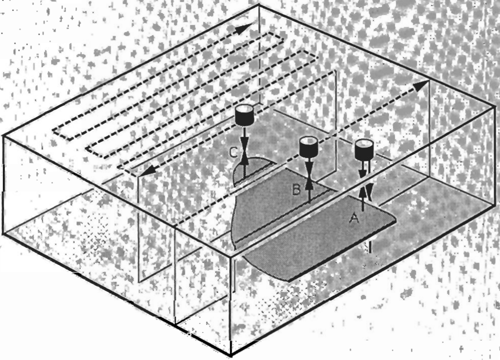
# Acoustics Australia

Vol. 19 No. 1 APRIL 1991

Australian Acoustical Society



## SPECIAL ULTRASONICS ISSUE

# Acoustics Australia

Vol 19 No 1

April 1991

**Acoustics Australia is abstracted and indexed in Engineering Index, Physics Abstracts & Acoustics Abstracts**

## ARTICLES

*COVER ... Diagram illustrating ultrasonic A,B and C scans (see article by Clark and Bishop)*

## ACOUSTICS AUSTRALIA INFORMATION

### GENERAL BUSINESS

* subscriptions
* advertising
Mrs Leigh Wallbank
Tel: (02) 528 4362
Fax: (02) 523 9637

### ARTICLES & REPORTS

Dr Howard Pollard
Fax: (02) 523 9637

### NEWS, BOOK REVIEWS, NEW PRODUCTS

Mrs Marion Burgess
Fax: (06) 268 8276

### PRINTING, ARTWORK

Scott Williams
Fax: (02) 523 9637

### SUBSCRIPTION RATES 1991

| | Surface Mail | Airmail |
|---|---|---|
| 1 year | A$39 | A$49 |
| 2 year | A$65 | A$85<br>(save $13) |
| 3 year | A$87 | A$117<br>(save $30) |

Agents discount: 15% of surface rate

Members & Sustaining members additional copies: 33% discount

Discount on new sub: 33%

**Address all correspondence to:**
**Acoustics Australia, PO Box 579,**
**Cronulla NSW 2230**
Tel. for all business: (02) 528 4362
Fax for urgent material: (02) 523 9637

### ADVERTISING RATES

| B&W | Non-members | Member or Sus Mem |
|---|---|---|
| 1/1 Page | $475 | $450 |
| 1/2 Page | 310 | 295 |
| 1/3 Page | 240 | 225 |
| 1/4 Page | 200 | 190 |

Spot colour: $50 per colour
Prepared insert: $150
Column rate: $10 per cm (1/3 p width)

**Discount rates:** (3 consecutive ads in advance)

| | |
|---|---|
| Non-members | 10% |
| Memb/Sustaining members | 20% |

Special rates available for 4-colour printing

**All enquiries to:** Mrs Leigh Wallbank
Tel (02) 528 4362 Fax (02) 523 9637

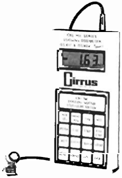
**Acoustics Australia is published by the Australian Acoustical Society (incorporated in NSW).**
**Responsibility for the contents of articles rests upon the authors and not the Australian Acoustical Society.**
**Articles may be reproduced in full provided adequate reference is quoted.**

**Printed by Cronulla Printing Co Pty Ltd, 16 Cronulla Plaza, Cronulla 2230**
**Tel: (02) 523 5954, Fax (02) 523 9637**

**ISSN 0814-6039**

**CIRRUS 700 SERIES - SOUND LEVEL METERS AND DOSEMETERS**

- ✱ Fully Programmable functions
- ✱ Select any 16 from over 120 options
- ✱ 2 Channel Instrument
- ✱ Measures, Stores, Calculates, Recalls, Communicates and more
- ✱ Continuous Storage of Short Leq.
- ✱ Selected Intervals and Data Storage for Event Recording



*AND THE PRICE - YOU WILL BE PLEASANTLY SURPRISED*

**DAVIDSON**
*Measuring up to your needs*
MB & KJ DAVISON PTY. LTD. (Inc in Vic.)
17 Roberna Street, Moorabbin Vic. 3189
Ph. (03) 555-7277 Fax. (03) 555-7956

Suite 1, 6th Floor, 10 Help Street, Chatswood N.S.W. 2067
Ph. (02) 410-9893
W.A. Hinco Engineering (09) 244-2777
S.A. Graphic Electronic Industries (08) 365-1000
ACT/TAS/QLD MB & KJ Davidson (03) 555-7277

**BAN NOISE**

A Division of Vales & Associates Pty. Ltd.

***Materials:***
A wide range of materials
including composites.
Raven Door Seals

***Equipment:***
Screens
Partitions
Audiometric &
Music Rooms

***Member ANCE Inc.***

***Installations:***
Specialising in Mining Equipment
& Large Fork Trucks
Custom built Acoustic Floor Mats

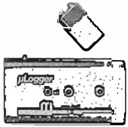
**UNIT 37/2 Richard Close**
**NORTH ROCKS NSW 2151**

**Phone (02) 630-5784**

***FORGET EVERYTHING YOU HAVE EVER HEARD ABOUT DATA LOGGERS***

The multichannel *µLogger*® is completely modular, allowing the best possible adjustments to any measuring application

- 1-16 channels
- Resolution: 16 bits
- Measures: voltage, resistance, frequency, + digital input.
- Dimensions: 120x65x80mm
- Weight 150 grams



**ETMC TECHNOLOGIES**
6 Pound Road, Hornsby 2077
Tel: (02) 477-1764

# A View Of Ultrasonics Research in Australia

## An Introduction to the Special Issue on Ultrasonics

**D C Price**
**CSIRO Division of Applied Physics**
**Lindfield, NSW 2070, Australia**

This issue of Acoustics Australia is somewhat unusual in that it deals specifically with ultrasonics, the branch of acoustics that is concerned with frequencies above the audible limit (i.e. greater than about 20 kHz). The original objective was to present an overview of some of the more recent and novel applications of ultrasonics, with particular reference to the situation in Australia. However, it quickly became apparent that only a significantly less ambitious aim could possibly be satisfied in the limited space (and time) available, and a selection of topics, which is not claimed to be representative of either ultrasonic applications or research in this country, was made. The five articles received describe research being carried out in four different institutions in Australia on applications of ultrasonics in the biomedical and non-destructive inspection/materials evaluation areas. Unfortunately, because of space limitations, it has been necessary to carry two of these articles over to the next issue.

Uses of ultrasound can be generally divided into two broad categories: those in which the acoustic wave is used as a measurement probe (diagnostic or low power applications) and those in which the ultrasonic energy is used to modify the material in which it is propagating or upon which it is incident (high power applications). All of the applications in this issue and, in fact, almost all of the ultrasonics research in this country, are related to measurement or diagnostic uses of ultrasound. These applications usually (but not always, see for example [1] employ sound waves of sufficiently small amplitude that only the linear elastic response of the propagation medium needs to be considered. Further elaboration on the quantities measured and typical applications will be given below.

While there is very little research in Australia in the area of high power ultrasonics, there are nevertheless many industrial and medical applications. Most processes by which ultrasound modifies material properties either require the use of sound waves of sufficiently large amplitude that the material response is non-linear, or depend on absorption of acoustic energy by the medium. Ultrasonic cleaning, cutting and welding or bonding have been well known in industry for many years, as has the use of ultrasound for physiotherapy. More recently ultrasound has been used for other therapeutic purposes (e.g. for hyperthermia treatment of some cancers), in some surgical procedures, such as the destruction of kidney stones by lithotripsy, and in various chemical processes [2]. Perhaps this large and growing range of applications indicates a fertile area that is being overlooked by our research establishments.

Measurement applications of ultrasound seek to determine properties of the propagation medium, which may be gas, liquid or solid and may be homogeneous or inhomogeneous, single- or multi-phase, by making measurements of ultrasonic velocity (or time of flight), attenuation coefficient or scattering amplitude. In a small number of important cases, such as in surface acoustic wave (SAW) signal processing devices, this measurement process is inverted: the propagation characteristics in a well-defined medium are used to determine the properties of the incident ultrasound beam.

Examples of ultrasonic measurement applications include the use of propagation velocity or Doppler shift to measure flow rates in liquids and gases. Determination of the time of flight of a pulse in a medium of known velocity of sound enables dimensional measurements to be made. The propagation velocity and/or attenuation, measured by transmission of an ultrasound pulse through a medium, are used to measure material properties or to detect defects. The great majority of applications, however, both in the medical and industrial areas, involve the detection and evaluation of ultrasound scattered from inhomogeneities in a material.

If the inhomogeneities are much smaller than the ultrasound wavelength, such as occurs in biological and industrial suspensions [3] in biological tissue [4] and in solids containing grain structure, porosity or a distributed second phase, statistical properties of the inhomogeneous distribution can be determined, at least in principle.

For inhomogeneities that are large compared with the ultrasound wavelength, the boundaries can often be mapped and an image produced. This situation occurs in medical imaging and in non-destructive inspection, and three of the papers [4] [5] [6] in this issue are at least partly concerned with imaging techniques. In many cases the simple pulse-echo principle is used. A short, broad-band pulse of ultrasound is projected from a transducer (which is usually a piezoelectric resonator) into the liquid or solid medium. The same, or sometimes another, transducer detects any scattered pulses (echoes), and both the amplitude and time of arrival of an echo can be recorded. The propagation time of the pulse, coupled with a knowledge of the sound velocity in the medium and, importantly, the incident beam geometry, allows the region from which the echo originated to be located.

Ultrasound image data is usually presented in at least one of three common formats, known as A-, B- and C-scans according to the number of spatial dimensions in which the incident beam is scanned over the material being examined. An A-scan is obtained with no scanning. It is simply the time-dependent signal received following the transmission of a pulse of ultrasound from a transducer in a single fixed position. For the very common single transducer pulse-echo geometry, an A-scan represents the reflectivity as a function of depth into the sample. All multi-dimensional images are constructed from a number of A-scans obtained with the transducer(s) in different positions.

A B-scan is obtained by scanning the transducer in one dimension, usually either along a straight line (a linear scan) or in an arc (a sector scan). A B-scan image is two-dimensional, with one axis representing the depth into the material (obtained by converting propagation time to distance using the known acoustic velocity) and the other axis representing a line along the object surface. This latter axis would be the scan line for a linear scan, or a line in the plane of the scan arc for a sector scan. The B-scan image usually shows the reflectivity or received signal strength, plotted as a colour or grey level, using either linear or non-linear (perhaps logarithmic) conversion, as a function of position in the image plane. B-scan images are used extensively in medical diagnostic applications [4] and less frequently for nondestructive inspection [5].

A C-scan image is obtained when the transducer(s) is scanned over the object surface in two dimensions. Like the B-scan image, the C-scan image is two-dimensional, but in this case the axes are orthogonal axes on the scanning surface. The image may be a plot of one of a number of quantities derived from the ultrasonic signals (the A-scans), mapped to a colour or grey level. For example, the propagation time to the first detected echo may be plotted, and this will indicate the apparent thickness of the material. This technique is commonly used to detect corrosion in pipes or pressure vessels. Alternatively, the amplitude of the first echo, or of an echo occurring at a particular depth, may be plotted to provide information about the presence and extent of defects. C-scans of the attenuation or time of flight of a pulse transmitted through a sample are used routinely for quality control in the manufacture of panels from composite materials for aerospace applications. Comparisons of C-scan images of different quantities derived from the same set of ultrasonic signals often yield more detailed information than the individual images. C-scanning is used extensively in non-destructive inspection, and examples may be found in [5] and [6]. Clark and Bishop [5] give further explanation of these three common imaging formats.

The papers by Graham Clark and Bruce Bishop [5] from the Aeronautical Research Laboratories, DSTO and by Bob Harrison [6] from ANSTO are both concerned with the non-destructive inspection of advanced engineering materials: fibre/epoxy composites and engineering ceramics respectively. For the purposes of this review, the major differences between these applications is in the frequencies required and in the material anisotropies. In both cases the initial aim is to detect and characterise defects that may occur in manufacture or in service. A longer term objective of nondestructive evaluation is to relate measured quantities to the properties of materials and structures that can only be directly determined by destructive testing, such as yield strength, fracture toughness, fatigue lifetime, etc.

There are two papers concerned with biomedical applications of ultrasound. Laurie Wilson [4] from the Ultrasonics Laboratory, CSIRO Division of Radiophysics, has reviewed the field of medical diagnostic imaging, with which many readers would have had some contact, and the less familiar but increasingly important technique of doppler shift measurement of blood flow rates. Current work at the Laboratory, formerly the Ultrasonics Institute of the Commonwealth Department of Health, in both of these areas is discussed. The use of high frequency ultrasonic techniques for evaluation of the cellular flexibility of red blood cells, which is of great importance for the evaluation of stored blood, in the diagnosis of certain diseases and in sports medicine, is described by Tony Collings [3] of the CSIRO Division of Applied Physics. The extension of this work to the evaluation of industrial suspensions is also described. Unfortunately it has not been possible to include this paper in the present issue. It will appear in the near future.

It should be superfluous to point out that in almost all applications of ultrasound it is important that the characteristics of the sound beam, and in particular the spatial distribution of power, intensity or pressure, should be known. The overwhelming majority of medical and industrial NDE applications of ultrasound employ piezoelectric "crystals" (usually poled ceramic discs, but sometimes crystals such as quartz or lithium niobate, and more recently polymers) that are fabricated into complex multi-component electro-mechanical resonators that produce frequency components in the range 0.5 to 20 MHz, and are subject to both manufacturing defects and inservice damage, such as delamination. In general, however, relatively little attention is paid to measurement of transducer characteristics, despite the obvious importance of this to quantitative diagnostic measurements. Recently, primary standards for ultrasound power, and a transducer calibration facility have been set up at the National Measurement Laboratory (CSIRO Division of Applied Physics). This facility and the techniques employed are described in the paper by Helen Chan, Paul Drew and Bob Chivers [1]. It is curious that the only real push to establish such a facility arose from consideration of the safety aspects of medical ultrasound, and not at all, apparently, from concern for the quantitative capabilities of ultrasonic techniques.

Finally, I would like to emphasise that the topics and authors included in this issue do not, and were not intended to , give a representative picture of ultrasonics works in Australia. First, although it was quite unintentional, all of the authors are from Commonwealth Government research institutions. There is some, but relatively little, ultrasonics-related research in Australian Universities and there is certainly some in industrial laboratories, such as those of BHP. There are manufacturers of ultrasound instruments in Australia, particularly in the medical area, and most of these support (or are supported by!) research and development activities at various levels.

Secondly, there are a large number of applications of ultrasound, and even of research areas, that are not mentioned here. Some have already been mentioned above, and there are other examples even in the group with which I am affiliated, on ultrasonic flow measurement, on the development of surface acoustic wave devices for use as selective biochemical sensors and on aspects of non-destructive evaluation using surface and plate waves. I feel no need to apologise for the selections made, however. All the authors are leaders in their respective fields, and their articles are without exception well-written and at a level that I hope will prove to be both interesting and informative to readers of Acoustics Australia.

## References

[1] H.L.W. Chan, P. Drew and R. C. Chivers: Standards for Medical Ultrasound and Transducer Calibration at the National Measurement Laboratory, Acoustics Australia, this issue.

[2] D. Ensminger: Ultrasonics. Fundamentals, Technology, Applications, New York: Marcel Dekker (1988).

[3] A.F. Collings: Ultrasonics: A Useful Tool in Biophysical and Biomedical Research, Acoustics Australia, to be published.

[4] L.S. Wilson: Recent Developments in Medical Diagnostic Ultrasound, Acoustics Australia, this issue.

[5] G. Clark and B.C. Bishop: Application of Ultrasonic C-Scanning to Aerospace Composites, Acoustics Australia, this issue.

[6] R.P. Harrison: High Frequency Ultrasonic Evaluation of Advanced Ceramics and Other Materials, Acoustics Australia, this issue.

# Recent Developments in Medical Diagnostic Ultrasound

**L.S. Wilson**
**Ultrasonics Laboratory**
**CSIRO Division of Radiophysics**
**126 Greville Street**
**Chatswood NSW 2067**

*ABSTRACT: Diagnostic ultrasound has achieved wide acceptance in its 30-year history, largely because of its cost-effectiveness and safety combined with a steady improvement in image quality. Australian scientists have played a major role in its development. The two most important modes of operation are imaging and Doppler, which may be combined. Current research includes tissue characterisation and automatic recognition and measurement, and adaptive focusing of transducers to reduce aberration.*

## 1. INTRODUCTION AND BRIEF HISTORY

Medical diagnostic ultrasound has achieved very wide acceptance since its introduction to clinical practice in the 1960s. In 1989, the number of ultrasound examinations performed world-wide exceeded the number of X-rays. Despite the growth of new imaging modalities (such as magnetic resonance imaging and CT scanning) the use of ultrasound continues to grow rapidly, largely because it is relatively safe and cost-effective. It remains an area of rapid technological advance, and Australian scientists have played a significant role in its development.

The first ultrasound examinations were made by United States experimenters in the early 1950s by adapting World War II sonar and radar equipment. Like all scans produced until the late 1970s, these early pictures were static scans, i.e. the result was a still picture which took at least several seconds to produce. Additionally, these early scans could detect only the large specular echoes produced by reflections at major interfaces between organs. The internal echoes produced by scattering from within organs (which are several tens of decibels smaller in magnitude) were not seen. Nevertheless, these scans displayed internal anatomy in a form not previously seen, and the non-ionising nature of the radiation prompted the early application of the technique to obstetrics.

Australia's involvement with medical ultrasound began in 1959 with the appointment of George Kossoff to the newly created Ultrasonic Research Section of the Commonwealth Acoustic Laboratories to investigate medical uses of ultrasound, notably imaging. (This group is still flourishing as the Ultrasonics Laboratory of the CSIRO Division of Radiophysics.) Work on a scanner began and the first images were published in 1962. The Laboratory soon gained an international reputation for the excellence of its images, and was responsible for a number of important developments. For example, an early innovation developed by the group was the quarter-wave matching layer, which reduces energy losses when sound passes from the high acoustic impedance transducer to the relatively low impedance of body tissues.

The group was largely responsible for one of the most significant developments of the early 1970s, the introduction of grey scale images [1]. Early echograms were displayed on storage oscilloscopes, and were insensitive to small, scattered echoes. To enable the display of these echoes, the large dynamic range of the echoes must be adjusted for the restricted dynamic range of the display, so that different levels of scattered echo size are displayed as different levels of grey. This requires a highly nonlinear amplifier, with an approximately logarithmic characteristic, and a display capable of reproducing the grey scale.

The introduction of grey scale images permitted easy differentiation of liquid-filled structures (containing no internal echoes) from solid structures (containing scattered echoes). Additionally, subtle changes in texture or echo magnitude could now be seen. It also hastened the end of static scanning. Because specular reflections were only seen at normal incidence, each part of the anatomy needed to be scanned from several different directions (or compounded) to form complete boundaries. But scattering is, on average, isotropic, and so a single view of the anatomy could elicit all of the anatomical information; hence the time required for a complete picture was reduced.

Until about 1980, most machines produced static scans which took several seconds to form an image. Real time systems, which display moving images at approximately television frame rates (more than about 10 frames per second) appeared during the late 1970s, and were initially used mainly in cardiac applications where the value of displaying movement was more important than the limited resolution available. However, resolution as good as static scans soon became available and all machines today produce images in real time.

During the past decade, the two main technical developments have been improved image quality, because of better transducers and their associated electronics, and major additions to diagnostic capabilities provided by Doppler measurements.

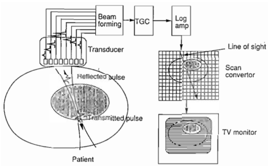


*Figure 1: Simplified block diagram of an echoscope equipped with an array type transducer. The driving pulses for a focused, apodised, steered beam are shown.*

## 2. A TYPICAL MODERN ECHOSCOPE

Figure 1 shows, in block diagram form, a typical machine. Short, broad-band pulses of ultrasound are normally employed, and these are generally produced by energising a damped, resonant piezoelectric transducer with a suitable driving pulse, usually tuned to the resonant frequency of the transducer. The choice of ultrasound frequency is a compromise between the improved resolution obtainable with high frequencies, and attenuation by tissue which increases with frequency. For most soft tissue the attenuation is approximately 0.5 dB per cm per MHz. Frequency selection is related to the depth of penetration required. The lowest frequencies (2-3 MHz) are used for abdominal scans in large patients, while 3-5 MHz is more common for obstetrics, 5-7 MHz in peripheral vascular studies, 10-15 MHz for ophthalmic ultrasound and up to 50 MHz for specialised scanners producing high resolution images of the skin.

While some machines use mechanical motion of a single transducer to scan a volume of tissue, most modern transducers consist of multi-element arrays, and each line of sight is generated by pulsing a group of elements. The beam may be focused and steered by introducing delays among the pulsed elements: when the delay is a linear function of element number, the beam is steered; a curved delay function results in focusing. The machine operator selects the depth in the image where optimum focusing is required. As the pulse travels from the transducer into the tissue, its transverse diameter reduces to a minimum at the focus, then increases again beyond focus. The pulse diameter determines the effective resolution, and at the 20 dB level this is about 3 mm for a 3.5 MHz transducer. At the focus the diameter is diffraction limited, and it varies inversely with ultrasound frequency.

Echoes are produced by reflections at discontinuities of acoustic impedance, and propagated back to the transducer. The velocity of sound in most soft tissue is between 1500 and 1600 metres per second, and so delay time can be simply related to depth in tissue [2]. Acoustic impedance for some materials in the human body are: air 0.0004, fat 1.35, brain 1.6, blood 1.62, muscle 1.7, liver 1.66 and bone 3.75 to 7.38 (the unit is $10^6$ kg m$^{-2}$s$^{-1}$). This leads to reflections typically less than 1% of incident energy at interfaces between different tissue types, but much larger reflections (in fact preventing useful penetration) at interfaces including gas or bone. Thus potential applications of ultrasound exclude such areas as most of the digestive tract (which contains gas) and organs shielded by bone such as the adult brain. Although most of the energy returned to the transducer is in the form of specular reflections, the majority of the information in the image is derived from scattered echoes originating within organs.

The same transducer acts as receiver and transmitter. On reception, the point of origin of the ultrasound is known from the delay, and so the effective curvature of the transducer is dynamically adjusted by changing the delays between elements to keep the transducer focused on the echo source. Additionally, the aperture (number of sensitive elements) is progressively increased as echoes from deeper structures are received, since a large aperture improves resolution for deeper structures. The elements are not uniformly energised, but modified by an apodising function, which reduces sidelobes and is also dynamically varied. The separate requirements for dynamic focusing, aperture and apodisation mean that beamforming electronics can be quite complex, and a typical top-end machine may have 128 independent processing channels, each controlling one element of the transducer array.

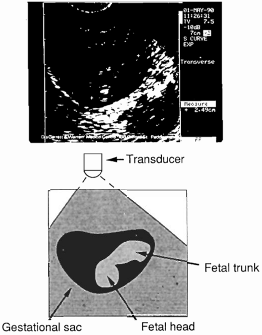


*Figure 2: High resolution sector scan of an early pregnancy (9-10 weeks gestation) showing fetal head (including resolution of some brain structures) and trunk. The crosses mark a measurement of fetal length, which is 24.9 mm.*

Mechanically scanned transducers produce a scan in sector format, where all the lines of sight radiate from a point corresponding to the transducer axis of rotation. Electronically scanned transducers are sometimes used in this mode by using the same elements for each line of sight and altering the inter-element phasing. An alternative mode is the linear scan, in which a separate group of elements is used for each line of sight, and images are commonly rectangular in shape with parallel lines of sight. Figures 2 and 3 show sector and linear scans of fetuses at two different ages of gestation, and illustrate the excellent detail observable with modern equipment.

After passing through the beamforming electronics, the echoes are amplified by a time-dependent amplifier which compensates for the attenuation of deeper echoes. A nonlinear amplification stage boosts the low-level scattered echoes relative to the much larger, but less informative, specular reflections, and ensures that most of the grey scale available in the display is available for discerning subtle variations in the level of backscatter from within organs. Further processing may enhance edges, or vary the dynamic range of the displayed echoes.

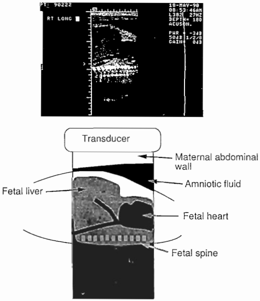


*Figure 3: Linear array scan of a late pregnancy (30 weeks gestation), showing the fetal abdomen in a longitudinal section. The fetal liver, hepatic veins, inferior vena cava, heart and spine are clearly seen.*

The echoes are digitised and written to a scan converter consisting of a digital memory (usually 512 by 512 pixels) which converts from the ultrasound scan pattern to a standard television raster. It also interpolates over any gaps which appear between lines of sight. The scan rate is limited by the speed of sound, and depends on the maximum depth of penetration and the number of lines of sight in the scan, and is typically 10 to 40 scans per second. Data is read out of the scan converter at the normal TV frame rate.

Ultrasound imaging is useful in all soft tissue organs not obscured by bone or gas; particular applications include studies of eye, infant brain, thyroid, heart, vascular system, breast, liver, pancreas, gall bladder, kidneys, male and female reproductive organs, selected muscles and joints (such as shoulder and infant hips) and, of course, all aspects of pregnancy.

## 3. DOPPLER ULTRASOUND

The well-known Doppler effect has been particularly useful in studies of moving blood [3]. Echoes scattered by cells in moving blood are shifted in frequency according to the Doppler equation

$$f_D = (v\cos\theta f_0)/c$$

where $f_D$ is the Doppler shift, v is the blood velocity, $f_0$ is the incident ultrasound frequency, c is the speed of sound and $\theta$ is the angle between the line of sight and the velocity vector. In ultrasound applications, the signal processing system measures blood movement from an increasing phase shift in the returned echoes. The technique is extremely sensitive: echoes from blood are 20—40 dB lower in intensity than echoes from soft tissue such as muscle, and blood is normally imaged as an echo-free medium. Since the surrounding echoes result from stationary tissue, the presence of a Doppler shift itself discriminates between blood and surrounding tissue, even when the stationary echoes intrude into the image of the vessel owing to reverberation or finite beamwidth effects.

The processing chain for a typical pulsed Doppler machine is shown in Figure 4. By range-gating, only echoes from a localised sample volume are selected. Doppler instrumentation is usually combined with imaging to assist in locating the sample volume. After selection of the sample volume, the transducer is repeatedly pulsed along the same line of sight. Received echoes are demodulated by mixing with quadrature (sine and cosine) signals at the ultrasound frequency over the sample volume. This produces a "Doppler signal" whose frequency components correspond to blood velocities. The last stage of processing is a Fourier transform of the Doppler signal to obtain these frequency components. The ability to measure all velocities in the sample volume simultaneously is powerful: one may measure separately the average or maximum velocity, or distinguish between laminar and turbulent flow, the latter producing a broader range of velocities.

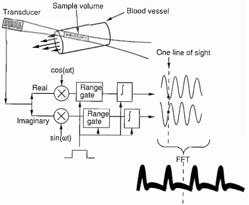


*Figure 4: Operating principle of pulsed Doppler ultrasound. Each pulse results in one complex point being calculated in the Doppler signal. After a suitable number of points in this signal have been accumulated, a Fourier transform provides an instantaneous Doppler spectrum, displayed with frequency (i.e. velocity) on the vertical axis, and power modulating brightness. Displaying a time series of such spectra shows the blood flow variations through the cardiac cycle.*

Typical Doppler spectral records are shown in Figure 5. The number of blood cells possessing a particular velocity modulates the brightness of the signal. Variation in velocity during the cardiac cycle is clearly evident. Because the blood velocity is usually in the range 0 to 100 cm $s^{-1}$, the Doppler signal contains frequencies in the audible range, and may be played through a loudspeaker to allow aural as well as visual discrimination among various types of blood flow. A common use of Doppler ultrasound is the detection of stenoses, or partial blockages, in vessels. The blockage shows up as a local increase in blood velocity because of reduction in the vessel area.

Another common Doppler measurement is assessment of the resistance to flow, which is usually measured in arteries "upstream" from the vessel or organ of interest. The vasculature has a characteristic impedance, and the blood-pressure wave propagates through it, with reflections at vessel bifurcations, and resistance as the vessel diameter reduces. The effective resistance of the vasculature is measured by comparing the peak systolic flow (coinciding with the arrival of the pressure wave) with the minimum diastolic flow, when the blood velocity has decayed to its minimum between pulsations. Large ratios of these two velocities correspond to high resistance flow, while more uniform flow corresponds to low resistance.

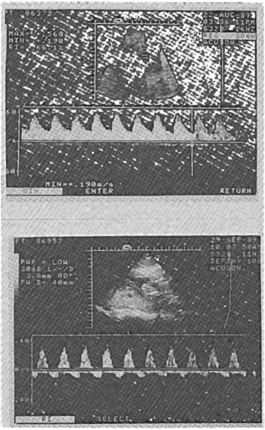


*Figure 5: Typical Doppler spectral displays. The small image at the top of each frame shows location of the Doppler sample volume. The pictures show umbilical flow to a fetus measured on two occasions five weeks apart. In the later (lower) image, the flow is more pulsatile due to a high resistance, which in this case indicated fetal distress.*

* * *

Initially, Doppler ultrasound was restricted to assessment of the heart and circulatory system. However, the nature of the blood flow to almost any organ is an indicator of the health or functioning of that organ. For example, changes in the Doppler waveform in the umbilical artery during the course of a pregnancy are well documented, and can be used to assess fetal well-being.

Conventional pulsed Doppler extracts information from only a very small part of the displayed image and usually suspends conventional imaging while in Doppler mode. Recently, it has become possible to combine imaging and Doppler information in a display mode known as colour Doppler imaging. In this mode of operation, sample volumes are placed throughout an area of the image, and all lines of sight intersecting this region are pulsed several times. The average velocity of blood flow in each sample volume is calculated and displayed by colouring the region according to the blood speed and direction. Colour Doppler imaging is particularly useful in mapping flow across a vessel, or detecting the presence of small vessels.

## 4. WORK OF THE ULTRASONICS LABORATORY

Some of the contributions of the Ultrasonics Laboratory to the early development of medical ultrasound diagnosis have already been mentioned. The Laboratory continues to make significant contributions to the subject. Current areas of research are bioeffects, transducer design (with particular emphasis on removal of aberrations), Doppler, tissue characterisation and assessment of meat quality for the Australian beef industry.

The possibility of harmful *bioeffects* of ultrasound continues to motivate considerable research, especially when one considers the number of obstetric scans being performed at sensitive stages of pregnancy. A research program at UL is the heating effect of ultrasound, especially in the fetus. To date, no harmful effects of diagnostic ultrasound have been found when it is used at current diagnostic levels. (This point is discussed further by Chan et al in the next issue).

Variations in sound speed (such as when ultrasound passes between muscle and fat) can cause aberrations in images, due to refractive effects. Occasionally, anatomical features are displayed slightly out of their correct position, or a single feature can be shown in two different positions on an echogram (a well-known manifestation of this aberration is the artifactual representation of a single pregnancy as a twin pregnancy). A more subtle effect of tissue inhomogeneity is defocusing of the ultrasound beam. This is particularly deleterious on image quality since the defocusing occurs in fat layers located immediately under the skin. (The effect is analogous to the astronomer's difficulty in viewing astronomical objects through the atmosphere.) The *STARS (Subcutaneous Tissue Aberration Removal Scheme)* research program aims to adaptively modify the delays applied to different elements of array transducers to cancel the delays caused by differing amounts of fat under the skin [4]. The intention is to image and automatically map the interfaces producing the aberration, and calculate the corrections required. To date, it has been shown that the increase in beamwidth produced by passing ultrasound through a fat layer can be reduced by appropriate delays in the transducer beamforming circuitry.

*Doppler ultrasound* has been the subject of considerable technical advances and new clinical applications in the last few years. At UL, the use of Doppler ultrasound to measure the total average blood flow to an organ has been of particular interest. In this operation mode, the average blood velocity is integrated over the whole of the vessel lumen by using a sample volume which includes the entire vessel. The total flow is calculated as the average blood velocity multiplied by the area of the vessel. The total flow to an organ is of obvious physiological significance, and the technique is particularly applicable in obstetrics, where the umbilical vein flow is measured and can be used to assess fetal well-being.

One of the obstacles encountered in clinical acceptance of the volumetric Doppler flow measurement has been the difficulty of placing the sample volume on the image of the vessel (which moves with respiration, fetal movement, or cardiac pulsation). Additionally, the operator must measure the diameter and orientation of the vessel. The need for automating these procedures has led to research into automatically recognising vessel walls from an image, determining the position and orientation of the vessel, and measuring its diameter. Automatic recognition of structures in ultrasound images is not as straightforward as in many other types of images, mainly because the strength of an echo depends on the angle of incidence. But in the case of vessels with locally parallel walls, image processing techniques can track the local position of a vessel through a sequence of successive imaging frames, measuring the orientation and diameter from each frame. This research has culminated in an off-line demonstration

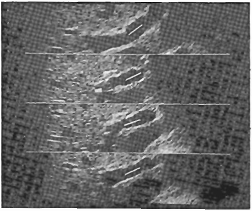


*Figure 6: Automatic tracking of a moving vessel for Doppler studies, showing the position and orientation of a Doppler sample volume changing with the movement of the vessel image due to the patient's breathing.*

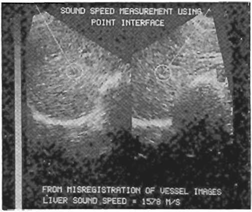


*Figure 7: Measurement of the speed of sound in a liver by scanning the same structure (a liver vessel) from two different directions with a purpose-built two-transducer echoscope. The distance scale of the two images assumes a speed of sound. When they are superimposed, any mismatch corresponds to an error in the assumed speed of sound.*

of a vessel tracking and measuring algorithm (Figure 6) which is currently being implemented in real time [5]. It is likely that automatic pattern recognition will play an increasing part in ultrasound imaging, as measurement of displayed structures (particularly fetal dimensions) plays a large part in clinical applications, but requires skilled operators.

Diagnostic ultrasound is becoming more quantitative, and it has been a goal of researchers to quantify the sometimes subtle changes in appearance or other echographic properties which are associated with disease, i.e. perform ultrasonic *tissue characterisation*. For example, liver cirrhosis can alter the echo magnitude, attenuation and texture of the ultrasound image.

Two properties which have come under close scrutiny are the attenuation and speed of sound in tissue. Gross changes in local tissue attenuation are easily seen in echograms from the presence of posterior shadowing or enhancement. Less clearly perceptible changes (associated, for example, with mild cirrhosis affecting the whole of a liver) may be measurable through precise measurements of these quantities. Attenuation has been determined by a precise measurement of the way in which scattered echo size varies with depth in the tissue. By doing this in the frequency domain, the frequency dependence over the transducer bandwidth of the tissue attenuation can be determined.

Sound speed is less easy to measure in principle; as in sonar, usually only direction of arrival and round-trip travel time are known, and distances are calculated from travel time, given the speed of sound. However, if two spatially separated transducers are used for simultaneous imaging of the same structure, discrepancies in the two displayed positions may be used for calculating the error in the assumed sound speed (Figure 7) [6].

Both attenuation and speed of sound have been found, in clinical trials, to be correlated with changes induced by disease in liver and spleen. However, a clear role for tissue characterisation has not emerged in clinical applications. Some of these techniques are being used in a research program on *meat quality*, aimed at assisting the Australian meat industry by quantifying factors such as tenderness or fat marbling.

## 5. FUTURE DEVELOPMENTS

Undoubtedly, transducers and their associated driving electronics will become more complex. Possible resolution improvement by compensating for tissue aberration has already been discussd. A major current limitation is the restriction on pulse repetition rate imposed by the speed of sound; each sound pulse must complete its travel before another can be transmitted. In some machines under development, reflections resulting from a single transmitted pulse are processed simultaneously by several receiver channels, each angled in a separate direction. Thus, the average time to produce each line of sight is reduced by a factor equal to the number of receive channels. This increase in speed would allow images in several planes to be built up simultaneously into a three-dimensional image which would be useful in diagnosing conditions where at present a complex geometry needs to be inferred from multiple separate sections. Applications which spring to mind are the diagnosis of fetal abnormalities or congenital heart defects. (Some three-dimensional ultrasound imaging machines, using conventional transducer technology, have already been built commercially.)

Transducer technology is benefiting from advances in miniaturisation, and transducers are being introduced into the body using techniques borrowed from endoscopy to improve resolution. Probes which view internal organs after being introduced into the oesophagus, vagina and rectum are well established. More recently, transducers are being introduced into blood vessels to view sources of stenosis (blockage) from inside the vessel, using very high frequencies with accompanying high resolution. Internal views of coronary arteries have been obtained, and ultrasonically guided remote-controlled intravascular surgery may soon become commonplace [7].

Doppler ultrasound has been an area of rapid technological improvement, and improvements which might appear in the next few years include angle-independent Doppler measurement. At present, only the axial (along the line of sight) component of blood velocity is measured, resulting in occasional inaccurate measurement or misdiagnosis due to poor angulation.

Diagnostic medical ultrasound is now a mature technology, but at the same time it is well placed to take advantage of developments in related fields, such as signal and image processing, pattern recognition and computer technology. Medical applications will continue to increase with the application of this new technology.

## ACKNOWLEDGEMENTS

The author wishes to thank his colleagues at the Ultrasonics Laboratory, particularly Mr M. Dadd, who assisted with preparation of the manuscript.

### REFERENCES

1 G. Kossoff, W.J. Garrett, D.A. Carpenter, J. Jellins and M.J. Dadd: Principles and classification of soft tissues by grey scale echography. Ultrasound in Medicine and Biology, *2*, 89-105 (1976).

2 P.N.T. Wells: Biomedical Ultrasonics, London: Academic Press (1977).

3 F.W. Kremkau: Doppler ultrasound: principles and instruments, Philadelphia: W.B. Saunders (1990).

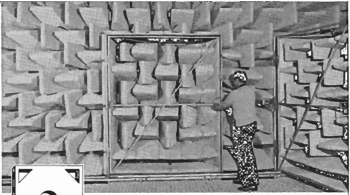
4 G. Kossoff, D.A. Carpenter, D.E. Robinson, D. Ostry and P.L. Ho: A sonographic technique to reduce beam distortion by curved interfaces, Ultrasound in Medicine and Biology, *15*, 375-382 (1989).

5 L.S. Wilson, M.J. Dadd and R.W. Gill: Automatic vessel tracking and measurement for Doppler studies, Ultrasound in Medicine and Biology, *16*, 645-652 (1990).

6 D.E. Robinson, C.F. Chen and L.S. Wilson: Measurement of velocity of propagation from ultrasonic pulse-echo data. Ultrasound in Medicine and Biology, *8*, 413-420 (1982).

7 N. Bom and J. Roelandt (Eds.): Intravascular Ultrasound, Dordrecht: Kluwer Academic (1989).

* * *



## Violins cause pain

**A lecturer in physiotherapy at Cumberland College of Health Sciences has completed a study on occupational overuse syndrome among professional violinists.**

**Elfreda Marshall** initially studied a group of pianists and 96 violin and viola players as part of her Masters degree in occupational health.

She found that 83 per cent of the musicians said they had pain associated with playing their instruments at some stage.

The common areas of discomfort felt by violinists were muscle pain in the arm, neck and forearm, and weakness in the fingers.

In a further study involving seven players ranging in age from 22 to 56, Ms Marshall found that at least half could rotate their heads only partially to the left.

According to Ms Marshall the most consistent predictor of pain was the number of hours the musicians played — four to six hours a day or 36 hours a week.

"Because much more time is devoted to practice than performance, we could improve practice methods and reduce the risks," she said.

Ms Marshall suggests one solution could be for violinists to use a stand during rehearsals which would take some of the violin's weight and minimise loads on the neck, back and left arm.

*From Laboratory News — Feb 1990*

## Primal Screech

Imagine the sound of fingernails being scraped across a blackboard. No one knows why sounds such as this can send chills up the spine, but the answer may lie with our primate cousins.

Psychologists started with a sound that people uniformly judged to be awful – the sound produced by running a metal garden fork across a slate surface. Next, a tape-recorded signal fed into a computer. A process called 'digital filtering' removed selected frequencies from the original sound. Volunteers listened.

It was found that removing the high frequencies had no effect on the sound's unpleasantness. When just the lower frequencies were removed the sound became quaint and not at all unpleasant.

Psychologists have discovered that scraping sounds bear a strong resemblance to the warning cries emitted by monkeys in the wild.

Our aversion to these sounds may be a vestigial reflex inherited from our primate ancestors.

*From New Idea – March 1987*

# High Frequency Ultrasonic Evaluation of Advanced Ceramics and Other Materials

**Robert P. Harrison**
**Australian Nuclear Science & Technology Organisation**
**Lucas Heights NSW 2234 Australia**

*ABSTRACT: This paper presents a review of two techniques for the Non Destructive Evaluation of materials using high frequency ultrasound. C-mode Scanning Acoustic Microscopy (CSAM) is operated in the 30—150 MHz range and is used mainly for subsurface defect evaluation. Detectability of defects of the order of 25 µm has been reported. Scanning Acoustic Microscopy (SAM) is operated in the 200 MHz — 8 GHz range and is predominantly a surface evaluation technique. It is possible to achieve a resolution of ~ 0.2 µm. A brief review of techniques used in CSAM to enhance defect detectability is presented.*

## 1. INTRODUCTION

The use of ultrasound for evaluation purposes has increased in the last decade by an extraordinary amount. This increase has come about by a combination of the wider application of advanced materials and the development of improved and new techniques.

Conventional non-destructive evaluation (NDE) techniques using ultrasound generally operate at frequencies of several hundred kHz to about 15 MHz (both of these limits are blurred). Inspection at high frequencies has not been practised greatly in the past due to a number of reasons. The main reasons were: lack of suitable transducers, high attenuation in the material (be this attenuation per se or scattering from grain boundaries), the lack of suitable instrumentation and finally the feeling that conventional NDE was sufficient.

The development of advanced materials, such as engineering ceramics, has led to the development of a number of techniques aimed at proving the structural integrity of manufactured components. Materials such as SiC, $Si_3N_4$, $Al_2O_3$ and $ZrO_2$ are being used and developed for engineering applications, in particular in areas where the high thermal stability of ceramics is desirable.

The need for high resolution NDE techniques arises from the high defect sensitivity of ceramics. Although they are generally high modulus, they are also more brittle than most metals. The critical defect size can be an order of magnitude lower in ceramics than metals, a fact that places a great demand on any inspection technique employed.

High frequency ultrasonics (for this paper's purpose, this means frequencies above ~30 MHz) is only one of a number of techniques which are now used to evaluate modern materials — both in the process development and manufacturing stages. This paper will concentrate specifically on two techniques with the same name — Acoustic Microscopy. The two techniques are different in that one is used almost exclusively for surface defect/elastic property variation measurement and the other for subsurface defect/homogeneity detection. The distinction between the two techniques is one of frequency. The surface techniques are generally in the frequency range 200 MHz to 2 GHz (and above, up to 8 GHz has been reported) and the bulk techniques in the frequency range 30 MHz to 100 MHz (occasionally up to 150 MHz).

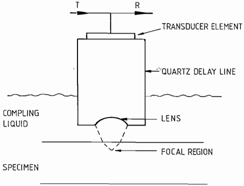


*Figure 1: A schematic showing the principle of CSAM imaging. The lens is positioned closer to the specimen than focus in order to inspect subsurface features.*

The lower frequency techniques have many common features with low frequency C-Scanning (see the article by Clark and Bishop in this issue) but are different enough to warrant further discussion. For this paper the two techniques will be described as CSAM (C-Scanning Acoustic Microscopy) for 30 MHz to 100 MHz work and SAM (Scanning Acoustic Microscopy) for above 200 MHz work.

## 2. C-SCANNING ACOUSTIC MICROSCOPY

The principle behind CSAM or subsurface acoustic microscopy is shown in Figure 1. A piezoelectric material ($LiNbO_3$, PVdF or similar) is excited by a short, high voltage pulse (generally a sub 50 nsec pulse of a few hundred volts amplitude, though these can vary considerably) and launches an ultrasonic wave into the coupling medium (usually water). The ultrasound then passes through the coupling medium/specimen interface (a proportion is reflected) and into the specimen. Within the specimen the ultrasound is subject to a number of interactions which can cause absorption, scattering, refraction or reflection, depending on the mechanisms involved. If none of these mechanisms were to be involved, the ultrasound would be reflected from the lower surface of the specimen and then back to the transducer, which acts as the receiver (a confocal system). The returned signal is then fed to a broadband amplifier which enables the signal to be displayed or captured for a variety of signal processing procedures.

**TABLE 1 –**

**Elastic Wave Velocities and Acoustic Impedances for Various Materials**

| Material | Density (g/cm³) | Wave velocity (m/s) Lngitud'l | Shear | Rayleigh | Impedance (Mrayl) |
|---|---|---|---|---|---|
| Aluminium | 2.7 | 6400 | 3100 | 2900 | 17.3 |
| Perspex | 1.18 | 2700 | 1330 | 1240 | 3.2 |
| Glass (crown) | 2.3 | 5660 | 3420 | 3130 | 13.0 |
| Steel (mild) | 7.85 | 5960 | 3230 | 3000 | 46.5 |
| $Al_2O_3$ | 3.98 | 10000 | – | – | 39.8 |
| $Si_3N_4$ | 3.19 | 12000 | – | – | 38.3 |
| $ZrO_2$ | 5.56 | 6500 | 3620 | – | 31.1 |
| SiC | 3.21 | 11000 | – | – | 35.3 |

**Note:** The densities given for $Al_2O_3$, $Si_3N_4$, $ZrO_2$ and SiC are the theoretical maxima.

The ultrasound is subject to attenuation while passing through the specimen material, and also to loss of amplitude due to reflection or refraction from regions of changing acoustic impedance. Acoustic impedance is defined as the product of ultrasonic pulse velocity and density (both in the material in question). The SI unit for impedance (acoustic will be inferred from now on) is the rayl: 1 $\mathrm{kg\,m^{-2}s^{-1}}$ (the impedances of various materials are given in Table 1, which includes the longitudinal, shear and Rayleigh wave velocities). This implies that a reflected signal will be obtained from any interface where there is an impedance change; for example, water/bulk, bulk/void, bulk/inclusion, adhesive joint, density variation, etc.

An example of a typical CSAM amplitude time base plot is given in Figure 2. This is termed an A-scan and can supply information such as pulse velocity within the specimen (thickness divided by time-to-"d" minus time-to-"b"), defect size (approximate) and distance of the defect from the front surface. Another commonly used presentation format is the C-scan. This is a planar projection of the amplitude (or distance from the surface) of the reflected signal (through-transmission is rarely used at high frequencies) and is produced in a manner shown in Figure 3. This shows how an image is built up in a raster scan fashion (usually on a computer display).

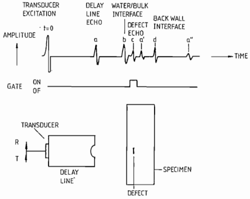


*Figure 2: Schematic of a typical A- scan from a sample in immersion. The electronic gate is positioned in a region where echoes from defects are expected and samples the signal in that region. Echoes a' and a" are multiples of the delay line echo.*

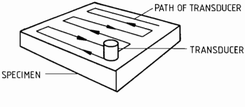


*Figure 3: This shows the data collection method for CSAM imaging. The transducer is moved over the specimen in a rectilinear pattern, the position of the transducer being monitored by pulse counting or encoders.*

The position of the transducer is determined by an encoder or by pulse counting (with stepper motors) and the reflected amplitude in a timegate is converted to a colour or grey scale and is then displayed on a monitor.

As mentioned previously, CSAM is usually performed with transducers in the range 30 MHz to 100 MHz. This move to higher frequencies than normal NDE is dictated by two main factors. The first is the quest to detect smaller defects (spatially), the second is to be able to resolve thinner layers.

The second reason stems from the length of the ultrasound pulse produced by the transducer. The best thickness gauging transducers can produce pulses of about 1 to 1½ cycles, which at 10 MHz represents a thickness of about 0.9 mm in steel. The minimum thickness that could be gauged would thus be approximately 0.45 mm (assuming the back surface reflection occurred 1½ cycles after the front). At 50 MHz the minimum thickness is approximately 0.09 mm (these are both under ideal conditions).

The more important of the two reasons is one of resolution. Ultrasonics is governed in much the same way as optics where resolution is concerned. The resolution of a system of two closely spaced reflectors is given by the Rayleigh criterion [1] as $1.22\lambda F$ where $\lambda$ is the wavelength and F the F-number of the lens (F = radius of curvature/diameter). This resolution is thus the distance between the minimum each side of the beam maximum. This is of the order of the transducer diameter (or larger) for planar transducers.

Increasing frequency is thus not enough by itself to increase the resolution of the system. This resolution improvement is brought about by the use of focused transducers. This can be performed in a number of ways. These include (i) the use of curved radiating elements; (ii) the use of focusing lenses and (iii) the use of phased arrays. The use of curved radiating elements at high frequencies (> 30 MHz) is in practice limited to piezoelectric polymer materials due to the fragile nature of piezo-ceramics. Phased array technology is a developing area of NDE (particularly in the medical field) but is beyond the scope of this article.

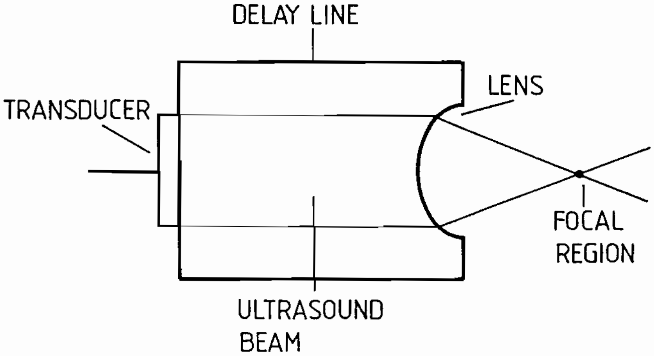
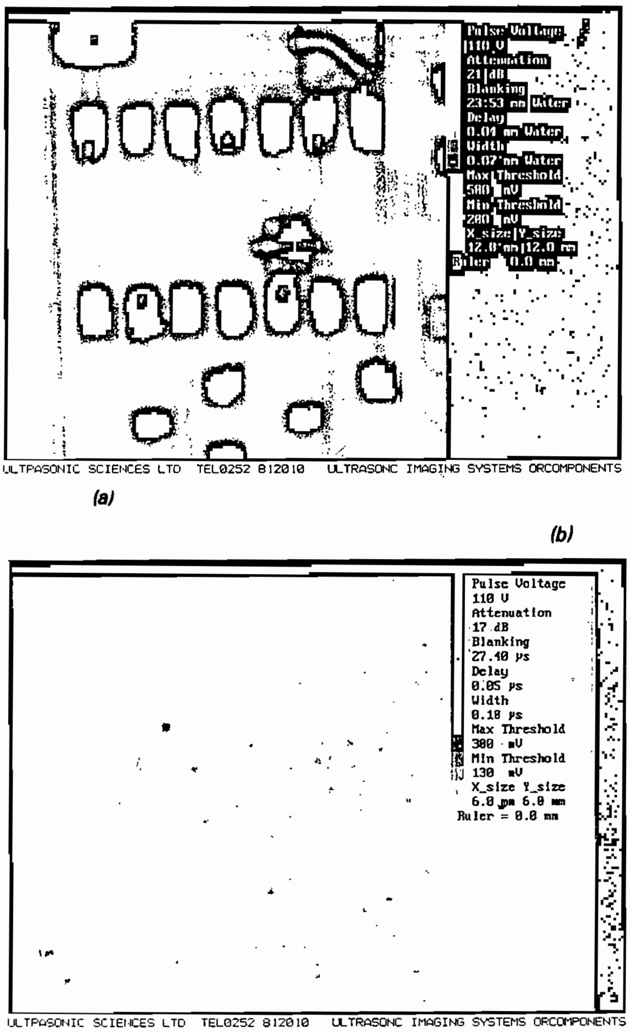


*Figure 4: A ray tracing depiction of the principle of focusing ultrasound with a refractive lens. Refraction is caused by the difference in the acoustic pulse velocity between the lens material and the coupling liquid.*


Pulse Voltage
110 V
Attenuation
21 dB
Blanking
23:53 mm Water
Delay
0.04 mm Water
Width
0.07 mm Water
Max Threshold
580 mV
Min Threshold
280 mV
X_size Y_size
12.0 mm 12.0 mm
Ruler 0.0 mm

ULTPASONIC SCIENCES LTD TEL0252 812010 ULTRASONC IMAGING SYSTEMS ORCOMPONENTS

*(a)*

*(b)*

Pulse Voltage
110 V
Attenuation
17 dB
Blanking
27.40 µs
Delay
0.05 µs
Width
0.18 µs
Max Threshold
300 mV
Min Threshold
130 mV
X_size Y_size
6.0 mm 6.0 mm
Ruler = 0.0 mm

ULTPASONIC SCIENCES LTD TEL0252 812010 ULTRASONC IMAGING SYSTEMS ORCOMPONENTS

*Figure 5: CSAM image (using a 50 MHz transducer) of:*
*(a) solder pads on a surface mounted device (imaged through the ceramic printed circuit board) and*
*(b) defects in a nickel based superalloy.*
*The actual image sizes are:*
*(a) 12 x 12 mm and*
*(b) 6 x 6 mm — the minimum scan area is about 2 x 2 mm indicating that higher resolution images are achievable (images by permission of Ultrasonic Sciences Ltd).*

The most common method of providing focused beams with ultrasound is to use lenses. The principle is shown in Figure 4. The ultrasound is generated by the tranducer element on the left. Focusing is achieved by using a convex lens surface between the delay line (usually quartz or, at very high frequencies sapphire) and the coupling fluid. The ultrasound is refracted at the quartz/water interface to form a diffraction limited spot at the focus. Spherical aberration caused by the extreme rays is generally a lesser problem than the diffraction limitations. This is due to the relatively large refractive indices (4 for quartz/water and 7.4 for sapphire/water lenses), which provide well-defined focal regions.

The dimensions of the focal spot and region are a function of frequency, transducer diameter and material impedance (for length of region only). The dimensions of the focal zone can be obtained from the following equations (these are useful approximations; for a more rigorous description refer to references [1], [2], or [3].

$$\text{Beam width } (-6\text{ dB}) \approx 1.22(V f)/(F d)$$

$$\text{Length of focal zone } (-6\text{ dB}) \approx 8(V/F)(f/d)^2$$

where $V$ = sound velocity in coupling medium
$F$ = frequency of transducer
$f$ = focal length of transducer
$d$ = diameter of lens element.

Note that f is the actual focal length of the transducer and not that calculated by optical theory, $R/(1-c_2/c_1)$, where R is the radius of curvature of the lens and $c_2$ and $c_1$ are the pulse velocities in water and lens respectively. The equations above use the actual focal length.

It can thus be seen that the dimensions of the focal zone (in water) for a 50 MHz focused transducer (12.7 mm focal length and 6.35 mm diameter lens) is (– 6 dB points);

beam width — 72 µm
focal zone length — 0.95 mm

It is important to note that the above beam width corresponds approximately to the resolution of a high frequency system, but is much larger than the detectability. It is possible, under conditions of high signal-to-noise ratio and low attenuation, to detect reflectors of at least 1/10th of a wavelength and maybe smaller. Indeed, reports have been made of the detection of sub 50 µm (down to 25 µm) seeded defects in $Si_3N_4$ (wavelength 240 µm). [4]

The width of the focused beam dictates the way in which C-scan images are built up. If the –6 dB width is 72 µm, then a distance between sample points of less than this is required in order to ensure that no information between data points is lost. Indeed a sample spacing considerably smaller than this may be necessary if small changes in signal level are being monitored. It is clear then that high resolution mechanical scanners are needed. A number of such scanners have been reported in the literature and some are available commercially. Generally a step size (drive is usually by stepper motor) of 25 µm or below is specified. It now becomes apparent that high resolution scanning of large specimens will take up considerable storage space (for the ultrasonic signal data) and also considerable time if full coverage is specified. It thus becomes necessary to scan as fast as possible, but high speed scanning is not always feasible as the transducer can be quite large.

An alternative to moving the transducer is to move the specimen. This is quite often used in inspecting the chip-to-substrate bond in electronic components. (This is to assess the degree of bonding between the chip and the heat sink and is specified for some aerospace applications. A typical procedure is shown in reference [5].) Inspection times of less than about 4 seconds per component can be achieved in this manner.

Figure 5 shows two C-scans which are typical of the results which can be obtained with CSAM techniques. Figure 5a shows an image of the solder pads in a surface mount device. This device was mounted on a ceramic printed circuit board, on which solder pads were present. Inspection from the top surface is not possible because the solder tabs are beneath the component. The image is a recording of the amplitude reflected from the pcb-solder-pad/surface-mount-device solder pad interface and gives an indication of the quality of the solder joint. High amplitude reflections (the light shaded areas within the rectangular solder pads) are an indication of a suspect joint.

Figure 5b is a C-scan image of a nickel based superalloy test piece produced by the powder route. The defects are less than 50 $\mu$m in diameter and are readily detectable. The image is 6 mm square which shows that the smallest clearly defined defects are about 25 $\mu$m in diameter. Examples of ceramics evaluation can be found in references [6-11].

The generation of C-scan images is the simplest and most direct method of obtaining information about "defects" or "features" within materials. C-scans provide very useful information but are only indicators of reflected amplitude changes within the specimen, and give little or no information about the nature of the features revealed. In some cases, such as the chip/substrate bond inspection mentioned above, this is all the information that is required, in this instance the proportion of good bond at the interface between the chip and its associated heatsink. However, there is a move towards the analysis of ultrasonic data to provide much more information about the revealed features. The key points of a number of techniques will now be discussed.

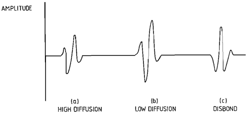


*Figure 6: Schematic showing the waveforms reflected from the various bond types in zircaloy/uranium diffusion bonds.*

### Phase techniques

These techniques allow information regarding the impedance of a defect indication to be obtained. Thus voids and tungsten inclusions in, for example, $Si_3N_4$ will give rise to reflections of different phase, having lower and higher impedances respectively than the surrounding material. An example of this in practice is illustrated in reference [12] which describes a technique for evaluating the diffusion bond between zirconium and depleted uranium. The diffuse interface gives rise to a range of reflections depending on the condition of the bond. Figure 6 illustrates the three conditions. Figure 6a is the reflected signal obtained when a good high-diffusion bond is obtained. Figure 6c shows a non-bond where the phase of the reflected signal is reversed. Figure 6b shows the intermediate condition where some diffusion has occurred but the bond line is relatively thin. (In this case, the bond quality was assessed by evaluating the phase of the reflected signal and also measuring the amplitudes of the various phase components.)

### Frequency techniques

The use of frequency-dependent techniques to improve resolution is rapidly increasing. The range of techniques is large; from simple narrow and filtering to split-spectrum processing to the recent developments in frequency modulated chirp techniques. Filtering techniques can be useful in increasing the signal to noise ratio in some instances. The use of broad band transducers inevitably increases system noise over narrow band systems and some materials show frequency dependent attenuation, displaying windows of relatively low attenuation. Split spectrum processing is a more sophisticated technique whereby the band pass region of the transducer is split into many bands with defect signal processing being performed in each band and then reconstructed. This technique has proven successful in noisy materials such as Austenitic steels [13].

The FM chirp technique is a recent development which takes its parentage from radar techniques. In this, a short pulse is sent to the transducer with a modulation in frequency (usually linear). The detecting equipment then correlates any signal components in the returned signal with this known input and provides an output. Very good S/N ratio enhancement are obtainable with this technique [1,14].

### Inversion techniques

These use the pattern of the scattered/reflected ultrasound and the known ultrasound beam geometry to determine the form of the defect. Considerable computing power is required and is not, at present, a practical real time technique. However, inversion techniques, along with expert systems and adaptive networks promise to contribute significantly in many areas of NDE in the near future.

The above techniques are not restricted to high frequency work and are indeed used more frequently at low frequencies (< 20 MHz) due to the computing requirements of most of the techniques. A technique, not mentioned above, which is used in high frequency work on occasions is signal averaging. This is used to enhance the S/N ratio, which is a particular problem at frequencies much above 50 MHz where attenuation is significant.

### Deconvolution techniques

It is inevitable that the C-scan image of a small defect (smaller than the focal spot size) will be somewhat enlarged due to the extended nature of the beam of interrogating ultrasound. If the beam profile is known, then, given certain assumptions regarding the defect form, the size of the defect can be accurately determined (this is a simplified version of the inversion techniques mentioned above). High accuracy can be obtained where, for example, planar defects are expected, such as in the bonding between two materials or where a material has been heavily deformed by rolling or forging thus "flattening" any defects present. There is very little in the literature on this technique, though the author has used it to good effect in a closely related field.

## 3. SCANNING ACOUSTIC MICROSCOPY (SAM)

While CSAM techniques are generally applied to sub-surface imaging and detection of defects, SAM techniques are predominantly surface or near surface techniques. This is, in the main, determined by the ultrasound attenuation which is proportional to frequency squared. This limits the upper frequency for CSAM work to about 150 MHz. SAM studies, however, are not constrained by the bulk properties to the same extent and higher frequencies are used to generate as short a wavelength as possible.

Whereas the information gained from CSAM studies concerns changes in impedance within the specimen, SAM images are built from the information gained from changes in elastic

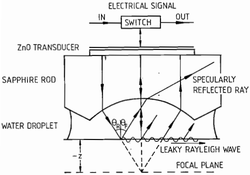


*Figure 7: Ray model for describing the contrast mechanism in SAM imaging. Note that the numerical aperture of the lens must be large enough to allow extreme rays to generate the Rayleigh waves.*

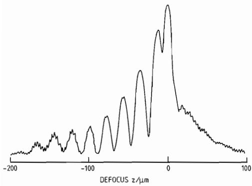


*Figure 8: V(z) curve for aluminium at 237.5 MHz. Focus is at z = 0. Negative values of z indicate movement of the transducer towards the specimen.*

properties. This section will detail the contrast mechanisms used in SAM and will briefly describe a range of possible applications. Further information can be obtained from references [16] and [17].

It was noted in the introduction that SAM is essentially a surface technique. It might be imagined that to gain the highest resolution the lens should be operated at the focal length with the ultrasound focused at its diffraction limited spot. It is possible to do this and obtain images of surface features, however, the image contrast will be very poor. SAM images are usually generated with the lens closer to the specimen surface than focus. What then happens is that contrast is obtained by the interference between the directly reflected paraxial rays and the Rayleigh waves generated on the specimen surface. This is described with reference to Figure 7.

This figure shows how contrast is generated. This is a simplified ray model but it clearly illustrates the contrast mechanism. It is important that the lens used should have a sufficiently large numerical aperture to include the Rayleigh angle (this is the critical angle where the refraction causes surface waves to be generated) which is given by

$$\theta_{crit} = \sin^{-1}(c_{liq}/c_{sol})$$

It can be seen that, compared with operation at focus, the normal ray undergoes a change in path length of z before being reflected and an additional amount z on the return journey. The ray incident at the Rayleigh angle has a path reduction of $z.\sec\theta_R$ and then excites a Rayleigh wave on the surface. This is then leaked back into the coupling liquid at the Rayleigh angle and returns back through the lens to the transducer: note that it is only those rays at or near the Rayleigh angle that contribute significantly to the received signal. Thus, in the fluid the change in path length is $2.z.\sec\theta_R$. Add to this the path travelled through the solid of $2.z.\tan\theta_R$ — equivalent to an acoustic path in the liquid of $2.z.\tan\theta_R \sin\theta_R$ (because the ratio of velocities $c_{liq}/c_{sol} = \sin\theta_R$). There is also a phase change of $\pi$ associated with the excitation and re-radiation of the Rayleigh wave. Thus the phase difference between the two waves is [16]:

$$\begin{aligned}\Delta\phi &= (2.z - 2.z.\sec\theta_R + 2z.\tan\theta_R\,.\,\sin\theta_R)k + \pi \\ &= 2.k.z(1-\cos\theta_R) + \pi\end{aligned}$$

where k is the wave vector in the liquid.

This will give a periodicity of oscillation as the lens is moved towards the specimen of

$$\Delta z = 2\pi/[2k(1-\cos\theta_R)]$$

There is a dependence here on $\theta_R$ the Rayleigh angle, which is determined by the acoustic pulse velocity within the material. Thus, for example, two grains side by side in a material will give different contrast if they are oriented differently (for example {100} and {111}) because the acoustic velocity depends on crystal orientation. The effect of contrast on defocus is shown in Figure 8. This is a V(z) curve of aluminium at a frequency of 237.5 MHz (from [10]). It was generated by moving the transducer in the z direction, that is normal to the specimen surface, and recording the transducer output. It is important to note that the periodicity in the near defocus region (that is from $z = 0$ to $z = -100\,\mu m$) is caused by the effects discussed above and not by any near field effects of the transducer. The reason for operating the lens in the defocus region is clear when it is considered that regions of different elastic properties within the specimen give rise to very similar amplitude response at focus (this is a purely reflective/refractive response with no Rayleigh wave contribution). It is only as the transducer is moved closer to the specimen (−z) that the Rayleigh wave contrast mechanism comes into play.

It is also clear from the rapidly varying periodicity of V(z) that specimens must be very flat and that the transducer must be normal to the specimen interface so that fringes do not occur (this practical information is described in detail in reference [16]).

The resolution that can be obtained with SAM instruments is significantly better than CSAM techniques. The best resolution for room temperature water-coupled devices is about 0.2 µm (at 4.2 GHz). This can be bettered, but only significantly by moving to liquid helium coupled devices. In these, attenuation in the coupling fluid (liquid He) becomes negligible below 0.2K and a resolution of 20 nm has been reported [16].

The range of application of SAM is very wide. The field has expanded rapidly in the last ten years and examples are widespread. These include:

- electronic packages and devices [18]
- adhesion of thin films [18, 19]
- surface cracks [20, 21, 22]
- elastic property variation [2, 16].

An example of elastic property monitoring is shown in Figure 9. Figure 9a shows the SAM image of unetched polycrystalline nickel recorded with $z = -4\,\mu m$ (that is 4 µm defocus towards the specimen). Figure 9b was recorded with $z = -7\,\mu m$. The variation in contrast from the various grains is very marked.

*Figure 9: SAM images of polycrystalline nickel: (a) was recorded at a defocus of 4 μm, and (b) at 7 μm (from reference [16]).*

## 4. CONCLUSION

This paper has described two techniques for evaluating modern materials for the presence of subsurface and surface defects/microstructure variations. CSAM techniques can be used to detect defects and debonds in a variety of materials at significant depths, the depth depending on the resolution required. The range of signal processing and imaging techniques have been described very briefly and show the wide range of procedures that can be used. It is also apparent that full inspection of components takes considerable time due to the size of the focal zone and the fact that only a thin slice of the component (in the depth sense) can be inspected at any one time due to the limited focal zone (there are techniques being developed to overcome this problem in part, such as axicon and dynamic focusing lens systems). In addition, curved surfaces are a problem which require contour following transducers and allowances for changes in the focal zone. SAM techniques are surface or very near surface techniques. A limiting aspect of the technique however is the need for very flat specimens and also precise control of the transducer/surface distance. This really limits SAM to process development and failure type studies; similar restrictions apply to CSAM, though the technique is also used on a production basis in a number of industries.

## REFERENCES

1 G.S. Kino: Acoustic Waves: Devices, Imaging and Analog Signal Processing, Englewood Cliffs, Prentice Hall (1987).
2 U. Schlengermann: Acustica *30* 291-300 (1974).
3 M.G. Silk: Ultrasonic Transducers for Nondestructive Testing, Bristol: Adam Hilger (1984).
4 T. Nonaka, Y. Hayakawa, S. Takeda, T. Igarashi, Y. Takishita, T. Miyata, H. Yamamoto, S. Yamaguchi and H. Nishimori: Non Destructive Testing (Proc. 12th World Conference), 784-789 Amsterdam: Elsevier (1989).
5 U.S. Military Standard: MIL—STD-883C (1983).
6 S.J. Klima: Materials Evaluation 44, 571-576 (1985).
7 J.J. Gruber, J.M. Smith and R.H. Brockelman: Materials Evaluation *46* 90-96 (1986).
8 T.N. Claytor, H.M. Frost, T.H. Feiertag, G.A. Sheppard and P.D. Shalek: Materials Evaluation *47* 532-537 (1989).
9 D.C. Kunerth, K.L. Telschow and J.B. Walter: Materials Evaluation *47* 571-575 (1989).
10 A. Vincent and A. Moughil: NDT International *22* 283-291 (1989).
11 D.B. Stang, J.A. Salem and E.R. Generazio: Materials Evaluation *48* 1478-1482 (1990).
12 R.L. Crocker and R.P. Harrison: Proceedings of 4th European Conference on NDT, London 13-18 Sept. 1987: London, Pergamon (1987).
13 B. Baligand, M. Grozellier and D. Romy: Materials Evaluation *44* 577-581 (1986).
14 P. Das and D.R. Arsenault: Research Techniques in Non Destructive Testing Vol. IV, Ed. R.S. Sharpe: London, Academic Press (1980).
15 Hung-Fa Shyn, V. Goncharoff and J.E. Jacobs: International Advances in Nondestructive Testing *10* 43-60 (1984).
16 G.A.D. Briggs: An Introduction to Scanning Acoustic Microscopy: Oxford, Oxford University Press (1985).
17 C.F. Quate, A. Atalar and H.K. Wickramasinghe: Acoustic Microscopy with Mechanical Scanning — a review. Proc. IEEE *67* 1092-1114 (1979).
18 A.J. Miller: Institute of Physics Conference Series *67* 393-398 (1983).
19 C.F. Quate: Scanned Image Microscopy (Ed. E.A. Ash): London, Academic Press (1980).
20 K. Yamanaka and Y. Enomoto: J. Appl. Phys. *53* 846-50 (1982).
21 M. Nikoonahad, P. Sivaprakasapillai and E.A. Ash: Electron. Lett. *19* 906-908 (1983).
22 C. Ilett, M.G. Somekh and G.A.D. Briggs: Proc. R. Soc. Lond. *A393* 171-183 (1984).

# Application Of Ultrasonic C-Scanning To Aerospace Composites.

**G. Clark and B.C. Bishop**
**Aircraft Materials Division**
**DSTO Aeronautical Research Laboratory**
**Fishermans Bend VIC 3207**

*ABSTRACT: Organic-matrix fibre-reinforced composites are used widely in civil and military aircraft. They are however particularly sensitive to impact damage, and there is a need for a non-destructive inspection capability which will permit rapid characterisation of internal delamination damage. This paper describes the use of ultrasonic scanning for inspection of composite materials, and the way in which this approach has been implemented.*

## 1. INTRODUCTION

The number of aerospace applications of composite materials has increased enormously in recent years. Carbon-fibre /epoxy laminates are used widely in weight-critical parts, and are produced by laying up a laminate sheet from plies of woven or unidirectional carbon fibre which has been pre-impregnated with epoxy resin; the directions of the carbon fibre can be tailored to match the high-stress directions in the component, and the laminate can be moulded to shape as required. The high strength-to-weight and stiffness-to-weight ratios achievable with correctly designed composite materials have provided a major incentive for introducing these materials, and carbon fibre / epoxy laminates are now used widely in both civil and military aircraft for parts of the secondary structure (e.g. doors and fairings), and, particularly in military applications, for high load-bearing primary structure such as wing skins. In the F/A-18 operated by the RAAF, for example, carbon fibre laminates make up to approximately 9% of the aircraft weight, in two principal forms - the wing skins consist of monolithic carbon fibre laminate up to approximately 14 mm in thickness, while other surfaces are constructed from a sandwich made up from a pair of relatively thin carbon fibre laminates, separated by a lightweight honeycomb core.

Non-destructive inspection is an aspect of maintenance which is fundamental to the safe operation of a fleet of high-performance aircraft, and it is essential that current NDI procedures be modified to take account of the introduction of new materials which are being used in safety-critical applications. An area of particular concern is the detection and sizing of impact (and other) damage in composites. Laminated composite materials such as carbon-fibre / epoxy have excellent mechanical properties when tensile loads are carried by the fibres, but their through-thickness mechanical properties are generally poor. In particular, delamination damage is easily produced by fairly minor impacts; impact from runway stones, hail, bird-strike or dropped tools can produce large areas of sub-surface damage which may be invisible at the surface ("barely-visible impact damage" or BVID), and the presence of this damage can lead to significant reductions in the in-plane compressive strength of the whole laminate [1-3].

## 2. ULTRASONIC C-SCANNING

The detection and sizing of delaminations in laminated composites is performed using conventional ultrasonic scanning; essentially this involves using a piezoelectric ultrasonic transducer, usually with a resonant frequency between 1 MHz and 20 MHz, to project a signal, at normal incidence, into the laminate. The signal is usually a pulse, produced by exciting the piezo-electric crystal with a short burst of

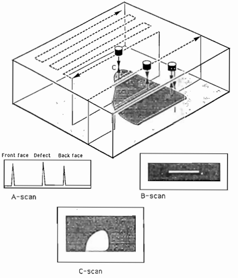


*Fig. 1. Schematic diagram showing the transducer scanning and display formats associated with A, B and C-scans.*

alternating voltage corresponding to the characteristic frequency of the crystal; the voltage applied is usually between 10-100 volts. While the voltage pulse has a short rise time and an equally short decay time, the resulting ultrasonic pulse often displays characteristics which are quite different, since the crystal tends to "ring"; damping of the crystal is therefore an important factor in determining the ultrasonic output. For most composite applications, the pulse is repeated at about 1 kHz (the pulse repetition frequency), although other frequencies both below and above this are used for other materials. Several transducer configurations are possible; the same transducer may be used as a receiver, or another transducer may be used in a through-transmission mode. Conventional scanning is based on measuring the amount of energy reflected from some feature in the sample; in practice, the amplitude of the back wall reflection, identified by the time-of-flight of the signal, is usually measured. Delaminations and other defects such as porosity, cracks and foreign inclusions cause attenuation of the forward and reflected signal in the laminate, and may be located by observing the reduced signal amplitude.

Figure 1 indicates schematically different ways of presenting scan data - A, B and C-scans. The A-scan is simply a representation of the return signal amplitude on a timebase. B-scanning involves scanning the ultrasonic beam linearly, to interrogate a section of the material, and the B-scan display is effectively a section through the component, showing the position of points from which reflections are obtained. C-scanning involves moving the transducer over the surface to produce a plan-view representation of the sample, showing the signal variation. By setting appropriate threshold levels for the display, the defective area, over which the back-wall echo is reduced or absent, will contrast with the background. This form of C-scanning is widely used for quality control purposes in laminate manufacture [4].

## 3. TIME-OF-FLIGHT C-SCANNING

The conventional approach to C-scanning described above does not provide any information about the depth-wise distribution of this damage [5]. This depth information, however, can be obtained by recording the position of defect echoes on the timebase of ultrasonic A-scan and using this time-of-flight information, rather than the back-wall echo amplitude, to construct an appropriate C-scan. This depth-wise information is quite important, for two reasons; firstly, the consequences of having a defect localised between two plies may be quite different from having a uniform distribution of defects throughout the laminate. Also, when damage occurs as a result of impact, the delaminations which result occur in a generally conical form i.e. the delaminations with the smallest area occur close to the impact point, and delaminations increase in area with increasing distance from the impacted surface. This form of damage can be clearly seen in Figure 2 which shows a section through a typical impact-damaged carbon-fibre composite panel. The second major application of the depth information concerns possible repair: the repair of damaged laminates usually involves scarfing out a large area of laminate surrounding the damage, and since scarf angles of 1 in 20 may be required to ensure satisfactory load transfer into the repair, the depth location of the damage can have a large influence on the amount of material which needs to be removed.

The method adopted at ARL [6,7] for using the time-of-flight information is to record the time-of-flight to the first return echo in the A-scan which exceeds a selected gate level, as a function of position on the sample. This first return echo will normally represent the back wall in the case of a sample in good condition, or the first delamination if the panel has been damaged. Two systems are in operation:

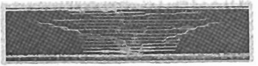


*Fig. 2. Section through 50-ply carbon-fibre composite laminate, showing the delaminations and ply cracks formed during low-velocity impact. The impact point is on the upper surface, and the delaminations and cracks have been accentuated using a fluorescent dye penetrant. Magnification: 3*

### Laboratory system

Since the coupling between the ultrasonic transducer and the sample is best obtained using a water immersion tank, the ARL laboratory system is based on a large (1.2 m square) tank (although larger tanks are used for some larger components). A conventional ultrasonic thickness gauge generates the ultrasonic signal, via a transducer in the tank, and processes the returned signal. A focussed probe provides higher beam intensities and by minimising beam spread, permits a much higher resolution image to be obtained. Scanning of the transducer is controlled by a PC-type computer which also handles construction of the C-scan image, display and storage. Figure3 shows an example of the output from this system; the item scanned is a wing panel from an F/A-18 aircraft which suffered impact damage - little damage was visible on the surface, but the C-scan revealed the depth and extent of large delaminations. This information is suitable for planning a repair of the panel.

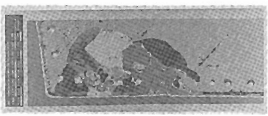


*Fig. 3. C-scan of an F/A-18 carbon fibre composite wing panel, damaged in flight, showing the presence of large delaminations invisible from the surface. The panel was scanned using the ARL time-of-flight immersion tank system, and the output is normally colour-coded to show the various delamination depths.Magnification: 1/3*

### Portable system

The success of the laboratory system was such that there was considerable interest in adapting the system for use on mechanical testing machines used for fatigue tests on composite specimens, and also as a unit which could be used to inspect aircraft skins. As a result of this, a small C-scanner was developed which has been designed to retain the imaging capability of the laboratory system while offering all the benefits of portability. The system is based on a small X-Y scanning frame which is attached to the surface of interest using vacuum cups, thus allowing it to be used vertically or inverted, as well as on horizontal surfaces. The movement of the transducer over the sample is controlled by a PC-type computer which also performs the analysis, providing output in real time. A major problem in adapting the laboratory system for portable use was to find a means of coupling the transducer to the specimen without use of a water tank; approaches examined included the use of water-jets (i.e. columns of water, squirted at the sample) and wheel (tyre) transducers. The latter was too limited in the range of frequencies available, and the former has obvious disadvantages for use on aircraft in service. The approach adopted was a pseudo-dry coupling system in which the water column in front of the probe is contained by a semi-permeable membrane, through which a small amount of water bleeds onto the specimen surface. This method has been extremely successful; the specimen surface remains almost dry, coupling is excellent, and the membrane withstands considerable wear even on fairly abrasive composite surfaces. This system can be used to provide efficient coupling regardless of the orientation of the scanner - inverted, vertical horizontal, or any combination of these. Coupling by this method also allows use of a variety of transducer configurations and frequencies.

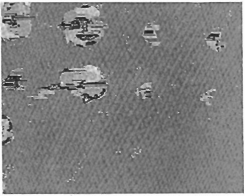


*Fig. 4. C-scans of F/A-18 carbon-fibre wing panel showing delaminations around fastener holes; the normal (non-delaminated) holes are on the right.*

Figure 4 shows a scan of part of a wing panel containing delaminations around fastener holes resulting from manufacturing and/or assembly processes. Delaminations only a few millimetres across can be located, despite the proximity of the fastener hole. Figure 5 shows the portable C-scanner in position underneath the horizontal stabiliser of an RAAF aircraft.

## 4. FACTORS INFLUENCING ULTRASONIC SCANNING

Several factors have been found to influence the performance of an ultrasonic C-scanning system, and required attention during the design of the ARL systems:

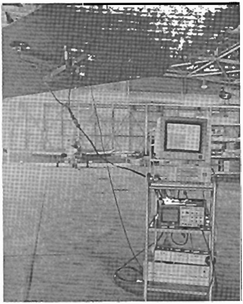


*Fig. 5. ARL portable C-scanner being tested on the lower surface of an F/A-18 horizontal stabiliser.*

- Probe frequency is particularly important; the numerous interfaces and voids present in organic-matrix fibre composites provide significant scattering. Signal attenuation for a given thickness of composite material can vary considerably depending on the orientation of the various ply layers used, and on whether the plies are made of unidirectional or woven fibres, or some combination of these. Generally, to achieve satisfactory return echoes, low probe frequencies of 1-2.5 MHz are preferred, although depth resolution then suffers. For higher resolutions, which may be required for single-ply resolution, or detection of small voids such as entrapped air bubbles, higher frequencies are preferred (e.g. 5-10 MHz), although these are usable only on laminates up to about 6 mm thick due to increased attenuation losses.

- Glass-fibre reinforced laminates present particular problems, since they are often thick and provide very effective scattering - in practice, success in detecting delamination in GFRP is dependent on factors such as thickness, fibre type, (woven, or chapped strand) and volume fraction (fibre/resin ratio). These parameters are usually less closely controlled during the manufacture of GFRP than is the case for carbon or boron-fibre composites. This type of material is not normally used for critical load-bearing parts in high-performance aircraft.

- Coupling between the probe and the surface is critical; as described above, the use of a water tank or a contained water column works well. Gel systems have also been tried, but do not provide consistent and reliable coupling when the transducer is being scanned over a large area automatically. Figure 6 shows two C-scans of the same component (a 56-

ply carbon-fibre laminate skin from a box beam which was impact-damaged in four places prior to being fatigue-tested to failure). One of these scans was carried out in an immersion tank, the other using the dry-coupled technique. The two scans display good agreement regarding the extent of delamination damage, although the rough surface immediately adjacent to the through-thickness failure has caused significant loss of coupling in the dry-coupled scan.

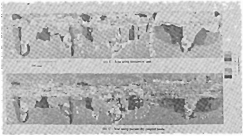


*Fig. 6. C-scans of the failure region of a carbon-fibre box-beam skin which was impact damaged (4 places) and fatigue tested to failure. The upper scan was made using the ARL immersion tank time-of-flight system, while the lower one used the ARL portable C-scanner. Correspondence is good, except for regions where motion of the contact probe of the portable unit was obstructed by gross surface damage.*

- Since the leading edge of the reflected signal is used to locate the reflector, any reflectors close to the surface may be masked by the ringing in the signal which is reflected from the front face of the specimen. This ringing, coupled with the pulse width sent out originally by the transducer, effectively sets a "dead time" during which reflections cannot be identified without more sophisticated processing, and the use of transducers which have shorter initial pulse lengths and reduced ringing through better damping is advantageous. A further complication can arise as a result of the fact that the system effectively looks for the first significant reflection; if a real delamination is located in the dead zone, it is not recognised, and a multiple reflection from the same delamination may appear as a false indication at twice the depth.

- A delamination or other strong reflector near the front face of the specimen necessarily prevents the signal reaching defects located deeper in the specimen. Deeper defects are effectively masked, although in practice, if both sides are accessible, this problem can be minimised by scanning from both sides. Furthermore, delamination damage due to impact tends to be conical in form, as was described earlier, and the deeper damage is usually larger and more significant. For the same reason, masking of defects near the front surface through reduced near-surface resolution, as described above, is not usually a major problem.

- The systems developed at ARL have been designed to have the capability to record either the time-of-flight or the amplitude of the reflected signal. Usually only one parameter is recorded, to ensure maximum scan rates, although hardware improvements would make combined scans feasible. The benefit of such combined time-of-flight and amplitude scanning is that the amplitude data can be used to identify defects such as clouds of voids, which, while being efficient attenuators, produce reflections which are much weaker than those from delaminations. In terms of defect sizing, it has been found that time-of-flight scanning is the preferred mode. This is the case because it is easier to identify the edge of an area which simply represents attenuation of a back face signal which is itself varying. Figure 7 shows three C-scans of an impact-damaged 20-ply laminate which illustrate this point. Figure 7a - an amplitude scan - shows the significant variation in the back-wall echo amplitude, against which the additional reduction in amplitude caused by the defect must be identified. Figure 7b shows the (much lower) variation in the reflectivity of the sample (excluding the back-wall), and Figure 7c shows the time-of-flight C-scan; the latter clearly provides the best means of identifying and characterising the damaged area.

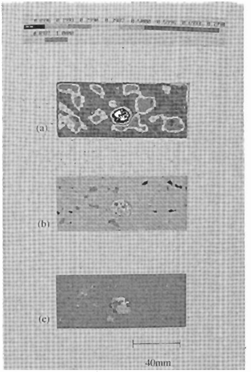


*Fig. 7. Pulse-echo C-scans of an impact-damaged 20-ply carbon-fibre panel. (a) showing back-surface reflection amplitude (conventional C-scan), (b) showing reflectivity of the material, excluding the back surface and (c) the time-of-flight C-scan, which provides the best resolution of the impact damage.*

## 5. CONCLUSION

The approaches and systems described above have been developed into reliable and effective instrumentation for inspection of composites, and provide significant advantages; the portable unit, for example, has been demonstrated to allow scanning of a wing skin area about ten times faster than by conventional scanning (i.e. by hand), as well as providing a real-time image of the damage, and a permanent record.

The use of time-of-flight scanning is now being adopted world-wide, and a number of systems based on the principles outlined above, but with various configurations, are being introduced.

Overall, the problem of detecting and characterising defects in composite laminates appears to have been satisfactorily addressed through timely research and development. It is worth noting, however, that there is a related problem this is still providing concern; the use of composites in aircraft has been matched by an increased use of adhesive bonding (metal/metal and metal/composite) - in the F/A-18, for example, the wings are attached to the centre section by adhesive bonding. The problem of identifying bonds which are weak, or which will degrade during service, has not yet been solved, and is receiving considerable attention both in Australia and overseas.

## 6. ACKNOWLEDGEMENTS

The authors would like to acknowledge the substantial contribution made by Mr. T.E. Preuss to development of the ARL C-scanning system software, and the input made by Mr. H.J. Morton and Mr. L. Sponder during the development of this equipment.

## REFERENCES

[1] Rosenfeld, M.S. and Gause, L.W. *Compression fatigue behaviour of graphite/epoxy in the presence of stress raisers,* Fatigue of Fibrous Composite Materials, ASTM STP 723, pp174-196, 1981.

[2] Potter, R.T., *The significance of defects and damage in composite structures,* AGARD Conference on Characterisation Analysis and Significance of Defects in Composite Materials, AGARD-CP-355, 1983.

[3] Clark G. and van Blaricum, T.J. *Carbon Fibre Composite Coupons - Static and Fatigue Behaviour after Impact Damage.* Structures Division Report 422, Aeronautical Research Laboratories, Melbourne (1986).

[4] Hagemaier, D.J. and Fassbender, R.H. *Nondestructive Testing of Advanced Composites.* Materials Evaluation, June 1979 pp43-49.

[5] Teagle, P.R. *The Quality Control and Non-Destructive Evaluation of Composite Aerospace Components.* Composites, 14 (No 2) April 1983 pp 115-128.

[6] Broughton, W. and Chester, R.J. *The Development of a Portable Ultrasonic Facility for NDI of Graphite/Epoxy Composites.* Non-destructive Testing Australia **23(2)**, (1986) pp38-40.

[7] Clark, G. and Preuss, T.E. Use of Time-of-Flight C-scanning for Assessment of Impact Damage in Composites. Composites **19 (2)** pp145-148 (1988).

◆ ◆ ◆ ◆ ◆

## LETTER

### AAS TIE

It gave me great pleasure to forward $20.00 in payment of the absolutely wonderful AAS tie which I took possession of at a recent meeting. I want to share the incredible change which has taken place in my life since acquiring this remarkable tie.

On the weekend, after I bought the tie, I visited a friend who has a farm. We found that when walking over a certain spot, the tie jumped in the air. My friend was most intrigued by this and on digging a hole, found that the tie had discovered an underground stream, meaning that the tie can double as a water diviner. My friend was very grateful, as shortage of water was of concern on his farm. Imagine by joy when he telephoned me the following week to tell me he had also found gold in this stream.

I find by wearing this tie in normal business, my ability to sell has increased fourfold and my staff are like putty in my hands. As I sit here dictating this to my nubile secretary, I notice that familiar look which comes into her eyes each time I wear the tie.

It goes without saying that my marriage has improved beyond all bounds and my children have enrolled to become doctors and/or lawyers.

As soon as possible, I will be ordering another tie, as I am dreading this one getting dirty. I would urge all members to purchase these wonderful ties, as hopefully it will change their lives as it has changed mine.

Yours ever gratefully,

**Glen Harries**
**Chairman, Vic. Division**

*While I can't imagine that the AAS scarf can also double as a water diviner perhaps it can change the wearer's life in a similar manner as the tie - have any purchasers found interesting effects?*

*Assoc Ed.*

## COUNCIL ACTIVITIES

The last meeting of the 1990 Council and the first meeting of the new Council for 1991 were held in Melbourne from 22nd November 1990. The election of office bearers resulted in only one change; Mr Warren Renew, who has made a valuable contribution as Treasurer for four years, was replaced by Mr Geoff Barnes from Victoria Division.

Society membership increased slightly again in 1990 to 407 with 29 admissions and 18 separations. Council elevated 5 members from Vic. Division and 1 from NSW Division as Fellows. (Details are given elsewhere in this issue). Council also ratified the Standing Committee's decision to elevate 15 applicants to Member, one to Affiliate and 3 to Student grade. The response from Sustaining Members was disappointing as only about half have so far renewed their membership.

**1990/91 Budget ...** Estimated Council expenditure for the year is around $34,000, exceeding the 89/90 expenditure by about $4,000 due almost entirely to an increase in cost of publication of Acoustics Australia which will be subsidised by the Society by about $15,000. The other major items are secretarial and administration of about $8,000 and travel of $4,500.

Because of the implications on increases in costs on membership fees, Council considered in detail the cost projections for Acoustics Australia. Council decided to continue to maintain a standard similar to that of recent issues and has aksed the editors of the journal to continue to explore further economies including computer based printing preparation, standardised artwork and elimination of some non-technical information of limited value.

**1991/92 Budget Estimates ...** Council expenditure is expected to be about $47,000. This includes an amount of $16,000 for Acoustics Australia and $10,000 to support international standards meetings in Sydney to boost attendance at Internoise 91. It should be noted that funds for Acoustics Australia have been increased for the publication of a special issue at the time of the conference.

**Conference ...** Plans are well advanced for Internoise 91 and the Western Pacific Regional Acoustics Conference IV. The President's Prize will be awarded at the later conference for the best paper presented by a member of the Society. The 1992 annual conference will be held during November in Ballarat, Victoria.

**Code of Ethics ...** In response to a submission from A/Prof Ferg Fricke and Dr John Goldberg of New South Wales Division, the Council has decided to set up a sub-committee to reconsider a code of ethics for members of the Society.

**Liaison ...** Dr. Neville Fletcher continued to represent the Society on the National Committee for Physics and the National Committee for the Environment. Dr. C. Don attended a meeting of the Council of the Australian Institute of Physics regarding the development of closer co-operation between the two societies. The Society continued to support the Federation of Australian Scientific and Technological Societies.

*from report by Stephen Samuels, President*

## NSW

### November Technical Meeting

On 14 November, **Dr Doug Cato**, a Senior Research Scientist in the Underwater Systems Division of the Materials Research Laboratory spoke on "Songs of humpback whales in Australian waters".

Doug described the migration paths of the humpback whales, which follow the east and west coastlines for more than 2,000 km, as they move between their winter breeding grounds in the tropical waters and their summer feeding grounds in the Antarctic. Samples of songs recorded over several years in Australian waters were played and a brief background on whale biology and behaviour was given.

The spectacular songs are unique in the animal kingdom. They are something of an enigma, because although they are very complex and structured, they are also quite stereotyped between individuals, showing little variation. The potential for variation becomes evident as the songs change with time, but all whales in a stock seem to keep up with the change. The purpose of the song, and even the way in which it is generated, are not known.

*Norm Carter*

## ACT

### November Technical Meeting

On 7 November the ACT Group was fortunate to have two eminent speakers on the topic of "Bird Song, Cricket's Ears and Similar Acoustic Adventures". Approx 20 attended the meeting and over half continued discussions during an enjoyable dinner at the ANU.

**Prof Neville Fletcher**, from the CSIRO and located in the Research School of Physical Sciences at the Australian National University, whose interest in applying the methods of physical acoustics to understand the systems used for communication in animals, commenced the session. He explained the diversity, but at the same time the underlying unity, between the vocal and auditory systems of many animals, and discussed how their performance can be studied. The electrical analogies used in the analysis apply equally well to humans and to crickets, which have ears on their knees!

**Dr Ken Hill**, from the Research School of Biological Sciences at ANU, explained the way the mammal's ear encodes information from the acoustic environment and sends it to the brain. The feedback mechanism incorporates electrical and mechanical responses in the cochlea which are non linear and produce an enhanced response in the basilar membrane. The group were then taken on a tour of the laboratory where studies are being made on the hearing responses of animals and birds.

*Marion Burgess*

## VICTORIA

### November Technical Meeting

The November technical meeting was held at the Australian Road Research Board and was attended by approx. 45. **Mr Gernot Schubert** gave an address on "Noise attenuation developments for major transport corridor projects". Mr Schubert was involved in pioneering developments in Victoria in the suppression of traffic noise, particularly on the controversial south-eastern freeway. This freeway passes through densely populated residential areas and had the requirements of achieving an $L_{A10}$ of 53 dB(A).

Mr Schubert explained how the Road Research Authority had developed special panels, one of which is designed to dissipate sound and the other designed to absorb sound. The talk was well illustrated with examples of how these barriers had proved to be effective in achieving the required sound levels.

Following the Technical Meeting, the end-of-year dinner was held at a nearby restaurant. At the dinner, the President of the Society, Stephen Samuels, made a presentation to five members who have been admitted as Fellows of the Society.

*Glen Harries*

## STANDARDS

The year of 1990 was extremely fruitful in the area of standardisation in the field of acoustics and vibration. Standards Australia produced 23 standards, of which 9 were revisions of the existing documents and 14 were new publications. Topics ranged from the specifications for measuring equipment, noise emitted by various machinery and appliances and noise labelling to vibration on ships and human exposure to vibration. Seminars devoted to hearing conservation were held in Sydney, Melbourne and Perth, and were attended by over 300 participants .

A recently released standard is "**AS 2991** - Acoustics - Method for the determination of airborne noise emitted by household and similar appliances, Part 2 - Particular requirements for dishwashers"

The year 1991 shapes up to be as exciting and productive as the previous one. Standards Australia and the Standards Association of New Zealand will be hosting international meetings of ISO ands IEC to coordinate with Internoise 91 in December.

*Mark Potocki*

## CONFERENCES

### Westprac IV

Westprac IV is the official Conference of the Western Pacific Regional Acoustics Commission. In 1991, it is being sponsored by the Queensland Division of the Australian Acoustical Society and the Division of Environment, Department of Environment and Heritage, Qld.

It will be held in Brisbane from 26 - 28 November 1991 (the week prior to Internoise 91) and will provide an excellent opportunity for Australian acousticians to establish contacts with professionals in the rapidly developing Pacific rim. Intending authors are advised that abstracts should be submitted as soon as possible.

This is the first time that Australia has hosted the Westprac and the organisers are seeking strong support from fellow Australians. This is a unique occasion when there are two major conferences being held consecutively in Australia and members are urged to support both of these important events. Further information from: Conference Convenor, P.O. Box 155, North Quay, Queensland 4002.

### Internoise 91

Internoise 91, sponsored by the International Institute of Noise Control Engineering, is to be held from December 2nd - 4th 1991 at the University of New South Wales in Sydney and the theme is The Costs of Noise. Distinguished acousticians have been invited to contribute plenary papers; these will be presented by Tor Kihlman, Geoff Leventhall, David Bies, and Bob Randall. Already the organising committee has received many responses to the Call for Papers (abstracts were due by March 1st).

A feature will be the Special Technical Sessions planned on topics of current interest; these include Signal Processing for Active Noise and Vibration Control; Predicting Sound Transmission through Walls; Measurement of Sound Power; Noise in the Aluminium Industry; Regulation and Insurance for Industrial Noise Control; Aircraft Noise and a Special Session on Objective Noise Measurements Based on Human Perception, in honour of the late Professor Zwicker.

A Trade Display/Technical Exhibition is being organised, and intending participants should contact the Secretariat as soon as possible. Traditional social events are also planned and there will be technical and general tours arranged so that Australian acousticians and their companions will be able to meet their many distinguished counterparts from overseas.

Internoise 91 is the International Acoustics Event of the Decade in Australia. All A.A.S. members and their colleagues should plan to participate in this unique event, for further information contact Christine Bourke, Internoise 91 Conference Secretariat, IPACE Institute, P.O. Box 1, Kensington, N.S.W. 2033 Fax: (02) 662 6983.

### Internoise 90 Proceedings

"Science for silence" was the theme for Internoise 90 held in Gothenburg during August 1990. The proceedings of this conference contain three hundred and thirty one papers on a wide variety of topics relevant to the theme. These proceedings are now available for $US 120 (+$US 45 for overseas air shipment) from Noise Control Foundation, PO Box 2469 Arlington Branch, Poughkeepsie, NY 12603, USA. Payment must be in US funds on a US bank, or a bank that has a corresponding relationship in the US.

### Noise-Con

Noise-Con 91 will be held in Tarrytown, New York, from 14 to 16 July 1991. The theme for this, the eleventh in the series of national conferences, is "Noise Control: 20 Years of Progress". A major equipment, materials and instrument exhibition will be held in conjunction with the Conference and a noise control seminar will be held from 12 to 13 July.

"Reducing the Annoyance of Noise" was the theme for Noise-Con 90 held in Texas during October 1990. The proceedings of this conference contain eighty one papers on a wide variety of topics relevant to the theme. These proceedings are now available for $US 60 (+$US 22 for overseas air shipment) from Noise Control Foundation, PO Box 2469 Arlington Branch, Poughkeepsie, NY 12603, USA. Payment must be in US funds on a US bank, or a bank that has a corresponding relationship in the US.

### WorkCover NSW

The Occupational Health and Safety, Rehabilitation and Workers Compensation functions of the NSW Department of Industrial Relations have now been formed into a new body; the WorkCover Authority of NSW. The role of the Noise Section of the Division of Occupational Health has been upgraded, commercialised and renamed WorkCover Acoustics, with **Ken Mikl** as the manager. WorkCover Acoustics is able to provide a complete range of hearing conservation services, including noise hazard assessment, audiometry and noise control design and construction for working environments. WorkCover Acoustics can be contacted on 008 02 4205 or (047) 774 261.

### SPCC Move

The NSW State Pollution Control Commission has moved from Liverpool St to its new offices in Bankstown as part of its planned incorporation into the new State EPA scheduled for 1 July 1991. The new address is: Civic Tower, Jacobs St and Rickard Road, (PO Box 367), Bankstown NSW 2200 and tel (02) 793 0000 or fax (02) 793 0002

### New Company

Environmental Noise Control Pty Ltd was established in January and its office and factory are located at Chipping Norton in the western suburbs of Sydney. The company plans to manufacture a wide range of commercial acoustical enclosures, canopies and quiet rooms, sound proof doors and acoustic louvres. The directors of the company are Ram Krishnaswamy and Roy Mammone. Ram will be assisted in the field of industrial noise by Bob Blackall.. Environmental Noise Control aims to offer its experience and skill to acoustical consultants and noise control engineers to ensure that their design intentions are fully and accurately implemented. For further information: tel (02) 755 1077 or fax (02) 726 7142.

### Ultrasound Terminology

The American Institute of Ultrasound in Medicine (AIUM) has announced the publication of a new document entitled **Recommended Ultrasound Terminology**. This publication provides a listing of ultrasound terms and definitions for more precise communication between all those working in the area. The publication is available for $US 40 ($US 20 for AIUM members) from AIUM , Publications Dept, 11200 Rockville Pike, Suite 205, Rockville, Maryland 20852-3139, USA.

---

### Raymond Stephens 1902-1990

Former students and associates of Ray Stephens will be saddened by his death on 27th August 1990 after a long life of teaching and directing research in acoustics both at Imperial College, London and at Chelsea College. He was the author of a number of books, the first president of the Institute of Acoustics and recipient of numerous medals and honours including the Gold Medal of the Acoustical Society of America.

---

## 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 Cain, Mr J L Tai (Malaysia)

*Queensland*
Mr C B Brown, Mr J V Fahey

*South Australia*
Mr W A Reflinski

*Victoria*
Mrs K Terts (Tasmania)

### • Graded

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

**Affiliate**

*Queensland*
Mr C D Brown

*Western Australia*
Mr M J Sharman

**Student**

*South Australia*
Mr A C Zander

*Victoria*
Ms D C Bennetts

**Member**

*New South Wales*
Ms Sun Chao, Dr R Chivers (England),
Mr L W Mar, Mr I C Ryan

*Queensland*
Mr B Groothoff, Mr M A Simpson

*Victoria*
Mr B T McEniery, Mr I C Shepherd

*Western Australia*
Mr P G Drew, Mr S L H Litobarski

## NEW FELLOWS

At the 45th meeting of the Council of the Australian Acoustical Society in November 1990, six members were elected to the grade of Fellow with the following citations:

### Ronald George Barden

The grade of Fellow of the Australian Acoustical Society is conferred on Ronald George Barden for substantial contributions to the teaching and administration of acoustics, promotion of industrial noise control and hearing conservation, development of acoustical standards and the practice of acoustics, and significant service to the Society particularly during the formation years.

### Kenneth Reuben Cook

The grade of Fellow of the Australian Acoustical Society is conferred on Kenneth Reuben Cook for significant contributions to the understanding of the testing of the acoustic properties of materials and related standards, research and teaching in acoustics and service to the Society.

### William Arthur Davern

The grade of Fellow of the Australian Acoustical Society is conferred on William Arthur Davern for notable study and work on sound absorption, significant contributions to building acoustics, noise control and development of standards and service to the Society.

### Graeme Edwin Harding

The grade of Fellow of the Australian Acoustical Society is conferred on Graeme Edwin Harding for his notable work in the fields of designing and manufacturing noise control products, contribution to acoustical standards and outstanding service to the Society over more than twenty-two years.

### Gerald Addison Brook Riley

The grade of Fellow of the Australian Acoustical Society is conferred on Gerald Addison Brook Riley for his significant contributions to the practice of architectural acoustics and noise control, standards and service to the Society.

*Left to right - Standing: Bill Davern, Ken Cook, Paul Dubout, Dr Ron Barden*
*Sitting: Gerald Riley, Graeme Harding*

### Neville Horner Fletcher

The grade of Fellow of the Australian Acoustical Society is conferred on Neville Horner Fletcher for outstanding research work in musical, biological and physical acoustics, significant contributions to the teaching and administration of acoustics and applied science, and enthusiastic service to the Society and its journal.

---

### Correction

For those who wondered about the "international connection" for the Advisory Committee in Vol 18, No3, p 60, we apologise for the error as the heading for this item should have referred to NATA and not NATO.

# BOOK REVIEWS

## HARMONY: A PSYCHO-ACOUSTICAL APPROACH

### Richard Parncutt

*Springer-Verlag, 1989, pp 225, hard cover, ISBN 3 540 51279 9. Australian Agents: DA Books, PO Box 163, Mitcham Vic 3132, A$84.75*

The first three chapters provide a useful introduction to the main concepts used by the author: Chapter 1 containing short summaries of existing physical and psychological theories of harmony, Chapter 2 introducing psychoacoustical terms and concepts, while Chapter 3 paves the way for the core of the book (the theoretical model and experiments of Chapters 4 and 5). Most of the introductory material is very readable despite the large number of references quoted. There are occasions when more details could have been quoted of other important investigations. For instance, the frequent references to Terhardt's work on virtual pitch and harmony would have been easier to follow if summaries of his more recent work had been included. Although Terhardt's papers would be familiar to an expert in this field, a more comprehensive critique of his pitch algorithm seems to be desirable before tackling chapter 4. Throughout the book there is a tendency to write non-specific sentences which talk about an idea or investigation without quoting specific details. If the book is conceived as one expert talking to another then there is no problem; for the general reader frequent reference to the useful glossary may be necessary.

In Chapter 4 the author states as the aim of his model: *"It formalises experimental data and psychoacoustical theory on the perception of tone simultaneities in such a way that: the data and theory are logically, concisely and conveniently expressed; the theory may be quantitatively tested; and the theory may be applied to music theory, analysis and composition."* A number of mathematical relationships are assembled including those for determining the pitch category, auditory level, critical bandwidth, masking level, audibilty, tonalness, multiplicity, tone salience, chroma salience, pitch commonality and pitch distance. These equations are then applied to predict the outcome of a number of psychoacoustical experiments described in detail in Chapter 5.

Strangely enough it is not until the author reaches Chapter 6 that he gives a clear statement of the capabilities of his model: *"The model predicts the number of audible harmonics in complex tones, the multiplicity and tonalness (and hence consonance) of musical tone simultaneities (tones, dyads and chords), the various possible pitches of simultaneities and their perceptual importances (saliences) and the roots of chords. It also predicts the strength of harmonic and melodic relationships between sequential musical sound (pitch commonality and pitch proximity). It quantifies sensory and cultural aspects of the tonality of chord progressions: repetitions, sequential harmonic relationships (including the roots of broken chords, consonance and implication (of triads, scales and keys). It enables 'objective' psychoacoustical analysis of harmonic progressions and may be applied in composition".*

The author gives two impressive examples of the application of his system to existing compositions by subjecting parts of Beethoven's Moonlight Sonata and The Girl From Ipanema to his model. Considering the complexities involved in writing music, in performance and then listening to music, it is remarkable that the whole process is becoming susceptible to technical analysis. Richard Parncutt's book is an important step forward in an exceedingly complex field of activity. It is not an easy book to read, the terminology and concepts required are numerous and range over several traditional fields of study. The problem is not made easier by the common trend in scientific literature to devise single-word terms, often quite bizarre, for complex ideas. The author has mercifully introduced a number of multiple-word terms which are much easier to grasp and to remember. The book is essentially a long research report and is therefore not designed for light reading. Nevertheless, anyone working in this field will appreciate the innovative thinking of the author and should find the book stimulating.

*Howard Pollard*

*Howard Pollard was Associate Professor in Physics until his retirement. His research interests were and continue to include musical acoustics. He is also Chief Editor for Acoustics Australia.*

---

## NOISE MANAGEMENT AT WORK

### Worksafe Australia

*Various packages, see details below. Direct purchase from Noise Project, Worksafe Australia, GPO Box 58, Sydney NSW 2001 (tel: 02 265 7530)*

In September 1987, noise induced hearing loss was identified as one of the six priority areas for prevention by the National Occupational Health and Safety Commission. The strategy developed for dealing with this area placed considerable emphasis on the needs for the promotion of hearing conservation programs in industry and the development of materials for use in such programs. The Noise Management at Work package represents a major effort by officers of Worksafe Australia's Information and Prevention Programs Branch and Publicity and Promotions Unit, with additional technical help from Worksafe's Research and Scientific Division and the Department of Health, Safety and Welfare of Western Aust. The program objectives were to increase the level of community and workplace support for actions to reduce noise-induced hearing loss and to increase and improve action to reduce noise. The Management at Work resources were produced in 1990 and have been pilot tested in the western suburbs of Sydney. There are a range of items which are available individually or as part of packages. Discussing each item in turn:

"Noise Management at Work Control Guide" (cost $120) offers a comprehensive approach to the management of noise. The 43 page core contains a step by step procedure for the approach by management. These steps include; establishing a basis for action, assessing the present position, setting goals and policies, establishing a noise management strategy and monitoring and evaluating the program. A glossary and other technical details complete the core. The following 12 modules, each of the order of 10 pages, range from case studies and in-house control, through noise policy and evaluating options to training information and personal protection. The information in the control guide is clearly presented, supplemented with diagrams, photographs and charts and it is easy to find the appropriate section (or sections). The spiral binding and graphic style give the impression of a manual which can be referred to quickly in meetings and discussions. A smaller version of the Guide, core plus only 4 modules, is available in the package for small business.

The Training Resources include:
- 8 Fact Sheets ($20 for 10 sets of 8). Each deals with a limited number of points on noise and hearing and is a single folded page with attractive graphics on the outside. They are easy to read with dot points and, in the case of "Fitting Personal Hearing Protection", clear line diagrams.
- Q&A Booklet ($5 for 10 copies). This small booklet has 8 commonly asked questions, such as "How could hearing loss affect me?", with brief but clear answers and some supplementary technical information on the last few pages.
- Multilingual Audio cassette ($5 per copy) This contains the content of the Q&A booklet in Arabic, Cantonese, Croatian, Greek, Italian, Maltese, Serbian, Spanish, Turkish and Vietnamese.
- Sticker ($10 for 10). To be used in the workplace and the message is that noise controls are being developed for this location.
- Poster ($20 for 5). The large logo highlights the risk of noise.
- Video ($45 per copy). This 16 minute video is an excellent training aid. It presents the effects of hearing loss on working and social activities with emphasis on the young. The explanation of the various approaches to noise control should help the worker to understand why noise control and management procedures have been implemented (and perhaps indicate where they could be implemented).

The prices above relate to the purchase of additional components of the training resources. The training resources are available with the full control guide for $170 or with the reduced guide for small business for $55.

The diverse parts of the "Noise Management at Work" certainly appear to satisfy the program objectives. The package not only provides useful information for the OH&S officer, it also is a valuable reference for management in their approach to reducing the noise exposure of their employees. The package, and in particular the control guide, would also be of assistance to consultants during their discussions with clients.

*Marion Burgess*

*Marion Burgess is research officer at the Acoustics and Vibration Centre of the Australian Defence Force Academy. The Centre is involved with continuing education activities in the areas of noise and vibration.*

* * * *

# NEW PRODUCTS

## PETERS

### Diagnostic Audiometer

The Alfred Peters Diagnostic Audiometer AP32 is a compact, lightweight instrument for use where portability is essential. It has been specially designed for use by peripatetic teachers, hearing aid dealers, school medical officers of health, and other audiologists on the move, to allow measurements to be made "on site". However the AP32 is equally at home in consulting rooms where where its ease of use and high accuracy make it ideal for manual audiometry.

The instrument has 9 test frequencies ranging from 250Hz to 8kHz and an attenuation range of -10dB to +110dB Hearing Threshold Level (HTL) in 5dB increments allowing excellent discrimination of small hearing differences. In addition, speech audiometry can be carried out using the desk top microphone supplied or a tape recorder via the auxilliary input socket.

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

## PULSAR

### Sound Level Meters

The Pulsar Model 83 series of sound level meters consists of three units which, between them, meet the various educational and commercial requirements of survey grades. All models of the 83 have a measuring range from 30 to 135 dB (A) with both "Slow" and "Fast" meter responses and "Maximum Hold".

The different measurement grades in the 83 series are set solely by the type of microphone used. The educational grade, Model 83P, has a fixed half-inch electret. The 83PE has a similar microphone on a sliding boom which extends to 50 mm from the case. The 83P2 features a screw-on microphone capsule which is interchangeable with other manufacturer's units. The 83/100A Kit contains the meter, calibrator, windshield etc in a lightweight carrying case.

### Noise and Exposure Meters

The Pulsar Model 85 series of industrial sound level meters show, directly on scale , both the noise level and the corresponding allowable exposure time. Different scales are available for the 8 hour limit of 90 or 85 dB(A). the normal measuring range is from 80 to 120 dB(A) and a "30 dB button is provided permitting measurements down to 50 dB(A).

*Further information: Pulsar Instruments, Industrial Estate, Hunmanby, North Yorks, YO14 OPH, UK*

*The Pulsar Model 85 Noise Exposure Meter*

## CIRRUS

### Industrial Noise Measurement Kit

The CRL 222K is a complete kit for the measurement of industrial noise and includes the CRL 222 plus calibrator, windshield etc in an attache style case. The CRL 222 has the capability to measure L(eq) and Sound Exposure Level (SEL) as well as conventional sound level and its big acquisition range makes it perfect for use in hearing protection programmes.

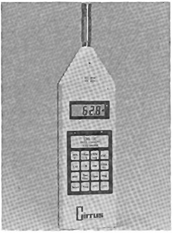
### Self Calibrating Sound Level Meter

The CRL 221C is a totally self contained sound level meter with a built-in calibration generator which obviates the need for a separate calibration source. The microphone s inserted into it's acoustic cavity before calibration can be verified. The analogue meter provides easy measurement of fluctuating levels and the CRL 221C has a wide measuring capability from 35 to 135 dB(A) with Fast and Slow responses.

### Data Logging Sound Level Meter

The CRL 702 is a data logging sound level meter with over 60 functions accessed via the 16 keys on the meter's key pad. The data can be logged as a summary in event format or in detail as short L(eq). The data acquired can be transferred to an MS-DOS computer allowing the user to examine the total noise history or use the base data to re-analyse the data calculating new indices or L(eq) for part of the logged noise period. The CRL 702 can be used in all circumstances where an older analogue sound level meter could be used.

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



*The Cirrus CRL 702*
*Data Logging Sound Level Meter*

## BRUEL & KJAER

### Torsional Vibration Meter

The torsional vibration meter, type 2523, is small, lightweight and battery powered and allows rapid and accurate measurement of torsional vibrations. Torsional vibrations are found in just about every rotating system, such as engines, motors, crankshafts and turbines. The laser transducer is aimed at a piece of reflective tape and the angular velocity, angular displacement and rotational speed are immediately available.

*Further information: B&K, PO Box 177, Terrey Hills NSW 2084 Tel: (02) 4502066*

# NEW PUBLICATIONS

### ISVR Technical Reports

University of Southampton

No 182 1990, **N Lalor** – "Practical considerations for the measurement of internal and coupling loss factors on complex structures", 11 pp

No 185 1990, **K R Holland, F J Fahy, C L Morfey** – "The prediction and measurement of the one-parameter behaviour of horns", 58 pp

No 187 1990, **P A Nelson, H Hamada, S J. Elliott** – "Adaptive inverse filters for stereophonic sound reproduction", 51 pp

No 188 1990, **K R Holland, F J Fahy** – "A low cost end-fire acoustic radiator", 43 pp

No 189 1990, **S Lin, D Anderton** – "One way to reduce thermal effects in a piezoelectric pressure transducer mounted in the combustion chamber of an CI engine", 42 pp

No 192 1990, **X Wang, N Lalor** – "Acquiring SEA paramenters on complex structures by a transient test method", 15 pp

## UNDERWATER ACOUSTICS 4 DAY COURSE

The Australian Maritime College is conducting a course in Underwater Acoustics which provides a solid introduction to the underwater acoustics field, and involves tutorials and practical test tank demonstrations.

**Course Date:** Mid-day 22 July to
Mid-day 26
July,1991

**Course Fee:** $650

For more details contact:

Heather Strutt
AMC Search Ltd.
P.O. Box 986
Launceston TAS 7250
Telephone: (003) 260 703
Facsimile: (003) 266 493

## GRIFFITH UNIVERSITY BRISBANE

### PhD Studentship In Pollution From Transportation

Funds are available in 1991 for a studentship for a full-time PhD program in Pollution from Transportation. The stipend for the studentship which will be annually renewable is $17427 per annum (may be tax free), and the conditions of the award are similiar to those of the Australian Postgraduate Research Award Priority Stipend. A research Master's degree or Bachelor's degree with a least upper second class honours, or equivalent, is essential. The study will focus on transportation noise and its effects on communities. Science or Engineering graduates with a demonstratable interest in the human dimensions of the project or students of Environmental Studies, Psychology or Geography with good quantitive and computing skills will be considered.

People interested in undertaking full-time PhD studies in the area of transportation noise and its effects on communities encouraged to contact Dr Lex Brown, Head, School of Environmental Studies, Division of Australian Environmental Studies, Griffith University, Nathan, Queensland 4111 (Telephone: 07 875 7645) for further details by 12 April, 1991.

# PUBLICATIONS BY AUSTRALIANS

***We are grateful to Dr Richard Rosenberger for preparing this list of publications.***

**Time Dependence of Loudspeaker Power Output in Small Rooms**
**G ADAMS**
*University of Sydney, NSW 2006*
J. Audio Eng. Soc. **37** (4), 203-309 (1989).

**Novel Approach to Evaluate the Interaction of Pulsed Ultrasound with Embryonic Development**
(1) S B BARNETT
(2) D A WALSH, J A ANGLES
(1) Ultrasonics Institute, 126 Greville St., Chatswood, NSW 2067
(2) Veterinary Clinical Studies, Sydney University NSW 2006
Ultrasonics May 166-170 (1990)

**Format Estimation by Linear Transformation of the LPC Cepstrum**
(1) D J BROAD
(2) F CLERMONT
(2) Computer Sciences Lab., ANU, Canberra, ACT 2601
J Acoust. Soc. Am. Nov. 2013- (1989).

**Results for Two Children using a Multiple-Electrode Intracoclear Implant**
(1) P A BUSBY, et al.
(2) G H NICHOLLS
(1) Dept. of Otolaryngology, University of Melbourne, Parkville, VIC. 3052
(2) Dept. of Surgery (Otolaryngology), University of Sydney, NSW 2006
J. Acoust. Soc. Am. Dec. 2088- (1989).

**Characterization of High Frequency Ultrasonic Fields using a Polarimetric Optical Fiber Sensor**
HLW CHAN et al.
Div. of Applied Physics, CSIRO, Lyndfield NSW 2070
J Appl. Physics 66 (4), 1565-1570 (1989).

**Noise Generated by the Interaction of Turbulent Jets with Circular Cylinders**
(1) M R Davis
(2) N H PAN
(1) Dept. of Civil & Mechanical Eng., University of Tasmania, P.O. Box 252C, Hobart 7001
(2) Electricity Commission of New South Wales P.O. Box 5257, Sydney NSW 2001
J. Sound Vib. 135 (3), 427-442 (1989)

**Qualification of Room Diffusion for Absorption Measurements**
J L DAVY, W A DAVERN, P DUBOUT
Div. of Building, Constr. and Eng., CSIRO, P.O. Box 56, Highett, VIC 3190
Appl. Ac. 28 177-185 (1989).

**Teaching Lip-Reading: The Efficacy of Lessons on Video**
(1) B DODD, M GREGORY
(2) G PLANT
(1) Speech Hearing and Language Research Centre, Macquarie University, NSW 2109
(2) National Acoustic Laboratories, 126 Greville St, Chatswood, NSW 2067
British J. Audiology 23 229-238 (1989).

**Comparison of Ray and Wave Approaches to Acoustic Impulse Propagation Prior to a Shadow Boundary**
C G DON, A J CRAMOND
Dept. of Appl. Physics, Chisholm Institute of Technology,
900 Dandenong Rd., Caulfield East VIC 3145
J. Acoust. Soc. Am. Mar. 1017-(1990).

**Case History: Stack Silencers for the Eraring Power Station.**
J C FRYER
James Howden P/L., PO Box 84, North Sydney NSW 2060
Noise Control Eng. J. 32 (3) 89-92 (1989).

**Beamforming in the Presence of Correlated Arrivals using Structures Correlation Matrix.**
L C Godara
Dept. of Electrical & Electronic Eng. Univ. College, UNSW.,Australian Defence Force Academy, Northcott Dr. Campbell ACT 2600
IEEE Transaction on Acoustics, Speech and Signal Processing, Jan. 1-15 (1990).

**Solid-Water Interaction in Liquid Storage Tanks**
R K GUPTA, G L HUTCHINSON
Dept. of Civil and Agricultural Eng., University of Melbourne, Parkville VIC 3052
J. Sound Vib. 135 (3) 357-374 (1989)

**A Computer Model (UBSUB) to Appraise Road Transport Operations, Land use Planning, Environmental Noise Pollution, and Social Impact**
K S JRAIW
PO Box 86, Hawthorn, ViC 3122
Proc. Internoise 89 2 719-722 (1989) (Distribution: Noise Control Foundation PO Box 2469 Arlington Branch, Poughkeepsie, NY 12603 USA).

**Coherent Detection of M-ARY Phase-Shift Keying in the Satellite Mobile Channel with Tone Calibration**
I KORN
School of El. Eng and Comp. Science, The University of New South Wales, Kensington NSW 2033
IEEE Trans. on Communications 37 (10), 997-1003 (1989).

**M-ARY Frequency Shift Keying with Differential Phase Detector In Satellite Mobile Channel with Narrowband Receiver Filter**
I KORN, M NAMET
The University of New South Wales, PO Box 1 Kensington NSW 2033
IEEE Proceedings - I. Communications, Speech and Vision 137 (1), 33-77 (1990).

**Nonlinearity, Chaos, and the Sound of Shallow Gongs**
(1) K A LEGGE
(2) N H FLETCHER
(1) Dept. of Physics, University of New England, Armidale, NSW 2351
(2) Acoustics and Vibration Centre, Australian Defence Force Academy, Campbell ACT 2600

**Optimum Oversampling**
R A NILAND
Appl. Mathematics Dept., University of Sydney, NSW 2006
J. Acoust. Soc. Am. Nov. 1805-1812 (1989).

**Active Noise Control in Ducts: Some Physical Insights**
S D SNYDER, C H HANSEN
Dept. of Mech. Engineering, University of Adelaide, GPO Box 498, Adelaide SA 5001
J. Acoustic. Soc. Am. July 184 (1989).

**Multidelay Block Frequency Domain Active Filter**
J S. SOO, K K PANG
Dept. of Electrical and Computer Systems Engineering, Monash University, Clayton VIC 3168
IEEE Transactions on Acoustics, Speech, and Sig. Proc. Feb. 373-376 (1990).

**Determination of Blocking Locations and Cross-Sectional Area in a Duct by Eigenfrequency Shifts**
Q WU, F Fricke
Dept. of Architectural Science, University of Sydney, NSW 2006
J. Acoust. Soc. Am. Jan. 67-75 (1990).

# DIARY

• Indicates an Australian Activity

# CONFERENCES and SEMINARS

## 1991

**April 29 - May 3, BALTIMORE**
MEETING OF ACOUSTICAL SOCIETY OF AMERICA
*Details: Acoustical Society of America, 500 Sunnyside Blvd, Woodbury, NY 11797, USA*

**May 3-5, ANNAPOLIS**
INTERNATIONAL SYMPOSIUM ON MUSICAL ACOUSTICS
*Details: Catgut Acoustical Society, 112 Essex Ave, Montclair, N.J. 07042, USA.*

**May 7-9, BALANTONFURED**
9th FASE SYMPOSIUM
*Details: Optical, Acoustical & Filmtechnical Soc., H-1371, Budapest, PP Box 433, Hungary.*

**July 1-4, LE TOUQUET**
ULTRASONICS INTERNATIONAL 91
*Details: Ultrasonics International 91, Butterworth Scientific Ltd, P.O. Box 63, Westbury House, Bury St, Guildford, Surrey GU2 5BH, U.K.*

**• July 8-12, SYDNEY**
INTERNATIONAL MECHANICAL ENGINEERING CONGRESS
*Details: Conference Manager, Institution of Engineers, 11 National Circuit,Barton, ACT 2600*

**July 14-16, NEW YORK**
NOISE-CON 91
*Details: NOISE CON Conference Secretary, PO Box 2469 Arlington Branch, Poughkeepsie, NY 12603, USA.*

**July 15-19, SOUTHAMPTON**
4TH CONFERENCE ON RECENT ADVANCES IN STRUCTURAL DYNAMICS
*Details: Conference Secretary, ISVR, Southampton SO9 5NH, U.K.*

**August 19-24, AIX-EN-PROVENCE**
12TH INTERNATIONAL CONFERENCE ON PHONETIC SCIENCES
*Details: Secretariat, Universite de Provence, 29 Avenue Robert Schuman 13621, Aix-en-Provence Cedex 1, France.*

**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

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

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

# 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

**May 15-16, CANBERRA**
Basics of Underwater Acoustics
*Details: M. Burgess, Acoustics and Vibration Centre, Australian Defence Force Academy, Campbell ACT 2600 Tel (06) 268 8241 Fax (06) 268 8276*

**July 22-26, Launceston**
Underwater Acoustics
*Details: J. Foster, AMC Search Ltd, PO Box 986, Launceston, Tas 7250 Tel (003) 260 761 Fax (003) 266 493*

**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*

**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*

### *ADVERTISER INDEX*

| | |
|---|---|
| **AMC Search** | **27** |
| **Band Noise** | **2** |
| **Bradford** | **Inside front cover** |
| **Bruel & Kjaer** | **Back cover** |
| **Chadwick** | **10** |
| **CSR/Bradford** | **Insert** |
| **Davidson** | **2** |
| **ETMC** | **2** |
| **Great Aust Sound Co** | **21** |
| **Griffith University** | **27** |

Readers are asked to mention this publication when replying to advertisements.

# COUNCIL OF THE AUSTRALIAN ACOUSTICAL SOCIETY

| | |
|---|---|
| President | Dr Stephen Samuels |
| Vice-President | A/Prof Bob Hooker |
| Treasurer | Mr Geoff Barnes |
| General Secretary/Federal Registrar | Mr Ray Piesse |
| Archivist | Mr Paul Dubout |
| Chairman of Council Standing Committee on Membership | Mr Ken Cook |

## Councillors

**(Effective from 23 November 1990)**

| New South Wales | Queensland | South Australia | Victoria | Western Australia |
|---|---|---|---|---|
| Prof Anita Lawrence | A/Prof Bob Hooker | Mr Bob Boyce | Mr Geoff Barnes | Mr John Macpherson |
| Mr Ray Piesse | Mr Warren Middleton | Mr Peter Heinze | Dr Stephen Samuels | Mr Tibor Vass |

---

## SUSTAINING MEMBERS

**AQ-VIBE DIVISION**
**AQUA-COOL TOWERS PTY LTD**
67 PRINCES ROAD
RIVERSTON 2765

**ASSOCIATION OF AUSTRALIAN ACOUSTICAL CONSULTANTS**
SCIENCE CENTRE FOUNDATION
PRIVATE BAG 1
DARLINGHURST 2010

**BHP STEEL,**
**COATED PRODUCTS DIVISION**
SHEET & COIL PRODUCTS
PO BOX 77
PORT KEMBLA 2505

**BILSOM AUSTRALIA PTY LTD**
19 TEPKO ROAD
TERRY HILLS 2084

**BORAL AUSTRALIAN GYPSUM**
676 LORIMER STREET
PORT MELBOURNE 3207

**CSR BRADFORD INSULATION**
PO BOX 1754
NORTH SYDNEY 2059

**BRUEL & KJAER AUSTRALIA PTY LTD**
PO BOX 177
TERREY HILLS 2084

**FOAMLITE AUSTRALIA PTY LTD**
PO BOX 331
SUNNYBANK 4109

**G P EMBELTON & CO PTY LTD**
147-149 BAKERS ROAD
COBURG 3058

**INC CORPORATION PTY LTD**
22 CLEELAND ROAD
OAKLEIGH SOUTH 3167

**JOYCE AUSTRALIA**
5-9 BRIDGES ROAD
MOOREBANK 2170

**NAP SILENTFLO PTY LTD**
51 NORFOLK STREET
GLEN WAVERLEY 3150

**PEACE ENGINEERING PTY LTD**
2/20 MARIGOLD STREET
REVESBY 2212

**FLAKT RICHARDSON**
**SOUND CONTROL**
PRIVATE BAG
WEST FOOTSCRAY 3012

**REINFORCED EARTH PTY LTD**
70 CHIVERS ROAD
SOMERSBY 2250

**SOUNDGUARD**
**A Division of Pyrotek Pty Ltd**
147 MAGOWAR ROAD
GIRRAWEEN 2145

**STRAMIT INDUSTRIES LTD**
52 MANDOON ROAD
GIRRAWEEN 2145

**THE CHADWICK GROUP**
292 BURNS BAY ROAD
LANE COVE 2066

---

## ENQUIRIES

* Notification of change of address
* Payment of annual subscription

General Secretary
AAS– Science Centre Foundation
Private Bag 1, Darlinghurst 2010
Tel (02) 331 6920

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

*New South Wales*
AAS–Science Centre Foundation
Private Bag 1, DARLINGHURST 2010
Tel (02) 331 6820

*South Australia*
AAS C/–Department of Mech Eng
University of Adelaide
GPO Box 498
ADELAIDE 5001

*Western Australia*
AAS–W A Division
PO Box 1090
WEST PERTH 6005
Sec: Ms P Gunn
Tel: (09) 327 8669

*Queensland*
AAS C/– Warburton Franki
57 Manilla St,
EAST BRISBANE 4169
Sec: Mr C Brown
Tel: (07) 391 8311

*Victoria*
AAS–National Science Centre
191 Royal Parade
PARKVILLE 3052
Sec: Mr D Watkins
Tel: (03) 628 5753

### SOCIETY SUBSCRIPTION RATES

From 1 APRIL 1991 membership subscriptions will be as follows:

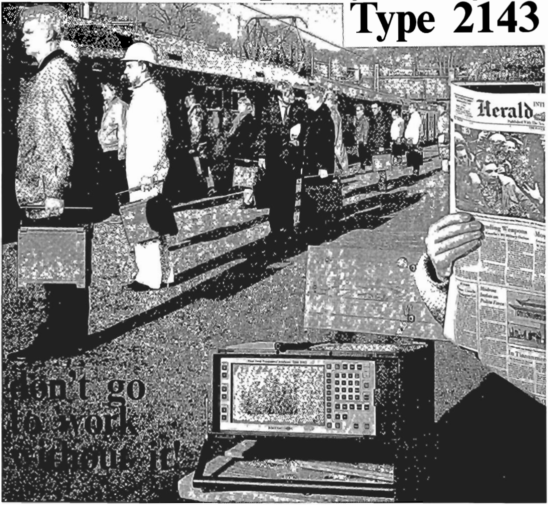
| | |
|---|---|
| Fellow and Member | $85 |
| Affiliate and Subscriber | $68 |
| Student | $50 |

### ANNUAL CONFERENCE

Copies of past conference proceedings may be ordered from:

Publications Officer
Australian Acoustical Society
15 Taylors Road, DURAL 2158

# Real-time Frequency Analyzer Type 2143



Whatever problem you are working on (quality control, noise and vibration analysis or environmental noise, for example), this Brüel & Kjær "go-anywhere" analyser gives you the perfect solution.

***Designed for use in the field, it offers you:***

**● True portability (it weighs less than 10kg) ● Advanced triggered multispectrum facility ● Battery operation 1/1-, 1/3-, 1/12- and 1/24-octave digital filters ● A back-lit display ● PC/MS–DOX compatible disk format ● A water-resistant front panel ● A large non-volatile memory for over 512 1/3-octave spectra ● Direct, preamplifier and charge inputs ● Option for F.F.T. operation ● Easy operation with on-screen help function ● Output to a variety of printers ● Option for two channel upgrade.**

---

**Brüel & Kjær**

| NEW SOUTH WALES. | WEST AUSTRALIA | VICTORIA | QUEENSLAND |
|---|---|---|---|
| (02) 450 2066 | (09) 481 0189 | (03) 370 7666 | (07) 252 5700 |