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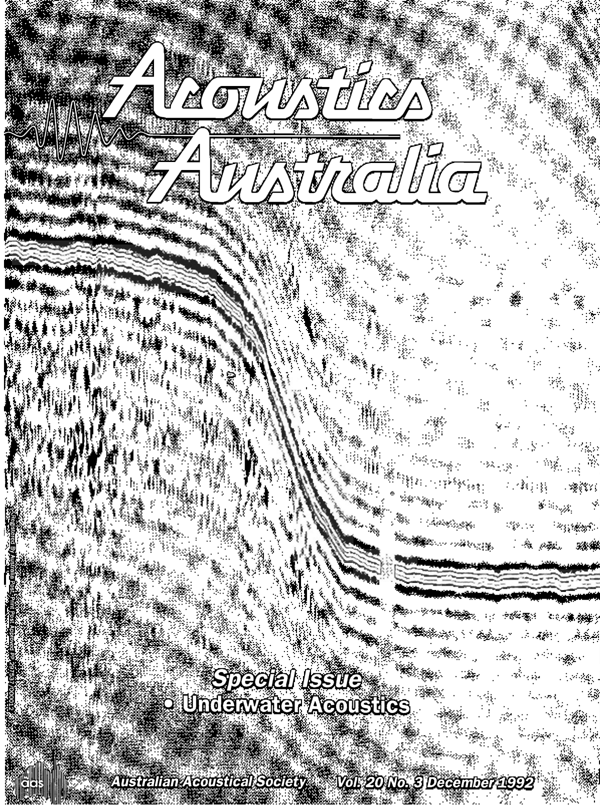

Special Issue
• Underwater Acoustics

Australian Acoustical Society Vol. 20 No. 3 December 1992

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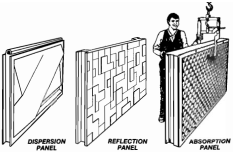

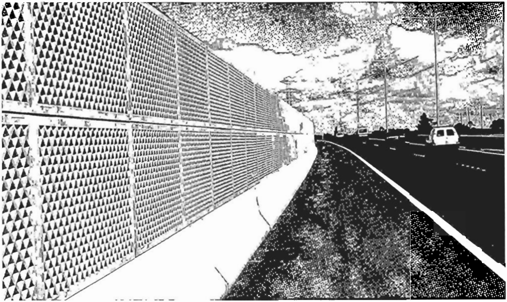

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CONTENTS

December 1992

ARTICLES

COVER :

The year 1992 marks the sesqui-centenary (150th anniversary) of the discovery of the Doppler effect. Reproduced on the cover is the Wigner-Ville distribution of the acoustic energy received by a microphone during the flyover of a turbo-prop aircraft. This joint time-frequency distribution shows the received energy as a function of both time (horizontal axis: 0 - 3- s) and frequency (vertical axis: 50 - 200 Hz). The dominant feature in the source spectrum is the spectral line corresponding to the propeller blade rate, which is equal to the product of the shaft rotation rate and the number of blades of the propeller. The frequency of this line, when received by a stationary observer on the ground, changes with time due to the acoustical Doppler effect; this is clearly demonstrated in the photograph. From the variation with time of the Doppler-shifted blade rate, the speed and altitude of the aircraft are estimated to be 150 kn and 700 ft, with the source (or rest) frequency of the blade rate being 117 Hz. The technique has also been applied to the processing of underwater acoustic data from a hydrophone. The photograph was submitted by Brian Ferguson, Gary Speechly and Lionel Criswick of the Australian Defence Science and Technology Organisation.

EDITORIAL

The response to our request for articles for a special issue on underwater acoustics has been most enthusiastic, revealing a healthy state of activity throughout Australia in this branch of acoustics. This issue contains 7 articles on a representative array of topics with a continuation in the April 1993 issue when a number of current activities reports will be printed. We are most grateful to Dr Marshall Hall of DSTO who was responsible for soliciting articles and arranging for referees.

We are now asking all contributors to Acoustics Australia to supply articles and other material on 3.5 in disks (in either Macintosh or IBM format) in order to streamline the editing-printing process. As well as an improvement in accuracy through the elimination of traditional type-setting, this step has led to a major reduction in production costs. We can accept formatted articles using any standard word-processor. If there is any doubt about compatibility, it would be advisable to include a plain ASCII text version.

Additional copies of this special issue are available at A$10 for surface mail and A$14 for airmail. Orders should be placed with Mrs Wallbank (see p 80 for address, tel and fax).

Howard Pollard, Chief Editor

SUSTAINING MEMBERS

Underwater Acoustic Signal Processing - A Review of Selected Topics

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Abstract: This paper reviews the recent research carried out at the Defence Science and Technology Organisation in the area of underwater acoustic signal processing. Topics relevant to acoustic surveillance are discussed, e.g., beamforming, towed array shape estimation, frequency estimation, frequency line tracking, detection and Doppler analysis.

1. INTRODUCTION

The Defence White Paper (Ref. 1) emphasises the importance of surveillance in the air-sea gap around Australia for the defence of the island continent, as well as the need to defend major focal areas and their approaches against submarine attack. It is difficult to foresee a time when underwater acoustic systems will not have a major role in both pro- and anti-submarine warfare for shipping surveillance and intelligence gathering.

The last fifteen years have seen the development and operational deployment of sophisticated sonar systems. The BARRA sonobuoy, developed jointly by the Defence Science and Technology Organisation (DSTO) and the U.K. Ministry of Defence, consists of a planar array of 25 hydrophones. Towed arrays, similar to the Kariwara array which is intended for the new Collins Class submarines, are widely deployed by overseas navies for surveillance and anti-submarine warfare (ASW) purposes. These passive systems, unlike the more widely known active "pingers" familiar from World War II movies, do not emit sound into the water, but simply listen for noise generated by the "target".

The expected improvements in performance achieved by the use of high gain, multi-sensor sonar systems, such as those described above, have been largely countered by the quietening of modern submarines. Better designed propellers and the mechanical isolation of vibrating machinery from direct contact with the hull have reduced the amount of acoustic energy radiated into the ocean.

The development of sophisticated sonar sensor systems has been paralleled by research into the signal processing of the received data. Algorithms that assist in the detection, localisation and classification of acoustic sources are of direct relevance to the defence requirements for surveillance and intelligence gathering, and have formed the focus of signal processing research in the Maritime Operations Division. Some of these algorithms are described in the next section.

2. SIGNAL PROCESSING TECHNIQUES FOR UNDERWATER SOUND

Several areas in signal processing, such as beam forming, array shape estimation, frequency estimation and tracking, detection and Doppler analysis are of particular relevance to the acoustic surveillance task. Recent advances in these topics are discussed below.

2.1 Beamforming

The aim of beam forming is to extract information about the direction of a source from measurements of a propagating field taken using an array of sensors. In the conventional beamformer (CBF), the outputs from the individual sensors are weighted (i.e., subjected to amplitude and time delay adjustment consistent with an assumed source direction), and then summed coherently. The direction for which this sum is a maximum is the presumed bearing of the source.

The problem with the CBF is the existence of large secondary maxima (or sidelobes) in directions other than the source direction. These sidelobes can easily be confused with the main lobe from a weak secondary source. An adaptive beamformer uses estimates of the noise field to adapt the sensor weights to the changing environment, and so maintain its performance. These algorithms have been successful in reducing the effect of sidelobes in the directions of interfering sources and in resolving closely spaced targets, but at the expense of an increased sensitivity of the beamformer to system errors (e.g., phase errors in the outputs from the sensors, or any correlation of the noise field).

Byrne and Steele (Refs. 2,3,4) have shown that a high-resolution bearing estimator can be constructed which is robust against perturbations such as system phase errors and correlated arrivals. The new method accepts as data the matrix of estimated single-frequency cross-sensor correlations (i.e., the input cross-spectral matrix). When the noise is correlated, the degrading effects of phase errors are found to be concentrated in certain eigenvectors of the cross-spectral matrix. Stable bearing estimation can be achieved by exploiting the stable eigenvectors, and ignoring those which are sensitive to system errors.

Figures 1 and 2 display the relative responses plotted against wavenumber obtained from a towed array of 25 omni-directional sensors with a sensor spacing of $d = \lambda/10$. (The wavenumber is equivalent to the sine of the bearing.) In this example, two signals were present at wavenumbers of $0.07\ \pi/d$ and $0.13\ \pi/d$. Several different simulation results are plotted together for the case when no phase errors are present, and for the case when 5° random phase errors are present.

Figure 1 shows the results obtained for the conventional and adaptive (MLM) beamformers. The conventional beamformer shows robustness to phase errors but is unable to resolve the two signals. The adaptive beamformer clearly resolves the two signals when no phase errors are present, but is extremely sensitive to the presence of phase errors.

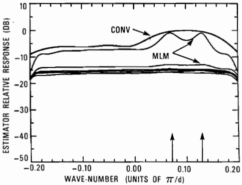

Figure 1. Relative responses for conventional (CBF) and adaptive (MLM) beamformers (from Ref. 4). The top curve shows the conventional estimator response, with and without phase errors (no discernible difference), the next curve shows the response from the MLM for the no-phase- error case, and the bottom five curves are the MLM responses for independent simulations with 5° phase errors.

Figure 2 shows the results obtained using Byrne and Steele's high resolution bearing estimator (SFS). Clearly the signals are resolved and the technique is highly robust to phase errors. An added advantage of this technique is that it is computationally much less demanding than the adaptive technique.

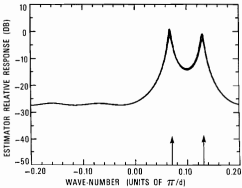

Figure 2. Response from sector focussing stability (SFS) technique using eigenvectors 3-6 showing limited spread of results from different simulations and robustness to phase errors (from Ref. 4).

2.2 Array Shape Estimation

When beamforming is carried out on the sensor outputs of an acoustic towed array which is not straight, a degradation of performance occurs. However, if the positions of the hydrophones are known, most of the performance loss can be eliminated, even if the array is severely distorted. Techniques to estimate the shape of a towed array at any particular time are therefore important to optimise the performance of the array for bearing estimation.

Two different approaches can be applied to array shape estimation. The first is to fit the array with heading and depth sensors at suitable positions along its length. From a model for the propagation of shape perturbations down the array, the hydrophone displacements at intermediate positions between these sensors can be inferred. The more accurate the model used, the fewer heading and depth sensors required. This approach assumes that most of the shape disturbance is tow-point induced, and does not arise from environmental effects, e.g., shear currents. The latter produce effects which do not propagate down the array in a simple manner.

The dynamical behaviour of a towed array in response to tow-point induced motion has been discussed extensively by Kennedy (Ref. 5) and Dowling (Ref. 6), and is governed by a partial differential equation, known as the Paidoussis equation (Ref. 7). Gray et al (Ref. 8) and Riley et al (Ref. 9) have developed a discrete form of this equation, and established a Kalman filter for the estimation of the sensor positions by relating these positions to the states of the system. They have tested their algorithm using both simulated data and real data obtained with an instrumented towed array, with good results.

The second approach to array shape estimation requires the presence of an acoustic source in the far field. Data from the hydrophones themselves are used to estimate the shape of the array, and non-acoustic sensors, such as heading and depth sensors, are not required.

Ferguson (Ref. 10) and Ferguson et al (Ref. 11) describe two techniques that use this approach. The first is an optimisation technique, where the "sharpness" is calculated by integrating the product of the beam output power squared and the sine of the beam steer angle over all beam steer angles from forward endfire to aft endfire. The estimated positions of the hydrophones are those for which the sharpness is a maximum. The other method uses the eigenvector corresponding to the largest eigenvalue of the cross-spectral matrix to extract the phase of the signal at each of the hydrophones and then, after assigning a direction to the source of the signal, uses the relative phase information to estimate the positions of the hydrophones along the array.

A comparison of the beam patterns obtained from these two methods with that obtained assuming a linear array is shown in Fig. 3 for real data. The improvement in performance achieved by the use of an array shape estimation algorithm is evident.

2.3 Frequency Estimation, Tracking and Detection

The traditional method of display of passive sonar data to the operator is in the form of intensity modulated frequency-versus- time plots, called variously spectrograms, lofargrams, etc. Detection is achieved when the operator notices the appearance of a discrete frequency on the plot, frequency estimation is carried out by determining which frequency cell contains the signal, and tracking consists of following the evolution of this frequency as a function of time.

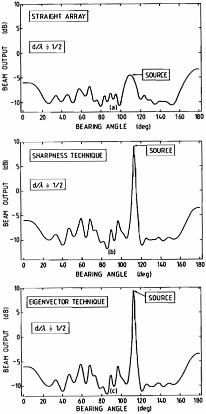

Figure 3. Variation of the output power with beamsteer angle for an adaptive beamformer processing real data from an experimental towed array: (a) assuming that the array is straight, (b) using the array shape inferred from the sharpness optimisation technique, and (c) using the hydrophone positions estimated by the eigenvector technique. The frequency of interest is close to the design frequency (i.e., d=λ/2) of the array (from Ref. 11).

The signal processing algorithm underpinning the spectrogram is the Fast Fourier Transform (FFT). The spectral power in each frequency cell is calculated from the FFT of the data time series and plotted in the spectrogram. However, the FFT phase, which is obtained concurrently with the power for each cell, is ignored in the conventional display. In a series of papers, McMahon and Barrett (Refs. 12,13,14) have shown that the hitherto discarded phase information can be exploited to obtain a near optimal frequency estimator, called the Phase Interpolation Estimator (PIE). Recently, Quinn (Ref. 15) has also developed a frequency estimator which exploits the FFT phases.

An example of the use of the PIE algorithm for real data is shown in Fig. 4, where the estimates from the PIE algorithm are plotted as a function of time. The frequency variations displayed by the data in this figure are all well within a single FFT frequency cell (0.46Hz), thereby revealing the improvement in accuracy of the PIE over conventional FFT processing.

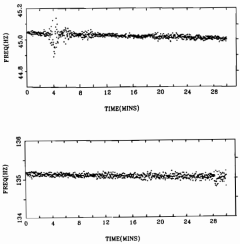

Figure 4. Application of the PIE method to real passive sonar data. The fundamental (first harmonic) and third harmonic of a nominally 45 Hz acoustic projector are plotted as a function of time. Sampling rate was 470.7 Hz and the FFT resolution was 0.46 Hz.

The data displayed in Fig. 4 were obtained at a high signal-to-noise ratio (SNR). As the SNR is decreased, "outliers" (or estimates far removed from the true frequency) become increasingly prevalent. A priori knowledge of the extent and rapidity of the likely frequency changes can be incorporated into an algorithm that rejects the highly improbable outliers and produces smoothed frequency estimates as a function of time. Such an algorithm is designated a "frequency tracker". A number of standard tracking algorithms (alpha-beta, Kalman, Probabilistic Data Association) (see Ref. 16) exist in the literature and can be applied to the frequency tracking problem.

An alternative approach, due to Streit and Barrett (Ref. 17), makes use of the Hidden Markov Model (HMM), which has recently found wide application in the field of speech processing. In this method, the range of frequencies (or gate) over which a track is allowed to wander is divided into a finite number of frequency cells, and each cell is associated with a state of a Markov chain. In the original work of Streit and Barrett, each cell coincided with a FFT frequency cell, but this restriction is unnecessary. In addition, a zero state is included to allow for the possibility of the track wandering outside the allowed frequency range, or terminating altogether. Statistical information on the likely extent of the frequency fluctuations, and on the probability of the track initiating or terminating are conveyed to the tracker by means of matrix inputs to the Hidden Markov Model.

In the original formulation, the only spectral information passed to the HMM was knowledge of which frequency cell within the gate contained the maximum power. In a later extension to the method (Ref. 18), complete knowledge of the phases and amplitudes in all FFT cells within the gate was passed to the HMM. As a result, the performance of the tracker was greatly enhanced, and tracking of frequency fluctuations less than the width of an FFT cell was now possible.

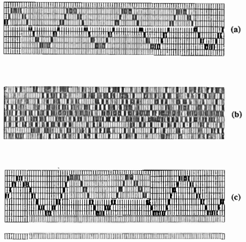

Figure 5. (a) A hidden Markov state sequence; (b) the intensity modulated spectrogram arising when the state sequence is embedded in white Gaussian noise; (c) the reconstructed state sequence obtained from the spectrogram using a Viterbi tracker. The vertical axes are marked in frequency units of (a) 0.16 Hz; (b) 1 Hz; (c) 0.16 Hz. The horizontal axes are marked into time units of 1 s in all cases.

In Fig. 5, an example is presented of a frequency track obtained by using the HMM tracker with simulated data. The upper plot shows the true computer-generated "hidden" track. The vertical axis is subdivided in frequency units of 0.16Hz. White Gaussian noise (SNR = -21dB) is added to the signal shown in Fig. 5a, and the resultant spectrogram is plotted in Fig. 5b. The frequency subdivisions on the vertical axes correspond to the FFT bin size of 1Hz. Fig. 5c displays the track reconstruction (frequency subdivisions = 0.16Hz) produced by the HMM tracker with phase and amplitude information included. Fig. 5c should be compared with Fig. 5a to assess the tracker performance. The zero state is shown under the gate cells in Fig. 5c.

The inclusion of a zero state in the HMM allows for the possibility of track initiation and termination, and thus incorporates an implicit detection process into the HMM tracker. The use of the HMM as a detector of unstable frequency lines has been addressed by Barrett and Streit (Ref. 19) and Barrett and Holdsworth (Ref. 18).

2.4 Doppler Analysis

One of the applications of frequency estimation techniques is to obtain speed and range estimates of a "target" by means of the well-known Doppler effect. The increased accuracy available from frequency estimators such as the PIE algorithm leads to observable Doppler shifts on lines at lower frequencies than would otherwise be possible.

Quinn (Ref. 20) has derived from first principles a parametric form for the "instantaneous frequency" as a function of time for the cases of stationary target and stationary receiver when motion is in a straight line relative to the stationary target or receiver. He has developed an algorithm which produces estimators of the closest distance between target and receiver, the relative speed, the rest frequency, the time at closest approach, and the covariance matrix of the estimators. The technique is automatic, and will work even if only a section of the Doppler track is available, e.g. if the closest point of approach has not yet been reached. The method is currently being applied to real sonar data.

3. FUTURE DIRECTIONS

Acoustic systems are likely to continue to play an important role in helping to meet Australia's surveillance and intelligence gathering requirements. With the forthcoming operational use of long towed arrays and projected sonobuoy developments, signal processing must continue to form a prominent part of any overall sonar system.

With the continuing quietening of modern submarines, the conventional passive sonar system, relying as it does on spectral lines emitted from on-board machinery, will encounter increasing difficulties unless new signal processing techniques are developed to restore the effective signal-to-noise ratio. In the future, we may expect the transient sounds emitted during particular operations (e.g. flooding the torpedo tubes, or trimming the diving planes) to be more fully exploited than they are now. Essentially passive systems, such as towed arrays, may contain an active adjunct which emits a ping, the echo of which is detected by the towed array.

One technique being investigated at DSTO with an eye to future applications is matched field processing. In this approach, a detailed knowledge of the environment in the neighbourhood of the source and receiver is exploited to improve target localisation. For example, because of its cylindrical symmetry, no bearing information can be obtained from a vertical line array with conventional processing. However, this cylindrical symmetry can be broken by the presence of inhomogeneities in the environment around the receiver. A bottom slope means that multipath interference is different in one direction compared with another. A careful comparison of the spectral powers in different beams steered in the vertical direction with the predictions from propagation models can lead to an estimate of the target bearing. Similar arguments can be used to obtain target range estimates.

Another technique of the future is likely to be passive synthetic aperture sonar. In this approach, a relatively short towed array has its effective aperture increased by processing the data as the array is towed through the ocean. Data from different positions in the ocean and different times are coherently combined to simulate the output of a physically larger array. The success of the method relies on the signal in the ocean being coherent over distancesequal to the length of the effective synthetic aperture, and temporal coherences equal to this distance divided by the speed of sound. Preliminary investigations overseas indicate coherences of this sort may be possible in some circumstances.

It is difficult to anticipate which of these, or other, techniques will be successful in improving the effective signal-to-noise ratio in future processors. What we can be sure of is that future sonar systems will be more sophisticated than they are now, and the accompanying signal processing will fully exploit the burgeoning technology of the computer age.

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The Biological Contribution To The Ambient Noise In Waters Near Australia

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Abstract: A major component of the ambient noise in oceans and seas near Australia is generated by biological sources. Invertebrates, fish and whales produce a wide variety of sounds that have a significant affect on the performance of sonar and other uses of sound in the ocean. Choruses that result when large numbers of individuals are calling commonly cause levels to rise by about 20 dB, and at times more than 30 dB, over different parts of the frequency range 50 Hz to 5 kHz. Their distribution and occurrence is complex because they depend on the behaviour, habitats and migrations of the animals responsible, but are intrinsically predictable. Some whale sounds are so intense that they are detectable as individual transients for some tens of kilometres.

1. INTRODUCTION

Sound is used extensively to transmit information through the ocean because it travels with far less loss of energy than does electromagnetic radiation. However, the very properties that make sound so effective in this respect result in high ambient noise levels, since sources at large distances can contribute to local noise levels. The absorption of sound in water is substantially less than in air. As a result, sources contribute to the background noise from much larger distances than in air, and ambient sound pressure levels, even in quieter parts of the ocean, are comparable to those of a busy city street.

The high ambient noise levels provide a major limitation on the effectiveness of passive sonar and other underwater listening devices, since the signals of interest must be detected against this background noise. Moreover, noise levels vary over a wide range as a result of variations in weather conditions, shipping activity, or biological behaviour and habitat. Such variation may be temporal, seasonal or geographical and is commonly of the order of 20 dB, but may at times exceed 30 dB. The effect of a variation of 20 dB in typical ocean conditions is to vary the distance over which a signal is detectable by a factor of about 10. Effective use of sound in the ocean, therefore, requires an understanding of the ambient noise and the ability to predict the levels and their variation.

Early studies of ambient noise in the ocean [1,2] established that it comprised three main components:

(a) that generated by fluid motion in the vicinity of the surface (wind dependent noise: that from wind/wave action, and rain noise)

(b) the noise of distant shipping (known as *traffic noise*)

(c) biological noise.

Wind dependent noise is the prevailing component of the ambient noise and extends over a frequency range from less than 1 Hz to in excess of 30 kHz. Traffic noise is usually evident at frequencies below about 100 Hz in regions where there is significant shipping and good sound propagation. Biological noise is a very variable component of the ambient noise because of the diversity of animals responsible, in terms of their behaviour, habitats and migrations. Their sounds vary in frequency from below 20 Hz (fin whales [3], blue whales [4]), to 200 kHz (dolphins [5], shrimps [6]).

The oceans and seas around Australia are particularly rich in biological sounds. Marine animals make extensive use of sound because of the limitations the medium imposes on the effectiveness of the other senses. Vision is fully effective only in clear, shallow waters. The sense of smell is limited because water currents are too slow to adequately disperse the scent chemicals. The study of marine animal sounds is therefore an important component of the study of their behaviour.

This paper discusses the more significant biological contributions to ambient noise around Australia, and some of our recent work in this area.

2. GENERAL CHARACTERISTICS OF BIOLOGICAL NOISE IN AUSTRALIAN WATERS

While a wide range of animals produce sounds, not all are important in terms of the contribution to the ambient noise. The most significant contributions are (a) the choruses, which result when large numbers of animals are producing sounds and (b) the intense transients of the higher source level sounds. The choruses increase the general background noise level while the transients are evident as individual signals which need to be distinguished from our own signals.

Biological noise is evident in all waters around Australia, but is most pronounced in shallow tropical waters where, for much of the time, it is the dominant component of the ambient noise. An example is shown in Figure 1 which summarises conditions in the Timor Sea [7,8]. Low shipping densities result in low levels of traffic noise, so that low frequencies (say below 100 Hz) tend to be dominated by wind dependent and biological noise. Above 100 Hz, the noise is usually biological in origin, except during high winds

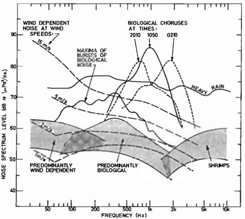

Figure 1. Summary of the components of ambient noise in shallow water in the Timor Sea. The shaded areas indicate the prevailing noise at low wind speeds. The wind dependent noise curves were determined from measurements at many locations around Australia (ref. 22).

or heavy rain. High levels of wind dependent noise would obscure the general background of biological noise but not the diurnal choruses that result when large numbers of individual animals are calling. The general background of biological noise comprises sounds from fish and invertebrates. These sounds are either short duration and broad band like the stridulatory clicks of invertebrates and fish teeth sounds, or are harmonic and drumming sounds of some seconds duration characteristic of sounds generated by fish swim bladders [9]. Only the very high noise levels of heavy rain can compete with the highest levels of biological noise.

3. SNAPPING SHRIMPS

The most ubiquitous biological component of the ambient noise is that due to snapping shrimps, since it is evident throughout the world in shallow, warm waters, usually in depths of less than about 60 m and latitudes less than about 40°. This was recognised in the earliest studies of ambient noise [1,10]. The shrimps responsible belong to the genera *Alpheus* and *Synalpheus*. Each shrimp has one enlarged claw (more than half the body length) which produces a sharp click when snapped closed. Large numbers of shrimps clicking result in a crackling or sizzling sound characteristic of shallow waters around mainland Australia. Although shrimp noise has been measured for many years, it is only recently that sufficiently broad band recordings have been made to show the true width of the pulse as between 5 and 8 microseconds [6]. The energy extends to at least 200 kHz. Figure 2 shows a spectrum representative of Australian shallow waters where shrimp noise is high (favourable habitat) [6]. Lower levels occur where habitats are less favourable, as in the example of Figure 1. The shrimps prefer conditions where they can hide in or under objects on the bottom, such as rocks, shells and debris. Variation in level, like that evident between Figures 1 and 2 may occur over short distances (e.g. hundreds of metres) as conditions on the bottom change. Spectral shapes may also vary with different locations.

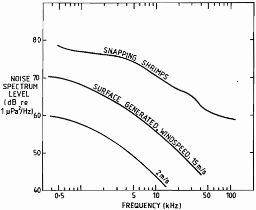

Figure 2. The noise from snapping shrimps, typical of the higher levels in favourable habitats, compared with surface generated (wind dependent) noise.

4. BIOLOGICAL CHORUSES

The term *biological chorus* is used here to mean the continuous noise (averaging time   1 s) produced when large numbers of individuals are producing sounds. So many sounds overlap that the noise level is far higher than that of an individual sound. In some choruses, the individual sounds may still be detectable, while in others they merge together. Choruses are common in Australian waters, causing levels to vary by more than 20 dB over periods of a few hours (more than 30 dB under some conditions). They occur frequently (usually daily), and contribute over a broad frequency band. Different choruses have different diurnal, seasonal, geographic and spectral characteristics. Shrimp noise is usually considered to be in a separate category, since it does not show the pronounced diurnal and seasonal variation of other choruses, having remarkable persistency. It also covers a different frequency band.

A number of studies of ambient noise around Australia have shown the presence of choruses from which the general nature of their occurrence and spectral characteristics were determined. These were reported some time ago [7]. Statistical analysis showed that choruses were widespread in waters near Australia, contributing in the frequency band from about 400 Hz to about 5 kHz. Most choruses lasted for a few hours and the most consistent time of occurrence was just after sunset, although choruses were also sometimes observed just before sunrise and around midday. Examples of chorus spectra in the Timor Sea are shown in Fig. 1, while the rise and fall of evening choruses in three oceanic areas are shown in Figure 3. Spectrally different choruses were often observed at the same location, sometimes overlapping in their times of occurrence. The typical increase in noise level during a chorus was about 20 dB. There was some evidence of seasonal variation, but data were too limited to draw conclusions. These measurements were made either in shallow water, or in deep water within 6 km of shallow water. More recently, Kelly, Kewley and Burgess [11] have reported a chorus of similar spectral characteristics in deep water north west of Australia.

While this work gave some idea of the general nature of choruses near Australia, the data were insufficient to predict the behaviour, distribution and occurrence of particular choruses, except for the expectation that choruses might be

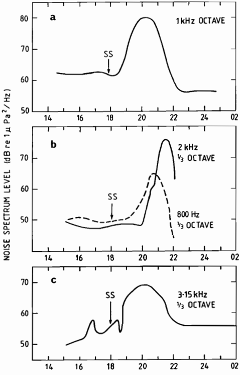

Figure 3. Examples of the rise and fall of evening choruses in tropical waters of (a) the Timor Sea (latitude about 11°S), (b) the west Pacific Ocean (about 2°S) and (c) the east Indian Ocean (about 10°S). The spectrum level has been averaged over the octave or 1/3 octave band containing the spectral peak. "SS" gives the time of sunset.

widespread in the few hours following sunset. It was also not clear that the full spectral range of choruses had been observed. These results were obtained by measuring ambient noise 24 h per day for periods of 10 to 20 days at a small number of locations. To adequately categorise the choruses throughout the region for all times of year would require this type of measurement to be repeated for all months in a grid pattern with spacing small enough to cover the geographical variation, which would be expected to vary with variations in habitat and migration patterns of the animals. Such an extensive program of measurements would be well beyond the resources that could reasonably be expected to be allocated to such a project.

Instead, we have taken the approach of identifying the sources of choruses, determining the acoustical characteristics of their sounds, and relating this to their diurnal and seasonal behaviour. This requires identification of the source species and study of their behaviour in relation to sound production. By identifying the preferred habitats of the individual animals, and, where appropriate, their migration patterns, the results can be extrapolated throughout the region. This research is interdisciplinary, requiring expertise in marine biology as well as acoustics, so we have been working with biologists from other institutions (James Cook University, the Queensland Museum and the University of Sydney in particular).

5. RECENT MEASUREMENTS OF CHORUSES

The approach in recent measurements has been· two pronged: (a) intensive diurnal and seasonal measurements at a particular location to determine the characteristics of the choruses represented there and to identify the species responsible, and (b) "spot" measurements throughout the region of interest to extend the measurements and check the predictions from the intensive measurements. The first set of intensive measurements have been made using two hydrophones permanently moored in 20 m of water inside the Great Barrier Reef, latitude about 17° S. The hydrophones were linked by 2 km of cable to an island and data transmitted from there to a small research establishment ashore. This site has species represented in many areas near Australia. Some preliminary work on the identification of sources and their sound production has been reported by McCàuley [12].

Measurements using the moored system have shown that the frequency range of choruses extends to frequencies well below that shown in the earlier series of measurements, and that diurnal variation is more complicated. Some examples of the spectra measured during the rise and fall of one type of chorus observed at this location are shown in Figure 4. These were recorded on the 12 August 1986 at the times of day shown. The frequency range of this chorus extends from about 50 Hz to about 2 kHz, with the highest levels, up to 30 dB above background, being observed at lower frequencies. Thus, in general, choruses cover the frequency band from about 50 Hz to 5 kHz, rather than from about 400 Hz to 5 kHz as indicated by the earlier measurements. Figure 4 shows evidence of two broad spectral peaks possibly representing two choruses, one peaking around 500 Hz, the other between 50 and 200 Hz. The sounds responsible for the lower frequency peak and other choruses of similar frequency observed at this location and in the general area are typical of those made by fish drumming or strumming the swim bladder with attached muscles. The peak frequencies are related to the resonant frequencies of the fish swim bladders. For soniferous fish, these frequencies are typically of the order of 100 Hz [9]. Significant seasonal variation in chorus behaviour is evident at this site.

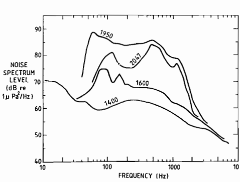

Figure 4. Examples of chorus spectra at the times of day shown, at the recording site in the Coral Sea.

The high level choruses recorded in earlier measurements [7] were typical of impact or stridulatory sounds of fish and invertebrates in their acoustical characteristics, and spectra peaked at frequencies from 700 Hz to 3 kHz. The significant difference in the recent measurements is the obvious presence of lower frequency choruses produced by typical fish swim bladder sounds. Such sounds were observed in earlier measurements, often producing continuous low level choruses, but they were not sufficiently numerous in their occurrence to produce the high levels of the other choruses. For example, the "predominantly biological" background noise in Figure 1 contains a large proportion of sounds which are typical of fish strumming and drumming the swim bladder, whereas the high level choruses are typical of the impact and stridulatory sounds. The absence of high level choruses from fish swim bladder sounds in the earlier measurements may have simply been the result of the limited seasonal sampling, given the seasonal nature of such choruses. The deep water chorus reported by Kelly et al [11] comprised sounds characteristic of those generated by fish swim bladders.

The diurnal, seasonal, and geographical variation of the choruses can be expected to depend on the behaviour of the animals in relation to sound production. Where sound is associated with feeding, perhaps incidental to it (such as fish scraping teeth on coral) choruses will, of course, be related to times and conditions of feeding, and so exhibit diurnal regularity. Sound used for communication during spawning can be expected to produce choruses with strong seasonal dependence. Seasonal dependence will also result from species migration, i.e., it will be determined by the time the animals pass through a particular area. Animals are to be found in the habitats that provide the most chance for their survival, i.e. where the appropriate food is available, where they can find shelter from predators, etc. This in turn depends on the nature of the sea floor (the presence of corals, rocks vegetation, etc.), the presence of nutrients, the water properties and the other species in the area. The diversity of habitats can be expected to provide significant geographical variation in choruses.

Some whales also produce choruses. The source strengths of their individual sounds are significantly higher than those of fish or invertebrates, so smaller numbers of individuals are needed to produce a substantial chorus. Although the popular conception is that whale numbers are very low, this is true only for a few species, and some of these have shown substantial recovery of stock numbers in the last 20 years. The most significant whale chorus is that from sperm whales.These are toothed whales, and they often congregate in large schools like the smaller toothed whales (e.g. dolphins, killer whales). Schools of 10 to 50 sperm whales are common [13], but there are reports of schools of thousands of individuals [14]. Sperm whales generally keep to deep water. Significant numbers are to be expected in waters around Australia, as have been observed in the Tasman Sea [14].

Sperm whales produce intense clicking sounds which result in high level choruses with most energy between 1 and 5 kHz and maximum levels comparable to the other choruses. The occurrence of sperm whale choruses is more difficult to predict than those of fish and invertebrates, because their behaviour is more complex and less predictable. These whales are nomadic and their migration patterns are ill defined. Their choruses are well known to sonar operators who refer to them as the "carpenter fish" since some consider that they sound like many carpenters hammering.

Humpback whale sounds were responsible for a persistent chorus observed near New Zealand in the late 1950s which had almost disappeared by 1961 as a result of the decrease in whale numbers through whaling [15]. The significant recovery of humpback whale stocks in Australian waters has resulted in increasing chorus activity (though this has not been observed in New Zealand waters). These are baleen whales (i.e., they have baleen plates in place of teeth to filter food) and their sounds are distinctively different to those of the toothed whales.

6. INTENSE BIOLOGICAL TRANSIENTS

The sounds of some animals are so intense that individual calls are audible for considerable distances, and thus detectable by sonars as signals rather than as part of the background noise. Some calls sound remarkably mechanical. These individual calls are transient in nature, having durations ranging from a fraction of a second to around 20 s, and in this respect contrast with the continuous sound of a chorus. The most intense sounds are those of the lager whales. Source levels have been estimated from measurements in the northern hemisphere to lie in the range 170-190 dB re 1 μPa^2 at 1 m [4,16-18]. Our measurements of received sound levels in Australian waters are consistent with these estimates, and such sounds would be audible for some tens of kilometres, depending on conditions (discussed in more detail in reference 19). While these source level estimates are broadband, many of the sounds are harmonic, so have high narrow band levels.

Perhaps the most difficult whale sounds to categorise are those of the humpback whale, which produces a wide variety of sounds in a well structured pattern or song [17,19,20]. Durations vary from about 0.1 to more than 4 s, and most of the energy lies in the range 100 Hz to 4 kHz. The rules of the song structure are complex. The characteristics of the sounds, the song structure, and even the rules themselves change with time. These whales migrate along the east and west coastlines of Australia, and although numbers were depleted by whaling activities which ceased in the early 1960s, there has been a significant recovery since then. The rate of increase of around 10% per year has been sustained for at least the last 10 years [21]. Our work on humpback whale sounds in Australian waters is discussed in reference 19.

7. UNIDENTIFIED SOUNDS

There still remain some sounds in the ocean which have yet to identified, but in spite of the apparent mechanical nature of some, all the evidence indicates that these are biological in origin. The difficulty in identification relates to the difficulty in finding and visually identifying the animal responsible. While the sounds may be audible for several kilometres, the source can be visually identified only at close range. It is more effective to build up a catalogue of identified sounds by seeking out animals of the species likely to be significant sound producers and recording their sounds, and this is the approach we have been taking.

8. CONCLUSIONS

Invertebrates, fish and whales produce sounds which contribute to the general ambient noise in waters near Australia. The most important contributions are the biological choruses and the intense biological transients. From the available data, we can say that choruses are wide spread in both shallow and deep waters near Australia, especially in the tropics. They regularly cause increases of between 20 and

30 dB in ambient noise level over the frequency band from about 50 Hz to 5 kHz, and so have a substantial effect on the performance of passive sonar or underwater listening devices. These choruses are intrinsically predictable because they depend on predictable aspects of the behaviour and habitat preference of the animals responsible. Temporal variation in choruses is both diurnal (e.g. related to feeding activity) and seasonal (e.g. related to breeding and spawning). Geographical variation depends on migration patterns and preferred habitats. The most significant biological transients are those of the large whales since they produce the most intense sounds. These are audible for some tens of kilometres.

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Acoustic Properties Of Marine Sediments

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Abstract: A review is presented of the basic relationships describing the acoustic and other wave properties of marine sediments in terms of the properties of their constituents. As water saturated sediments are two phase mixtures , these relationships are complicated, and more so by the non-homogeneity and varied nature of sediments. The chief parameter of relevance to wave propagation - sound speed and attenuation, and shear wave properties - are discussed, and recent developments on the effects of non-uniformity of the sediment, such as , for example, depth gradients, are examined.

1. MARINE SEDIMENTS

Acoustic propagation in the ocean, in particular the shallow seas of the continental shelves, may be strongly affected by the acoustic characteristics of the lower boundary, the sea floor. The sea-bed beneath this boundary is usually composed of unconsolidated sedimentary deposits sitting on bed rock. These can vary in thickness from metres to kilometres, but the range of interest for underwater acoustic studies lies probably in the first few hundred metres.

The acoustic properties of these sediments depend largely on their composition and mechanical properties. Sea bed sediments may be considered as two phase composite materials consisting of granular solids and pore fluid. The chief physical properties of sediments which show variations are the sizes and distribution of sizes of the composing particles, and the structure of the sediment as indicated by its porosity. Particle sizes may range from several millimetres (coarse gravel) to the submicron range (fine clays). Porosities may span the entire range from high porosity suspensions (90% for some clays) through compacted sands (35%) to low porosity sandstones (below 30%).

The composition of the sea-bed sediments varies widely throughout the oceans. Three different types of general environment have been distinguished - the continental shelf and slope, the abyssal hill and the abyssal plane. For example, the continental shelf environment is characterised by sediments originating from terigeneous sources and is composed of sand, silt and clays whereas the deep sea abyssal planes are usually covered with layers of silt-clays with thinner intercalated layers of sand and silt which have been carried along the bottom in turbidity currents and cover the original rough topography. The abyssal hills are mostly covered with relatively thin layers of pelagic and siliceous oozes with thicker deposits of calcareous ooze around the equator and on sea mounts where the sea floor is above the calcium carbonate compensation level. [In sediment nomenclature, pelagic clay is composed of less than 30% siliceous or calcareous material, calcareous ooze contains more than 30% silica in the form of Radiolaria or diatoms.]

The properties of sediments may also vary with depth into the sediment. For example, there may be layering in their composition, particularly on continental shelves due to the depositing of different types of sediment at different periods in time. There may also be a variation with depth due to the effects of overburden pressures, mainly a consolidation, and increasing hydrostatic pressure within the sediment.

2. ACOUSTIC PROPAGATION IN SEDIMENTS

The mechanical and acoustic properties of sediments vary because of the wide range of sediment compositions and constraints. A large number of physical parameters are involved, the more important being porosity, grain properties including sizes, shapes and sorting, elasticity moduli and density, and inter-granular stresses involving grain interlocking and consolidation. The acoustic parameters of most interest are the dilatational wave velocity (sound speed), attenuation and characteristic acoustic impedance, as well as shear wave velocity and attenuation. These parameters are inter-related to many of the mechanical properties of the sediment and several theories have been developed to account for these relationships as explicitly as is possible.

The acoustic behaviour of natural unconsolidated sediments is essentially that of a suspension of particles in fluid, with usually a small rigidity or shear modulus present. The first generally useful attempt at relating the acoustic properties to the composition of the medium was that due to Wood (1941) [1] who noted that the bulk adiabatic compressibility of a dispersion of one or more solids and fluids equals the sum of the compressibilities of the individual components multiplied by their proportional fractions of the total volume. A simple equation, known as Wood's equation, viz

$$c = \sqrt{K/\rho}$$

where $\frac{1}{K} = \frac{\beta}{K_f} + \frac{(1-\beta)}{K_r}$ and $\rho = \beta\rho_f + (1-\beta)\rho_r$,

yields values of sound speed in sediments (other than sands) close to those measured. Here c is sound speed, β is porosity, and K_f, K_r, ρ_f and ρ_r are the bulk moduli and densities of fluid and grains.

Because of discrepancies between measured and predicted values of sound speed, further development of this theory was made by Gassman (1951) [2] who determined that the effective elastic modulus of the fluid saturated porous medium may be affected by fluid-particle interactions and should be calculated from the elastic moduli of the solid material, of the fluid and of the skeletal frame made up of the particles. This modification effects some reconciliation between predicted and experimental results but a more acceptable explanation and accounting for other acoustic properties - attenuation and impedance - had to await the development of a more general theory of wave propagation in a porous elastic medium.

A. Wave propagation in a porous medium

The acoustic characteristics of porous elastic media were extensively examined by Zwikker and Kosten (1949) [3] who experimented with air filled materials such as flexible foams and other acoustic absorbers. The theories developed were simplified, rotational or shear waves not being considered, and it was the later work of Biot (1956) [4] which established the basis for a more rigorous treatment of the topic. Biot considered the same basic situation as Zwikker and Kosten, that of a fluid filled elastic porous solid, but established a more fundamental approach aimed at including all pertinent physical mechanisms in a quantitative manner.

For a single phase isotropic medium the stress (σ) strain (u) relationship may be written as:

$$\sigma_{ik} = 2\mu u_{ik} + \lambda \delta_{ik} u_{ll}$$

where μ and λ are the Lamé constants, δ_{ik} is the Kronecker delta function. (Use is made of the terminology and suffix notation as in Landau and Lifshitz [5]). Wave equations may be developed by equating body forces to the product of density and body acceleration viz:

$$\partial\sigma_{ik} / \partial x_k = \lambda \partial u_{ll} / \partial x_i + 2\mu \partial u_{ik} / \partial x_k = \rho \ddot{u}_i$$

substituting $u_{ik} = \frac{1}{2}(\partial u_i / \partial x_k + \partial u_k / \partial x_i)$ gives

$$\rho \ddot{u}_i = \lambda \partial^2 u_i / \partial^2 x_k + (\mu + \lambda) \partial^2 u_l / \partial x_k \partial x_l$$

Considering one dimensional propagation in the x direction yields the equation

$$\mu(\partial^2 u_x / \partial x^2 + \partial^2 u_y / \partial x^2 + \partial^2 u_z / \partial x^2) + (\lambda + \mu) \partial^2 u_x / \partial x^2$$
$$= \rho(\partial^2 u_x / \partial t^2 + \partial^2 u_y / \partial t^2 + \partial^2 u_z / \partial t^2)$$

This may be separated into two equations viz:

$$\partial^2 u_x / \partial x^2 - \frac{1}{c_l^2} \partial^2 u_x / \partial t^2 = 0$$

where $c_l = \sqrt{(\lambda + 2\mu) / \rho}$

and an equation related to the y or z axis such as

$$\partial^2 u_y / \partial x^2 - \frac{1}{c_t^2} \partial^2 u_y / \partial t^2 = 0$$

where $c_t = \sqrt{\mu / \rho}$, and these may be recognised as dilatational and shear equations respectively.

For a two-phase medium such as water saturated sediments, Biot developed a series of constitutive equations to describe their elastic properties in terms of their basic components. He considered a unit cube of the solid fluid system, the stresses, σ_{ij}, acting on the solid part and the pore pressure, p_f, on the fluid part. Development of the body forces acting on the solid and fluid parts leads to two coupled differential equations involving motion of the solid (displacement u_i) and of the fluid (flow of fluid relative to the solid w_i). For one dimensional propagation in the x direction these equations are [6]:

$$\mu(\partial^2 u_x / \partial x^2 + \partial^2 u_y / \partial x^2 + \partial^2 u_z / \partial x^2) + (\lambda + \mu) \partial^2 u_x / \partial x^2$$
$$- C \partial^2 w_x / \partial^2 x = \rho \ddot{u}_x - \rho_f \ddot{w}_x$$

and

$$C \partial^2 u_x / \partial x^2 - M \partial^2 w_x / \partial x^2 = \rho \ddot{u}_x - (\rho_f / \beta) \ddot{w}_x - (\eta / k) \dot{w}_x$$

Here M is a measure of the pressure required to force a given volume of fluid into the aggregate whilst the total volume remains constant. The coefficient C represents the coupling between the volume change of the fluid and that of the solid. Both C and M which are related to the terms developed by Gassman may be expressed in terms of the bulk moduli of the fluid (K_f), of the grains (K_r) and of the skeletal frame of the sediment ($\mathbf{K}_b$) as $C = \frac{K_r - \mathbf{K}_b}{D - \mathbf{K}_b}$ and $M = \frac{K^2_r}{D - \mathbf{K}_b}$ where $D = K_r(1 + \beta[K_r / K_f - 1])$.

This frame modulus $\mathbf{K}_b$ is complex to account for viscoelasticity of the frame which may contribute to the attenuation of waves in the sediment.

The densities of the sediment and of the fluid are denoted by ρ and ρ_f respectively, but the fluid mass term (ρ_f/β) is usually multiplied by a structure factor (g) because not all of the pore fluid moves in the direction of the pressure gradient due to the multidirectional nature of the pores. As a result, less fluid flows and hence there is effectively a greater inertia.

The last term of the second equation (η/k) takes into account the viscous drag of the fluid, of viscosity η, through the porous medium of permeability k. This assumes Poisseuille (laminar) flow of fluid through cylindrical pores. Biot incorporated corrections to this term to compensate for deviations from Poisseuille flow at "high" frequencies and irregularities of the pore structure. The coefficient of the term $\dot{w}_x$, becomes $\eta F(\kappa)/k$ where

$$F(\kappa) = \frac{\kappa T(\kappa)}{4(1 - 2T(\kappa) / j\kappa)}$$

$T(\kappa)$ is the Kelvin function and κ is equal to $a\sqrt{\omega \rho_f / \eta}$, a being a parameter with the dimensions of length and depending on the size and shape of the pores.

Dilatational and shear wave equations can be separated as before and then trial solutions substituted. The conditions for solution are satisfied by three possible waves - two dilatational and a shear wave - and the velocities and attenuation constants computed. (If $\eta > 0$ their wave numbers are complex). One of the dilatational waves, the first kind wave, gives a sound speed value near that of the fluid and is the sediment wave usually detected. The other wave, the second kind wave, is characterised by a lower speed (~100 m/s in sediments) and has only been detected in a fused glass bead medium [40].

The feature which distinguishes Biot theory from these previous formulae is the attempt to make use of fundamental sediment properties to compute acoustic properties. However several of the parameters utilised such as the sediment skeletal frame elastic properties and the parameters pore size (a) and structure constant (g) are difficult if not impossible to specify. In addition, Biot theory applies only to a uniform medium, which is clearly contravened in real sediments the properties of which exhibit strong depth dependencies.

3. MEASURED ACOUSTIC PROPERTIES

The acoustic properties of marine sediments depend on many of the physical properties of the sediment itself. A recent review of Bachman[9] presents many regressions on the effects of different properties such as grain size, density, porosity on acoustic properties, to support widely used empirical equations published by Hamilton [8].

A. Sound speed

Sound speed data is available from both remote and in-situ measurements. The most authoritative work in the latter field is that of Hamilton [7] who reviewed measurements and their relationships with the physical properties of sediments within the top 30 cm of the sea bed. In these layers the sediment is in a loose non-consolidated state, hence frame bulk modulus (K_b) and shear modulus would be expected to be low, and Wood's equation should hold. However, the measurements indicated that all sediments have sound speeds greater than predicted by Wood's equation as is indicated in Fig.1. Hamilton attributes the greater than expected values of sound speed to the existence of rigidity and frame bulk modulus in the mineral structure of the sediment. He calculates a new sound speed by replacing the bulk modulus of the sediment (K) used in Wood's equation, by $(K + 4\mu/3)$ where μ is a shear modulus obtained from shear velocity measurements on samples or in-situ on the sea-floor. This will displace to higher sound speeds the sound speed porosity curve of Wood in a similar manner to Gassman's formula, but the agreement between theoretical and experimental results is still far from satisfactory. (As μ is strongly dependent on depth within the sediment, these modifications are of doubtful value in characterising sound speeds at depths in sediments.) Fig1. also shows a Biot curve at 1000 Hz, with parameters appropriate for a sand sediment chosen, the most influential being values assigned to frame modulus. As different parameters should be substituted for the different sediments utilised in this figure, the better fit for the Biot curve is more apparent than real.

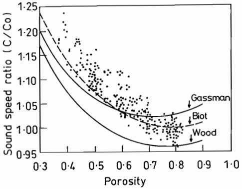

Figure1. Measured values of sound speed ratio (c/c_o) plotted against sediment porosity (from Hamilton [7]). Also shown are the theoretical curves of Wood, Gassman using a frame modulus of 400 MPa, and Biot using a frame modulus of 40 MPa.

Two features are evident in the data presented in Fig.1. Firstly the sound speed increases with decreasing porosity at a rate greater than allowed by all the theories employing a constant frame modulus. This might imply that frame modulus increased with decreasing porosity, a not unreasonable expectation. Secondly, there is considerable scatter in the data points, there being a considerable range of sound speed values observed at each porosity value - between 5 and 10%. Some of this variation can be attributed to experimental error, in both porosity and sound speed determination, but much of it must be due to differences in sediment composition, for example, grain size and packing, affecting frame modulus in particular.

Another factor which may contribute to the scatter is the variations in frequencies at which the sound measurements were made. It has been shown that there may be a velocity dispersion at a frequency dependent on the sediment permeability and effective pore radius [6]. To accommodate these discrepancies, many authors [12-14] have introduced empirical modifications to Woods equation to make it fit sound speed data and therefore be more useful in predicting sound speeds from porosity or estimated porosity values.

Both wave velocities c_l and c_t vary with depth in homogeneous sediments, and this characteristic is often included in underwater propagation models - linear speed gradients being usually assumed. The main causative effects for these gradients are overburden pressures and possible changes in composition of the sediment, and there have been several studies on this. For example, both Dolmenico [15] and Taylor-Smith [17] have measured the effects of increasing static load on the sound speed, porosity and shear wave velocity of laboratory samples of sediments. Their relationships have been used by Ogushwitz [18] to compute sound speed profiles using Biot theory which have agreed with the measured data of Gardner et al [19] on Gulf Coast sands, and of Mulholland [20] on ooze from the Ontong-Java plateau as indicated in Fig.2. Extensive work by Carlson et al [21] has also suggested that to a depth of 1.4 km the physical state of sediments depends on overburden pressure and temperature. It has also been recently noted

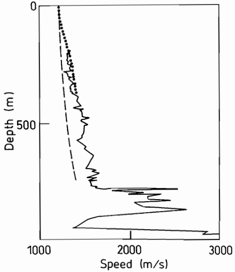

Figure 2. Relationship between sound speed and depth of sediment for an ooze-chalk-limestone sequence - solid curve from field data, dashed and dotted curves as predicted from Biot theory with different estimates of porosity (from Ogushwitz [18]).

by Hall [35] that these gradients lead to a coupling of the shear and dilatational waves.

Marine sediments are also in general characterised by a layered structure and may therefore exhibit anisotropy about the z (depth) axis. This problem has been investigated most notably by Yamamoto [22], and important feature being that only anisotropy of permeability seems to have significant effects.

B. Attenuation constants

Damping of acoustic waves in the sediment can be attributed to two mechanisms, the visco-elasticity of the skeletal frame and viscous damping due to relative motion of the permeating fluid and the solid particles. Biot theory can be used to predict the propagation attenuation, after appropriate values have been substituted for relevant parameters, such as the viscoelasticity of the frame modulus, permeability and pore size.

Attenuation constants have been measured on many types of sediment at different sites, many of the results being summarised by Hamilton [7]. Values of attenuation constant ( ) obtained from high frequency (> 10kHz) pulse transit methods range from .56 dB/m/kHz for very fine sands to .066 dB/m/kHz for clay silt [24]. Particular attention has been paid to the exponent n in the attenuation frequency (f) relationship

$$\alpha = bf^n$$

b being a constant. The value of n has been found to vary from 1.26 for fine sand to 1.0 for very fine sand, silt and clays. These different values are consistent with Biot's theory - n being greater for high permeability sediments which may exhibit additional damping in particular frequency ranges due to the effects of viscosity.

In recent years there have been a number of low frequency measurements [25-28,31] which indicated that attenuation might be as much as two decades lower than the values ex-

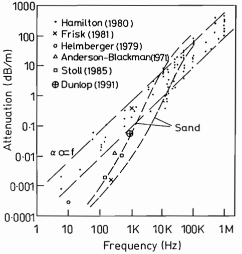

Figure 3. Laboratory and field data of sediment attenuation constant plotted against frequency. Also shown are curves of the calculated attenuations of two sand samples based on Biot theory (from Stoll [29]).

trapolated from Hamilton's high frequency data using the above equation. These discrepancies have been resolved to some extent by Stoll [29] who incorporated into Biot theory his measured values of frame damping. This is illustrated in Fig.3. which shows measured attenuation data and the prediction of Stoll's theory. Recent work at different frequencies by Holland and Brunson [16], and Dunlop [30] are in agreement with Stoll's predictions.

There is little published data on the variation of attenuation constant with depth into the sediment, such available data [10] indicating small changes in the top ten metres of the seabed.

4. OTHER ACOUSTIC PROPERTIES

Other acoustic properties might be considered, e.g. the characteristic acoustic impedance and thus the reflectivity properties of a sediment interface. A recent analysis [33] of Biot theory has shown that another wave type - a second kind rotational or shear wave - can propagate in a porous elastic solid such as fluid saturated sediments. However it is unlikely that either this wave or the second kind dilatational wave will be detected in marine sediments as their characteristic impedances indicate very small amounts of energy conversion, although their generation may have slight effects on reflectivities [6] at interfaces. Analysis of the reflectivity of the sea floor using Biot theory [34] has also indicated significant discrepancies in the traditional treatment of the sea-bed as a lossy fluid, some of which are illustrated in Fig.4.

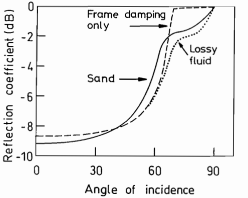

Figure 4. Relationships between the reflection coefficient and angle of incidence of an acoustic wave incident on a water sediment interface calculated by applying Biot theory to a sand sediment, the sand sediment with frame damping only, and a lossy fluid of the same approximate damping constant (from Dunlop [6]).

There have been extensive measurements of shear modulus and shear waves in sediments [36]. The significance of the shear modulus gradient in describing the acoustic reflectivity of the sea floor has been discussed recently by Hall [35]. The relation between shear modulus and the generation of other types of waves at the interface, notably Scholte and Love waves, has also been investigated [37] and this together with the connection between low frequency acoustic waves and seismic activity established by Kibblewhite [38] has been followed by Stoll's [39] investigation of seismic induced shear waves.

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1993 Australia Prize

The 1993 Australia Prize for scientific excellence will be awarded in the field of "Sensory Perception". The Minister for Science and Technology, Ross Free, in making the announcement said :

"Sensory perception covers scientific enquiry into perceptual and sensory mechanisms and processes associated with sight, sound and other senses in humans and animals".

It also covers ways that this knowledge can be applied to mimic, extend or replace parts of such sensory systems".
The Australia Prize is an international award of $250,000 for an outstanding achievement in a selected area of science and technology promoting human welfare.

It was first awarded by the Federal Government in 1990.

Mr Free said the Australia Prize showed the government's continuing commitment to excellence in science and technology, and recognised the significance of applying the results of scientific research in today's world.

Nominations for the Prize had already been sought worldwide and the winners will be announced in January 1993.

(Laboratory News Aug '92)

Ocean Acoustic Thermometry
- The Heard Island Feasibility Test, 1991

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Abstract: In January, 1991, a feasibility test of a new method of measuring global ocean temperature was conducted off remote Heard Island in the southern Indian Ocean. For five days, low frequency acoustic signals were transmitted from an underwater source to a number of hydrophone receivers around the world. A variety of coded signals were broadcast and travel-times measured to establish whether a future global network could use the observed variability of such acoustic travel-times to deduce very small changes in the temperature of the interior of the ocean.

1. INTRODUCTION

In 1989, Munk and Forbes proposed a novel solution to the problem of observing long-period changes in global ocean climate. They hypothesised that long-range acoustic transmissions (of order 10 Megametres) could be used to measure path-averaged temperature in the interior of the ocean simultaneously along many different paths . With an appropriate number of sources and receivers, such measurements would yield valuable information about the response of the ocean to atmospheric warming brought upon by, for example, increases in CO_2 and other "greenhouse" gasses.

Munk and Forbes' suggestion that an experiment be conducted to test the feasibility of the idea resulted in the Heard Island Feasibility Test (HIFT) of January, 1991. An outline of the experimental design, its conduct and preliminary results follow.

2. BACKGROUND

The idea that low-frequency long-range acoustics might be used to measure path-averaged temperature in the ocean sprang from Munk, O'Reilly & Reid's [1988] re-examination of a 1960 experiment by Shockley et al. [1982] in which 300 lbs of explosives were detonated near the sound axis off Perth, Western Australia. Signals from this event were recorded on axial-depth hydrophones cabled to shore in Bermuda, 18 Mm distant, 3.7 hours later. The success of such transmissions depends on both source and receivers being at or near the axis of the sound (SOFAR) channel. The SOFAR channel constrains (by refraction) acoustic rays from spreading vertically, so provides a low propagation-loss waveguide. Its axis is typically 1500 m deep in equatorial waters, 1000 m in temperate waters and rises close to the surface at high latitudes. Sound speed is a minimum at axial depth (Figure 1), so although acoustic energy which propagates axially is the last arrival in ray terms, over near-antipodal distances, these shallow rays may be the only ones to survive.

Accurate timing of the arrivals of acoustic signals over such ranges is essential to mapping temperature changes at axial depth. A warming trend of 5 m°C/year at 1 km depth (a typical result of doubling CO_2 in numerical models of coupled ocean-atmosphere circulation) would reduce travel time along a 15 Mm path by 150 ms. Techniques for determining arrivals to within an accuracy of 1 ms over 1 Mm range have been established for a decade in acoustic tomography [Spindel & Spiesberger, 1981, Munk & Wunsch, 1982]. Although 1ms pulses spread to 10 ms after 1 Mm travel in the ocean, tomographers depend on signal to noise ratios of about 20 dB to measure travel times of individual arrivals to about 10% of their width or 1 ms. At 15 Mm range, 1 ms pulses are expected to have spread to 150 ms, so with similar 20 dB SnR, our travel time resolution should again be 10% or 15 ms. This should be sufficient to detect a CO_2 -induced reduction in travel time of 150 ms in the

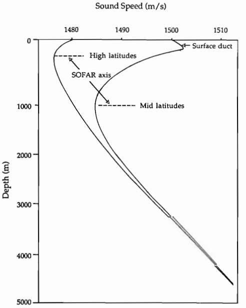


Figure 1. Generalised vertical profile of sound speed in the ocean. Acoustic thermometry takes advantage of the deep sound (SOFAR) channel axis.

presence of meso- and gyre-scale rms fluctuations (with time scales of months) which models show are of order 1 s.

Explosives are clearly not the acoustic source of choice but electrically driven acoustic sources are now available which will project phase- and amplitude-controlled low frequency energy (57 Hz, 208 dB re 1μPa) over reasonable bandwidth (±11.4 Hz). How did we use such sources in HIFT?

3. CONDUCT

The first and most critical decision was to select a transmission site which would provide the maximum number of independent acoustic paths to existing receivers, supplemented by a number of "receivers of opportunity". Refracted geodesic ray paths from a number of potential source sites were computed, allowing for horizontal refraction due to the poleward decrease of sound speed at axial depth. The source's operational depth limit was nominally 300 m, so a site where the sound channel axis was also shallow, and which permitted unimpeded transmission paths into the Atlantic, Indian and Pacific Oceans was chosen at latitude 53° 25' S, longitude 74° 30' E, 70 km southeast of Heard Island.

Communication between the source ship and 16 receiver sites (many of which were also ships) could not be guaranteed, so a firm transmission schedule was agreed upon and adhered to irrespective of delays or interruptions due to adverse weather or equipment failure. Table 1 lists the daily transmission schedule and signal characteristics. The signal characteristics were designed in detail by T.G. Birdsall and K. Metzger at the University of Michigan [Birdsall & Metzger, 1986].

Table 1. HIFT Signal characteristics and transmission schedule

Start Times (GMT)	Signal Type	f/±Df (Hz)	Digits/Q
0000 , 1200	CW	57	
0300 , 1500	Pentaline	57/5.7	3/10
0600 , 1800	M-Sequence	57/11.4	255/5
0900 , 2100	Long M-Seq.	57/11.4	511-2047/5

CW (single frequency) signals were sent continuously for one hour periods so although they could not be used for precise timing of arrivals they were the most robust indicator of the presence or absence of signal at extreme range. Two types of phase-modulated (± 45°) coded signals, Pentaline and M-sequence, were used. These codes leave half the power in the carrier. The Pentaline contained five major spectral lines easily identifiable with simple FFT processing at any receiver site. The M-sequences were designed specifically for coherent processing which has the potential for resolving ray-like arrivals, collapsing time-dispersed mode arrivals and measuring their amplitudes and stabilities individually.

The duration of each transmission was one hour, with a two hour period of silence between each transmission. This allowed the receivers to be certain of when they should and should not be receiving HIFT signals.

The above schedule was planned to operate for ten days, but equipment failure and bad weather forced an interruption after two days and a complete halt after five days. Figure 2 shows the time line and intensity of each transmission.

The source was actually a vertical array of five transducers

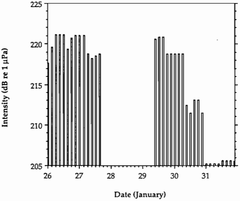


Figure 2. Timing and intensity of the HIFT transmissions. There was a 39 hour period of silence centred on January 28 while repairs were made to the acoustic source array.

each separated by about 8 m, centred at the axial depth of 150 m. They were driven in phase but due to their less-than-ideal separation (1/2 λ at 57 Hz is 13 m), did not form a particularly well-behaved horizontal beam. The general decrease in total intensity from start to finish is the result of steady attrition of sources from five on Jan 26 to one on Jan 31. Nevertheless, sufficient energy entered the sound channel to propagate halfway round the world, westward to Bermuda (and even to Nova Scotia) and eastward to California, even with only one source operating.

4. RESULTS

A map of the successful paths is shown in Figure 3. At most of the receiving stations the answer to the first question (is it loud enough?) was emphatically, yes (measured signal to noise ratios were in the range 5-35 dB). An exception was the Japanese receiving ship operating near Samoa. Although the New Zealanders in the Tasman Sea had good receptions, the signals apparently did not reach Samoa. Further evidence came from the west coast of the USA, where receivers with beam-forming capability showed that the received energy came from around the south of New Zealand, and not through the Tasman.

The second, and more important question was - can we resolve the signals well enough to achieve the required accuracy of 15 ms in travel time? The answer to that question is more complex. The sources were moving, suspended from a ship, so that horizontal accelerations in the ship's motion induced non-linear doppler shifts in frequency at the receivers. Processing the received M-sequence signals was as follows: complex demodulation, doppler identification and compensation then sequence removal. After perfoming these analyses on the Ascension Island receptions, the resulting time-resolution is about 100 ms. Removal of the effects of modal dispersion holds the key to reducing this closer to 15 ms. This is still currently being pursued.

Three examples of receptions at Ascension Island are shown in Figure 4, one for each of the three signal types, together with the spectrum of the transmitted signals. Note the onset of arrivals at 13 minutes after the start of recording, and the equally sharp cutoff after one hour of transmission (at least for the M-sequence). At carrier frequency, an "afterglow" persists which masks the cutoff for the CW

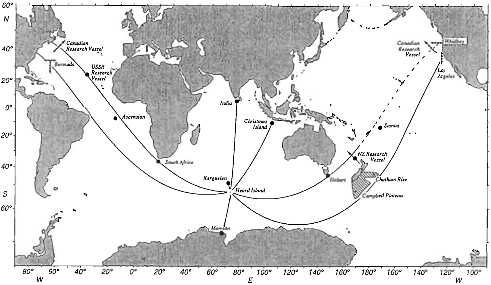


Figure 3. Successful transmission paths from Heard Island to receivers in the Atlantic, Indian and Pacific Oceans. The dashed portion of the Heard Whidbey path is in doubt.

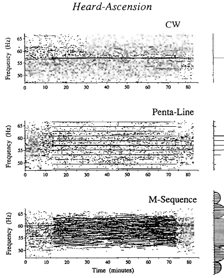


Figure 4. An hour-long example of each type of signal as received at Ascension Island. To the right is the spectrum of each transmitted signal.

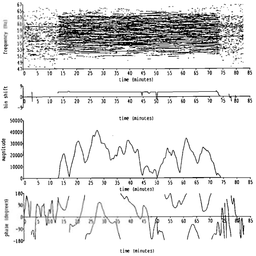
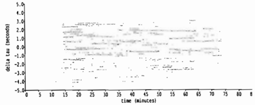


Figure 5. Detail of a one hour's reception of an M-sequence signal at Ascension Island. The bin shift (1 unit = 0.0139 Hz) represents the Doppler shift due to source-ship motion.

and Pentaline, but its amplitude is markedly reduced, as shown in Figure 5. This low amplitude, late arriving energy is probably from a number of diffuse reflectors along the path, not a single point reflection, so it's path remains unidentified.

If we look in the time-domain at "dot plots" which represent the persistence of individual arrivals, we see that coherent integration should be possible for periods of 10 to 20 minutes at a typical station such as Ascension Island (Figure 6a) and for nearly an hour at Christmas Island (Figure 6b). The difference in the coherency time scales is almost certainly due to the undisturbed path from Heard to Christmas, while the Heard to Ascension path must pass through the eddy-rich region spawned by the Agulhas Retroflection, south of the Cape of Good Hope.



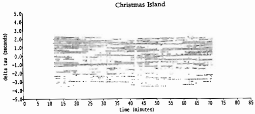


Figure 6. Arrival time dot plots for one hour's reception at Ascension (a) and Christmas Islands (b). Note the longer persistence of individual arrivals at Christmas than at Ascension Island. Delta tau is the time delay (in seconds) of arrivals relative to a reference time which has been corrected for source-ship motion.

Two vertical hydrophone arrays were deployed during HIFT, one off Southern California and the other off Bermuda, which were designed to allow the separation of vertical modes (if any survived further than 10 Mm). The one off Bermuda was recovered after some months and unfortunately did not contain any data, but the one off California did contain some useful records. They show that some higher order modes appear to have survived the trans-Pacific path, although precise modal identification is difficult.

5. CONCLUSIONS

The feasibility test has shown several key points:

1. Near-antipodal transmissions are possible with electrically-driven sources
2. Future sources could be as quiet as 195-200 dB re 1μPa, but must be more reliable than anything currently on the market
3. Single-hydrophone receivers are adequate, but mode-resolving vertical arrays are needed at some strategic points to improve travel time resolution to that needed to detect climate change in the ocean
4. A small number of widely distributed sources are required to obtain adequate coverage of the large shadow zones left by HIFT

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Reflectivity Of Sand Seabeds At A Frequency Of 10 Hz

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Abstract: Acoustic transmission loss in shallow water is sensitive to the plane-wave reflection coefficient (R) of the sea-floor, which can be affected by the shear modulus profile. For the purpose of demonstrating this effect, marine sand is modelled as a visco-elastic, one-phase medium in which density is constant, the first Lame modulus (λ) is constant, and the shear modulus (G) is isotropic and increases with depth in accordance with the results of relevant measurements. Such a medium is heterogeneous, so the shear (S) and compressional (P) displacement potentials do not in general satisfy separate wave equations. Determination of R therefore requires a fundamental analysis of the equations of elastic motion, which has been achieved using Richards' method of weakly-coupled potentials. The resulting model, called SAMEC, is applied to a geoacoustic profile for coarse sand (36% porosity), at a frequency of 10 Hz. The profile was derived using the Iwaski-Tatsuoka model for Real (G), and the Biot-Stoll model for λ and Imag (G). The ratio R/R_L, where R_L is reflectivity calculated by modelling the seabed as a liquid, is always less than unity. This ratio is a minimum at grazing angles of about half the critical grazing angle, and at these angles its value (at 10 Hz) is -0.2 dB. For transmission of 10 Hz sounds in water 200 m deep, over a coarse-sand seabed, the corresponding effect is to increase the Transmission Loss at 100 km range by 13 dB.

1. INTRODUCTION

Sound transmission in the ocean is affected by the reflectivity (R) of the seabed, especially in shallow water. This paper considers a sand seabed and the depth dependence of its shear modulus, and addresses the effect of coupling between compressional and shear waves on its reflectivity. It will be shown that long-range Transmission Loss is sensitive to this effect. Attention will be focussed on the lower boundary of the audio-frequency band, namely 10 Hz. The effects of roughness of the sea-floor will be neglected, since only extremely rough sea-floors would cause significant scattering at a frequency of 10 Hz.

Only one type of seabed will be addressed, namely a half-space of unconsolidated uniform coarse sand grains. Shallow reflecting layers (presumably of consolidated grains) often occur in continental shelves, but their effects are beyond the scope of this paper.

The acoustic properties of the seabed are the terms that are substituted into the wave equation and the boundary conditions in order to determine its reflectivity. In general, these properties are the profiles of the density and the elastic moduli. The density ρ_b of unconsolidated seabed is either measured or calculated by averaging the densities of the granular material, ρ_r, and the pore water, ρ_w, taking into account the porosity β of the seabed:

$$\rho_b = \beta\,\rho_w + (1 - \beta)\,\rho_r . \qquad (1)$$

Under the assumption that the elasticity at any point is isotropic, only two elastic moduli are required, and of those available the bulk (B) and shear (G) moduli will be discussed. A third parameter, the Lame modulus (λ_b), will sometimes be referred to. This modulus is related to B and G by [Pollard, 1977, p. 14]:

$$B = \lambda_b + 2/3\,G .$$

2. ELASTIC PROPERTIES

The results of many measurements have indicated that the shear modulus of an unconsolidated granular medium depends on P_c, the average of the three orthogonal inter-grain pressures, or "confining pressure" [Stoll 1989, p. 89]:

$$G = L\,P_c^{\,p}, \qquad (2)$$

where the coefficient L is independent of P_c. Typical results for the exponent p have lain between 0.4 and 0.6. According to Contact theory [Stoll 1989, p. 54], p = 1/3. For their lowest strain of 10^{-6}, Iwasaki and Tatsuoka [1977] concluded from their measurements that

p = 0.4 ;

and that (converted to S.I. units),

$$L = 900\,\frac{(2.17 - e)^2}{1 + e}\,(10^4 g)^{0.6}, \quad 0.61 < e < 0.86, \qquad (3)$$

where e, the void ratio, is related to porosity by $e = \beta/(1 - \beta)$. [The corresponding range of porosities for Eq. (3) is $0.38 < \beta < 0.46$].

The confining pressure within a granular medium is calculated as follows. For a medium under its own weight only, and for constant ρ_b, the vertical inter-grain (effective) pressure at depth z is given by [1]:

$$P_e(z) = (\rho_b - \rho_w)\,g\,z , \qquad (4)$$

where g is gravitational acceleration. In terms of the Lame modulus λ_b and shear modulus G, Hooke's law for stress σ_{ik} in an isotropic medium may be written [Pollard, 1977, p. 14]:

$$\sigma_{ik} = \lambda_b\,(\varepsilon_{11} + \varepsilon_{22} + \varepsilon_{33})\,\delta_{ik} + 2\,G\,\varepsilon_{ik} ,$$

where ε_{ik} are the strains. Since there is no horizontal normal strain ($\varepsilon_{11} = 0$ and $\varepsilon_{22} = 0$), the resulting vertical normal strain ε_{33} is given by

$$- P_e(z) = \sigma_{33} = (\lambda_b + 2\,G)\,\varepsilon_{33} ,$$

and the horizontal pressures are each given by

$$- P_h(z) = \sigma_{11} = \sigma_{22} = \lambda_b \, \varepsilon_{33} .$$

The average of the three pressures is therefore:

$$P_c(z) = - (\lambda_b + 2/3\ G)\, \varepsilon_{33}$$

$$= \frac{\lambda_b + 2G/3}{\lambda_b + 2G} P_e(z) . \quad (5)$$

The numerator and denominator in Eq. (5) are the bulk and plane-wave elastic moduli respectively.

From Eqs. (2) and (5), it can be seen that G depends on P_c, which in turn depends on G. Obtaining the G(z) profile is therefore not a straightforward process. Near the sea-floor however, $G << \lambda_b$, and P_c in Eq. (2) may be replaced by P_e, which is given by Eq. (4).

At the sea-floor (z = 0), the inter-grain confining pressure is zero and the shear modulus there, denoted by G(0), is also zero. Since seabeds are two-phase coupled media (comprising water and solid grains), there are two bulk (or compressional) waves, called the first and second kind waves. The corresponding bulk moduli will be denoted by B_1 and B_2 respectively. Since G(0) = 0, the bulk modulus of the first kind of wave at the sea-floor, $B_1(z{=}0)$, is obtained by averaging the compressibilities of the granular material (B_r^{-1}) [2] and the pore water (B_w^{-1}), to give the Wood (1941) equation:

$$1/B_1(0) = \beta / B_w + (1 - \beta)/B_r .$$

At depth z beneath the sea floor, $B_1(z)$, which is quasi-real (Imag B_1 << Real B_1), is given approximately by

$$B_1(z) = B_1(0) + \Delta B(z) ,$$

where $\Delta B(z)$ is the Bulk modulus of the granular structure if it were in a vacuum but subjected to the same confining pressure. ΔB is proportional to G (which is unaffected by the presence of liquid), and the coefficient of proportionality depends on the grain packing and the elastic Poisson ratio of the granular material[3]. Data cited by Hamilton [1976] for the compressional and shear speeds in unconsolidated seabeds indicate that these speeds vary with confining pressure in such a way that λ_b is slowly varying, at least for depths up to the order of 100 m.

The dispersion in the three elastic moduli (B_1, B_2, and G) and the corresponding Kramers-Kronig causality peaks[4] in the spectra of their imaginary parts are calculated from the seabed's geophysical properties using the Biot [1956] porous medium theory as developed largely by Stoll [1989]. From examples presented by Yamamoto [1983], it can be seen that the bulk modulus of the second kind of wave (B_2) is proportional to G and increases with frequency, but whereas G is quasi-real, B_2 at low frequencies is quasi-imaginary (Real B_2 << Imag B_2). Since $|B_2| = 0$ at z = 0, its effect on water-borne sound should be small: as frequency decreases the longer waves sense the value of B_2 at greater depth, but this is offset by the frequency-dependent decrease in B_2.

A useful list of the 13 geophysical inputs required for the Biot theory has been presented by Holland and Brunson [1988]. Some of these properties, such as structure factor (α), porosity, permeability, and pore-size (a_p), are correlated with grain-size. The Biot/Stoll theory gives plausible predictions for a structure of uniform spheres, but its extension to a wide variation in grain sizes or grain shapes is not yet on a firm footing. Porosity may be estimated from the mean grain-size using the scatter-diagram published by Hamilton and Bachman [1982][5], but in actual seabeds there is a spread in grain-size and grain-shapes.

3. THE REFLECTIVITY COEFFICIENT

Since the seabed is a solid, both vertically polarized shear (SV) and compressional (P) wave motions are excited in it by an incident compressional wave. In a heterogeneous solid medium the SV and P displacement potentials do not in general satisfy separate wave equations [Richards, 1974]. Gradients in the G(z) profile cause continuous coupling between the P and SV vibrations, the significance of which increases as frequency decreases (longer wavelengths will sense a larger value for G) [6].

Determination of R therefore requires either: (i) that the seabed be characterized by a number of homogeneous layers and the separate wave equations solved using the Thomson-Haskell method - e.g. Fryer [1981]; or (ii) that a fundamental analysis of the equations of elastic motion be undertaken. The latter has been achieved [Hall, 1990] using Richards' [1974] method of weakly-coupled potentials. In Hall's reflectivity model, ρ_b is assumed to be independent of depth, and λ_b is given by

$$\lambda_b(z) = \lambda_0 + m\, G(z)$$

where m is a constant[7]. For the G(z) profile as given by Eq. (2), the derivative G'(0) does not exist (since the exponent p < 1) [8]. In order to obtain an analytic function for G, and one for which the second derivative at the sea-floor is zero, as is required to keep the analysis tractable, G is modelled by:

$$G(z) = \frac{\Gamma z}{(1 + k z^2 / D^2)^{0.3}} , \quad (6)$$

where D is the grain diameter, and k is around 4 [9]. The initial gradient Γ is chosen so that Eq. (6) will be consistent with Eqs. (2) and (5) at z >> D. In the mathematical analysis, the depth component (Z) of the P displacement potential in the seabed satisfies a second order linear differential equation whose coefficients are functions of G and its derivatives up to third-order[10]. An expression for R is obtained by requiring the fields to satisfy the boundary conditions (continuity of normal particle displacement and normal stress) at the sea-floor.

Since the real part of G increases without bound as depth becomes infinite, there is no loss of either compressional or shear energy to infinite depth [11].

The geophysical properties for the case of a uniform coarse quartz sand (Mean grain diameter = 0.7 mm [0.5 ϕ-units], standard deviation = 0), underlying a water medium whose density and sound-speed are 1024 kg/m^3 and 1520 m/s respectively, were calculated as: porosity = 0.36 [Hamilton and Bachman, 1982]; density = 2065 kg/m^3 [Eq. (1)]; and static permeability = 3.2×10^{-10} m^2 [Holland and Brunson, 1988]. By solving the resulting (quadratic) compressional frequency equation (Stoll, 1989, p. 15) at 10 Hz, the compressional sound-speed c_p at the sea-floor has been found to be $c_p(0) = 1693 + i\, 9$ m/s. The shear frequency equation [Stoll, 1989, p. 19] is solved for shear-speed c_s at an arbitrary large depth. The corresponding value of G is $\rho_b c_s^2$, which when substituted into Eq. (2) yields $L = (1.47 + i\, 0.018) \times 10^6$ SI units.

The corresponding result calculated from the reflectivity model is shown in Figure 1 as a function of grazing angle. The solid curve shows the reflectivity obtained when coupling between the P and SV waves is included, while the dashed curve shows the approximate result obtained if the coupling is neglected. It can be seen that neglecting the coupling over-estimates $|R|$, particularly at about half the critical grazing angle, where the difference is 0.2 dB. At higher frequencies the effect of the coupling would be less, because as the wavelength decreases the wave senses a lower value of G.

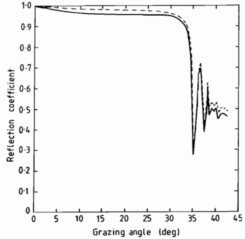

Figure 1. Reflectivity vs Grazing angle of a coarse quartz sand at frequency 10 Hz. Key: ———— Coupling between P and SV waves included; - - - - - P-SV Coupling neglected.

An interesting feature of the reflectivity results is the difference between the calculated critical angle at the sea-floor and the apparent critical angle from the curve. The reason for this is that at low-frequency, the absorption is small and the waves refracted at significant depths make a significant contribution to the reflection. Thus at 10 Hz the apparent critical angle is about 32°, whereas the sea-floor critical angle is arcos (1520 /1693) = 26°. At higher frequencies, with higher absorption, sub-bottom refraction will be negligible and the apparent critical angle will merge with the sea-floor value.

4. TRANSMISSION LOSS IN THE WATER COLUMN

Although an error in reflectivity of 0.2 dB over a limited range of angles does not appear to be significant, it can be important for long range Transmission Loss (TL) in shallow water because the number of reflections will be large. Most normal-mode TL models require the geo-acoustic parameters of the half-space to be specified as constants within a small number of layers. In order to replicate the reflectivity curves shown in Fig.1, the geo-acoustic parameters for cases with and without coupling were given values as follows [12]:

	Coupling Included	Coupling Neglected
Compressional Speed (m/s)	1792 + i 9	1792 + i 9
Shear Speed (m/s)	342 + i 2	0 + i 0

On running the normal-mode program STOKES [Hall, 1992] with a water depth of 200 m, Mode 1 at 10 Hz was found to have a damping rate of 0.213 dB/Km, whereas the no-coupling approximation resulted in a value of 0.086 dB/Km. Over a range of 100 Km, the difference in TL should therefore be 13 dB. This is borne out by the example calculation of TL shown in Fig. 2 (for which the source and receiver are both at a depth of 50 m). At 100 Km, the correct TL is 102 dB and the no-coupling approximation predicts a TL of 89 dB. Figure 2 can also be used to examine the impact that neglect of coupling has on detection ranges. If the threshold TL for detection were, for example, 85 dB, then the corresponding detection ranges would be 67 and 40 Km respectively. Neglect of coupling in the seabed can therefore result in a significant over-estimation of the detection range.

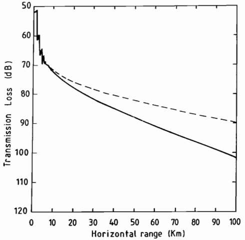

Figure 2. Transmission Loss at frequency 10 Hz in water of depth 200 m over a coarse quartz sand seabed. Key: as for Fig. 1

5. CONCLUSIONS

(a) An intrinsic property of an unconsolidated seabed is that it is inhomogeneous by virtue of the depth-dependence of its elastic moduli. There is therefore coupling between the shear and compressional waves.

(b) For coarse sand at a frequency of 10 Hz, omission of this coupling can increase the predicted seabed reflectivity by 0.2 dB, and cause long-range Transmission Loss to be significantly under-estimated.

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FOOTNOTES

1 the hydrostatic pressure is subtracted from the total pressure since it does not contribute to the inter-grain stress (if the grain density were equal to the water density, the inter-grain stress would be zero)

2 It is of interest in this context to compare the properties of calcite and quartz (the 2 predominant minerals in marine sand). Their densities are similar (2170 and 2650 kg/m^3 respectively), whereas their bulk moduli are quite different (77 and 38 GPa). Hence it is important to also know the mineralogy of a seabed.

3 For face-centred cubic packing of uniform spheres (β = 0.260), ΔB= 2/3 G (independent of the grain Poisson ratio ν) and the depth-variation in Lame Modulus ($\Delta\lambda$) beneath the sea-floor is zero. For simple cubic packing (β= 0.476), ΔB

$$= \frac{(2+\nu)}{3(1-\nu)} G \text{ and } \Delta\lambda = \frac{\nu}{1-\nu} G. \text{ (For quartz, } \nu = 0.15.)$$

4 The Kramers-Kronig relations between the real and imaginary parts of a coefficient of proportionality between a cause and an effect, such as a modulus of elasticity, are derived from the conditions that the cause and effect are both real functions, and that the effect cannot precede the cause.

5 Care must be taken not to apply their regression equation to a seabed whose mean grain-size is coarser than 2 ϕ, for which it will predict too low a porosity (as can be seen from the scatter-diagram).

6 Conventional analyses (Stoll, 1989) treat the sediment as homogeneous and therefore predict no coupling between the fast bulk wave and the shear wave.

7 For simple cubic packing of grains, $m = \frac{\nu}{1-\nu}$
(for quartz grains, m = 0.177)

8 A simple way to handle this singularity would be to represent G(z) by a Heaviside step function at the sea-floor (z=0), but there is no obvious choice for the constant value to be ascribed to G.

9 On the basis that, for simple cubic packing, the grains in the first layer touch 5/6 as many grains as those in the underlying layers, so the shear modulus at depth D/2 should be reduced by that factor (in addition to the variation in confining pressure), it can be shown that $k = \frac{4(9-d)}{9(d-1)}$, in which $d = (6/5)^{1/0.3}$ (giving k = 3.8)

10 Quasi P and S potentials in the seabed satisfy (coupled) second order linear differential equations. By requiring displacement and stress to satisfy boundary conditions at the sea-floor, an expression is derived for R that includes, amongst other things, gradient G'(0) and ratio Z(0) /Z'(0), where Z(z) is the quasi P potential function. Providing G" (0) = 0,R is independent of the quasi S potential. In the Born approximation, Z(0) /Z'(0) is unaffected by coupling to or from the quasi S wave. The initial value of Z'(z) /Z)z) at a large depth is obtained by converting the second-order d.e. to a Helmholtz equation (the coefficient of which depends on G and it derivatives through to fourth order) and solving this using the WKB method. The ratio Z'(z) /Z(z) is given by a Riccati expression that is integrated numerically from the large depth to the sea-floor.

11 If G and λ_b are both real, there is no loss of sound energy to heat, and $|R| = 1$ at any grazing angle.

12 The sound-speed in the water column was set to a constant 1520m/s. c_p = 1520/cos 32°, imag (c_s) was obtained from the Biot/Stoll model, and real (c_s) was determined so as to match the reflectivity curve in Fig. 1. at the angle where the difference between the two curves is the greatest (namely around 15°).

The Ultimate Limits of Lithography

In 1959 the celebrated physics Nobel laureate Richard Feynman first posed the question: "Why can't we write the *Encyclopaedia Brittanica* on a pinhead?". If an electron beam could be focused to a spot only one atom in diameter, he reasoned, then it might interact with individual atoms on a surface and writing on an atomic scale would be possible.

Recent advances in electron optics have now made this feat possible. A group at Cambridge University have used a focused electron beam (diameter of beam 0.5 nm) to write a portion of the Encyclopaedia Brittanica sufficiently small to demonstrate that the entire Encyclopaedia could indeed be put on a pinhead. The same technique has been used to write the Institute of Physics logo by cutting dots through a piece of amorphous aluminium oxide 50 nm thick. Each dot has a diameter of 5 nm which is 50 times smaller than currently possible with conventional optical lithography.

Advances in lithography have enabled dramatic progress to be made in microelectronics. In 1960 there was one device on a silicon chip - now there can be over 50 million. The potential to produce structures ten times smaller than currently available will greatly increase the power of semiconductor technology. If structures 100 or 1000 times smaller can be produced a new breed of quantum device may be possible. Nanometre-scale lithography will also be increasingly used to develop nanostructures for biological and medical applications.

(Extracted from 'Ultimate limits of lithography' by C Morgan, G S Chen, C Boothroyd, S Bailey and C Humphreys in Physics World, November 1992).

Acoustic Bottom Backscatter Measurements At High Frequencies

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Abstract: The backscatter of acoustic energy from the sea floor has been measured in shallow water, at acoustic frequencies of 100 kHz and 200 kHz. Measurements are reported for a location off Cairns with a muddy-sand bottom with extensive bioturbation. Measurements were made as a function of acoustic grazing angle and azimuth. Site environmental measurements were also made, to characterize in detail the area of the acoustic measurements. The equipment developed for these measurements is briefly described.

1. INTRODUCTION

The backscatter of acoustic energy from the sea floor is of significance to the performance of active sonar systems. The backscattered energy gives a background signal against which a sonar must work. Experimentally determined bottom backscattering strength has been reported by a number of authors, including McKinney and Anderson, [1] Boehme et al [2] and Stannic et al. [3] Since the basic processes involved in high-frequency bottom backscattering are not completely understood, direct measurements of this parameter are required in order to help in the development and verification of models. The measurements reported here are the first measurements in the Australian region of bottom backscatter at such high frequencies.

This paper briefly describes the equipment used to make the backscatter measurements, the measurements themselves and the supporting environmental measurements. The acoustic measurements were performed over a range of grazing angles from 2° to 90°. Azimuthal dependence of the backscatter was also investigated. The environmental measurements included side-scan sonar survey, sound-speed profiles, sediment samples and stereo photography.

2. EQUIPMENT

Two distinct sets of apparatus were used to collect data on bottom backscattering. In both cases the apparatus was mounted on the sea floor and used a mechanism for moving directional transducers so as to ensonify the sea floor at different angles. The electronic package used for controlling the experiment and collecting the data was the same for each case.

The first set of apparatus, known as the tower, was based on a structure consisting of a metal frame-work tower mounted on a steel reinforced concrete base (Figure 1). The transducers were located at the very top of the tower on a pan and tilt mechanism which allowed the transducers to be trained in elevation and azimuth. The underwater electronics package was mounted within the metal structure. The centre of the transducers was 4.84 m above the sea floor, the concrete base was 1.55 m wide, and the tower tapered to a width of 0.40 m at the base of the pan and tilt mechanism. The tower was instrumented with tilt sensors to report the attitude of the structure, and with a compass to report the orientation of the structure.

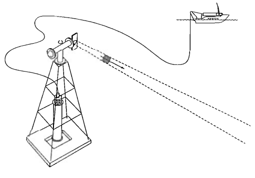

Figure 1. Arrangement of tower on sea floor, showing umbilical to surface.

The tower allows measurement of bottom backscattering strength as a function of grazing angle, with measurements able to be made at grazing angles from 50° to 2.5°. It is inherent in this technique that the region of the sea floor being ensonified is not identical for each grazing angle. The ability to sweep the transducers in azimuth allows the variation of backscatter with azimuth to be investigated.

The second set of apparatus, known as the frame, was based on a structure of a metal frame-work cube of approximately 3 m on each side (Figure 2). Attached to the base of the cube was an A-frame which could be rotated about an axis close to the sea floor. The transducers were mounted at the tip of the A-frame with the acoustic axis of the transducers aligned with the direction of the A-frame. Thus as the A-frame was rotated, the grazing angle of the acoustic energy at the sea floor also changed. The distance from the face of the transducers to the axis of rotation was 2.22 m. The frame was also instrumented with tilt sensors and a compass. It also had a video camera and flood lighting. A stereo camera pair was mounted so as to obtain stereo photographs of the region of acoustic backscatter.

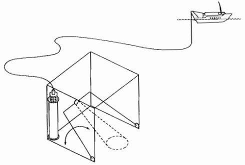

Figure 2. Arrangement of frame on sea floor, showing umbilical to surface.

The frame allows measurement of bottom backscattering strength as a function of grazing angle, with measurements able to be made at grazing angles from 90° to 2.5°. The advantage of this apparatus is that the region of the sea floor being ensonified remains approximately the same for each grazing angle. A disadvantage is that the short range of acoustic transmission results in only a small patch of the sea floor being ensonified; this means that the results may be less representative than results obtained from relatively large ensonified patches. The frame has no capability of sweeping the transducers in azimuth.

Separate, adjacent transducers were used to transmit and receive the acoustic energy. Each transducer had a single circular slab of piezoelectric ceramic as the driving element. Two transmit/receive pairs were used, one at a frequency of 100 kHz and the other at a frequency of 204 kHz. The beamwidth of the 100 kHz transducers was 14° and of the 200 kHz transducers was 8° on the tower and 12° on the frame. The beamwidths at the two frequencies, for the frame, were deliberately chosen to be similar in order to measure the bottom backscatter from essentially the same patch of sea floor.

The apparatus on the sea floor was controlled by a set of electronics mounted in a pressure tight housing. At the core of this electronics was a PC-compatible computer. This computer directly controlled such items as the transducer transmit signal, the pan and tilt mechanism, the A-frame mechanism, and the stereo camera. It also monitored the readings of the inclinometers, the compass, and the position of the moving items.

The acoustic transmit signal was sent out as a short pulse of energy. The mode of the transmitted pulse could be selected between continuous wave or frequency-modulated. The transducer transmit signal was entirely generated in this sea-bed apparatus, with the centre frequency, pulse length, mode type, and mode characteristics (such as length of FM sweep) all being set via the wet-end computer.

The wet-end electronics was connected to the ship by an umbilical cable. This cable served to directly relay the acoustic returns to the dry-end electronics on the ship, and also served to pass control and monitoring messages between the dry-end and the wet-end. At the dry-end, there was one computer for control and monitoring of the experiment, as well as a second computer for digitizing and logging of the returned acoustic data. The acoustic signal was rectified and low pass filtered to 20 kHz before being digitized at 10^5 samples per second and stored on optical disk for later analysis.

Calibration of the acoustic measuring system was performed in a configuration with the transducers facing each other, separated by approximately 3 m (which is well beyond the near-field distance for these transducers). By passing a signal through the entire system, the calibration directly included all elements. The remaining effects to be allowed for in the actual backscatter measurement are the acoustic path (spreading and absorption effects) and the ensonified area on the sea floor.

3. EXPERIMENTS

The experiments were carried out using the vessel HMAS Protector in three locations off Cairns (latitude 16°S) in north Queensland. This region is tropical and has a muddy-sand sea floor showing evidence of considerable bioturbation. There are no discernable ripples or other periodic features, but many burrow-holes and mounds are evident, the size of which varies from a few millimetres up to 0.5 m or more in length.

Measurement of sediment samples from the sites of the experiments showed the sediment to be mostly mud, with the peak value of ϕ varying from 3 at the shallowest site to 5 at the deepest site (ϕ is a logarithmic measure of grain diameter, with ϕ values of 3 and 5 corresponding to grain diameters of 0.12 mm and 0.03 mm respectively). The water depths were between 22 and 58 m at the various sites.

Prior to the bottom backscatter measurements, a side-scan sonar survey was made of each area. Mosaics were constructed from the side-scan paper records and the sites for detailed measurements were selected by referring to these mosaics. Sites were chosen on the basis of being representative of the area and being uniform over the region ensonified during the backscattering measurements.

Measurements of bottom backscattering strength were made while sweeping the grazing angle and also (using the tower) while sweeping the azimuthal angle. Measurements were made at a number of locations in each region.

Grazing angle was varied by setting the transducer tilt to the desired elevation. Between 0° and 15° the grazing angle was incremented by 2.5° steps. Above 15° grazing, the interval was 5°. The actual grazing angle of transmissions was calculated by taking into account the transducer tilt and the structure inclination in X and Y directions (orthogonal in horizontal plane).

The length of sample recorded was varied with grazing angle, ensuring that it always extended beyond the time interval of the return. At each grazing angle, acoustic returns from 50 pings (acoustic pulses) were recorded.

Stereo photographs of the sea floor were taken from the frame, during the backscattering measurements. The sound speed profile was measured during each acoustic measurement either by direct measurement of sound speed or by calculation from measured temperature and salinity.

4. RESULTS

The bottom backscattering strength S_b is calculated from

$$S_b = RL_b - SL + 40 \log r + 2\alpha r - 10 \log A$$

where SL is source level, RL_b is reverberation level, r is range, α is absorption coefficient (Francois and Garrison [4]), and A is the area of sea bottom ensonified. The area ensonified depends on both the transducer beam pattern and the acoustic pulse length. At the high frequencies and warm temperatures occurring during these measurements, the choice of absorption model is important.

For each acoustic pulse, or ping, the mean level of the backscatter return was calculated by taking RMS average of data points corresponding to a narrow spread of angles centered about the grazing angle. Thus time discrimination is used to select a narrow angular aperture, which was chosen to vary with the secant of the grazing angle from ±1° at 60° grazing, to ±0.5° at 2.5° grazing.

The linear average and standard deviation of the RMS values were then computed from 50 pings. Pings whose average level was more than 3 standard deviations from the mean were rejected from the data set. The mean of the filtered data set was recalculated to give the average bottom return.

The beam patterns of the transmit and receive transducers were circularly symmetric, and the ensonified area of the bottom was taken to be the projection on the bottom of the circular beam at the -3 dB points of the beam. At most angles the area was further limited by the pulse length, resulting in the ensonified area being given by

$$A = r\beta\ (c\tau / 2\cos\theta_g)$$

where β is the beamwidth of the transducer, c is the speed of sound, τ is the pulse length, and θ_g is the grazing angle.

Some typical results are presented here. Figures 3 and 4 show results, at frequencies of 100 and 200 kHz respectively, for the deepest site (water depth 58 m and ϕ = 5). These results were obtained with the tower, used over five different azimuths each separated by 45°. In these figures, the different point shapes represent different azimuths. Figure 5 shows results, at frequency of 100 kHz, obtained with the frame at the shallowest site.

The continuous curve shown on each of these figures is a least squares fit proportional to the square of the sine of the grazing angle. It is evident that this curve underestimates the backscatter at small grazing angles and overestimates at large angles.

As is evident in these figures, little azimuthal dependence of backscatter was observed. By comparing Figures 3 and 4, the difference between 100 kHz and 200 kHz can be examined. The 2 dB excess of the backscatter at 100 kHz compared to 200 kHz is typical for the results obtained. By comparing Figure 5 with Figures 3 and 4, it is evident that the scatter in results for the frame is considerably larger than the scatter for the tower. This is probably caused by the averaging of backscatter over a larger ensonified area for the tower measurements.

Although not illustrated here, we can report that the mean backscatter results from the tower and the frame were quite close to each other. Also, backscatter results comparing frequency-modulated and continuous pings also were quite close to one another.

5. CONCLUSION

The techniques developed have permitted accurate measurements of bottom backscattering strength. Measurements have shown consistent results. It is noteworthy that the backscatter at 200 kHz is measured to be slightly less than at 100 kHz, contrary to the prediction of most models.

It is intended to report in a later publication a more detailed account of the backscatter results obtained and of the ancillary environmental measurements. Fitting of the data with sophisticated bottom backscattering models will also be investigated.

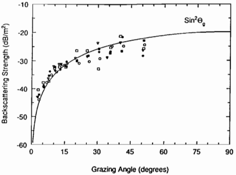

Figure 3. Bottom backscattering strength, frequency 100 kHz, shallow site N1, tower measurement.

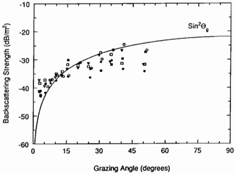

Figure 4. Bottom backscattering strength, frequency 200 kHz, deep site N1, tower measurement.

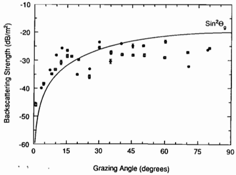

Figure 5. Bottom backscattering strength, frequency 100 kHz, shallow site W1, frame measurement.

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Acoustic Scattering from the Sea Surface

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Abstract: This paper gives a brief summary of current theoretical and numerical work on the problem of scattering from the sea surface. The surface is treated as a random process. The Kirchhoff and perturbation theories for this problem are summarised. The direct numerical treatment of the problem for a model surface varying in one dimension only is discussed and a summary of some recent results is given. Finally the extension of these techniques to deal with the fully three-dimensional problem of scattering from a two-dimensional surface is briefly outlined.

1. INTRODUCTION

When sound propagates through the ocean scattering occurs in the vicinity of the sea surface due to a number of mechanisms. These include volume scattering caused by changes in sound speed in the upper ocean, interaction with bubble plumes near the sea surface and surface scattering at the rough interface between the sea and the atmosphere. All three processes are significant and all three are usually present in practice. Volume scattering in the ocean has been studied extensively both analytically and experimentally in the last twenty years, and significant advances have been made (Ewart and Reynolds [1], Flatté et al [2], Uscinski [3]). Bubbles are present near the sea surface for a number of reasons, but in particular they are formed by plunging breakers. Indeed by studying the acoustic backscattering from the bubble distributions near the sea surface using relatively simple sonar apparatus, Farmer and co-workers have been able to infer much about the two-dimensional distribution of breaking surface waves, a problem that has defied analysis by more conventional oceanographic measurement techniques. Such work has been at the forefront of the new field of acoustic oceanography (see for example Farmer and Vagle [4]). Henyey [5] gives a theoretical treatment of scattering from these near-surface bubble plumes. The third process, scattering of sound at the interface of the ocean and the atmosphere, is discussed below.

2. FORMULATION OF THE SCATTERING PROBLEM

It is reasonable to model the ocean surface as a random process, where the one-point probability density function of wave amplitude is approximately normal (Phillips [6]). The process is then completely specified by its auto-correlation function, or equivalently the fourier transform of this quantity, the power spectrum. Recent work has done much to elucidate the precise form of this spectrum in two dimensions (see Banner [7]). The scattering problem is solved for each of a number of statistically independent realizations of the surface, and then an ensemble average over realizations is taken. For each such surface it is assumed that one can model the scattering as a frozen problem, where the surface is time-independent. Implicit in such modelling is an ergodic assumption, in that time averages are supposed to be equivalent to ensemble averages.

The formulation of this scattering problem, which is linear, but inherently stochastic, is well-understood, and we can obtain a Fredholm integral equation of the second kind for the normal derivative of the pressure field. If the pressure field is written $p(x,y,z)$, then the normal derivative of the pressure on the surface $z = \zeta(x,y)$ satisfies the integral equation

$$\frac{1}{2}\frac{\partial p(\mathbf{x})}{\partial v} = \frac{\partial p_{inc}(\mathbf{x})}{\partial v} + \iint_S \frac{\partial G(r)}{\partial v}\frac{\partial p(\mathbf{x}')}{\partial v}dS' \qquad (1)$$

where the notation $\frac{\partial}{\partial v}$ represents the normal derivative.

This result is derived from the Helmholtz integral formula (see, e.g. Holford [8]). The mean location of the surface is at $z=0$ where cartesian coordinates (x,y,z) are chosen with the x- and y- axis parallel to the mean level of the surface and the z-axis normal to it. The rough S surface is given by $z = \zeta(x,y)$, where $\zeta(x,y)$ has Gaussian statistics and has the appropriate correlation function. The rms surface height is h.

For the three-dimensional scattering problem, for example, where the surface varies in two dimensions, the Green's function, $G(r) = \frac{1}{4\pi r}\exp(ikr)$, where $r = |\mathbf{x} - \mathbf{x}'|$, $\mathbf{x} = (x,y,\zeta(x,y))$ and $\mathbf{x}' = (x',y',\zeta(x',y'))$. For a two-dimensional approximation where one assumes a corrugated surface, i.e. varying in one dimension only, the appropriate Green's function is a Hankel function.

The above formulation is valid for an arbitrary incoming pressure field p_{inc} and acoustic wave number k, and assumes a Dirichlet boundary condition at the ocean surface, which arises as the pressure is essentially zero there (a 'pressure release' boundary condition). Note that the normal pressure gradient $\frac{\partial p(x',y')}{\partial v'}$,which is to be determined, appears inside the integral operator, so that inversion of (1) is required to find it. Once the pressure gradient on the surface has been found by some means, an expression can be written down for the evaluation of the scattered wave at any point away from the surface:

$$p(\mathbf{x}) = p_{inc}(\mathbf{x}) + \frac{1}{2}\iint_S \frac{\partial G(r)}{\partial v}\frac{\partial p(\mathbf{x}')}{\partial v}dS' \qquad (2)$$

3. ANALYTIC SOLUTION PROCEDURES

The difficulty in solving equation (1) arises from several sources. First, the surface $z = \zeta(x,y)$, is a stochastic quantity, which appears explicitly in the kernel of the integral equation through the Green's function evaluated on the surface. Secondly, for realistic models of the sea surface (i.e. realistic correlation functions) there is a wide range of scales present. In addition the two-dimensional nature of the surface presents difficulties in any numerical procedure where a large number of surface features, and hence mesh points, must be considered.

There are two major strategies that may be tried in order to make progress. The first is to look for an analytical approximation to the solution of the integral equation (1). The second is to attempt a direct numerical attack on the problem. There is a long history of analytical treatments of this problem. The simplest, and also a method that is surprisingly successful, is the Kirchhoff approximation. In terms of the formulation given here this corresponds to neglecting the integral term in equation (1) and approximating $\frac{\partial p(\mathbf{x})}{\partial v} = 2\frac{\partial p_{inc}(\mathbf{x})}{\partial v}$. One can then evaluate the wavefield at any point away from the surface using equation (2) above. Indeed, the integrals involved may be manipulated to find the ensemble average angular distribution of energy scattered from the surface. The crucial point is that by writing down an explicit but approximate form for the unknown function $\frac{\partial p(\mathbf{x})}{\partial v}$ the normal pressure gradient is decoupled from the kernel of the integral equation, so making the problem tractable.

An alternative approach is to expand the unknown pressure gradient in a power series in terms of the product of the acoustic wavenumber and the rms surface height, kh, and to do the same with the kernel function. By collecting terms of like order and solving recursively, a series expression can be developed for the pressure gradient on the surface. This perturbation theory becomes more laborious as higher order terms are calculated and is clearly inadequate for large kh.

Both perturbation theory and the Kirchhoff method will be inappropriate when both the rms surface height and the rms surface slope are large, but it would appear that in practice such large values are not typically found in the ocean. These two basic procedures have recently been supplemented by various new approximations that seek to take into account the best features of the two theoretical approaches (Dashen, Henyey and Wurmser [9], Voronovich [10]). Similarly the composite roughness approximation (McDaniel and Gorman [11]) decomposes the surface into two parts, a large scale and a small scale surface. The Kirchhoff approximation is applied to the large scale surface and perturbation theory to the small scale part of the surface. The difficulty with such approximations is that it is difficult to estimate the conditions under which they are accurate, without resorting to direct numerical simulation. In addition, all these techniques become more inaccurate as the grazing angle, i.e. the incident angle measured from the horizontal, approaches zero.

4. NUMERICAL SIMULATION

The other major line of attack that has been pursued in the past ten years is that of direct numerical simulation.Following earlier work in optics (Axline and Fung [12], Fung and Chen [13]), numerical formulations were set up independently by Kachoyan and Macaskill [14, 15] and Thorsos [16]. Although these two approaches differ in detail, the basic ideas are much the same. A number of realizations of a Gaussian random surface with the appropriate correlation function (Gaussian in the earlier work and then Pierson-Moskowitz in Thorsos [17]) are generated using for example a spectral method, where a numerical approximation to a white noise signal is generated and then filtered using the desired spectrum. For one dimensional surfaces the number of surface points treated, say N, typically varies between 256 and 1024. For each realization of the surface the integral in (1) is approximated using for example the trapezoidal rule. This leads to a system of N linear equations involving the unknown pressure gradient at the N points on the surface. This system can be inverted directly to find the pressure gradient on the surface and once this is known the scattered pressure can be found. This process is repeated for somewhere between 50 and 500 realizations and then the results are averaged to give an estimate of the ensemble average angular distribution of the scattered pressure.

The results obtained using these techniques are then essentially exact, and they can be used over the full range of physical parameters. Numerical limitations are found at very low grazing angle, and when the wavenumber is either very large, as then it is difficult to deal with the oscillatory integrand in the integral equation, or when the wavenumber is very small, as then very large surface lengths are required to adequately sample a sufficient number of acoustic wavelengths.

Using this approach, Thorsos [7] has been able to assess the adequacy of the approximate theories for an acoustic frequency of 200 Hz, for a Pierson-Moskowitz model sea spectrum in two-dimensional simulations. He shows that for moderate incident angles, if all other parameters are held constant, there is a transition from essentially specular reflection at very low wind speeds, i.e. low surface roughness, through to scattering over a wide range of angles at larger wind speeds, when the surface becomes rougher. In particular, the backscattering increases with surface roughness. Thorsos has also shown that the Kirchhoff technique is especially accurate for forward scattering in the specular direction, but is inadequate for backscattering. First order perturbation theory on the other hand is uniformly accurate except in the specular or forward scattering direction. However, by including higher order terms in the perturbation approximation, these deficiencies can be made negligible. Interestingly, the perturbation theory is far more successful with this more realistic power-law spectrum than it is with the Gaussian single-scale spectrum (see Thorsos and Jackson [18]). In summary Thorsos finds that analytical techniques work reasonably well in practice (e.g. accuracy to within 2-3dB for an acoustic frequency of 200 Hz) so long as the incident angle measured from the horizontal is greater than about 10°.

5. THE THREE-DIMENSIONAL PROBLEM

The above discussion indicates that one might conjecture that existing analytical theories will be adequate in practice for the full three-dimensional problem of acoustic scattering from a rough ocean surface. However, the numerical techniques to confirm this supposition are still under development and, at this stage, only preliminary results have been obtained. The difficulty is that for a surface of dimension $N \times N$ one arrives at a linear system of dimension N^2, so that direct inversion, with the number of operations proportional to N^6 is not really feasible. However, Macaskill and Kachoyan [19], have shown that iterative techniques can be employed, giving rise to an operation count proportional to N^4. Using this technique they have been able to simulate scattering from a surface with a Gaussian correlation function with 64 mesh points in each coordinate direction, giving rise to a system of dimension 4096. A single realization of such a surface was treated in under 2 hours cpu time on an Apollo 10000. It is expected that if a supercomputer were to be used, the execution time for a single realization would be reduced to a few minutes. Using 100 realizations, good agreement was found with data collected from a small-scale optical experiment conducted by O'Donnell and Méndez [20], even though the numerical treatment was a scalar one, whereas polarisation effects were evident in the experiments.

6. CONCLUSION

It is expected that future work will concentrate on further development of fully three dimensional scattering models and comparison of these with data from forthcoming experiments such as that proposed by Ewart et al [21]. For propagation studies it will be important to include scattering effects in parabolic propagation codes, so that the effects of volume and surface scattering can be treated together. To this end, parabolic approximations to the surface scattering treatments discussed above have been developed, using the full solutions as benchmarks (Thorsos [22], Spivack [23, 24], McDaniel [25]). Work along these lines is continuing, and many of the theoretical ideas discussed above will be incorporated in parabolic propagation codes in the next few years.

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NEWS... NOTES... PEOPLE... BOOKS... PRODUCTS

STANDARDS

ISO Working Groups

Perhaps it is not well known in the acoustics community that Standards Australia policy is to adopt, without modification if possible, ISO and IEC Standards as Australian standards. These ISO and IEC standards are drafted by Working Groups of the various Technical Committees. It is at the drafting stage that the different member bodies, as represented by their technical experts, have their most important input. Anyone who is willing to take an active role in a Working Group should contact Mark Potocki of Standards Australia on (02) 963 4111.

STANDARDS - Ultrasound

A new technical standard on *Acoustic Output Measurement and Labelling Standard for Diagnostic Ultrasound Equipment* has been published by the American Institute of Ultrasound in Medicine (AIUM). The purpose of this standard is to assure that all diagnostic ultrasound equipment is measured in a uniform manner such that the reported labelling requirements will mean the same thing among all manufacturers. The Standard is US$24 (US$12 for AIUM Members) and can be paid by credit card.

A Standard for *Real Time Display of Thermal and Mechanical Acoustic Output Indices on Diagnostic Ultrasound Equipment* focuses on the potential for thermal and mechanical bioeffects related to acoustic output of diagnostic ultrasound equipment. The Standard is US$19 (US$10 for AIUM Members) and can be paid by credit card.

AIUM Publications, 11200 Rockville Pike, Suite 205, Rockville, MD 20852-3139, USA; fax (301) 881 7303.

FASTS

The Federation of Australian Scientific and Technological Societies (FASTS) is developing its strategy to gain wider support for Science and Technology based policy. A prospectus, to be entitled "Investment in the Future", will show the kind of S&T policy that is required to achieve the economic performance, responsible management of the environment and better quality of life that the two major parties are promising - but not delivering.

Modelling And Simulation Congress

The International Congress on Modelling and Simulation will be held 6-10 Dec 1993 in Perth. The Modelling and Simulation Society of Aust (MSSA) is an interdisciplinary society which aims to promote, develop and assist the study and practice of all areas of modelling and simulation in Australia. In keeping with the environmental theme of this conference, acoustic modelling is one of the specific topics for the Congress. Members of the AAS are encouraged to attend and to submit papers for this Congress.

Further information: Anthony Jakeman, CRES, ANU, GPO Box 4 Canberra ACT 2601 ; Tel (06) 249 4742, Fax (06) 249 0757

Hearing Rehabilitation Conference

The International Conference on Hearing Rehabilitation will be held in Sydney, 14-18 July 1993. The conference programme will be for speech pathologists, specialist medical practitioners, occupational health workers and the consumers (hard of hearing people, their families and friends). Abstracts of papers should be submitted by 1 Jan 1993.

Further information: International Conference on Hearing Rehabilitation, GPO Box 128, Sydney, NSW 2001; tel (02) 262 2277, fax (02) 262 2323

WESTPRAC Newsletter

The Western Pacific Commission for Acoustics has recently published its first Newsletter. The main activity for this Commission is the organisation of the WESTPRAC Conference; last held in Brisbane in 1991 and next planned for Seoul in 1994. Those involved with the Commission come from the appropriate societies in Japan, China, Korea, Singapore, Australia, New Zealand and Hong Kong. The items in the Newsletter include a history of WESTPRAC from the Current Chairman, Dr Ken'iti Kido, a report on WESTPRAC IV and descriptions of the Acoustical Societies of China and Korea.

Worksafe Australia Award

A Worksafe Australia video on Noise has won an award at Futuresafe 92. Sponsored by the National Safety Council of Australia and Telecom Mobilenet, the award recognises the effective production of video-aided training packages. The video, which is part of Worksafe Australia's Managing Noise at Work Training Kit, was chosen from 11 entries in the category open to organisations of any size and included professional production assistance.

Interactive Computer Package

Worksafe Australia has developed an interactive, multimedia computer based training program which helps staff explore - using audio, graphic and photographic images - how devastating hearing loss can be in everyday life. The program also places the user in a simulated workplace setting where skills in recognising risk and developing solutions to noise problems can be practised. The package runs on IBM compatible 386 computers under DOS or OS/2 and is available from Worksafe Australia for $850 (tel 02 565 9555).

Uniformity for OHS

The special Premiers' meeting in late 1991 agreed that national uniformity in occupational health and safety standards must be achieved by the end of 1993. In response to the uniformity initiative, Worksafe Australia has established a tripartite taskforce to develop and implement a strategy to achieve uniformity. This task force comprises representatives from the CAI, ACTU and representatives from the States and Territories. The first tasks are to develop a framework of categories of hazards, prioritise the categories and establish a timetable.

Human Vibrations

In March 1993, **Prof M Griffin**, from the Human Factors Research Group at ISVR, Southampton, will be visiting the Eastern States and participating in Seminars and discussions on the effects of vibrations on humans. The seminars will be held in conjunction with Worksafe Aust, and various other interested Societies.

Further information: Acoustics and Vibration Centre, Aust Defence Force Academy, Canberra, ACT 2600. Tel (06) 268 8241 Fax (06) 268 8276

Action Levels for Noise in WA Workplaces

On 22 September, the West Australian Minister for Productivity and Labour Relations, announced the intention to lower the action level for noise in the workplace from 90 dB(A) to 85 dB(A), in line with the National Standard recently adopted by Worksafe Australia. The new action level will take effect from 1 January 1993.

Code of Practice for Noise in the Music Industry

In July, the Commissioner for OHS in WA released the *Code of Practice for Control of Noise in the Music Entertainment Industry*. This provides practical strategies for persons in the industry to ensure compliance with OHS&W regulations. This code was outlined by **John Macpherson**, from the Department, at the September meeting of the WA Division

H Vivian Taylor Awards

Four awards for excellence in acoustics studies have been made: Owen Church (Gippsland Campus), Richard Mills (Clayton Mech Eng) and Andrew Kiel (Clayton Pysics) of Monash University and Giorgio Paolucci (Applied Physics) of RMIT.

President's Presentation

In May, the Federal President of the Society, **Prof Robert Hooker**, spoke at a technical meeting of the WA Division. He discussed multi frequency excitation of an impedance tube for absorption measurements and work on windshields for impulsive noise measurements. At this meeting, **Mark Penketh**, from Kalgoorlie School of Mines, sought comments on noise control methods for airleg drills.

Orbital Engine Company Tour

The acoustic and vibration programmes of the Orbital Engine Company were discussed by **John Smyth** at a WA technical meeting in June. The major work of this company is the development of a 3 cylinder, 2 stroke car engine using the Orbital fuel injection system. The team has made significant improvements in the noise emissions from the engine using techniques such as finite element analysis and modal analysis to identify noise sources and minimise noise radiation from the engine block.

Interactive Sound Information System (ISIS)

On August 4, **Dr David Dubbink**, a US environmental planner, described and demonstrated his ISIS for interactive assessment of land transport noise for a joint meeting of AAS, IEAust and VicRoads. With a data bank comprising a wide variety of transport noise sources from air, rail and road vehicles, this system allows any selected noise to be played back to an audience as a simulation of what might be heard in a particular situation.

Meeting with Bruel

A large group attended the joint AAS, IEAust meeting on 16 Sept to hear **Dr P Bruel** speak on ground measurement of aircraft noise and continuing development of the sound level meter. His work on measuring aircraft noise is part of the continuing revision and development of ISO 3891. In describing the development of the SLM he also discussedthe importance of the peak response for assessment of impulsive or transient noises.

Hearing Aid Technology

Recent advances in hearing aid technology were discussed by **Stephen Jitts** at the October meeting of the ACT Group. The approach of the audiologist to the selection of the appropriate hearing aid for each individual was discussed.

Company Acquisition

In August 1992 the German Holding Company **AGIV** acquired an interest in the **Bruel & Kjaer** Companies in Denmark. AGIV is listed on the various German Stock Exchanges and comprised approximately 300 enterprises across Europe. Total turnover in 1991 exceeded DM 8.1 Billion and it employs some 37,000 people in the fields of electrical, electronic and power engineering as well as building and transportation industries.

NAL Change

Following a recently passed Act of Parliament, that which was previously known as the National Acoustic Laboratory (NAL) was set up as a statuatory authority. The new name for the establishment is the **Australian Hearing Services** (AHS) and it is responsible directly to the Federal Minister for Community Services and Health. The work programs associated with the effects of noise on the community are undertaken by NAL which is a division of AHS.

Loaded Vinyl

Birkmyre Pty Ltd (owners of Plastyne Products) have recently announced a change in marketing policy in relation to "Wavebar" and "Soundune" noise control materials. Where quantity suffices, Birkmyre will be willing to quote for direct supply of the specified materials. This move is designed to make the loaded vinyl even more competitive in the market place. A new product folder, with capability of the materials, has been released.

Rayleigh Medal

The Institute of Acoustics (UK) has awarded the Rayleigh Medal in 1992 to **Sir James Lighthill** for his research in acoustics. The many contributions of Sir James Lighthill to the theory of fluid dynamics are universally recognised as among the outstanding ones of the past half century. His work in aeroacoustics, nonlinear acoustics and in cochlear mechanics has had a dramatic, immediate and enduring impact, both for acoustics itself and for the relation of acoustics to other disciplines such as fluid mechanics and biomechanics.

NAP Silentflo

Notice is hereby given that effective from 1st July, 1992, Barclay Engineering Pty. Limited of 12 Catalano Road, Canning Vale, W.A. is no longer the licencee in the state of Western Australia for NAP Silentflo Noise Control Products.

All enquiries should now be directed to: NAP Silentflo, 58 Buckland Street, Clayton 3168 Vic. Phone: (03) 562 9600 Fax: (03) 562 9793 Trade Enquiries welcome.

* * *

We were sorry to hear that Glen Harries, Chairman of the Victoria Division, had suffered a severe stroke. His friends and associates wish him well and hope for a full recovery.

* * *

NEW MEMBERS

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

Affiliate
New South Wales
Mr N Nakhla

Student
New South Wales
Mr D M Eager (ACT), Mr M J Harrison
Western Australia
Mr M Penketh

Subscriber
New South Wales
Prof J Wolfe
Queensland
Mr G. R Wyman

Member
New South Wales
Mr J G Alekna, Mr W L Huson, Dr E L LePage, Prof J H Rindel (Denmark)
Queensland
Mr J R Davey
Victoria
Mr N D Clutterbuck, Mr M J O'Reilly
Western Australia
Mr T J McMinn, Mr T C Reynolds

Books...

BASIC ACOUSTIC EMISSION
Ian G. Scott

Gordon and Breach Science Publishers,1991, pp246, soft cover, ISBN 2 88124 352 5
Aust Distributor:DA Books PO Box 163, Mitcham, Victoria, 3132. Price: A$80.50.

This book is Volume 6 and the latest in a series of monographs relating to non-destructive testing. This volume contains 246 pages of basic information including diagrams on acoustic emission (AE) and some associated application techniques. Initially, and as the book is read, one can virtually hear the author giving the lecture as the book is written as if a transcript of a series of talks.

The first impression I gained was that the chapters were printed out of order as the second chapter is a section on AE applications while latter chapters are devoted to the basics of AE. In the first chapter the reader is given a brief historical overview of the modern day development of acoustic emission. Chapter 2 while titled Applied Acoustic Emission is a series of introductory statements on some applications of AE. The text is informative for those who want an introduction to applications of a wider science without getting involved in the many problems of AE such as the effects caused by propagation of elastic waves in various media. In chapters 3 and 4 which the author has titled Elementary and Advanced Basic Acoustic Emission, the reader is given valued information on sensors, calibration and deformation mechanisms. Chapter 5 is devoted to Aircraft Applications and finally chapter 6 is devoted to the future of AE.

Throughout the text, the author has been very honest and referenced many of his statements which both validates his comments, but more important, allows the reader to use the text as an index to quickly find detailed information on any particular subject included in the text. The book contains a lot of very useful information which would assist the student who is starting out in the field and the administrative engineer type person who wants a realistic understanding of AE without bothering about the fine detail that is required for the correct application of AE.

The book does have a number of limitations, but I feel that this is because of the authors honesty rather than technical expertise. Many authors would venture into unfamiliar territory using the literature as a back-up just to produce a complete statement of a topic. Ian Scott has not fallen into this trap. While making some reference to AE applications in pipelines, pressure vessels, bridges and petro-chemical plants, he has only written with significant detail on the aircraft industry as he spent the majority of his working life with Aeronautical Research Laboratories in Melbourne.

To sum up, the book contains a lot of valuable information, however, I found it a little hard to extract specific items in some cases. In my opinion the topics and chapters could have been arranged in a more fluent format, but then others may prefer the style of this book. For a book titled Basic Acoustic Emission, it does not attempt to completely cover all aspects of the science and could be twice the size and include topics where the science is more frequently applied such as in structural integrity evaluation of civil structures, mine monitoring, process control and safety. The book could be frustrating to some readers in that it introduces the reader to a topic which is more technical than the casual reader would require, and yet not detailed enough for those with a science background who would appreciate a deeper treatment of the technology. The future for AE is very bright once those in science/engineering/management realise the wide range of reliable applications for which AE can be used.

Finally, I would buy the book and find it useful in my personal library, but any such library would require other publications on AE to ensure that a more complete representation of the science of acoustic emission is available. The author has been wise and honest, but the reader is left with an incomplete statement of acoustic emission.

Brian Wood

Brian Wood is a Principal Research Scientist with the CSIRO's Division of Geomechanics at Lucas Heights. He has been involved in the research, development and application of acoustic emission in a wide range of metal, ceramic, rock and composite materials in a wide variety of structures (but not aircraft) for over 25 years.

New Products...

CIRRUS
Outdoor Microphone

A new portable microphone system allows outdoor noise measurements to be made in most weathers. The **MK 425** is light in weight, simple to operate and takes all its power from the sound level meter in use. It is a precision grade, general purpose unit which incorporates an electret microphone capsule. The assembly consists of the the microphone and its associated preamplifier, rainshield and windshield fitted onto a short mast and mounted on an adjustable height tripod.

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

PULSAR
SLMs

The Pulsar **Model 45** sound level meter is available as either a type 1 precision or type 2 General Purpose instrument, both meeting IEC 651. The instrument is ruggedly constructed and features a 34 dB wide analogue display. The measuring range is between 30 and 144 dB and the response includes slow, fast and impulse. **Model 22** is a type 2 general purpose grade sound level meter which fully meets international Standards. This popular model has recently had a significant price reduction. The **Models 25 and 26** are integrating and peak sound level meters. They have been designed to assist safety officers to meet the requirements of regulations. The meters have a die-cast slim line case and analogue display.

Further information: Pulsar, Bridlington Rd, Hunmanby, North Yorkshire, YO14 OPH, UK

ELSAM
Acoustic Microscope

At the heart of the Elsam is its acoustic objective, which transforms high frequency electrical oscillations into sound waves. These waves are focussed by a sapphire lens and transmitted to the specimen via a coupling medium. The lens collects the reflected echoes which are the reconverted into electrical signal and made visible on the screen. With the new conical objective, the efficiency of the subsurface excitation is considerably improved.

Further information: Leica Instruments Pty Ltd, 45 Epping Rd, North Ryde, NSW, Tel: (02) 888 7122 Fax: (02) 888 7526

QUEST
Vibration Sound Monitoring Systems

Quest Electronics has several vibration-sound monitoring systems to meet the requirements of a wide range of applications. Each system measures displacement, velocity and acceleration. The complete unit comes in a carrying case.

Audiometer Calibration Systems

Bulletin 948-97 describes and illustrates the audiometer calibration systems offered by Quest Electronics. The brochure covers five type 1 and four type 2 systems.

Further information: Selby Scientific & Medical, Private Bag 24 Mulgrave Nth Vic 3170 , Tel: (03) 544 4844 [008 135 838] Fax: (03) 543 7295

PROTAC

Passtop Hearing Protection

The Passtop ear plug is made to measure from HTV polysiloxane which provides a mixture of softness and rigidity. The standard style contains an acoustic filter which is elective for medium and high frequencies. The Passtop HF contains a microphone and receiver and allows for effective communication in noisy environments

Further information: Protac Aust,9/49 Jijaws St, Sumner Park, Brisbane, Qld 4074,; tel (07) 279 2142, fax (07) 279 1621

BIRKMYRE

Wavebar

The loaded vinyl produce, Wavebar, is now manufactured on a fully synthetic, high tensile polyester base cloth - thus eliminating the problems encountered with the out-dated hessian base cloth. The product is also available laminated to aluminium foil, **Quad Zero Wavebar.** For any outdoor application, **Outdoor Wavebar,** is suitable and can be produced in any colour.

Further information: Birkmyre, PO Box 408, Mount Druitt, NSW 2770. Tel (02) 832 1666, Fax (02) 675 3956.

OPEN UNIVERSITY

Underwater Sensing Course

This training package has been produced at the Open University in the UK and sponsored by a consortium of contractors and the UK Defence Research Agency. The package has been designed for training newly recruited engineers in underwater technology and for retraining personnel whose job function has changed. It comprises five multimedia modules - each comprising approx 8 hours of video and 4 hours of audio cassette as well as extensive tutorial material.

Further information: Acoustics and Vibration Centre, Aust Defence Force Academy, Canberra, ACT 2600. Tel (06) 268 8241 Fax (06) 268 8276

New Publications

Journals

Acoustics Bulletin Vol 17, No 3 1992 Contents include "Some elements of Cymatics" by **Chivers**, "Localisation of acoustical modes in 1-D fractal composites" by **Craciun** and **Bettucci** and "Review of Standards for railway noise" by **Walker.**

Applied Acoustics Vol 36 Nos 1,2,3-4 1992; Vol 37 Nos 1,2,3,4 1992

Australian J of Audiology Vol 14 No 1 1992

Canadian Acoustics Vol 20 No 2 1992

Chinese J of Acoustics Vol 11 No 3 1992 (In English) Includes articles on high intensity sound, transducer performance, ultrasonic tomography, laser ultrasonic generation, sonar systems.

J Aust Assoc Mus Instr Makers Vol 22 No 2 1992 Includes 'Preventing overuse injuries in oboists' by **Ruth Blatt**

J Catgut Acoustical Society Vol 2 No 1 (Ser II) 1992 Includes 'The application of acoustic emission techniques in wood science and technology' by **V Bucur**

New Zealand Acoustics Vol 5 No 1 1992

Shock & Vibration Digest Vol 24 Nos 8,9,10,11 1992

Reports

Quarterly Progress & Status Report 1/ 1992 Royal Institute of Technology, Stockholm

14th ICA IN BEIJING

About a dozen Australians travelled to Beijing in September for the 14th International Congress on Acoustics. For most it was their first visit to China, so that the trip had general as well as scientific interest.

More than 800 people attended the Congress, which was good for a meeting held outside Europe or North America, and this was a relief to the International Commission, which had to confirm its decision on the venue some three years ago, not long after the tragic events of Tienanmen Square. There was, naturally, a large representation from China itself, and Japan provided a large fraction of the overseas participants, but other countries were also well represented. There were 848 papers all told, with a fairly heavy emphasis on physical acoustics, including ultrasonics, quantum effects, transduction, and signal processing, these fields together accounting for nearly half of the papers. Informal observation, however, suggested a major audience interest in the sessions dealing with architectural acoustics. The biological aspects of acoustics accounted for only 200 of the papers presented, while noise and atmospheric sound together comprised less than 100 papers.

The conference was organised with plenary lectures on most mornings, making a total of 12, of which one on medical ultrasonics was given by George Kossoff of the CSIRO Ultrasonics Institute. There was only a small instrument exhibition, but China is clearly active in acoustic instrumentation and one could not but be impressed at the specifications of the high-power loudspeaker developed by the Chinese Institute of Acoustics – would you believe an *acoustic power output* of 10 kilowatts!! (The operating principle is apparently modulation of the flow of a horn-loaded compressed air jet.) The frequency range is about 500 Hz to 2.4 kHz and the effective range about 15 kilometres. Apart from more mundane applications, appropriate uses were stated to include broadcasting warning messages from nuclear power stations! Unfortunately (?) we did not hear a demonstration!

The Congress was held in the 21st Century Hotel, a new joint Japanese-Chinese venture specially designed for congresses and summer schools, located about 15 kilometres from the centre of Beijing. It was a pleasant venue, and the distance meant that not too many people drifted off during the day. Organisation was good, and for the first time the complete abstracts of the Congress were published in advance as a supplement to Acustica. The full proceedings were published as four A4 volumes with a total thickness of 90 millimetres. It should be possible to buy sets from the Institute of Acoustics in Beijing.

Social events during the Congress were well chosen and capably organised. Among the highlights was a performance by a team of incredibly skilled acrobats, contortionists and jugglers, who danced on broken glass, caught a variety of heavy or fragile objects in piles on their heads, sometimes while balancing on a tall unicycle, and carried out complicated contortions while balancing trays of liquid-filled glasses on hands, feet and foreheads. There was, of course, Peking duck and other pleasant Chinese food to eat, both every day and at the Conference banquet, and almost unlimited light Chinese beer to drink at almost no charge–though soft drinks all had to be paid for.

The Congress tour to the Great Wall was a great success, with our twelve buses preceded by a police escort–not in any sense for protection, but just to clear a quick way through the traffic. Indeed we had this escort wherever we went in buses in Beijing, and almost felt neglected when we had to make our own way. People were happy and friendly, and there were no restrictions on our movements. Even the rather intimidating declaration forms designed to stop people selling their possessions while in China were simply torn up without examination by the officials at the exit ports.

After the Congress many overseas visitors took advantage of special tours that had been arranged at very reasonable rates. The most popular, with nearly 80 participants, went first to the ancient capital of Xi'an, famed for its terracotta warriors and for many other treasures. The next stop was Guilin, in the centre of that most remarkable region of limestone peaks that feature in so many Chinese scroll paintings. A five hour boat trip along the river Li confirmed that these peaks, which extend for nearly 100 km, really look exactly like the paintings–it is not a peculiar Chinese view of perspective! The tour then went on to Guangzhou (Canton) and home via Hong Kong. Those who chose the tour to Tibet had a similarly interesting time, but most suffered problems with altitude sickness.

The 15th ICA will be held in Trondheim, Norway, in 1995. Put it in your diary!

Neville Fletcher

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Diary ...

CONFERENCES and SEMINARS

• Indicates an Australian Activity

1992

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

1993

March 15-18, HONOLULU
AIUM 37th Annual Convention
Ultrasound in Medicine
Details: AIUM Convention, 11200 Rockville Pike, Suite 205, Rockville MD 20852-3139, USA

April 21-23, SOUTHAMPTON
ACOUSTICS 93
Details: Prof Fahy, University of Southampton, Southampton SO9 5NH, UK. Tel 0703 592291 Fax 0703 593033.

April 28-30, BLACKSBURG
RECENT ADVANCES IN ACTIVE CONTROL OF SOUND & VIBRATION
Details: Conf Cord, Virginia Polytechnic Inst & State Univ, Mech Eng, 203 Randolph Hall, Blacksburg, VA, 24061 0238 USA. Tel 703 231 4162, Fax 703 231 9100

May 2-5, WILLIAMSBURG
NOISE-CON 93
Noise Control in Aeroacoustics
Details: Noise Con 93,David Stephens, Mail Stop 426, NASA Langley Research Centre, Hampton, Virginia, 23665-5225; tel (804) 864-3640

May 10-13, TRAVERSE CITY
NOISE & VIBRATION CONFERENCE
Details: Society Automotive Engineers, Communications& Meetings, Warrendale, PA 15096, USA

May 31-June 3, ST PETERSBURG
NOISE 93
International Noise and Vibration Control Conference
Details: c/Malcolm Crocker, Mech Eng, 210 Ross Hall, Auburn University, Auburn, AL 36849-3501, USA

June 25-27, IOWA
INTERNATIONAL HEARING AID CONFERENCE
Details: University Iowa Conference Centre, Memorial Union, Iowa City, IA 52242, USA

June 26 - July 2, BERGEN
13th INTERNATIONAL SYMPOSIUM ON NONLINEAR ACOUSTICS
Details: Prof Halvor Hobaek, Dept Physics, University Bergen, Allegt 55, Bergen, Norway 5007, Tel 0475 21 27 87, Fax 0475 31 83 34

July 6-8, VIENNA
ULTRASONICS INTERNATIONAL 93
Details: U193 Meetings management, Straight Mile House, Tilford Rd, Rushmoor, Farnham, Surrey GU10 2EP, UK

July 6-9, NICE
NOISE & MAN
6th International Congress on Noise as a Public Health Problem
Details: Noise & Man 93, INRETS LEN, Case 24, F 69675, Bron Cedex, France

July 7-9, PARIS
PUMP NOISE AND VIBRATION
Details: Pump Noise & Vibration, SHF, 199 rue de Grenelle, 75007 Paris, France.

July 14-18, SYDNEY
• INTERNATIONAL CONFERENCE ON HEARING REHABILITATION
Details: Hearing Rehab. Conf Secretariat, GPO Box 128, Sydney, NSW 2001; tel (02) 262 2277, fax (02) 262 2323

July 28 - Aug 1, STOCKHOLM
STOCKHOLM MUSIC ACOUSTIC CONFERENCE
Details: SMAC 93, KTH, Box 70014, S 10044, Stockholm, Sweden; tel (468) 7907873, fax (468) 7907854,

August 24-26, LEUVEN
INTER-NOISE 93
People Versus Noise
Details: INTER-NOISE 93, TI-K VIV, Desguinlei 214, B-2018 Antwerpen, Belgium, Tel (03) 216 09 96 Fax (03) 216 06 89

August 31-September 2, SENLIS
4th CONFERENCE ON INTENSITY TECHNIQUES
Structural Intensity and Vibrational Energy Flow
Details: CETIM, BP 67, 60304, Senlis, France Tel (33) 44 58 34 15 Fax (33) 44 58 34 00

August 30-September 1, LEUVEN
INTERNATIONAL SEMINAR ON MODAL ANALYSIS
Details: ISMA, TI-K VIV, Desguinlei 214, B-2018 Antwerpen, Belgium,Tel (32) 16 28 66 11 Fax (32) 16 22 23 45

September 15-17, BUCAREST
10th FASE
Details: Comm. d'Acoust. de L'Acad Roumaine, Calea Victoriei 125, 71 102 Bucarest, Romania

December 6-10, PERTH
• INTERNATIONAL CONGRESS ON MODELLING AND SIMULATION
Modelling Change in Environmental and Socioeconomic Systems
Details: Anthony Jakeman, CRES, ANU, GPO Box 4 Canberra ACT 2601 ; tel (06) 249 4742, fax (06) 249 0757, email tony@cres.anu.edu.au

1994

February 27 - March 3, AMSTERDAM
96th AES
Details: Sec, AES Europe Office, Zevenbunderslaan 142/9, B-1190 Brussels, Belgium

July 18-21, SOUTHAMPTON
5TH International Conference on RECENT ADVANCES IN STRUCTURAL DYNAMICS
Details: ISVR Conference Secretariat, The University, Southampton, SO9 5NH, England.

August 23-25, SEOUL
WESTPRAC V
Details: Dr Il-Whan Cha, Yonsei University, Seoul, Korea

August 29-31, YOKOHAMA
INTERNOISE 94
Details: Yoiti Suzuki, Sone Lab, Riec, Tohoku Univ. 2-1-1 Katahira, Aoba-Ku, Sendai, 980 Japan. Tel 81 22 266 4966, Fax 81 22 263 9848, 81 22 224 7889

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