



Acoustics Bulletin

January 1983 Volume 8 Number 1

INSTITUTE OF ACOUSTICS

Calls for Papers

The Meetings Committee of the Institute of Acoustics is always pleased to receive offers of contributions to any of its meetings. Contributions are particularly sought for the following:

Acoustics and the Sea Bed

University of Bath, 6-7 April 1983

Meeting Organiser: Dr N G Pace

School of Physics, University of Bath, Claverton Down, Bath BA2 7AY

(200 word abstracts immediately)

Sonic Emission

Late July 1983

Meeting Organiser: Dr R W B Stephens

Department of Physics, Chelsea College, Pulton Place, London SW6

(200 word abstracts as soon as possible)

Studio Design

Autumn 1983

Meeting Organiser: Mr N Spring

Sandy Brown Associates, 6 Fareham Street, London W1V 3AH

(200 word abstracts required)

Local Government Noise Problems and Construction Industry Noise

Autumn 1983

Meeting Organiser: Mr R Hill

AIRO, Duxon's Turn, Maylands Avenue,
Hemel Hempstead, Herts HP2 4SE

(200 word abstracts required)

IOA Policy on advertisements

Members of the Institute will be aware that advertising material is printed within the Bulletin and also accompanies various occasional communications to Members.

The rates for all such advertising are available from our Advertisement Manager, Mr Collins, and are quite competitive. The income generated from this source on occasions amounts to over one third of the production cost of the Bulletin, and this has helped in a small way to keep subscriptions down.

Because the Bulletin is only published quarterly, the majority of the advertisements it contains can be considered as long-term and of continuing usefulness — both to the advertisers and to the readers. Where the timing is appropriate, advertisements for job vacancies, etc, are also published in the Bulletin.

Since there are several other occasions throughout the year when it is desirable or necessary to communicate with Members the opportunity exists to use these occasions to distribute additional advertising material. Such material, particularly for job vacancies where the advertiser seeks an early appointment, is presumed to be of direct interest to Members, and Council has therefore for a trial period of one year decided to offer the additional facility of a monthly Appointments Sheet, details of which are given on page 25 of this Bulletin.

The policy on acceptability of adverts is that they must be of relevance to the field of acoustics generally or be of such a general and non-controversial nature that the standards of professionalism on which we pride ourselves are not lowered. It should of course be noted that we do *not* publish a list of Members' names and addresses as do some societies, since it is known that this is a cause of much unsolicited material through the post over which none of us would have any control. ☐

D J Johns

Chairman, Publications Committee

Material for the April issue of Acoustics Bulletin should reach Mrs F A Hill at 25 Elm Drive, St Albans, Herts AL4 0EJ, no later than Friday 25 February.



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The Institute of Acoustics was formed in 1974 by the amalgamation of the Acoustics Group of the Institute of Physics and the British Acoustical Society and is now the largest organisation in the United Kingdom concerned with acoustics. The present membership is in excess of one thousand and since the beginning of 1977 it is a fully professional Institute.

The Institute has representation in practically all the major research, educational, planning and industrial establishments covering all aspects of acoustics including aerodynamic noise, environmental acoustics, architectural acoustics, audiology, building acoustics, hearing, electroacoustics, infrasonics, ultrasonics, noise, physical acoustics, speech, transportation noise, underwater acoustics and vibration.

Membership of the Institute of Acoustics

Membership of the Institute is generally open to all individuals concerned with the study or application of acoustics. There are two main categories of membership, Corporate and Non-corporate. Corporate Membership (Honorary Fellow, Fellow, Member) confers the right to attend and vote at all Institute General Meetings and to stand for election to Council; it also confers recognition of high professional standing. A brief outline of the various membership grades is given below.

Honorary Fellow (HonFIOA)

Honorary Fellowship of the Institute is conferred by Council on distinguished persons intimately connected with acoustics whom it specially desires to honour.

Fellow (FIOA)

Candidates for election to Fellow shall normally have attained the age of 35 years, have had at least seven years of responsible work in acoustics or its application, and have made a significant contribution to the science or profession of acoustics.

Member (MIOA)

Candidates for election to Member shall normally have attained the age of 25 years, must either (a) have obtained a degree or diploma acceptable to Council and have had experience of at least three years of responsible work in acoustics, or (b) possess an equivalent knowledge of

acoustics and cognate subjects, have had experience for not less than seven years of responsible work in acoustics or its application, and must have been a Non-corporate member of the Institute in the class of Associate for not less than three years.

Associate

Candidates for election to the class of Associate shall have attained the age of 18 years and (a) be a graduate in acoustics or a discipline approved by Council, or (b) be a technician in a branch of acoustics approved by Council, or (c) be engaged or interested in acoustics or a related discipline.

Student

Candidates for election to the class of Student shall have attained the age of 16 years and at the time of application be a bona-fide student in acoustics or in a related subject to which acoustics forms an integral part. Normally a student shall cease to be a Student at the end of the year in which he attains the age of 25 years or after five years in the class of Student, whichever is the earlier.

Full details and membership application form are available from: The Secretary,
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25 Chambers Street
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President's Letter

Dear Member,

Institute of Acoustics

President

Dr D E Weston
Admiralty Underwater
Weapons Establishment

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ISVR, Southampton University

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Liverpool Polytechnic

Honorary Secretary

Dr F J Fahy
ISVR, Southampton University

At the Autumn Conference, smoothly organised by John Walker and his colleagues, there were two special and happy occasions that I would like to mention. Frank Fahy's citation for the 1982 Tyndall Medal appeared in the Bulletin last April, and at the Conference I presented him with the Medal itself. We were then treated to an interesting discourse on measurement of sound intensity. This came complete with some ambitious demonstrations, reminding us that acoustics is largely an experimental discipline.

Ray Stephens' birthday and his retirement as Chief Diploma Examiner were acknowledged in the last Bulletin. It was very pleasing that both Dr and Mrs Stephens were able to attend the Conference Dinner as Guests of Honour. At our October Council Meeting we decided we would like to institute a named lecture to be known as the Stephens Lecture. Dr Stephens has kindly agreed to let us make free with his name in this way, and it was therefore possible to announce this development during the Dinner. The details remain to be worked out.

Continuing on the subject of conferences, there will be the usual wide range of specialist meetings next year. But unfortunately it does seem there will not be an Autumn Conference, nor a major Spring Conference covering a range of topics. The reason for this is the channelling of energies into the Inter-Noise Meeting in Edinburgh in July 1983. This shows every promise of being a very popular and populous meeting, with a few hundred papers and probably several hundred delegates. The IOA Annual General Meeting will be held at 5.30 pm on Thursday 7 April at the University of Bath, during the Conference on Acoustics and the Sea-Bed organised by the Underwater Acoustics Group of the Institute.

The October Bulletin seems too early to wish people a Happy Christmas, especially when one is actually writing in August. This Bulletin is rather late for the purpose — but at least I can wish you all a merry and prosperous New Year!

Yours sincerely,

David Weston

IOA Autumn Conference - Bournemouth

The weather at Bournemouth during registration for the Autumn Conference rivalled the worst that the Lake District, venue of earlier Autumn Conferences, could have provided. It was very wet and windy but thankfully it improved in the following two days to allow those with time to spare to enjoy a stroll on the East Cliff close to the hotel.

By the end of the two days, 93 participants had registered for the Conference, which was organised by ISVR of Southampton University. Four technical sessions were arranged on Speech Communication, Sound Intensity Measurement, Machinery Noise Control and Subjective Effects of Noise. The Conference also marked the occasion of the Tyndall Medal Presentation and Lecture by Dr F J Fahy of ISVR. A technical exhibition was open from Sunday evening until Monday evening. This provided an opportunity for delegates to keep abreast of the latest developments in acoustical and vibrational measurement and analysis equipment.

THE CENTRE PIECE of the Conference was the Tyndall Medal Presentation and Lecture. The Medal is presented by the Institute in recognition of contributions to teaching and research in acoustics. Dr Fahy was a well-deserved choice this year and he was presented with the medal by the IOA President, Dr David Weston. Dr Fahy's lecture was entitled *Sound waves and energy* but before embarking on that topic he took the opportunity to review Tyndall's life and achievements in the area of scientific teaching. It became clear to us all that Tyndall was a man whose knowledge extended over many branches of science and that his qualities as a lecturer were acknowledged in both Europe and the United States. Dr Fahy left Tyndall's life story to move on to a more modern approach to the subject of sound waves and energy. He presented a series of convincing demonstrations under quite difficult conditions, illustrating the relationships between sound pressure, amplitude, particle velocity and sound intensity.

The brief reports on the technical sessions which now follow have been contributed by Dr W Ainsworth, Dr F J Fahy, Professor E J Richards and Professor D W Robinson, who were coordinators and Chairmen for the Sessions on Speech Communication, Sound Intensity Measurements, Machinery Noise Control and Subjective Effects of Noise, respectively.

Speech Communication

This session began with three papers on speech production. C Scully and E Allwood (University of Leeds) pre-



Dr Frank Fahy, surrounded by the equipment used in his demonstrations, receives the Tyndall Medal from the President, Dr David Weston

sented a paper on *Glottal losses in a composite model of speech production*. The effects described in the paper were illustrated by some most interesting tape recordings. The next paper, *The target theory of speech production in the light of mandibular dynamics* was presented by two visitors from Stockholm University, B Lindblom and R Schulman. They reported some recent articulatory measurements and discussed them in relation to the vowel target theory. Next, L Roves from Nijmegen University discussed *Spectral properties of glottal flow pulses as a function of speakers, vowel and stress level*.

The theme changed to that of speech analysis. N D Black and R Linggard from Queen's University, Belfast, described *A filter bank model of the cochlea*, which incorporated a mechanism for spectral enhancement. R W Bladon (University of Oxford) then gave an entertaining paper on *Problems of normalising the spectral effects of variations in the fundamental*. He suggested that the formant frequencies of certain vowels vary with the fundamental much more than most of the audience had realised. Finally, R Linggard and P McCullagh (Queen's University, Belfast) outlined a *Neural firing model of the basilar membrane*.

In the afternoon session three papers on automatic speech recognition were presented. R K Moore and his colleagues from RSRE, Malvern, presented a paper entitled *Towards an integrated discriminative network for automatic speech recognition*, in which they described a technique for automatically differentiating between similar sounding words. J S Bridle and M D Brown (JSRU, Cheltenham) discussed *A data-adaptive frame rate technique and its use in automatic speech recognition*. It was shown that this technique enables good recognition performance to be obtained with reduced computation and storage. M J Russell, R K Moore and M J Tomlinson (RSRE) then presented a paper on *Automatic speech recognition using local timescale variability information*.

On Tuesday morning, R Linggard and D Rankin (Queen's University, Belfast) described *Sectorgrams — a new way of looking at speech*, which they thought might be useful for normalising speech. However, some of their disadvantages were also pointed out. In the next paper, *The computer analysis of prosody*, D Lindsay and W A Ainsworth (University of Keele) discussed a program for choosing the optimal prosodic rules to describe intonation contours. The human analysis of prosody was the subject of the following paper by D R Scott and A Cutler (University of Sussex) who described some experiments concerning *Segmental cues to syntactic structure*.

The author of the next paper, *The synthesis of rhythmic structure*, S Isard (University of Sussex), was not able to attend the conference, so it was read by Donia Scott. The topic of synthesis continued with *The use of multi-pulse excitation in speech synthesis from text* by A P Varga and F Fallside

(University of Cambridge). This was followed by two papers on speech coding: *Adaptive transform coding of speech at 9.6 kB/s and below* by J M Rye and B C Dupree (JSRU) and *Speech coding at 32 k bit/s for use in the switched telephone network* by L S Moye and J A S Angus (Standard Telecommunication Labs Ltd). This latter was amusingly illustrated with tape recordings.

The final session was on the subject of speech perception. C J Darwin and J Seton (University of Sussex) began with a paper on *Perceptual cues to the end of aspiration*. B Cranen, R van Bezooijen and L Boves (University of Nijmegen) discussed an experiment relating to the *Acoustic correlates of auditory ratings of some vocal speech parameters*. Finally, G A Foster (University of Sussex) described *The integration of audio-visual stimuli as a function of temporal desynchronisation*.

Sound Intensity Measurement

The session had an international flavour, four of the seven papers being presented by visitors from overseas. Bernard Ginn of Brüel and Kjær illustrated his talk with examples of application to the determination of the sound powers of a motor-pump assembly and of a bottle labelling machine, and, in the workshop session, showed how the contribution of aircraft cabin window vibration to the total sound power transmitted into the cabin was isolated using intensity measurement.

The presentation by M Pascal of CETIM, France, was announced as being a first for the IOA—a lecture in French—but M Pascal unexpectedly, and very clearly, gave an exposition in English of the origin and evaluation of errors associated with discrete spatial sampling of intensity fields. Ulf Kristiansen, of the University of Trondheim, in Norway, then provided a most entertaining display of energy flow diagrams for sound fields generated by vibrating beams.

In the first of two papers, Peter Watkinson of ISVR described the technique and problems of measuring *in situ* sound absorption by studio absorbers using sound intensity measurements. The technique is of practical interest because the absorption of individual items can be evaluated separately from other absorbers present in a room. In his second paper, Dr Watkinson showed how sound intensity fields of transient sources can differ from steady state sound fields

from the same sources and presented examples of measurements made around a model impact machine.

Frank Fahy of ISVR compared the results of measurements of transmission losses of panels using standard and intensity based techniques. He also showed that the intensity distribution in so-called diffuse fields in rooms lacks energy near grazing angles. Finally, Mr Krystad of Norwegian Electronics described a very interesting new transducer for measuring acoustic particle velocity which will be used together with a conventional microphone to make intensity measurements.

The Workshop indicated a strong and growing interest in applications of intensity measurement among engineers in industry and research laboratories.

Machinery Noise Control

The session on Machinery Noise Control proved to be very successful and a very successful forum for sharing

new ideas. Two topics dominated the presentations, that of noise source identification, quantification and reduction, and that of active cancellation assuming that the source cannot in itself be modified.

Papers on the *Energy Accountancy Method* were recognised to carry enormous promise, and a fertile area for more work of interest to both structural and acoustic engineers. Active cancellation was recognised as a palliative in the operator area after other methods of noise control had been exhausted and the two areas of work were seen essentially to be complementary.

One paper scanned the two areas of study, it being a study of how active cancellation of vibration could lead to as much as 10 decibels reduction in the acoustic power output.

Practically all the papers recognised that the primary source consisted of an impact mechanism, and much of the discussion centred on the difficulty, particularly in the high frequencies of



The Civic Reception: the Mayor, Mrs Sheila McQueen, welcomes the organiser of the Conference, Dr John Walker of ISVR. They are watched by the Escort to the Mayor — her husband Ian — and the IOA President

cancelling sharp impulsive emissions. One paper from Holland on cigarette machine noise was particularly recognised as an example of how a detailed study by those receiving and using machinery could influence future design at very little cost.

The Working Group discussion meeting attracted very few people not already working in the field, which was a pity. As the central theme remains that of relating impact to structural vibration and from this to acoustic emission, the attendance suffered from there being no 'vibration' sessions.

Subjective Effects of Noise

The seven papers in this session were linked thematically by a progression from so-called non-auditory effects to direct damage to the ear caused by noise. They could also be viewed as a sequence of effects on an ascending scale of noise and ranged from the realm of speculative research to hard realities of legislative action.

C G Rice gave a succinct account of the state of knowledge on sleep disturbance illustrating common ground between disparate laboratory and survey studies and distinguishing between going-to-sleep and not being awakened. Both an average (or equivalent continuous) night-time noise level as well as the number and maximum level of loud events which punctuate it have to be accounted for.

D E Broadbent described experiments contrived to simulate disturbance caused to people engaged in mental tasks or creative work at home or in the office. Psychological tests are notoriously susceptible of explanations *post hoc facto* and some of the results described were superficially contradictory. It takes ingenuity to find a theory subtle yet flexible enough to fit them into a pattern. Dr Broadbent showed convincingly that effects on performance are repeatable when all essential test conditions are replicated, and explained why contrary results could arise from quite small changes of test detail. It appears that people use the faculties of association, short-term memory and internal speech in a way that optimises their performance. Which faculty is dominant depends crucially on the precise task and noise may change it, occasionally for the better.

A possibility that noise may be at least a contributory cause of accidents in industry was reviewed by P A Wilkins.

One may simply not hear premonitory sounds or mishear verbal warnings, either because of the noise itself, because of temporary hearing threshold elevation or because of too efficient hearing protection. Dulled attentiveness and resulting carelessness may also play a part. Accident statistics on this important subject are meagre and indeed the total literature is sparse if one judges by the usual standards required of scientific evidence. The problem of experiments is formidable: situations cannot be contrived for the benefit of the experimenter. The only method is prolonged observation and even then a control situation similar except for the noise is necessary for comparison.

Tinnitus, of the temporary or persistent kind, has long been known to be a concomitant of loud industrial noise. Until recently it remained a symptom without remedy and for that reason was uneasily disregarded in the context of hearing conservation, although R R A Coles, in discussing this topic, observed that it has sometimes attracted extra compensation in individual civil cases. As a backcloth he described pilot results of the MRC National Study of Hearing, showing that a phenomenal number of people, about 1 in 5 of the population, experienced tinnitus, even discounting the temporary variety that is the immediate aftermath of loud noise. Significantly, the proportion sharply increases between those who do not work in a noisy place (about 1 in 7) and those who do (about 1 in 4).

The remaining papers dealt with practical aspects of hearing loss prevention in industry. For the occupational hygienist a big problem in monitoring observance of noise limits is the actual determination of individual noise exposures. S J Karmy described an experiment in self-reporting by the employees in a large and varied workshop. They had only to mark a check list of the tools used and to estimate how long in each case. The total exposure calculated from this compared quite well with direct measurement using personal sound exposure meters. The self-reporting method would not replace the use of instruments but it could be an economical way of supplementing measurements when large numbers of employees are involved.

Turning to broader aspects of hearing conservation, A Sinclair contrasted experience of the 1972 Department of Employment's Code of Practice with

the more rigid requirements foreshadowed in the latest HSE Consultative Document, whilst conceding that even the latter was not an end point so long as some risk to hearing remained. He argued for a national re-appraisal of the proposals in the light of industry's general financial position, advocating statement of principles and less emphasis on the means of achieving them. Dr Sinclair highlighted the dilemma of industrial audiometry. To confine it to employees at high risk, above 105 db(A), would merely quantify the damage occurring in a small number of employees. To extend it to low risk was ethically correct but means of doing so have to take into account the case load of referrals to the industrial physician as well as the overheads in staff, equipment and record keeping.

A R Dove gave the final paper, comparing the HSE proposals with those in a draft directive of the Commission of the European Communities (CEC) which is now on its way to the Council of Ministers having been published in the Official Journal on 5 November. The European proposals go further than the domestic ones by including safety risks, and they would at best harmonise on hearing damage risk for only five years after coming into force. Thereafter the noise limit would be compulsorily reduced to 85 db(A). Scope for applying the doctrine of 'reasonable practicability' would be diminished though not extinguished. Hearing protection, except on safety grounds, would be compulsory above 85 dB(A) and so, by implication, would audiometry. Mr Dove pointed out ominous social implications in enforcing the wearing of protectors by perhaps one quarter of the entire manual work force and also of compulsory health surveillance and what it might lead to. One ray of light is the likelihood that the CEC proposal will be tempered in its political passage through the Council and National Parliaments, but its timing and ultimate fate are unpredictable.

It is regrettable that the wealth of new and important material in this session should have been imparted to an abysmally small audience. This circumstance may in part be remedied by the publication of the Proceedings. Unfortunately the same does not apply to the open forum session which followed. It was attended by an almost identical audience and provoked an animated discussion, in which the pros and cons of industrial audiometry

featured prominently, but its record is lost to posterity. The rival attraction of a (well-attended) IOA regional meeting on the HSE consultative document the following week may have had some influence on the attendance.



Dr Stephens holds up the Wedgwood plate presented in honour of his eightieth birthday

Away from the technical aspects of the Conference, two enjoyable social functions were provided. The Conference participants were invited by the Mayor, on behalf of the Council of Bournemouth, to attend a Civic Reception at the Town Hall. This was a most pleasant occasion. We were all impressed by the welcome given by the Mayor and the interest shown in the Institute by the Mayor herself as well

as by several former Mayors of the Borough who also attended.

We returned from the Town Hall to the Queen's Hotel for the Conference Dinner. The President, Dr Weston, took the opportunity to mark the occasion of Dr Raymond Stephens' 80th birthday by presenting Dr Stephens and his wife with a beautiful Wedgwood plate. It was also announced that in recognition of Dr Stephens' life-time work in acoustics a special Lecture named after him would be given in future, details of which have yet to be finalised.

So, after a short gap, the Autumn Conference has been revived successfully, but whether the IOA continues to arrange two major conferences each year is a matter for the Council to decide. As it is held during term-time, it is of necessity organised away from an academic location. The Queen's Hotel served us admirably in giving us accommodation and conference facilities within the same building. The Borough of Bournemouth made us most welcome and had, during all the stages of organisation, been most helpful with advice and guidance. It remains for me to thank, on behalf of the Institute, all the contributors and particularly the Session Co-ordinators who provided us with such an interesting programme. Finally my thanks are due to the secretarial staff at IOA and ISVR who contributed so much to the smooth organisation of the Conference. □

J G Walker

NEW ELECTIONS

At its meeting on 28 October 1982, Council approved the following elections.

Fellow

D E Commins S G Morgan

Member

R A F Barnes	J R Shattock
A J Bennetts	W Sherry
P Berriman	D Sims
A R Carruthers	J R Stirling
P F Dobbins	S J Stratton
J Y Guigne	C J Tubby
A V H Holdich	R A Wong
P A D Jackson	W H Wong
M L Lau	B R Wood
S G Lindsey	M S Woods
R K Moore	S T Yam

Associate

T S Berge	T G Jones
S R Braund	S J Lovell
P Chisnall	S W Lui
L Dewhurst	H Morgan
P Economou	J Pearson
S Ellis	D C Sales
K M Fan	D R Smith
M R Forsdyke	M A Swan
D C Hosker	G D Turner
M D Ironside	M R Wawro
K M Johnston	R A Westlake
D T Jones	A Whitfield

Student

S S Li

Theory of Wave Propagation in Random Media

An informal, interdisciplinary meeting on the above topic was held in Robinson College, Cambridge, on 9 and 10 September. It was attended by about 40 participants drawn mainly from the fields of acoustics and solid state physics.

The theory of wave propagation in systems with some type of disorder is of relevance to a wide variety of disciplines. In acoustics one thinks immediately of the scattering of underwater sound by fluctuations in the ocean, of sound waves by turbulence, or of ultrasonic waves by regions of stress in a solid. In structural acoustics one may be concerned with the propa-

gation of vibrations in engineering structures with periodic stiffeners; in practice all such structures will have random deviations from the ideal design which may influence the propagation to a greater or lesser extent. In solid state physics there are phenomena which are essentially acoustical in nature, for example the vibrations of a lattice of atoms (the 'phonons'). However the effect of disorder on the electrical transport properties of solids is of even greater importance in this field. The electrons which carry the charge are governed by a wave equation, the Schrödinger equation, which has the same general mathe-

matical structure as linear wave equations in acoustics. For electrons the source of the disorder is the aperiodic potential which they feel when in an imperfect or amorphous material. This potential plays the same role as the fluctuating local speed of sound or refractive index for the scattering of acoustic or electromagnetic waves.

Since 1958 solid state physicists have come to realise that disorder can have a profound effect on the electron wavefunctions (the solutions of Schrödinger's equation), so much so that imperfect or amorphous materials may cease to conduct electricity. That year marked the publication by Philip Anderson at Bell Laboratories of a celebrated, if rather difficult, paper entitled *Absence of diffusion in certain random lattices*, often quoted, seldom read, according to him. Sir Nevill Mott

of the Cavendish Laboratory opened the meeting at Robinson College by describing the impact this paper has had on our understanding of electrical conduction in disordered materials. As Mott had pointed out soon after 1958, Anderson's theory means that, for sufficient disorder, the electron wavefunctions no longer extend throughout space but are localised in different regions of the material in such a way that they cannot transport electric charge over large distances. In 1977 Mott and Anderson were awarded the Nobel prize for physics largely as a result of their work on this subject.

The two other talks given by members of the solid state 'camp' were also concerned to a large extent with 'Anderson localisation'. This simply reflects the overriding importance the phenomenon, which is still imperfectly understood from a theoretical point of view, has come to assume for physicists interested in the electronic properties of disordered materials. Denis Weaire from University College, Dublin, illustrated this with a graph showing an exponential rate of increase in the number of articles devoted to this subject in the solid state journals over the last few years. He discussed the part numerical simulations have played in helping to elucidate localisation behaviour in systems of varying dimensionality.

John Pendry of Imperial College, London, showed that a disordered one dimensional wave system always becomes non-transmitting if made long enough, a consequence of localisation related to the absence of diffusion or conduction (there is no disorder threshold for localisation in one dimension). He did this by calculating moments of the statistical distribution of transmitted intensities, an approach rather similar to that used by the speakers on underwater acoustics.

Talks given by members of the acoustics 'camp' covered a variety of topics using different theoretical techniques each adapted to the particular application in hand. Manfred Heckl from Berlin gave a wide-ranging talk taking in sound propagation in open plan offices, reverberation in forests (of randomly distributed square trees!) and structure-borne sound. (During this talk a solid state physicist was heard muttering 'acoustical phonons' on the subject of railway track vibrations.)

Charles Macaskill and Barry Uscinskii from the Department of Applied Mathematics, Cambridge, discussed

Proceedings of the Institute of Acoustics

After extensive discussions in Publications Committee and Council, amendments to IOA publications policy have been agreed, with the ultimate aim that the Proceedings should constitute an archival publication of the Institute.

To this end, as from January 1983, the maximum length of papers is to be extended to eight pages and the pagination and numbering of the papers for each Meeting will be re-ordered to form Parts of integrated annual Volumes.

Delegates at Meetings will receive those Parts for which they have paid in their Meeting fee; it is hoped that with the increased content of the papers more libraries and individuals will have an interest in acquiring the complete Volumes. Abstracts of papers will continue to be published in Acoustics Bulletin.

Intending authors are asked to read carefully the notes on preparation of papers for Meetings sent to them by Meetings Organisers. □

the application of multiple scattering theory to sound propagation experiments in the ocean. Internal gravity waves in the ocean scatter acoustic waves primarily in forward directions, which allows the use of the parabolic approximation to the wave equation. In this approximation differential equations for the propagation of statistical moments of the wave fields can be derived and solved. The dependence on range of the 'scintillation index' (the mean square fluctuation in wave intensity) calculated in this way was compared with experiment and with other theoretical approaches.

Michael Howe from the Department of Mathematics, Southampton, investigated the propagation of sound in lined ducts using kinetic theory (solid state physicists call this the Boltzmann equation approach to transport theory). Waveguide modes in a duct are more readily attenuated the closer they are to cut-off (where the group velocity goes to zero). This suggests that for maximum attenuation a liner should be designed to scatter between modes, thus transferring energy into those near cut-off. Neither axially nor peripherally segmented liners can do this, the former because they do not break the cylindrical symmetry, the latter because they must conserve frequency and axial wavenumber simultaneously. But checkerboard liners (segmented both axially and peripherally) can, and are therefore more efficient as Howe's calculations showed.

Jim Woodhouse and Chris Hodges of Topexpress, Cambridge, attempted to provide a bridge between the two disciplines by showing that Anderson localisation can be important in an

acoustical context. They described experiments on a vibrating string with masses whose spacing can be varied. Moving the masses from regular to irregular positions can decrease the transmission along the string very substantially. This effect was shown to be due to the localisation of the modes (the acoustical equivalent of electron wavefunctions), whose shapes on the string had been measured. On a more theoretical note Woodhouse and Hodges pointed out that, in this sort of problem, the use of different types of ensemble average (eg linear or logarithmic) can lead to apparently very different conclusions, which shows that the underlying statistics are rather subtle.

This talk provoked a lively discussion as to the more general relevance of localisation to acoustics. Localisation is a result of backscattering and is most important in systems of low dimensionality. It is probably not relevant to the sort of problem discussed by Macaskill and Uscinskii where backscattering is thought to be unimportant. It may however be very important to vibration isolation in engineering structures which are often effectively one-dimensional (parallel stiffeners) and where the blocking of transmission can be strong. Several other areas of possible applications of localisation were also discussed.

A solid state physicist's impression of the meeting is given in a current issue of the Physics Bulletin. Notes and references relating to the conference are available from Chris Hodges, Topexpress Ltd, 1 Portugal Place, Cambridge CB5 8AF. □

Chris Hodges

Proceedings of The Institute of Acoustics - Abstracts

Acoustics and the Sea-Bed

6 - 8 April 1983 at the University of Bath

Presidential Address:

Influences of Bottom Profile on Ocean Acoustic Propagation

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A review of acoustic propagation in ocean ducts shows that much progress can be made merely by noting water depth, or for a range-dependent duct by noting the bottom profile, and leaving consideration of detailed bottom characteristics till later. A formula for the range-averaged level in layered water involves the cycle distance. There are difficulties in defining this distance, and previous attempts are extended to include a novel definition based on horizontal and vertical flux rates. The same formula works for range dependent ducts, provided the horizontal changes are slow. A very simple criterion for slowness and for adiabatic transfer of energy involves the cycle distance and the bottom profile, specifically the third range-derivative of depth. In addition a special treatment for profiles such as the error function shows that the adiabatic approach can be very accurate indeed. The adiabatic assumption and the cycle both enter into the calculation of summed bottom losses, and also provide another viewpoint on mode cut-off effects in upslope propagation.

Acoustic Properties of Sediments

Seismo-Acoustic Wave Velocities and Sediment Engineering Properties

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Measured interrelationships between seismo-acoustic propagation phenomena and geotechnical properties of the medium are inevitable. The time-honoured correlation for marine sediments is between sound speed and porosity leading to relationships involving density and hence to impedance and reflecting characteristics. But this apparently fundamental correlation only tells part of the story. A more detailed theoretical examination, such as that due to Biot, has to involve not only the porosity and elastic bulk moduli of the various constituents but also the system bulk modulus, its rigidity modulus and the permeability of the medium under consideration. Thus, while it is fashionable to talk of shear wave characteristics in explaining compressional wave reflexion losses at a boundary, shear wave velocity measurements have a much more significant part to play in elucidating the various components of Biot's equations.

The usefulness of these equations cannot be over-emphasised particularly when using

them to derive geotechnical quantities from measured seismo-acoustic data. Given the various wave velocities, particularly measured at a range of frequencies, their vertical gradients and an independent assessment of porosity (such as might be provided by an electrical resistivity observation), it is now possible to give a fairly precise estimate of the consolidation behaviour of most sediments as well as their permeabilities. While engineers argue that this estimate only defines the behaviour at low strain levels, building performance seems to indicate that this (the geophysically-derived quantity) is more appropriate than those engineering observations traditionally measured at high strains.

The Influence of Packing Structure and Effective Stress on V_s , V_p and the Calculated Dynamic and Static Moduli in Sediments

P J Schultheiss
IOS Wormley

Small piezo-electric transducers, capable of measuring shear wave velocities (V_s) in unconsolidated sediments under a wide range of effective stresses, have been developed. These transducers have been installed on an *in situ* probe and incorporated into various sediment test cells, together with compressional wave velocity (V_p) transducers. These developments have enabled V_s and V_p to be measured simultaneously in surficial sediments *in situ*, monitored during variable porosity and cyclic loading tests on sands, and recorded during consolidation and triaxial tests on sands, silts and clays.

Results have shown that a wide variation in V_s occurs for changes in packing structure and effective stress. Dynamic moduli calculated from V_p and V_s exhibit considerable differences both in magnitude and as a function of stress compared to the static mechanical moduli. Continuous measurements of V_p and V_s during cyclic loading have more clearly defined the behaviour of sand around the point of liquefaction.

It has also been postulated that the second, slower, bulk compressional wave, predicted in theory but rarely observed, might be more appropriate for calculating dynamic sediment moduli.

Transducers for Shear Wave Measurements in Water-saturated Marine Sediments

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Information about shear wave velocity and attenuation is crucial by modelling of sound propagation in shallow-water areas where the rigidity of the sea-bed has an essential

influence on the loss of acoustic energy from the water column.

Shear waves can today be generated and observed, though not with the flexibility and technical standard of compressional waves, but great uncertainties are most frequently involved in the determination of shear wave parameters from samples removed from the sea-bed and brought to the surface, due to disturbances inherent in sampling and recovery. As a result, attempts are being made at the Technical University of Denmark to develop transducers for measurement *in situ* of shear wave velocity and attenuation in water-saturated sediments.

Various transducer designs are being studied, including piezoelectric ceramic transducers, where the electric field is applied perpendicular to the direction of electrical polarisation, and various transducers for transformation of compressional waves to shear waves including transducers for resonance generation of flexural waves in plates radiating shear waves from the plate ends.

Various procedures for improvement of the coupling between the transducers and the sediments are being studied.

The paper will report on the results of the transducer developments as well as on values of shear wave velocity and attenuation measured during the laboratory tests performed in the tank facilities of the Industrial Acoustics Laboratory.

The Relationship Between Sediment Parameters and Acoustic Reflectivity of the Sea-Bed

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Reflections from the uppermost 10 cm of the surface sediment cover at the sea-bed from an 18 kHz echosounder have been analysed with a high resolution echo-strength recorder. It is capable of measuring reflection strengths from ten intervals with individual time windows of 133, 267, 533 and 1067 microseconds. The acoustic signals have also been digitalised and processed for the determination of the reflection coefficient from the amplitudes.

A comparison of the digitalised seismic sections with the sediment succession in selected cores shows a good correlation. These full wave sections allow an estimation of the degree of interference caused by the reflections at closely spaced thin layers, which affects the amplitude of the seismic wavelets and consequently the reflection coefficients. This can be avoided by using undisturbed signals.

The results of both methods are compared with sediment parameters such as the

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median grain size, water and clay contents. A log-linear relationship between the echo-strengths or reflection coefficients and the median grain size of the sediments could be established. The results show that the echostrengths can be used generally for a broad identification of sediment types at the sea-bed.

The Determination of Material Properties of the Sea-Bed from the Acoustic Plane-wave Reflection Response

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Investigations of acoustic bottom reflectivity attempt to infer the structure of the sea-bed (density and sound-speed profiles) from a limited knowledge of the reflection coefficient. For many applications, an adequate model for studying the acoustic interaction is provided by the scattering of plane waves by a one-dimensional inhomogeneous medium.

In contrast to formally exact solutions to this inverse scattering problem, Candel *et al* (J Sound Vib (1980), 68 (4), pp 571-595) propose an approximate scheme which is readily implemented numerically. Their method is based on applying the forward scattering approximation to a local wave decomposition of the acoustic field. As a result, the reflection coefficient is obtained as a non-linear Fourier transform of the logarithmic derivative of admittance. Inversion of the integral transform enables the recovery of admittance versus depth via numerical integration using a single impulse response of the sea-bed. Separate recovery of both density and sound-speed profiles requires at least two impulse responses corresponding to two distinct grazing angles.

In this paper, an implementation of Candel *et al*'s inversion algorithm is appraised for several bandlimited synthetic impulse responses generated for realistic geo-acoustic models of the sea-bed.

Impulsive Response of Sediment Layers with Variable Density Gradient

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The geo-acoustic behaviour of: (a) a semi-infinite sediment layer, with a continuously increasing density gradient, covered by a water semi-infinite medium and (b) a sediment stratum also with continuously increasing density gradient, sandwiched between two semi-infinite media (water and hard rock), was studied. Through the impulse response of above-mentioned bottoms, it is feasible to get the shape of the echo of a given sonar pulse. The analysis of the echo gives quantitative information about the stratum, ie density and gradient, thickness and velocity.

This work was carried out by a computer. The analogue sonar signal of a frequency of 1 kHz was introduced into the computer, digitised and processed together with the impulse response obtained by a specific computer program.

The sonar echo reflected back by a bottom shows a very low frequency modulation that is directly dependent on the density gradient. This modulation increases with the density gradient in frequency as well as in level.

A Depositional-process-oriented Impedance Model for Marine Sediments

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The remote identification of sediment properties by acoustic means depends on a thorough understanding of the causal relationships between the physical and acoustic properties of the sediment. As our understanding of these relationships increases, it becomes possible to predict the expected range and type of downcore variation in acoustic properties for a particular depositional environment. It is this concept of relating acoustic properties to depositional environment, first introduced by Hamilton, that is the key to remote sediment property identification. For example, detailed acousto-stratigraphic studies of deep-sea carbonates have shown that variations in the acoustic properties of these sediments ultimately result from fluctuations in oceanic conditions and climatic change. Thus downcore acoustic property variations in this regime show a characteristic range in values and cyclicity. Sediments from other depositional environments (eg deep-sea clays or turbidites) have different but characteristic shapes to their downcore acoustic property curves. This paper examines several approaches (spectral analysis, linear prediction) to quantifying these differences, and evaluates their usefulness in the remote identification of sediment properties.

Semi-Empirical Sea-Bed Models based on the Biot Theory

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The prediction of sound propagation in the ocean requires a knowledge of the acoustic properties of the sea-bed. In general, a knowledge of the complex compressional and shear moduli, and the density as functions of depth in the sediment are needed. The comprehensive theory of Biot (J Acoust Soc Am, 34, 1254-1264, 1962) predicts wave velocities and attenuations that agree favourably with experimental results for both sands and fine-grained sediments over a wide range of frequencies. To apply this theory, however, a detailed knowledge of the sediment structure is required. In particular, the permeability and its variation with the mean grain size and sorting have a large effect upon the predicted velocity and attenuation. We develop empirical relationships between these and other parameters, needed to implement the Biot model, and then apply this model to compute the acoustical properties of interest. The result is a semi-empirical sea-bed model that requires only a single sediment descriptor: mean grain size. When used to predict sound propagation, in environments where strong bottom

interaction occurs, this model provides good agreement with experimental results.

Acoustic Propagation in Coastal Floating Soft-Mud Sediment

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A Kaya

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This paper presents a new theory of sound speed and attenuation as a function of volume concentration, particle size and acoustic frequency in coastal floating soft-mud sediment. Since coastal soft-mud sediment contains not only mud particles but also concentrated pulp microfibrils, the new theory is based on a 3-phase suspension model composed of sea water, mineral particles and porous organic particles. The ratio, by volume, of the organic particles to the suspended particles and the porosity of organic particles are introduced in the theory as new physical properties.

The applicability of the theory was confirmed through experiments measuring physical properties and sound speed or attenuation at 200 and 800 kHz in the two types of sediment samples. In the case of the composite type containing porous organic particles, the measured results of sound speed or attenuation show better agreement with the results calculated by the 3-phase theory than with the results of the 2-phase theory developed by Urlick and Ament. On the other hand, in the case of the simple type not containing porous organic particles, the results of the 3-phase theory are the same as those for the 2-phase theory because the ratio by volume and the porosity of the particles are negligible.

Consequently, the 3-phase theory is more acceptable than the 2-phase theory for an estimation of acoustical properties in coastal soft-mud sediment.

Linked Sets of Acoustical Processes and Geo-Acoustic Profiles Describing the Interaction of Sound with a Class of Seafloor Structures

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The major acoustical processes influencing the interaction of sound with a seafloor having a single, horizontally stratified, depth dependent (but unlayered) sediment over a semi-infinite substrate are reviewed and used to develop a coherent structure for use in modelling applications. Four linked sets of acoustical processes and geo-acoustic profiles are presented. The first, and simplest, set includes only the fluid parameters of the water-sediment interface. The dominant process is reflection from the water-sediment interface. The second set adds the depth dependent compressional wave velocity and absorption as geo-acoustic parameters. This profile adds compressional wave refraction and absorption within the sediment as acoustical processes. The third set adds the substrate parameters and the sediment shear velocity

at the substrate to the geo-acoustic profile, and the effects of interaction with the substrate and energy lost to sediment shear waves generated at the substrate interface to the list of acoustical processes. The fourth, and most detailed, profile adds the depth dependent shear velocity and attenuation. This profile adds effects related to sediment shear wave propagation through the sediment layer and the reconversion of energy back to compressional waves. The use of a particular set depends on frequency and grazing angle.

A Transport-Theoretic Analysis of Pulse Propagation Through Refracting Ocean Sediments

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The reflection of acoustic pulses from the sedimentary layers of the ocean abyssal plains is analysed. The sediment model considered is one wherein the sediment density and sound speed are assumed to have mean values that increase slowly with depth. Superimposed upon this mean value-variation, however, are small, zero mean, highly anisotropic random fluctuations. The transverse correlation length of these fluctuations is assumed to be large while the correlation length in the depth direction is assumed to be small. The (two-point, two-time) mutual coherence function for the reflected complex pressure is computed using an extension of the stochastic transport theory originally developed by Barabanenkov *et al* (Izv Vyssh Uchebn, Zaved, Radiofiz 15, 1852, 1972). Our work extends the analysis already appearing in the literature (J Acoust Soc Amer 72(3), Sept 1982, 937-946) to the refracting case.

Acoustic Scattering

Some Statistics of the Sea-Bed and Acoustic Scattering Therefrom

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Acoustic backscatter, data on the mean speed of sound, density and attenuation in sea-bed sediments and their variability are reviewed, together with mathematical models relating scatter to material properties. A critical comparison is made of the likely contributions expected from scattering due to (a) roughness of the water-bed interface and (b) variability of sound speed and density within the bed, both on a wavelength and on a micro scale. The data point to a tentative conclusion that the former dominates in the harder bed types, eg exposed bedrock and stone, whilst the latter may dominate in softer sedimentary beds. Some higher order statistics of sea-bed backscatter are also reviewed in terms of the variability in scattered power with transit time and beam separation. Data are analysed in terms of the statistics of the acoustic character of the sea-bed on a longer or meso scale, using a simple

Markov derived patch model, based on 3 parameters, the median patch dimension, L , the high/low scatter contrast ratio, γ , and the high scatter patch density, ρ . Experiments in the 1.8-8 kHz band indicate median values of $L \approx 100$ m, $\gamma \approx 12$ dB, $\rho \approx 0.002$.

A Random Process Treatment of Acoustic Scattering from the Sea-Bed

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In typical acoustic, ocean-bottom scattering we have relatively little information about the bottom irregularities involved. In such a case it seems particularly important to use a statistical treatment. Previous work has largely focused attention on single-surface types of scattering. Of course attempting to deal with an ensemble (collection) of ocean bottoms might be expected to complicate the problem. However, the use of a stochastic representation (we employ the Wiener-Hermite version which has been used extensively in turbulence work) reduces the complexity to a set of single functions to be found. The expansion converges most rapidly when $k_0 \xi_0$ is small, where k_0 is the sound wave number and ξ_0 is the rms surface displacement. The expansion then becomes, for low order terms, a kind of perturbation treatment wherein it is relatively easy to calculate the first few higher order correction terms. In the limit $k_0 \xi_0$ large, where we can often use physical optics, the treatment is different, and will also be discussed. As an example of a simply obtained result we consider a surface at which the field vanishes. The surface is Gaussian and we have an acoustic field normally incident. The lowest order term in the specular reflection in this case has an amplitude of $e - (1/2) k_0^2 \xi_0^2$. The first one or two higher order terms are obtainable. The extension of this kind of treatment to a bottom, where the boundary condition is that the normal derivative of the field should vanish, is straightforward and will also be discussed.

Numerical and Experimental Studies of the Spatial Coherence of Acoustic Signals Scattered from a Rough Surface

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Simplified computations of acoustic spatial coherence using Eckart's coherent reflection coefficient are often inaccurate. Measured coherence values are usually larger than predicted. The authors have been developing the facet-ensemble method to compute the complex field scattered by a corrugated surface with large roughness (W A Kinney, C S Clay and G A Sandness, J Acoust Soc Am, in press). A comparison is provided here between amplitude values and spatial coherence values measured in water-tank acoustic scattering experiments and values predicted using the facet-ensemble method. In the experiments,

underwater signals were scattered from both mechanically generated and wind-generated wave surfaces. Overall agreement between measured and predicted values is shown. The use of the facet-ensemble method for predicting the coherence of ocean-bottom interacting signals is discussed. (Work supported by NORDA and ONR.)

Broad-Band Studies of Acoustic Scattering from a Model Rough Surface

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Experimental measurements at near normal incidence of the underwater acoustic back-scattering from a pressure release model rough surface with Gaussian statistics were conducted in a laboratory tank. Scattering measurements were obtained over the frequency range 20-1200 kHz, for a variety of transmitter and receiver positions. To obtain a source that has sufficient directivity and a wide enough bandwidth performance, to carry out the investigation, advantage was taken of the parametric array's unique properties.

Theoretical expressions for the mean intensity were developed, using the Helmholtz-Kirchhoff Integral. The Fresnel and Fraunhofer phase approximations were used to evaluate the scattering integral, and predictions for the mean intensities were compared with the measured values. The Fresnel approach gave scattering coefficients which were in closer agreement with the experimental values.

Experimental Studies of Near Grazing, Low Frequency, Forward Scatter at Rough Surfaces

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Most theoretical studies of near grazing scatter from a rough surface fail to be convincing because of the use of the Kirchhoff assumption, or the assumptions of 'small surface slopes' and 'no shadowing' and 'no secondary scatter' at the surface. On the other hand, starting in 1979 (J Acoust Soc Am 66, 1135-1144) I Tolstoy, by using N A Biot's and M J Lighthill's equivalent multipole boundary conditions, has investigated near grazing scatter without these assumptions, for deterministic surfaces such as hemispherical or ellipsoidal bosses on a plane. These works predict the existence of a weakly dispersive, coherently scattered, cylindrically divergent boundary wave with an amplitude which can exceed that of the direct volume wave at large ranges from a point source.

Our group has constructed several surfaces to verify and to extend the predictions of boundary wave propagation. In general, our results for grazing incidence at rigid deterministic surfaces agree with theory: For point source radiation over hemispherical roughness elements, the ratio of boundary wave amplitude to direct volume wave amplitude (BWA/VWA) is directly proportional to $k^{3/2}$ and $R^{1/2}$, where k = wave

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number and R = range; the high frequency cut-off is $kh = 1$, where h is the distance between scattering elements; for a surface of half-cylindrical roughness elements BWA/VWA is nearly proportional to $\cos^2 \theta$ where θ is the angle between the propagation direction and the normal to the cylinders.

We have discovered certain laws which have not been predicted: At a ridge between two rough planes the boundary wave diffracts in the same manner as the volume wave so that BWA/VWA is proportional to k^2 ; for a randomly rough surface, the high frequency cut-off is at $kL = 1$ where L is the spatial correlation length of the heights; BWA/VWA is directly proportional to the rms height of a randomly rough surface, as well as to $k^{3/2}$ and $R^{1/2}$.

The results of the laboratory model experiments can now be extended to a rocky sea-bed with the expectation that the forward scattered boundary wave behaviour may be used to determine the rms height and the spatial correlation length of a surface of steep-sloped, randomly spaced, roughness elements.

(This work was supported by the US Office of Naval Research.)

Sea-Bed Characterisation from Measurements of Backscattering Strength

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The variation of sea-bed backscattering strength with grazing angle has been measured by many authors. Particularly if the results close to normal incidence are included, the variation can often enable the sea-bed to be characterised. It is possible, for example, to distinguish a sand bottom from a gravel bottom. The measurements are, however, tedious and not generally used for this purpose.

The technique is described whereby the variation of backscattering strength with angle can be measured using a simple echo sounder of the type available on most boats. When the boat is moving echo signals from different grazing angles undergo different Doppler Shifts and the principle of the technique is therefore to measure the power spectrum of the return signal. This power spectrum is directly related to the angular variation of the backscattering strength. The power spectrum is Fourier Transform related to the autocorrelation function and it is in fact found to be particularly beneficial to measure this latter quantity.

This paper shows results of experiments using various surfaces in a small water tank. Each autocorrelation function is seen to be characteristic of the corresponding surface.

Computer Model Predictions of Ocean Basin Reverberation for Large Underwater Explosions

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Ocean basin reverberation results from interaction of the pressure wave from a

large underwater explosion with the boundaries of the basin and of the seamounts and islands within it. Its net effect is to raise the ambient noise level at low frequencies for periods lasting for up to several hours, depending on the size of the ocean basin and on the acoustic source level of the explosion.

A computer model for predicting the reverberant field for large underwater explosions, developed at the Naval Surface Weapons Center, has adequately matched experimental data for varying conditions in both the North Atlantic and the North Pacific Oceans, for high-explosive yields of up to one kiloton.

Experience to date indicates that the model can be applied to predicting the character of the reverberant field in either the North Atlantic or North Pacific Oceans for any explosive yield. It is probably safe to assume also that the model in its present form would correctly predict the general character of the received signal in other ocean basins, although signal levels might be grossly in error if propagation losses vary significantly from the average conditions that seem to obtain in the two basins considered here.

Measured Dependence of Transmission Loss and Reverberation from the Sea Bottom at the Fladenground Experiment

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During the Fladenground Experiment (FLEX) — part of the Joint North Sea Data Acquisition Program (JONSAP '76) — acoustical measurements on propagation loss, reverberation and ambient noise were carried out. In the area there exist two bottom types, well distinguishable by the medium grain size of the sediment and the acoustical transparency of the upper layer of the bottom observed by echo sounders. The one type of bottom seems to be a pleistocene bottom and the other with smaller grain size a recent one. Propagation loss measurements at frequencies of 100 Hz to 10 kHz show a significant difference in the absorption for the two types of bottom. It is remarkable that the recent, soft and more absorbing bottom produces much more reverberation, in disagreement with the literature. This was observed with repeated measurements at positions only about 30 nautical miles apart. The irregular behaviour of the reverberation is interpreted by backscattering out of the volume of the sediment rather than by surface scattering.

Statistical Properties of Sea-Floor Roughness

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The topography of the sea-bed can be an important factor affecting underwater sound propagation in the ocean. From the point of view of acoustical significance, sizes of topographic features and interfaces fall into three overlapping categories that are a function of acoustical experimental geo-

metry and frequency: large features that block propagation, intermediate features that primarily act as sloping bottoms, and small-scale features that act as scatterers. In this paper, statistical parameters of bottom topography of the latter two categories are obtained for use in acoustical scattering and propagation models. Power spectra of ocean bottom and sub-bottom roughness were determined from submarine topographic data obtained by narrow beamwidth echosounding, seismic reflection profiling, and sea bottom photogrammetry. Published spectra obtained from deep tow vehicle echosounding were also included. The spectra were compared to the asymptotic expression, $C(K) = aK^{-b}$, where $C(K)$ is the power spectral density, a is a proportionality constant, K is the wavenumber, and b is a constant which is characteristic of the class of roughness. Roughness power spectra are often assumed to have a dependence of $b=3$; however, the present study shows the value of b to range from about 0 to 3. The probability density functions of the topography samples free of seamounts and fracture zones were found to have a distinct symmetric central tendency closely approximating a Gaussian distribution.

Acoustic Propagation Studies

Effects of the Sea-Bed on Acoustic Propagation

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The sea-bed is known to be the controlling factor in low-frequency ocean acoustics. A lossy sea-bed causes attenuation of water-borne sound due to both compressional-wave attenuation in the bottom and to the coupling of sound into shear waves. The complicated frequency-dependent effect of the sea-bed on propagation has been studied theoretically, and it is found that bottom losses increase with decreasing frequency down to near the cut-off frequency of the ocean waveguide, where interface waves on the sea floor become important propagation paths. It is also found that while propagation levels in the water column are strongly dependent on bottom type, a feature such as the optimum frequency of water-column propagation is only slightly dependent on sea-bed properties. An extensive set of broadband propagation data collected in different areas of the Mediterranean Sea and of the eastern North Atlantic are shown to support the above theoretical findings.

Modelling Low Frequency Sound Propagation in Solid/Fluid Layers

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This paper reviews current techniques for modelling acoustic propagation loss under shallow water conditions where the effects

of shear in the sea-bed are important. A point of particular interest is the case where the velocity of sound in the water is less than the compression velocity in the sea-bed but greater than the shear velocity. Here, normal modes that would be trapped in the absence of shear waves become lossy and decay with range through conversion into downward refracted shear waves.

After discussing the loss mechanisms briefly in terms of ray theory several wave treatments are described. These include numerical techniques for dealing with the discrete and continuous spectrum of modes and virtual or lossy modes. No model is suitable for all conditions, but one, Kutschale and Di Napoli's Fast Field Program, is a powerful tool which copes with the complete spectrum of modes including interface waves in a mixture of solid and liquid layers. The FFP is particularly useful at low frequencies when there are no discrete modes (because the sediment shear or compression velocities are low) or when the modes are lossy or near cut-off.

Some examples from an upgraded version of this program are discussed.

Some New Models for Sound Propagation in Bottom-Limited Ocean Environments

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The interaction of sound with the ocean bottom requires that acoustic propagation models have capabilities which usually are not available in models designed to handle only water-borne energy. Three new models are discussed that are designed specifically to handle the requirements imposed by interaction of sound with the ocean bottom. The first model is a normal mode model which uses exact complex eigenfunctions and eigenvalues. Previous normal mode models generally approximate the true (complex) eigenfunctions with real eigenfunctions and then perturbatively compute the complex eigenvalues using the real eigenfunctions as basis functions. The new model (COMODE) does not use perturbation methods but rather computes the exact complex eigenvalues and eigenfunctions. The absolute accuracy of COMODE has been checked against a direct numerical integration of the wave equation. The connection between COMODE and the direct method (the 'fast field program' or FFP) is briefly discussed.

The second model discussed is a coupled normal mode program which, like COMODE, uses exact complex eigenfunctions and eigenvalues. Unlike COMODE, however, the coupled mode model can handle environmental parameters (eg bathymetry) that vary with range. In addition, the coupled mode model computes not only energy propagating away from the source but also backscattered energy. The model thus serves as a useful benchmark for approximate solutions which do not include backward-going energy.

The last model discussed is a parabolic equation (PE) model. The PE model gives

the numerical solution to a 'one-way' wave equation. The one-way equation, which allows energy to propagate only outward from the source, can be applied simply to a range-dependent problem. The PE model thus gives an approximate but efficient numerical solution for sound propagation in an environment that changes with range. The PE model discussed here uses an implicit finite-difference (IFD) method of solution and is designed to handle the closely related problems of strong bottom interaction and wide-angle propagation. The accuracy of the IFD method has been tested by comparison with selected benchmark calculations for both range-dependent and range-independent bottom-limited ocean environments. The efficiency of the method has been tested by comparison with a previous PE model which solves the parabolic equation using the 'split-step' Fourier method developed by Tappert.

A B Wood Memorial Lecture

Acoustic Propagation in a Wedge-Shaped Ocean

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The radiation field in a wedge-shaped domain is of interest in connection with acoustic propagation in the ocean over the continental slope. In order to determine the field, the wave equation must be solved, and for the case of perfectly reflecting boundaries a solution can be obtained and is known to consist of a sum of normal modes. More generally, when the bottom is not perfectly reflecting, the problem is much more complicated because the wave equation is no longer separable, implying that the modes have range-dependent eigenvalues. In this case a possible technique for determining the field in the ocean (but not in the bottom) is to introduce an 'effective' pressure-release bottom parallel to and below the real bottom. This adequately represents the phase change that is experienced by the modes on being reflected from the bottom, provided the critical grazing angle is not too large, and it enables the solution for the 'perfect' wedge to be utilised in the more general case by a simple shift in origin of the co-ordinate system. Other factors, such as the up-slope, range-dependent mode cut-off depth, are incorporated into the new solution by treating the bottom as locally flat.

Underwater Acoustic Propagation Dependence on Sediment Type for a Sloping Bottom

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An adiabatic normal mode description of low frequency underwater acoustic propagation over thickly sedimented sloping bottoms employs the physical mechanisms of spreading loss, renormalisation loss or gain, attenuation, differential mode excitation and reception, and mode cut-off. Combinations of these mechanisms determine the depth dependence of propagation on range, source and receiver depth, sedi-

ment type, and sediment attenuation value. A study with a numerical normal mode model shows the sensitivity of propagation predictions to uncertainties in the physical parameters characterising the sea-bed. Similarly, the model results give estimates of the accuracy required of acoustic field measurements in order to obtain values for these environmental parameters. For accurate predictions of the acoustic field after it has propagated over a sloping sea-bed, accurate values of the sediment attenuation in the shallow portions of the slope are generally more important than are such values for the deeper end of the slope. On the other hand, the variation of the acoustic field levels with source or receiver depth may be more substantial than variations in level associated with the dependence of propagation on sediment attenuation value or sediment type. For upslope propagation predictions the importance of including, in an environmental description of slopes, local variations in sediment type also depends upon receiver depth, the range of the receiver from the region of local sediment variations, and the acoustic field property being examined.

Ray Invariants, Plane Wave Spectra, and Adiabatic Modes for Range Dependent Shallow Ocean Acoustics

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L B Felsen
Department of Electrical Engineering and Computer Science, Polytechnic Inst, New York, USA

Ray acoustics and adiabatic mode theory offer alternative ways of analysing sound propagation in a shallow ocean with gradually sloping bottom. The respective utility of these formulations resides in the fact that they are related by spectral Fourier transforms so that, via Poisson Summation, the one describes collectively the effects of the other. The stability of the collective behaviour in the range dependent environment can be meaningfully phrased in terms of invariants that smear out a group of rays so that it forms an adiabatic mode or a group of adiabatic modes so that it forms equivalent rays. This direct connection fails when bottom slopes cause an originally totally reflected ray to pass through critical incidence, or when an originally trapped mode passes through cut-off. The resulting coupling to the radiation spectrum can be addressed by fleshing out the ray acoustic skeleton with coherent plane waves (Arnold and Felsen, paper submitted to J Acous Soc Am, April 1982) or by providing local plane wave generating functions for the adiabatic modes (Kamel and Felsen, paper submitted to J Acous Soc Am, April 1982), thereby repairing the singular behaviour in the critical region in either case. Thus, the plane wave spectrum is seen to play a fundamental role in expressing the general relation between rays and modes, in stating the corresponding invariants and in providing uniform transition functions in critical regions. These aspects are here fully developed with strong emphasis on the physical content of the various representations and on their numerical utility.

Interface Waves

Ocean-Bottom Interface Waves of the Stoneley-/Scholte-Type: Properties, Observations and Possible Use

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The physics of seismic interface wave propagation along the sea-floor are discussed briefly together with some closely related bottom-interaction phenomena occurring in underwater acoustics. To overcome the existing lack of field-data, three-component Ocean-Bottom-Seismometers with VHF-telemetry and variable-depth hydrophone have been developed at SACLANTCEN. Since 1979 they have been deployed during several sea-trials in coastal waters to record the ground-roll from small explosions or sweep-signals from towed LF-projectors. In addition to these propagation-data noise-samples of the ambient background and passing merchant ships were taken. Numerous time-series were analysed with different software-packages to obtain seismic sections, particle-hodographs, dispersion-curves, attenuation-coefficients and power- or cross-spectra. Propagating quite slowly, transmitting only very low frequencies and forming site-dependent mode-patterns the observed wave-type indicates a high sensitivity to the not easily measurable shear-parameters. Therefore interface wave measurements offer a good indirect method to probe the upper sea-bed *in situ* over ranges of several miles.

Shear Modulus Profiling of Near Bottom Sediments Using Boundary Waves

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Knowing the shear modulus is an essential element in the estimation of the mechanical strength of sediments and rocks. Theory and experience show that the propagation of boundary waves (Scholte-, Love- or Stoneley-type) along a liquid/solid or solid/solid interface is highly dependent on the shear moduli. The boundary waves are dispersive, and measuring the velocity of a boundary wave vs frequency is a method for shear modulus profiling.

This paper presents theoretical models for evaluating such profiles from measured velocities, based on the depth separated wave equation. Experimental results using a variable mono-frequency vibration exciter as a source and mono-axis seismometers as detectors are discussed. This instrumentation results in a wave propagation along a sediment/water (or sand/air) interface which is completely dominated by boundary waves. A frequency range 10-100 Hz could be covered. Allowing a penetration of 5-10 m in loose sand deposits, the range of applicability of the present equipment is estimated to be a maximum of 30-40 m. Shear velocity profiles are estimated from the measured data.

Concepts for the development of a field operative instrumentation for geotechnical and geophysical surveys are discussed.

Excitation and Propagation of Interface Waves in a Stratified Sea-Bed

H Schmidt
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A numerical model based on the Thompson-Haskell matrix method and Marsh's approximation of the Hankel transform is used to model the stress waves propagation through a stratified medium from a point source in one of the layers. Special emphasis is given to the excitation and propagation of interface waves in shallow water sea-beds. For realistic material parameters the geometry- and frequency-dependence is analysed. For selected cases synthetic seismograms and hydrophone signals are determined and compared to experimental data.

Acoustic Phase Changes and Boundary Waves on a Rough Sea-Floor

I Tolstoy
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The acoustic scatter from a surface with a dense distribution of small bosses can be obtained by (a) integrating the Rayleigh scatter from the bosses over the surface and (b) replacing the resulting integral by a boundary condition. This approach, first used by Biot (1968) for hemispherical bosses on a rigid wall, bypasses the usual small slope limitations of perturbation theory and has been generalised to the case of arbitrarily shaped roughness elements at an interface between fluids (Tolstoy, 1982). Interesting predictions of the theory are (1) a phase change for reflected waves and (2) the possibility of a subsonic boundary wave, the field amplitude of which may exceed that of the direct acoustic arrivals from a source of sound near the surface. The existence and properties of the latter have been verified experimentally on a rough rigid wall model (Medwin *et al.*, 1979). Conditions for the existence of this wave on a rough sea-bed are determined here, with particular reference to a pebbled model. (This work was supported by the Office of Naval Research.)

Equipment Developments

Electronically Focused, Multibeam Side Scan Sonar

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The along-track resolution of a side scan sonar can be increased by increasing the length of the transducer array, effectively narrowing the beamwidth. This causes the near field to extend to an excessive range. In order to implement short range, high resolution imaging the transducer array must be focused. A problem then occurs that the requirements of total operating range and maximum resolution place unreasonable constraints on the maximum towing speed.

An imaging system is described wherein a bank of digitally programmable phase

shifters is controlled by a microprocessor to simultaneously focus a transducer array and form multiple beams. The multiple beams are required to ease the towing speed constraint by imaging a larger area for each transmitted pulse ('ping') than could be achieved with a single beam system of the same resolution.

The system is extremely flexible, providing a number of operating modes, eg maximum resolution at minimum range with the resolution degrading as range increases, or constant resolution over the full range. A number of towing speeds are possible, whereby the system automatically degrades the resolution at increased towing speeds to ensure the formation of a contiguous image.

Development of a Sonar to Measure the Size of Sea-Bed Material

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A transducer has been developed at the University of Birmingham capable of working efficiently over the frequency band 400 kHz to 600 kHz. By using this transducer the backscattering power spectra of sea-bed surfaces can be measured at various angles of incidence. In situations where multiple-Bragg scattering occurs the size of the particles can be measured from the resonance peaks observed in the power spectra. An experimental sonar system has now been produced which transmits a wide-band signal over the 400 kHz to 600 kHz band. A microprocessor-based spectrum analyser measures the power spectrum of the backscattered echo signals. The paper will describe this system together with some recent results. It will highlight situations where the technique has been able to measure particle sizes accurately as well as discussing areas where problems have yet to be overcome.

The Chirp Sonar: A New, Quantitative, High-resolution Subbottom Profiling System

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For the past two years we have been developing (with US Office of Naval Research support) a quantitative, extremely high-resolution sub-bottom profiler. This system (the Chirp Sonar) uses a long (typically 100 msec) 2.5-5 kHz FM pulse to drive a specially designed transducer and provide the bandwidth and energy output necessary for high resolution with substantial penetration. The transducer, receiving array, instrument motion sensors, and associated electronics are mounted in a vehicle that is towed approximately 100 meters above the bottom. Data telemetered up the coaxial tow-cable is digitised in real-time by a shipboard computer. This computer also generates the outgoing pulse and can be used to experiment with various outgoing pulse schemes (eg FSK). Post-processing consists of: (1) correction for

instrument motion; (2) stacking; (3) matched filter processing (to compress the chirp); (4) correction for spherical spreading loss and energy lost at interfaces; (5) calculation of sediment attenuation (by examining the frequency dependence of energy from a particular horizon); (6) correction for sediment attenuation; and (7) display on a graphic recorder. The resulting record should be a near artifact-free image of the impulse response of the sediment column. This record is then used to estimate quantitative sediment characteristics based on the application of statistical and geological sediment classification models.

A Deep-towed Sound Source and Hydrophone Array System: Performance Prediction Analysis and Hardware Description

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A deep-towed system with a new measurement capability is being developed. This new capability will be of extreme interest to those members of the marine science community who are concerned with geological, geophysical, and geoacoustic parameters of the deep ocean floor and subbottom. The system is designed to operate at tow depths to 6000 meters and subbottom acoustic penetration of 500 to 1000 meters.

The basic system configuration has a sound source at the head of a multi-channel hydrophone array. When towed near the bottom, the system provides the geometry for improving geoacoustic parameter measurement precision. The performance prediction analysis presented compares the improvements that can be achieved from this deep-towed configuration with the more conventional surface-towed approaches which operate in the deep ocean environment. Also presented are trade-offs for the deep-towed system characteristics, including array length and array altitude.

Hardware fabrication has been initiated to meet the stringent requirements of the deep-towed configuration. This hardware includes a low-frequency sound source; a 24-channel, 725-meter-long hydrophone array; a digital duplex telemetry system; and a digital recording system. A description of this hardware is also presented.

The deep-towed sound source system, which operates over a frequency band from 260 Hz to 650 Hz and has a peak source level of 199 dB/1 μ Pa at 1 meter, has been tested. The remaining subsystems are currently under construction in preparation for a June 1983 sea test.

Poster Presentations

Determination of the Acoustic Properties of the Sea Floor by Measuring the Electric Impedance of a Transducer

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Rayleigh's reflection coefficient of sound waves at the sea floor — assumed to be quasi liquid — depends on density, sound velocity and attenuation of the sediment. This paper presents a method to determine these properties of the bottom by measuring the complex electric impedance of a transducer, which is in physical contact with the bottom. The relation between the acoustic properties and the electric impedance of a transducer embedded in a lossy medium can be derived under certain assumptions.

An equipment has been set up to measure the admittance diagram of a transducer, and some *in situ* experiments have been run at selected positions. Difficulties arose in getting a definite coupling between the radiating surface of the transducer and the sediment. The measured admittance diagrams are significantly different for different types of sediment. The shape of the admittance diagram yields the type of the sediment. The attempt to fit the measured diagrams in diagrams which were computed with parameters of actual sediments was only of partial success. Qualitative reasons for this behaviour will be given.

Acoustic Velocity Measurements in Surficial Sediments of the Beaufort Sea

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A geotechnical site investigation of a continental shelf area now customarily includes the acquisition of high resolution subbottom profiling information by means of a ship-decoupled or 'deep-tow' profiler. Such devices normally comprise an acoustic source of mid-audio frequency together with an appropriate hydrophone or short receiving array mounted together on the end of a long tow cable by means of which they can be deployed close to the sea-bed. In this way, vertical-incidence travel time sections are obtained with enhanced resolution and decreased noise as compared with surface-tow devices. The author has previously reported improvements to such tools which can be made by extending their acoustic receiving capability from single to multiple channel over an appropriate horizontal spread in order to observe reflections at various angles and so derive interval velocities in sediment layers.

Experience during the summer of 1982 in the Beaufort Sea (Canadian Arctic) indicates that it is possible (without disrupting their basic profiling function) to extend further the use of such deep-tow systems for the observation of headwaves in appropriate sediment conditions, namely when sediment acoustic velocity increases to c 1.10 times that of the bottom water within c 2 meters of the sea-bed. This method allows acoustic velocities to be determined in areas where the lower boundary of a sediment layer cannot be discerned sufficiently precisely to allow the use of the wide angle reflection method. In Arctic regions the possibility of ice-bonding in sea-bed sediments is a potential engineering hazard. The identification of ice-bonding with anomalously high compressional

wave velocities makes the measurement of that parameter important in these areas.

The Influence of the Sedimentary Succession upon the Acoustic Penetration in the Western Baltic

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The acoustic penetration in the sea-bed has been investigated along a transect in the Western Baltic where the various near-surface geological units are known through sediment cores. An 18 kHz echosounder fitted with a high resolution echosounder was used. Interval reflection strengths having time windows of 133 microseconds in the near-surface to 1067 microseconds down to a maximum of ten time windows have been analysed.

Penetration was very limited where sands and gravels constitute the surface sediment cover of the sea-bed, as most of the acoustic energy was reflected from the top-most layer, and fair to good in muds and clays, which sometimes have intercalated sands or are underlain by glacial deposits. The latter normally forms a strong reflector and a fairly good correlation could be established between the grain size parameters and interval reflection strengths. The reflector could normally also be followed through various depths and is typified by higher reflection strengths whose values are related to the difference in grain size between the various sediment layers.

Influence of Microstructure on Viscous Attenuation in Unconsolidated Sediments

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The viscous attenuation of compressional waves within unconsolidated sediments has been predicted to depend upon the product $bF(\kappa)$ in which b is related to the permeability, and κ is given by $l'(\omega\rho_l/\mu)^{1/2}$ where ω is angular frequency, μ and ρ_l are fluid viscosity coefficient and density respectively and l' is a parameter with the dimension of length that depends upon both the size and shape of the pores. The effect of tortuosity of pores q has been incorporated implicitly in the choice of l' also. However tortuosity is included explicitly in a density parameter $m=q^2\rho_l/\Omega$ which appears in the equations of motion where Ω is the volume porosity of connected pores.

Recent developments in the theory of sound propagation in air-filled rigid porous media separate effects of pore shape and of tortuosity explicitly. Thus a shape factor ratio $(n/\sqrt{s})$ is introduced where n is a dynamic shape factor and s is a steady flow factor that influences permeability. Tortuosity is related to an impedance factor (f_g) measured and calculated for fluid diffusion through granular media through $q^2=f_g^{-1}$. It should be noted that tortuosity influences permeability also. Values of tortuosity and shape factor ratio appropriate to underwater sediments are

Acoustics and the Sea-Bed

discussed. The sensitivity of viscous attenuation in model sediments to these parameters supposing extreme values of stiffness, rigidity and frequency are demonstrated.

Acoustically Induced Changes in Sea-Bed Reverberation

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This paper describes and attempts to explain a side effect whereby the viewing sonar triggered the sediment into liberating its gas and consequently changing its back-scattering qualities. The extent, existence and acoustic effects of naturally occurring gas in sediments is reviewed.

The phenomenon was observed whilst investigating the causes of sonar contact loss at 100 kHz. This involved a continuous monitor of the acoustic and environmental conditions prevailing in a 72-hour period whilst anchored over a 'fixed' acoustic range off Dunoon in the Clyde estuary.

Forty-two hours into the experiment the sonar blanked out — reducing to the noise level at all ranges — whilst the environmental sensors yielded no change, excepting the acoustic velocimeter which gave apparently irrational values. After half an hour the transmission characteristics were back to their previous levels although the sea-bed reverberation was significantly reduced.

The only valid explanation for these effects was that the sediment had degassed. Why, though, had the sediment suddenly degassed itself?

Although the power incident on the sea-bed was in the order of milliwatts the resonant sediment entrained bubbles were encouraged by deformation to migrate to the sea-water at a faster rate than normal. The increased gradient in the bubble population with depth encouraged the bubbles within the anoxic layer also to migrate faster. The action of this increased traffic through the sediment finally caused it to break down and liberate the remaining bubbles as a cloud whose concentration did not allow quick resolution into the sea-water.

The direct evidence as to the existence of this mechanism is lacking; however, on subsequent, similar experiments the effect was again observed.

At present the phenomenon is a scientific curio which probably has no commercial value, however, it may be as well to be wary of the effect when studying reverberation in detritus rich sediments.

Normal Modes of Acoustic Waves in the Ocean with Poro-elastic Bottoms

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The solution for normal modes of acoustic waves propagating in the ocean with porous elastic bottoms varying continuously with depth is obtained. The dynamics of the vertically heterogeneous bottom is represented by the propagator matrix derived

from the Biot's theory. The effects of basic soil properties, such as porosity β , permeability k_s , and rigidity, G , on the acoustic propagation are examined numerically. The acoustic attenuation in the ocean is governed by the three non-dimensional bottom parameters: $k_s f / \nu \beta$, $\beta [2.7-1.7 \beta]$, and $[2.7-1.7 \beta] K_f / G$. Here, f = frequency, ν = kinematic viscosity of fluid, K_f = bulk modulus of fluid.

Good agreements are obtained between the theoretical calculations and the experimental data from the Mediterranean Sea.

(Research sponsored by ONR.)

Acoustic Propagation Measurements with a Bottom-mounted Array

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Acoustic propagation measurements were taken with a bottom-mounted array on the UK continental shelf in the summer. Propagation loss, homogeneity and coherence results from these measurements are presented here. This work is part of a continuing effort at DREA in shallow water acoustics. A 54 m modular digital hydrophone array with a 1 Hz to 3 kHz frequency response was deployed horizontally on the bottom in approximately 100 m of water. Many runs out to 100 km were made with explosive and cw sources. The most interesting deployment was near a boundary between exposed and sediment-covered bedrock. The bottom structure along the runs was determined largely with a sub-bottom vertical reflection profiler. Large low-frequency propagation losses measured on runs over exposed bedrock show the need for shear-wave conversion in our models. The spatial homogeneity and spatial coherence of signals arriving at the horizontal array are also discussed.

Geoacoustic Modelling of Deep Ocean Abyssal Plains

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Geoacoustic models of the ocean bottom have been developed for two abyssal plain sites in the northeast Pacific Ocean. The first site is an acoustically 'hard' bottom of relatively thin layers of sandy turbidites in the Tufts Abyssal Plain, and the second site, located in the Alaskan Abyssal plain, overlies an acoustically 'soft' bottom where the artificial sediments are predominantly silt and the sediment column is at least 1 km thick. At the first site, interaction of low frequency sound with the bottom is confined to near-surface strongly-reflecting layers, whereas the 'soft' layer of unconsolidated sediments at the second site permits the development of a caustic beneath the sea floor. Consequently, the Alaskan Plain site was modelled by regions of constant sound speed gradient corresponding to layers of shallow unconsolidated and deeper consolidated sediment. The Tufts Plain site was modelled by layers of constant sound speed. Model parameters were determined from analysis of seismic reflection and refraction profiles taken at the

sites, and also from traditional bottom loss measurements. The validity of the geoacoustic models was demonstrated by direct comparison of propagation loss measurements with numerical predictions from normal mode calculations using the model parameters to describe the bottom.

A Microcomputer Based Multichannel Seismic Profiling System

M Shishido
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A fully microcomputerised multichannel seismic profiling system has been developed by the co-operative works of Ocean Research Institute of Tokyo University and Nippon Electric Co Ltd since 1978.

The built-in microcomputer has two-fold functions. One is a real-time data logging processor to sample and record multichannel seismic data on digital magnetic tapes in what is called SEG-B format.

The other is off-line processing of seismic records such as demultiplexing, CDP stacking, filtering or deconvolution. The processed data are recorded on an electrostatic printer plotter on-board.

The sampling intervals and the record lengths of the system for 12-channel streamer cable are from 0.5 msec for 1 second length to 4 msec for 8 second length. The short interval can be as short as 10 seconds for 8 seconds record including read-after-write operation. The system has a nominal dynamic range of 168 dB with the use of quarternal gain control.

The system has been tested successfully several times in conjunction with either air guns or water guns in the Japan Trench along the Pacific coast and significant improvements have been obtained through these trials.

A Hydrographic Depth Display and Analysis System

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Broad beam echo sounders typically receive many echoes from wide angle reflections, layers and fish especially in deep water. This paper describes a real-time and post analysis system to aid hydrographic surveying by tracking and analysing many echoes simultaneously. Both processed and unprocessed data are displayed in colour coded form on a graphics display allowing the operator to monitor processing and make alterations if desired.

Echo tracks appear as a line along the leading edge of each echo. The one automatically selected as representing the true sea-bed is displayed in a different colour enabling quick identification. In the off-line system the criteria for selection of this echo are operator adjustable. This facility is a valuable research tool since it enables one to classify echoes, investigate their statistics and extract any particular type of echo according to its shape or time history. In post analysis mode the operator can

select different echoes or make hand drawn or computed modifications to correct for hyperbolic echoes.

The tracking algorithms can deal with deep or shallow soundings from most echo sounders including the Precision Depth Recorder where echoes are interspersed with bursts of several pings alternating with quiet periods.

Acoustic Precise Measurement of Physical Properties of Floating Soft-Mud Sediment

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In order to measure precisely the density or concentration and thickness of floating soft-mud layer lying above solid bottom layer in sediment, acoustic reflection method operated under short pulse of high frequency such as 200 kHz seems to be available. In this method, measurement of transfer function which relates to the physical properties in the layers is essential. In such high frequency, this function should be obtained easily because sedimentary model can be simplified in 2-layer system.

Thus, since the function depends on acoustic impedance of the layers, the relationships between the acoustic impedance and density or concentration of the soft-mud can be expressed by the transfer function. Furthermore, a natural frequency to the transfer function which corresponds to the thickness of the soft-mud is clarified. The transfer function of the soft-mud and sediment layers formed in laboratory tank was obtained by the digital sampling of incident and reflected pulse wave at 200 kHz, while core sampling of these layers was made to calculate theoretically the transfer function. As the results, the experimental values of density, concentration and thickness agree with the theoretical values within a few percent error.

The conclusion is that the acoustic method is available to obtain precisely the physical properties of the floating soft-mud sediment.

Transient Parametric Arrays Terminated at a Water/Sand Interface

N G Pace and R V Ceen
University of Bath

A spatial impulse response model of the parametric array is developed and used to give physical insight into its behaviour when operated in a transient mode. Particular emphasis is given to the cases where the primary field is discontinuously terminated. In such cases effects due to the finite aperture of the parametric array and effects due to its termination may be seen by a point hydrophone either as separated or superposed events in time, depending on the geometry.

Experimental results consisting of signals received on a hydrophone from terminated parametric arrays are presented and dis-

cussed in terms of the model. The termination is achieved either by a sheet of absorbing ρ c-rubber or by a water/sand interface, the hydrophone being positioned at a greater range from the transducer than the termination. The experimental results presented for the case when the hydrophone is buried in sand are extensive.

Frequency Limitations of the Truncated Parametric Array

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Recent research in non-linear generation of sound offers new solutions to the problem of obtaining a low frequency narrow beam sound source for bottom penetrating sonars. In the application considered here shallow water operation is required, and the parametric array is truncated at the sea-bed. There are constraints on operating frequency and bandwidth, such as resolution and absorption in the sediment, but the distances involved are orders of magnitude greater than those previously considered in laboratory experiments. A theoretical investigation of the terminated parametric array in the frequency domain has shown that the effect of these dimensional requirements is to introduce nulls in the frequency response within the range of frequencies of practical interest. Results are presented giving usable bandwidth of a parametric array in terms of source to sea-bed range, transducer dimensions and angle of incidence between secondary beam and sea-bed. Examples are also given of the effects on typical sonar waveforms of exceeding this frequency limit.

Computer Modelling of a Sea-Bed Mounted Acoustic Wave Spectra Instrument

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This paper describes the computer modelling of an echo sounder system that measures the height of sea waves and shows the distortion in the measured spectra of these waves.

The results that are obtained agree with those that would be expected from the real echo sounder system. These show that the distortion in the measured wave spectra is increased for short length and high amplitude waves and is reduced by decreasing the beam width and depth of the echo sounder.

Three types of wave profiles are used in the model. The most important of these is the Stokes wave, which is a very good representation of a fully developed sea wave.

Two techniques are used to produce sea surfaces. The first utilises a digital filter to produce a random sea surface. The other is more general and combines a number of individual waves to create a sea surface. This second technique is a precise representation of the sea surface and produces results that verify this.

Applications of Acoustic Techniques in Sediment Transport Research

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Visual observations of sediment transport in the marine environment are frequently restricted by water turbidity. In some circumstances this can be overcome by acoustic techniques. Five developments currently under investigation are described:

- 1 The use of acoustic noise made by mobile non-cohesive sediments (sand and gravel) to determine the threshold of movement and estimate the size and quantity of mobile material.
- 2 Suspended sand is being measured by the use of a probe which monitors the number of sand grain impacts impinging on a piezoelectric ceramic sensor.
- 3 The concentration of suspended sand is also being quantified by backscattering 2 MHz acoustic pulses from range gated cells within the water column immediately above the bed.
- 4 Doppler processing of the backscattered signal is under investigation to achieve simultaneous velocity and concentration measurements of suspended sediment near the sea-bed.
- 5 In order to determine accurately the rate and scale of the movement of sand bedforms under adverse conditions a self recording echo sounder known as the acoustic bedform monitor has been developed.

Unconditionally Stable Ocean Bottom Reflectivity Calculations

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The main purpose of this paper is to draw attention to the usefulness, in bottom-interaction calculations, of the method of B L N Kennett (1974 *et seq*). The characteristics of this method are: (a) the quantities ρ , λ , μ , Q_p and Q_s may have any specified variation with depth; (b) λ , μ , Q_p and Q_s may have any specified variation with frequency at each depth; (c) the method is exact in the sense that all interactions between up- and down-going waves and between shear and compressional waves are explicitly included; (d) the equations used in programming the method for the computer have a clear physical interpretation; and, most important, (e) the method is unconditionally stable for all real values of frequency, ω , and horizontal wave-number, k . The method can be applied to any of the problems of marine seismology, eg seismogram synthesis, calculation of dispersion curves. The only real restriction on it is that the medium to which it is applied must be stratified.

Here we apply the method to the problem of calculating plane wave reflection coefficients from a visco-elastic ocean bottom at high frequencies and low grazing angles. For many velocity profiles the differences between a visco-acoustic bottom and a visco-elastic bottom are quite striking.

IOA Branch and Group Meetings

January to May 1983

19 Jan	14.15 h. Visit to BBC Solent, Southampton.	SB
20 Jan	18.30 h. <i>The role of the computer in acoustics</i> , D McNeal; <i>Audible intruder alarms</i> , AFA Minerva. At Liverpool Polytechnic.	NWB
26 Jan	18.15 h. Visit to BBC North East, Newcastle upon Tyne.	NEB
16 Feb	14.15 h. Visit to BBC Research Laboratories, Kingswood Warren.	SB
23 Feb	18.15 h. AGM and Bar Sports, Newcastle upon Tyne Polytechnic.	NEB
24 Feb	18.30 h. AGM . <i>Noise from office and home appliances</i> , D Baines. At Maxwell Building, Salford University.	NWB
16 Mar	10.00-16.00 h. <i>Planning and Noise</i> . At Town Hall, Darlington.	NEB
28 Mar	Speech Production and Perception. At University College London.	SG
30 Mar	10.30-16.30 h. Hearing Protection. At Portsmouth Management Centre.	SB
13 Apl	19.30 h. <i>Low frequency noise</i> , H Dawson. At Civic Centre, Southampton.	SB
20 Apl	14.00 h. <i>Planning and Noise</i> , R Atherton. At Civic Centre, Carlisle.	NEB
20 Apl	14.00 h. Visit to British Aerospace, Woodford.	NWB
6 May	20.00 h. Visit to Church Organ Builders, Stamfordham.	NEB
Date to be announced	'Dinner on the Occident Express.' Dining car service on the Watercress Line, Alresford to Ropley.	SB

Please send details of Branch and Group activities at least a fortnight before the Acoustics Bulletin copy date to Mr T Smith, Vice-President for Branches and Groups, British Gas (R & D Division), Engineering Research Station, Killingworth, Newcastle upon Tyne NE99 1LH. The following information should be included: date, time, venue or meeting point, and name and affiliation of speaker where appropriate.

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INTER-NOISE '83

The Institute is privileged to be hosting Inter-Noise '83 in Edinburgh, 13-15 July. Inter-Noise conferences are held annually, being located in the USA and in member countries of International INCE in alternate years. Inter-Noise is the premier noise conference, attracting large numbers of delegates from many parts of the world. All the signs indicate that Inter-Noise '83 will attain the high standards set in previous years and the organising Committee is presently dealing with more than 330 abstracts which have been submitted. It is anticipated that delegate numbers will be in excess of 500. A figure as high as 700 has also been suggested!

At Inter-Noise conferences, the largest group of delegates is always from the host country and we expect several hundred from the United Kingdom. Registration information will be available shortly so that it is not too early to start planning how to cover the £60 Registration Fee, travel and other costs.

Inter-Noise has had its anticipated effect on the normal Meetings Programme of the Institute. Members will have noticed the absence of noise-related conferences in the period up to July. Prospective speakers are saving their contributions for Inter-Noise, with the result that noise is out until late 1983. However, the Meetings Committee is working on a full programme for 1984, when we will return to our customary arrangements. □

H G Leventhall

In case you didn't hear . . .

FASE has a new President — our Immediate Past President, Professor Clarkson, previously the IOA representative on FASE.

The Federation has also recently announced the signing of a formal agreement with ASA, according to which the two organisations will work toward increased co-operation.

CEL have been awarded a contract, valued at more than £100,000, to supply a multi-channel computer controlled noise monitoring installation for Moscow Sheremetievo Airport. The equipment, based on the CEL-200 system, has been upgraded to withstand the severe Russian winters, and a comprehensive software package has also been provided which allows for both aircraft certification work and environmental noise monitoring work to be undertaken. □

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Bell Research at Loughborough

To the campanologist the name of Loughborough is inextricably linked with bell founding. Although the firm of John Taylor and Company has been resident in Loughborough only since 1840 its origins can be traced back to the fourteenth century. Prior to the development of canals and railways bells were always cast on site, but improved communications made it possible to have the advantages of a permanent foundry and Taylors found Loughborough's central location ideal. They now have an international clientele, not only for 'musical' bells for churches, clocks and carillons, but also for such diverse items as ship's fire alarm gongs and bells for channel marking buoys.

BELLS are cast in a nominal 80-20 copper-tin alloy and their general appearance has hardly changed since mediaeval times. The oldest English bells are from the fourteenth century, a little more conical than their modern counterparts and much less musical, but nevertheless obviously bells. The improvement in sound of the modern bell is probably due to the absence of some very anharmonic modes which are present in the ancient bell. The significant step of tuning bells came with the Hemony brothers in The Netherlands in the seventeenth century. They succeeded in making some very good bells, but unfortunately the secret was lost and it was not until the 1890s that tuning was put on a systematic basis by Taylors. In this they had the enthusiastic assistance of Canon

Simpson, a keen campanologist who recorded the notes of church bells from all over the country using a set of tuning forks, always matching the figures with a musical judgement. The happy relationship came to an abrupt end in 1895 when he published Taylors' secret tuning methods as two articles in *Pall Mall Magazine*.¹ About the same time Rayleigh² also published his paper on the normal modes of bells.

The precise shape of the bell varies considerably with the founder. Many continental bells have shapes defined by a complex pattern of arcs of circles, but some are just traditional shapes and outside The Netherlands, Germany and Austria they are not tuned. Taylors' bells differ in that their shape is defined by a fairly simple system of straight lines, circles and *ellipses* and they claim that this makes tuning simpler. Figure 1 shows half the vertical cross-section of a typical Taylor bell. The great increase in thickness just above the rim should be noted. Originally this was probably intended to strengthen the bell at the point of impact of the clapper. However, as will be explained later, it has a crucial effect on the behaviour of the bell and is a feature which is common to all European bells but absent in their oriental counterparts. In spite of the various shape definitions, there is very little difference between the modal patterns and frequency ratios measured by Grutmacher *et al*³ on a modern German bell, the classic work of van Heuven⁴ on a variety of ancient and modern Dutch bells and our own on Taylor bells. And, of course, all this agrees with Rayleigh, if we allow for the fact that modern bells are tuned — unlike Rayleigh's — and to an equitempered scale so that a bell is in tune with others in the peal or carillon as well as 'with itself'. Normally, in England, only the modes with the five lowest frequencies are tuned,

although a vast number actually contribute to the sound when the bell is rung. Typical frequency ratios and the traditional terminology are given in the Table.

When the Physics Department was formed in 1966 one of its aims was to be useful to local industry, and Taylors were quick to take advantage of this. For the members of the Physics staff with previous experience in acoustics it was interesting to change from suppressing noise to creating it! The immediate problem with which we were faced arose from the tuning of the small bells of the Canberra carillon. This required an understanding of the normal modes of bells and the phenomenon of bell 'warble'. An interest in the behaviour of other systems with axial symmetry naturally followed. We have just completed an exhaustive study of the normal modes of the modern English church bell and propose to make a similar investigation of a copy of a fourteenth century bell. Studies are also proceeding on the geometrical basis of the modern Taylor bell profile.

It has been proved by the authors using group theoretical arguments⁵ that the symmetries of an ideal basic bell require that the nodal patterns of its normal modes must consist of n circles ($n \geq 0$) parallel to the rim and $2m$ meridians ($m \geq 0$) at equally spaced azimuths. For any mode with $m > 0$ there must exist a partner mode equal in frequency, so that the pair form a degenerate doublet, the nodal patterns of the two being identical except that the meridians of one lie mid-way between those of the other. The absolute locations of these meridians are indeterminate, all azimuths being dynamically equivalent because of the bell's axial symmetry. Modes with $m=0$ are singlets since no such partners can exist for them. This degeneracy structure has been confirmed experimentally.⁶

In practice bells are almost always imperfect due to geometry and/or metallurgy so that the symmetries of the ideal bell are broken in small, complex and unpredictable ways. The results of these imperfections are: (1) to fix the absolute locations of the nodal meridians such that there is no obvious connection between those from different doublets, (2) to cause slight distortions of the nodal patterns, (3) to cause slight splittings between the frequencies of doublet members. It was first pointed out by Rayleigh² that it is beats between members of slightly split

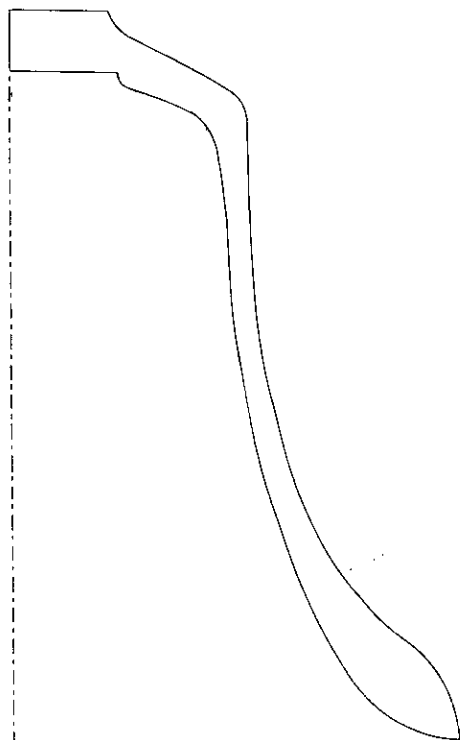


Figure 1 Profile of a typical modern Taylor bell

Characteristics of the 'musical' partials of a typical good quality church bell (actually a 70 cm Taylor bell)

Name	Frequency Ratio		Nodal Meridians	Nodal Circles
	Ideal†	Observed		
Hum	1	1	4	0
Fundamental	2	2.002	4	1 (near rim)
Tierce	2.378	2.367	6	1 (in waist)
Quint	2.997	3.014	6	1 (near rim)
Nominal	4	4.003	8	1 (in waist)

† These frequency ratios are based on the requirement that the bell be well tempered. It is common practice in the literature to round up the theoretical ratios and quote those of Tierce and Quint as 2.4 and 3 respectively.

doublets which causes the phenomenon known by campanologists as 'warble'.

It is common practice, for historical reasons, to refer to the components of the sound produced by a bell as 'partials': in the case of a singlet mode the partial is that mode alone, while for a doublet it consists of the pair (any splitting being only slight for a good bell). Analysis shows that for a typical church bell there are contributions from of the order of 100 partials in the audible region, but most founders maintain that only five of them, usually the lowest in frequency, are of substantial musical importance. The fact that warble can occur in any or all of these 'musical' partials is a reflection of the fact that they are all doublets ($m > 0$), and the fact that the warble frequencies can be different in all of them is a reflection of the complex nature of the imperfections responsible for the perturbation.

It is helpful in trying to interpret the sound of a bell to know the relative amplitudes of the various musical partials at various times after the strike. Figure 2 shows the basic decay curves (with the effects of warble removed) for these partials for the same bell, and is typical of the bells we have been able to examine. Notice that for the first second or so it is the Nominal which dominates, for the next eight or nine seconds it is the Fundamental and Tierce, and from about ten seconds onwards the Hum is completely dominant. This is probably the reason why the inexperienced ear detects warble most easily in the Hum.

A serious difficulty in trying to discuss warble is that basic research still seems to be needed into its psycho-acoustical aspects. The questions to which answers are needed concern the upper and lower frequency limits for warble to be (a) noticeable and (b) offensive.

It has to be borne in mind that not only is the amplitude of the oscillation decaying but so also is the base level about which the oscillation is taking place. A lower limit on noticeability is obtained by requiring the warble period to be longer than the decay time of the partial concerned, but this condition is probably over-severe.

Another complication is that whether warble matters in all musical partials, in some only or in none of them depends upon the bell's function. In change ringing only about the first second of the note following the strike will usually be heard properly, so from Figure 2 one sees that only a fairly rapid warble on the Nominal should be detectable. On the other hand if the bell is to be used for tolling or as a clock bell then warble in all partials, except perhaps the Quint, needs to be

kept within strict limits, but it is not desirable to remove it completely as it is one of the factors which contributes to the individual character of the bell. With carillon bells the situation is rather different and, although it is a matter of subjective judgement, it seems to us that warble should be reduced to a minimum, and if possible eliminated, in order to produce a good quality of note. Unfortunately it is in small carillon bells where warble is most frequently offensive in the immediate post-casting state.

There seem to be three possible approaches to suppressing warble: (1) to make the beat frequencies too low to be noticed, or at least to be offensive, in all the musical partials, (2) to make them too high to be noticed, (3) to arrange that only one component of each musical partial shall be excited. The first of these is the approach in fact used by founders, who rely upon careful casting to result in very small imperfections. For a church bell this is usually adequate, such small warble as remains being regarded as adding to the bell's individual character. If it is offensive this can be taken as an indication that something is seriously wrong with the internal structure and the bell is recast. In the case of very small carillon bells however, because of their relatively thick walls, warble on the Hum of the as-cast bell is by no means uncommon. With such bells—due to the characteristics of the human ear—the Hum is

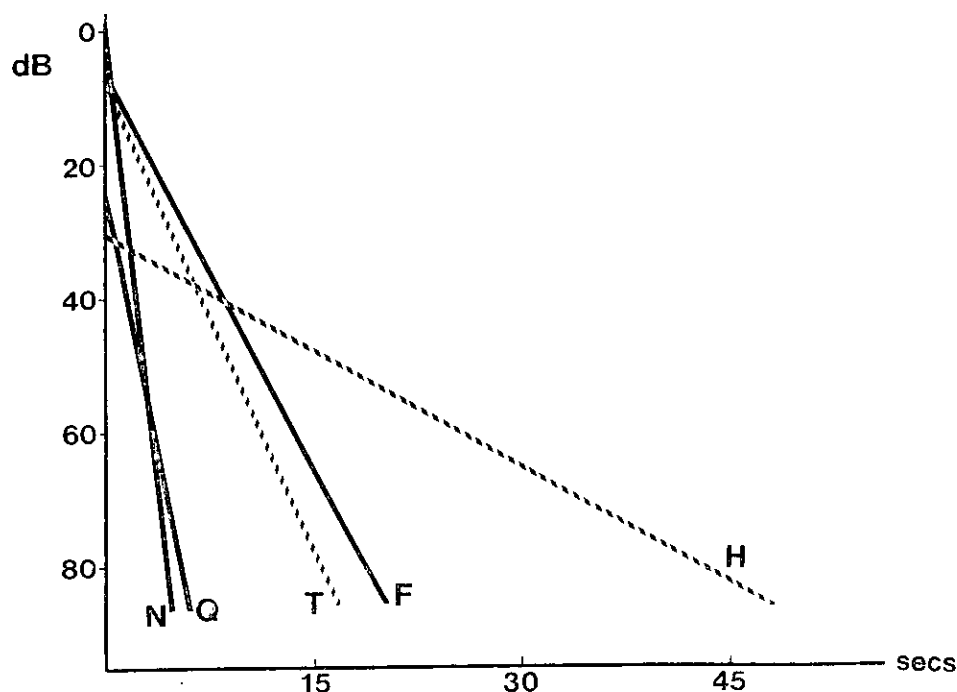


Figure 2 Relative decay of musical partials for a 70 cm Taylor bell

IOA REMUNERATION SURVEY

The Council of the Institute recently approved a proposal to carry out a remuneration survey of Institute Members. The survey will be similar to that of other professional bodies, but due to our comparatively small membership, the scope and detail of the analysis will be restricted. It is therefore important to achieve as high a response rate as possible in order to obtain meaningful results.

A short questionnaire will be circulated to all members along with a more detailed description of the survey. The confidentiality of all replies will be strictly observed. Names will obviously not be asked for and only an indication of age grouping will be required, the completed forms being returned to the Institute's Office.

It is hoped that all members will co-operate with the survey as the data should prove valuable to those in both public and private sector employment. ☐

M Blackaller and J Hyde

the note which dominates after impact and any warble on it must therefore be removed. The founders have developed a technique of grinding certain spots on the inside of the bell to remove the Hum-warble, but it is a matter of great skill to do this without increasing the warble of the higher partials because the locations of the nodal meridians of the various partials are unrelated.

The second approach to warble suppression mentioned above is really not practicable, as it changes the timbre of the bell unacceptably by increasing the warble frequency until it becomes a difference tone.

The third approach aims at controlling warble by reducing its amplitude rather than its frequency. It exploits the fact that one can remove warble from any one partial by arranging to strike at a nodal meridian of one doublet member, and hence at an anti-nodal meridian of the other. Even if the impact point is a short distance from the nodal meridian, that component will only be excited by a small amount compared with the other and the warble amplitude will still be very small. The reason why this method cannot easily be used to eliminate warble completely from all partials simultaneously is that in general no azimuth exists where all the partials have a common nodal meridian, due to the way in which their absolute locations are fixed by the imperfections. However, by applying a controlled perturbation to the basic system large enough to swamp the effects of the small uncontrolled imperfections it should be possible to produce a known common nodal meridian location. We have found that the most acceptable method of achieving this is to cast two ornamental ribs along diametrically opposed meridians and

arrange for the clapper to swing along the line joining them.

The mouth diameters of the bells in a carillon range from about 1.5 m down to about 15 cm. If they are all made the same shape the bells with the higher frequencies are very small and much too quiet, as they have only small radiating surfaces and are too thin to withstand a really heavy blow from a clapper. In the past two or more small balls were used together for the higher notes to increase the intensity, but this led to mechanical problems in getting the two clappers to strike exactly in unison and also the bells had to be very precisely tuned to avoid beats. Taylors therefore moved towards the use of thicker bells for the higher notes: a thicker bell is stiffer and a large thick bell can therefore be made with the same frequency as a small thin one. The problems arise when it comes to be tuned, as tuning is even more critical with a carillon than with bells for change-ringing.

A church bell, or large carillon bell, is cast so that its tunable notes are a few Hz higher than specification and metal is turned from appropriate parts of the inner surface until the five lowest notes are correct. The cutting locations are known to tuners skilled in the art and depend upon the location of the nodal circles in a rather complex, but consistent, manner. However with small thick bells not only is conventional tuning made difficult by the abnormal locations of the nodal circles, but extra modes appear inside the band which has to be tuned, and these have to be 'tuned out'. We enabled Taylors to solve this problem consistently by introducing them to the use of small transducers in order to monitor both nodal patterns and frequencies during the tuning process.

It will be noticed from the Table that the Tierce and the Quint have equal numbers of nodal meridians and circles but that the latter are differently located. This situation arises frequently amongst bell partials. Consequently the traditional *ad hoc* method for classifying bell partials has been to quote the number of nodal meridians, $2m$, and the number and position of nodal circles, n , for the component modes. This has never been satisfactory because of the anomalous position of the Hum, being the *only* partial with no circles. We have found that there are also problems with numerous higher partials, probably unknown to earlier workers, with a variety of numbers and positions of rings. Clearly a better understanding of the mechanisms responsible for the various modes is required in order to replace the *ad hoc* scheme with one on a sound physical basis.

We have taken a good quality modern English church bell and measured the frequencies and nodal patterns of all the partials up to about 9 kHz as accurately as our equipment would allow. Accurate measurements of the geometry of the bell were then made and used as the basis for a finite element calculation of the normal modes. We were then able to match up experimental and theoretical modes and so decide the physical nature of each experimentally found partial by looking at the finite element solution for its form. Families of partials were then identified which had a real physical basis.

Firstly there are modes which are primarily in the plane of Figure 1 and divide into 'ring' driven and 'shell' driven. For a given value of $2m$ there is always one partial which corresponds to the heavy ring on the rim of the bell going into its inextensional radial mode,⁷ and driving the shell along with it. Consequently the number of nodal rings varies with $2m$ depending upon the details of the nearest 'shell-alone' mode. This family includes the Hum, Tierce and Nominal, which shows the crucial importance of the thick rim. A second 'ring' driven mode for each value of $2m$ corresponds to the heavy ring going into its axial mode.

The remaining 'primarily in-plane' modes, which form a large majority in the region up to 9 kHz, are all essentially due to the shell going into its inextensional radial modes with the heavy ring at the rim being almost at rest and supplying a nodal ring close to

the rim. For a given value of $2m$ there is a sequence of these modes having 1, 2, 3, . . . nodal circles. The Fundamental and Quint are of this type. Again the role of the thick rim is clearly of prime importance.

The modes which are primarily out of the plane of Figure 1 are relatively high in frequency, difficult to excite and of little acoustical importance, eg torsional modes about the symmetry axis.

While it is a fairly simple matter to use a computer program to predict the normal modes of a bell with a numerically defined profile, it would be preferable to have an analytical expression for the profile since there would then be the possibility of obtaining analytical solutions for the normal modes. There is some hope of achieving this as we now know that it was originally defined in terms of arcs of ellipses and circles which were located with respect to a straight line 'frame'. This information is not required by the modern founders who operate by scaling from an 'ideal' standard shape established after a century of experimentation and consequently the geometrical basis of this shape has been forgotten through disuse. It is unfortunate that the shape development proceeded simultaneously with the tuning development. The contemporary founders' notebooks, although very detailed, are therefore confusing. We are currently engaged in tracing these developments. ☐

R Perrin
T Charnley

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Monthly Appointments Sheet

A monthly Appointments Sheet service is to be offered to advertisers and IOA Members for Situations Vacant and Wanted in fields relevant to acoustics. The Sheet will be mailed looseleaf, approximately monthly with *Acoustics Bulletin* and with other material mailed from Headquarters.

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INSTITUTE MEDALS 1984

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The medal is awarded, without regard to age, to persons of undoubted acoustic renown for outstanding contributions to acoustics. The medal is normally awarded to a United Kingdom and to a foreign acoustician alternately. A suitable citation accompanies the presentation of the medal to the recipient. As a condition of the award, each recipient is required to give a presentation in a suitable form, to the Institute, of an acoustical topic of his interest.

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This medal is awarded biennially to a citizen of the United Kingdom, preferably under the age of 40, for achievement and services in the field of acoustics. A suitable citation accompanies the presentation of the medal to the recipient. As a condition of the award, each recipient is required to give a talk on an acoustical subject of his choice. The award is made in even-numbered years.

A B Wood Medal and Prize

This is an annual award made for distinguished contributions in the application of acoustics, preference being given to candidates whose work is associated with the sea. The award consists of a silver-gilt medal, a parch-

ment scroll, and a cash prize. It is made alternately to a person domiciled in (i) the United Kingdom and (ii) in the USA or Canada. The recipient is preferably under 35 years of age in the year of award, which is normally made on a suitable occasion in the United Kingdom. Opportunity is given for the recipient to deliver a lecture at the time of the presentation.

Anyone wishing to put forward a name for consideration by the Medals and Awards Committee should write in strict confidence to the President, enclosing a brief outline of achievements, etc, before the end of February. The 1984 Medals will all be awarded to UK citizens. ☐

Acoustics in Physics and Engineering

A limited number of reprints of this 1981 Rayleigh Medal Lecture are available to Members working in the field of Physical Acoustics. The Lecture, by K U Ingard of the Aero-physics Laboratory, Massachusetts Institute of Technology, was presented at the Spring Meeting of the IOA at Newcastle-upon-Tyne on 22 April 1981 and subsequently published in *Acustica* 5/51 by S Hirzel Verlag of Stuttgart. Anyone interested in obtaining a (free) copy should contact Mrs Cathy Mackenzie at IOA Headquarters in Edinburgh. ☐

New Products

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New from GenRad is a program written specifically for the analysis of

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MCAVA can be implemented using a GenRad Series 2500 Modal Analysis System with a PDP 11/34 processor, 16 ADS channel, CTS board, 128K-byte memory and CDC Hawk disc file.

Further details from: GenRad Ltd, Norreys Drive, Maidenhead, Berkshire. Tel: 0628 39181. □

FASE/DAGA '82

This joint meeting was held from 13 to 17 September 1982 in the pleasant university of Göttingen. Over 400 delegates attended and the lectures were grouped into fourteen different subjects. The provision of seven lecture theatres arranged around a semi-circular gallery and the excellent timing arrangements prevented any difficulty in transferring from one theatre to another in the five-minute intervals between lectures. The first day was occupied by a colloquium on Speech Processing Aids and Cochlear Implants and the rest of the meeting followed the pattern of invited lectures in the morning followed by two sessions (of four to five lectures each) in the afternoons making a total of 56 sessions. Nearly a quarter of these were devoted to Speech (12) while others dealing essentially with audio frequencies were: Psychoacoustics (7), Noise (7), Room Acoustics (5), Building Acoustics (4) and Musical Acoustics (1). Physical Acoustics, Ultrasonics, Non-linear Acoustics and Sound Propagation occupied nine sessions and the other subject commanding considerable interest was Flow Acoustics (5).

The UK was represented among the invited speakers by M S Howe (Southampton) whose topic was *The production of sound by boundary layers and*

shear layers; P E Doak (Southampton) on *The acoustics of factories and other non-Sabine spaces*; and E F Evans (Keele University), whose talk on *Recent developments in understanding hearing mechanisms and hearing impairments* was well delivered and stimulated great interest. *The principles and applications of acousto-optics* was the title of the lecture given by a prominent worker in the field, A Alippi (Rome), while W Lauterborn (Göttingen) gave a lecture of wide interest entitled *Solitons and deterministic chaos: New concepts in non-linear acoustics*. Although the summaries in the Programme Booklet were quite informative, attendees, and others, will keenly await the arrival of the volume of the Proceedings early in the New Year.

Additional to the normal lecture programme was an evening lecture with demonstrations at the Third Physikalisches Institut given by its head, Prof M R Schroeder. The subject was *Demonstration experiments in Acoustics, Optics, Microwave Physics and Digital Signal Processing* and was so popular that it was repeated on the same evening. Finally a word of praise for the excellent arrangements made for visits of delegates and accompanying persons. □

RWBS

BRANCH AND GROUP NEWS

East Midlands Branch

A steering committee was set up in June 1982, under the guidance of Trevor Smith, to assess the viability of an East Midlands Branch. As a result an inaugural meeting was held at Derby Lonsdale College of Higher Education on Tuesday 16 November. A Meeting Notice was sent out to all Members of the Institute with the October Bulletin and in addition Midlands Members received notice a few days in advance of this.

The speaker was Professor E C Richards OBE Hon FIOA, of ISVR, who gave an interesting and informative talk on the causes, assessment and reduction of impact-generated noise in machinery.

Over fifty people attended the meeting, many of whom stayed after the talk for a drink in the bar. The steering committee was very encouraged by the response and as a result will be making formal representation to Council for approval to establish an East Midlands Branch, with officers elected at a General Meeting.

Martin Dearden MIOA, 42 Robincroft Road, Allestree, Derby DE3 2FR. Tel: home 0332 558889; work 0332 47181.

Standards

The following developments were noted during the last quarter.

BS Draft for Public Comment

82/53118 DC Acoustics. Specification for pure tone air-conduction threshold audiometry for hearing conservation purposes (ISO/DIS 6189.2).

International Standard

ISO 2631: Guide for the evaluation of human exposure to whole-body vibration.

ISO 2631: Addendum 2: 1982. (No equivalent BS).

International New Work Started

Noise of metal working machine tools. Will give a method of measurement (ISO/TC 39/SC 6/WG 4).

Noise of power presses. Will give a method of measurement (ISO/TC 39/SC 6/WG 4).

Noise of woodworking machines. Will give a method of measurement (ISO/TC 39/SC 6/WG 3). □

B C Grover

Speech Group Meeting: Speech Processing in the Auditory System

A meeting on Speech Processing in the Auditory System was held in the Department of Communication and Neuroscience, University of Keele, on 2 July. The meeting began with a review by Professor E F Evans (University of Keele) on the *Representation of complex sounds at the cochlear nerve and cochlear nucleus levels*. He described what was known about frequency and intensity analysis. Frequency coding is fairly well understood, but intensity coding is still in some respects a mystery. It is encouraging, however, that speech sounds are beginning to be used as stimuli in neurophysiological experiments.

The next two papers were concerned with computer models of different parts of the auditory system. P McCullagh and R Lingard (Queen's University, Belfast) presented their work on a *Space/time incremental model of the basilar membrane*; then P Frost (University of Keele) described his *Model ear program for speech recognition*. The latter incorporated some of the results from the experiments described by Professor Evans. It became apparent from these two papers that present-day computers are not really powerful enough for modelling the processing in the auditory system of any but the simplest of speech sounds.

It is sometimes forgotten that speech recognition can be influenced by visual information as well as auditory. This bias was corrected by M McGrath and Q Summerfield (MRC Institute of

Hearing Research, Nottingham) who described some experiments involving the *Detection and resolution of audio-visual conflict in the perception of vowels*.

After tea, R A W Bladon, C G Henton and J B Pickering (University of Oxford) presented some ideas *Towards an auditory basis for speaker normalisation*. This was followed by an interesting talk by G C R Green, A Rees and G A Stefanatos (Universities of Newcastle-upon-Tyne and Oxford) on *The auditory analysis of frequency and amplitude modulation*. They had measured scalp potentials evoked by auditory AM and FM signals, and found that the responses to FM were different in receptive developmental dysphasic children from those of normal children.

Finally, J R Foster and some of his colleagues from the MRC Institute of Hearing Research presented *A comparison of two forced-choice identification tests*, one of which had been developed at Nottingham and the other at Keele.

Thirty-five people travelled from many parts of the country for the meeting, and contributed much lively discussion at the end of each paper. □

IOA Annual Subscription

As detailed in a circular sent to all Members of the IOA, the following subscription rates will apply for 1983.

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Member: £28

Associate (over 30): £25

Associate (under 30): £21

Student: £10

NON-INSTITUTE MEETINGS

1983

22 - 24 February. London. *Sound Eighty Three*. Exhibition of professional sound equipment organised by The Association of Sound and Communications Engineers. Contact: ASCE, 4 Snitterfield Farm, Grays Park Road, Stoke Poges SL2 4HX.

15 - 18 March. *73rd Convention of the Audio Engineering Society*. Eindhoven, The Netherlands. Contact: Alex Balster, Polygram Record Operations International, PO Box 23, 3780 AA Baarn, The Netherlands.

21 April. *Research and Developments in Shock, Noise and Vibration*. SEE Symposium at Imperial College, London. Contact: SEE, Owles Hall, Buntingford, Herts SG9 9PL.

26-29 April. *4th Seminar on Noise Control—Engineers' Responsibility in Noise Control*. Szombathely, Hungary. Contact: OPAKFI, Budapest, Anker köz 1, H-1061, Hungary.

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Institute of Acoustics Meetings

1983

24 March	LEM	The Practical Applications of Audiometry in Industry	The County Hall, London
6 - 8 April	UWAG	Acoustics and the Sea Bed IOA Annual General Meeting	Bath
12 April	IEE	Speech Synthesis and Devices	London
21 - 22 April	HPA	Processing of Ultrasonic Signals, Analogue and Digital	Durham
28 April	LEM	A Survey of Vibration Nuisance from Road Traffic	The County Hall, London
18 May	BSA	Noise Induced Hearing Loss	London
26 May	LEM	A Code of Practice to Minimise Hearing Damage Risk in Discotheques	The County Hall, London
23 June	LEM	Automatic Monitoring—do we know what we are measuring?	The County Hall, London
July	SG	Speech Perception	Nottingham
13 - 15 July	M	Inter-Noise 83	Edinburgh
Late July	M(P)	Sonic Emission	Chelsea College, London
Autumn	BAG	Studio Design	London
Autumn	BAG	Local Government Noise Problems and Construction Industry Noise	London

1984

February/March	M(P)	Forensic Uses of Tape Recording and Speech Analysis	London
10 - 12 April	M	Acoustics 84 — Spring Meeting	Swansea

The Institute believes that one of the most important services offered to Members is the provision of a wide range of conferences. The Meetings Committee will be pleased to receive suggestions for conference topics as well as to have comments on the present Meetings Programme. Please send your views via the Secretariat in Edinburgh.

Key

M=Meetings Committee Programme

(P)=Provisional

BAG=Building Acoustics Group

HPA=Jointly with Hospital Physicists Association

BSA=Jointly with British Society of Audiology

UWAG=Underwater Acoustics Group

LEM=London Evening Meeting

IEE=Jointly with the Institute of Electrical Engineers

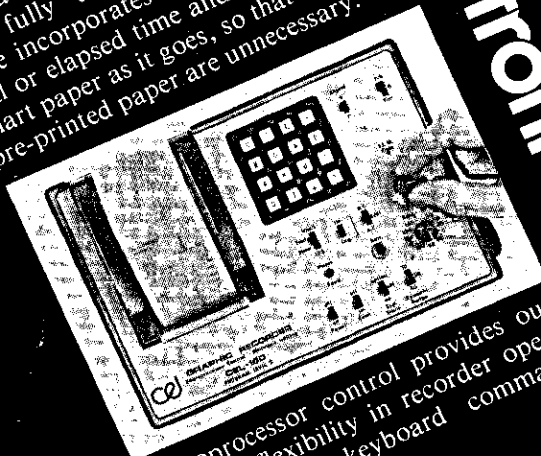
SG=Speech Group

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