Acoustics Bulletin

October 1988 Volume 13 Number 4

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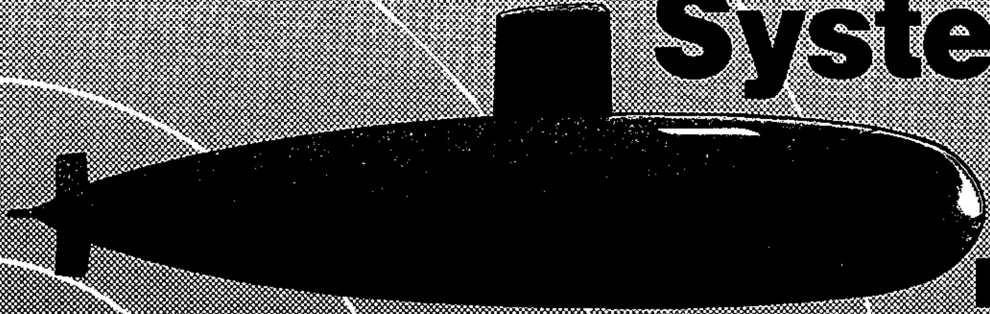

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October 1988 **Volume 13** **Number 4**

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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.

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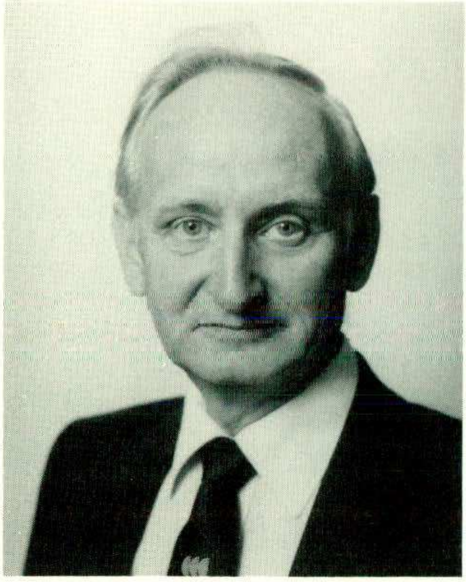

President's Letter

Institute of Acoustics

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Dear Fellow Member,

An opportunity to celebrate is always a happy occasion and I hope you will all want to join with me in congratulating the Institute of Sound and Vibration Research on reaching its 25th Anniversary. You will find elsewhere in this Bulletin a short history of the ISVR written by Professor P E Doak, who himself has been so influential in enhancing the reputation of acoustics in this country, and a copy of the letter I sent on your behalf to the present Director, Professor R G White.

At the June Meeting of Council it was decided that members should be kept better informed of the business that is transacted, and it was agreed that the Secretariat Notes would most usefully serve this purpose. Looking ahead Council will shortly be considering not only its own membership but also that of its various Committees. Although you will be formally asked to make nominations nearer to the Annual General Meeting, I would like to remind you at this early stage to start thinking about possible candidates. The adequate representation of members' interests is important to the wellbeing of the Institute, and this can only be done with your co-operation.

Of more immediate concern to some members will be news of the progress being made on the routes to CEng/IEng status. The formal Affiliation Agreement with the Institution of Mechanical Engineers was signed by the Presidents of the two Institutions on 6 July, and this now clears the way for us to process our own applications. The Engineering Division has formed the requisite sub-committees and these are finalizing the regulations and registration documentation that will be needed. In order to gauge the initial level of interest it would be appreciated if those members who are considering applying through the Mature Candidate Scheme would register their names with Cathy Mackenzie in Edinburgh. Information on the other routes will be given in the next Bulletin.

The new season of conferences and meetings is now under way and I hope you will find the programme attractive. Of particular interest is the Fourth Annual 'Reproduced Sound' Conference at Windermere during the period 3–6 November. This is a collaborative meeting which covers many topics, including the rapidly growing area of digital audio. Following this, and at the same location from 25-27 November, is the Autumn Conference, the topic for which is 'Noise in and Around Buildings'. During the meeting the Tyndall Medal will be presented to Dr M F E Barron for his work on auditorium acoustics. Windermere provides an ideal setting both to congregate socially and to communicate scientifically; I hope you will be able to be present on at least one of these occasions.

Yours sincerely,

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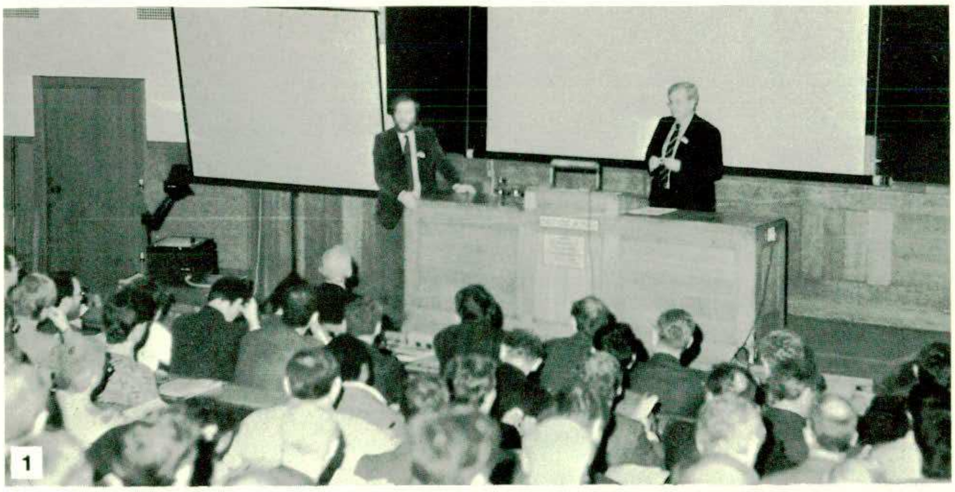

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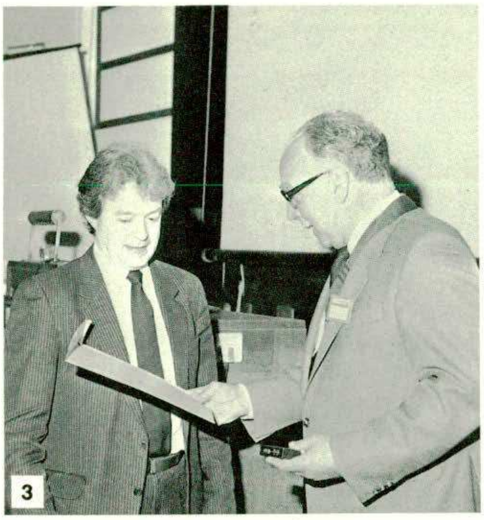

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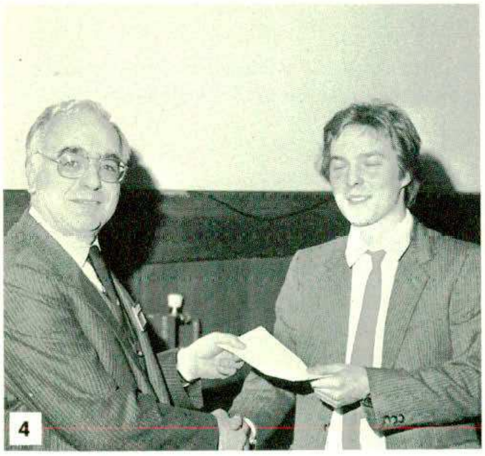

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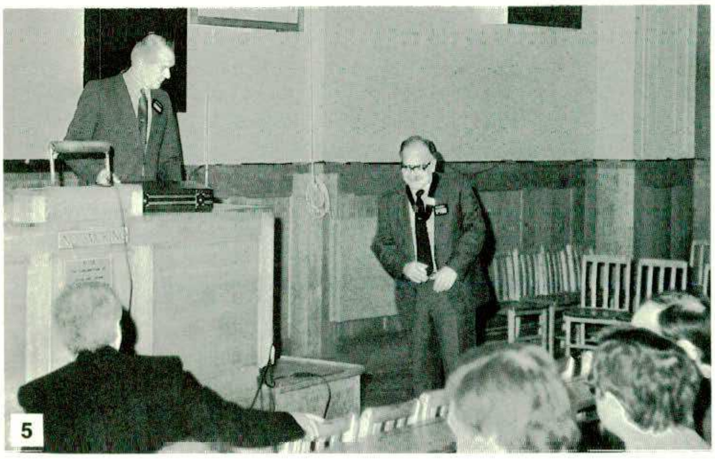
Faces at Acoustics '88

The 1988 Spring Conference at Cambridge on 5–8 April was a great success, attracting over 200 delegates — the highest number so far. The venue was superb, the catering excellent and the good fellowship memorable. Congratulations to Professor Ffowcs Williams, Dr Woodhouse *et al.* for the organization, not forgetting of course the usual competent and dedicated input from the Institute of Acoustics Head Office in Edinburgh. The photographs and captions (courtesy of Mike Ankers) illustrate some of the highlights of the Conference.

1 J E Ffowcs Williams and J Woodhouse open the first session
2 The changeover of President — C Rice takes over at the AGM
3 D G Creighton (Cambridge) receives the Rayleigh Medal from H O Berktay
4 The Simon Alport Memorial Prize is presented in the form of a cheque to J Wright (Celestion) by D Wallace (Cirrus Research Ltd)
5 D Weston (ARE, Portland) listens to the citation before presenting the R W B Stephens lecture
6 L Cremer presents his plenary lecture on sound field synthesis to a packed hall
7 The first invited lecture by L L Beranek on 25 years of concert hall acoustics
8 V F Humphrey (Bath) receives the A B Wood Medal from the President
9 Cathy Lee from Conference Contact helped to run the non-technical side
10 R Collyer of Scientific Atlanta reported substantial interest in the range of products on display
11 H O Berktay welcomes D L Birchall Limited to the Spring Conference Exhibition for the first time
12 Hakuto International Ltd are well-established supporters of our conferences
13 There was interest in the wide variety of surface absorbers from Applied Acoustics Venables
14 K Scannel (Lucas CEL) fails to convince D Wallace (Cirrus Research Ltd) . . .
15 . . . who in turn tries to tempt H G Leventhall, with equal success
16 Topexpress demonstrated the speed, power and lower cost of parallel processing



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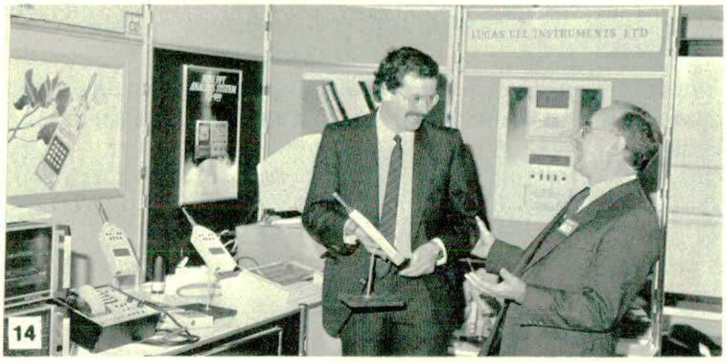

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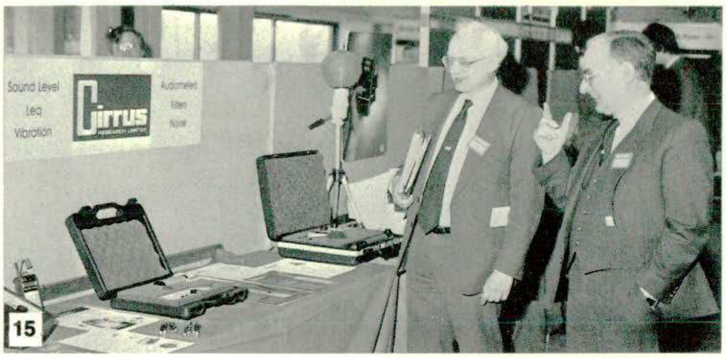

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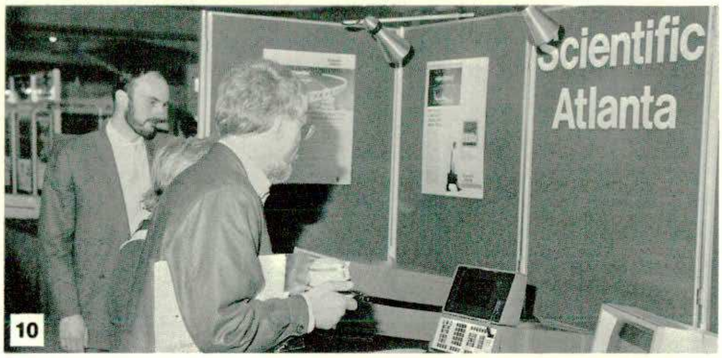

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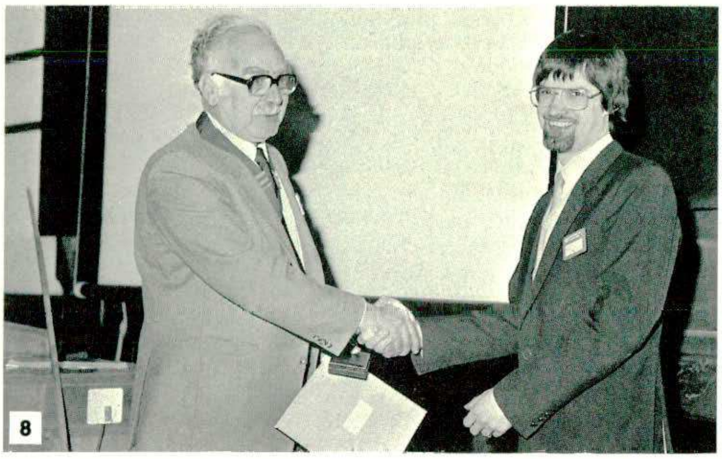
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Letter from the President of the Institute of Acoustics to the Director of ISVR, Professor R G White

Dear Bob, 5 July 1988

On behalf of Council and Members of the Institute of Acoustics it is my privilege to write and congratulate the ISVR on the occasion of its 25th anniversary.

There is no doubt that the contributions made by the Department through its teaching, research and consulting activities have been a major factor in improving the professional standing of acoustics and acousticians throughout the world. Moreover, the relatively short time scale in which these achievements have been accomplished more than justifies its undisputed international reputation.

Please convey our thanks to all past and present members of the ISVR for the individual contributions that they have made, and in particular to the founding Director, Professor Elfyn Richards, without whose foresight and charm many of us would not be so worldly and wise as we now are.

The Institute of Acoustics has always been appreciative of the support given by the ISVR, and hopes that this will continue to develop to our mutual benefit.

Please accept our sincere good wishes for a long and successful future.

Yours sincerely,

C G Rice

ISVR Short Courses 1988/9

1988	
12-14 December	Introduction to Noise Measurement Techniques
1989	
20-22 March	Vibration Measurement using Laser Technology
20-22 March	Active Noise Control
4-6 April	Image Processing
4-7 April	Digital Audio Signal Processing
11-13 April	Adaptive Signal Processing
11-13 April	Engine Noise and Vibration Control
17-21 April	Clinical Audiology
5-9 June	Applied Digital Signal Processing

Conferences at ISVR

International Conference – FASIG 1989; 3-6 April 1989

IOA Acoustics Conference, 27-30 March 1990

The Fourth International Conference on Recent Advances in Structural Dynamics, 15-19 July 1991

Further information regarding the above courses may be obtained from: ISVR Conference Secretary, Institute of Sound and Vibration Research, The University, Southampton SO9 5NH. Tel: 0703-559122 extn. 2310; Telex 47661 SOTONU G.

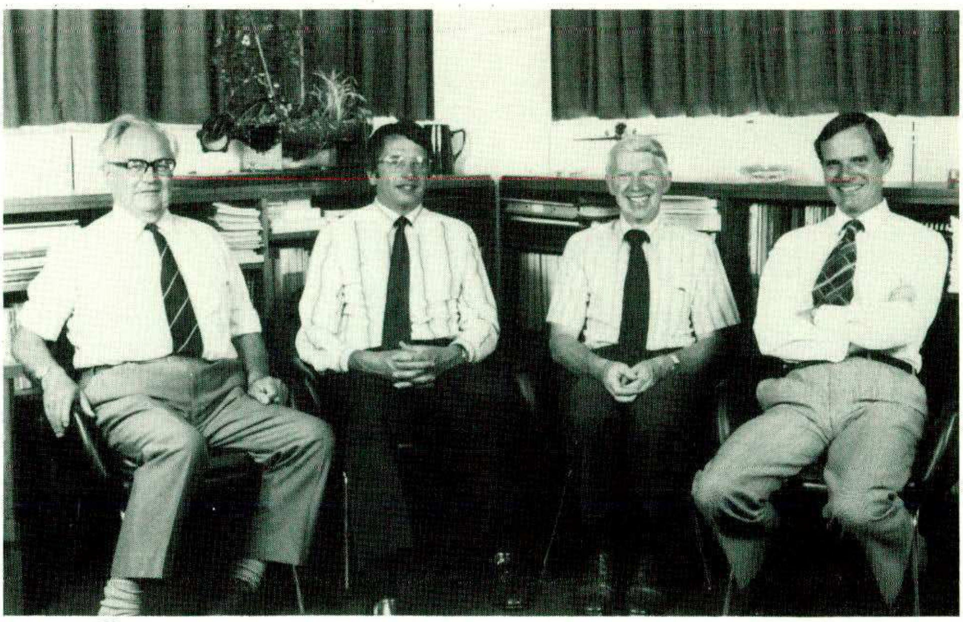
ISVR — the First

This year the Institute of Sound and Vibration Research (ISVR) of the University of Southampton, is celebrating its 25th Anniversary. That ISVR was born at all was due to the characteristic and legendary 'ten-year vision' of its founder, Professor E J Richards, subsequently Vice-Chancellor of Loughborough University of Technology. In the 1950s, as Professor of Aeronautics at Southampton, he perceived that noise and vibration were to become a 'disease' of new technology, for which the old style static stressing of machinery would be no cure. Already, with students and young researchers such as J E Ffowcs Williams and Alan Powell in the Department of Aeronautics doing pioneering fundamental work on the causes of the 'noise nuisance' of the then new jet aircraft, it was apparent to him that also ground vehicles and indeed all machinery would become 'infected', and furthermore that it would be necessary to combat 'industrial deafness' as well as 'noise nuisance'. A Department of Aeronautics could not legitimately lay claim to the required multi-disciplinary variety of engineering: therefore, a new 'Research and Teaching Institute' devoted to the subject in all its aspects was needed.

Laying the necessary groundwork took him a few years, but by 1962 he had succeeded in the first essential task: obtaining finance from industry, Hawker Siddeley Aviation, for a Readership and Lectureship in Noise Research. The next major step was to persuade the University and the DSIR (now the SERC), simultaneously but separately, to provide further sponsorship, laboratories, and recognition of 'Sound and Vibration' as a worthy engineering discipline. The University gave in first, with the ISVR established as a Department in the Faculty of Engineering in 1963, and the DSIR duly followed through in partnership to provide the major funding for both the new Rayleigh Laboratories and the initial research programme.

Before going on to Loughborough, Elfyn Richards presided over the growth of ISVR from an initial academic staff of five in 1963 to over fifteen in 1973; it is now over twenty-five, and consistently some 20 per cent of these have been positions financed by industry and/or national research organizations as non-UGC posts. Such sponsors have included the ICI (hearing research), the Admiralty (underwater sound and vibration), Perkins Engines, Ford and British Leyland from the motor industry, the CEGB (nuclear power plant), Rolls-Royce (aircraft engines), British Aerospace, and others. In addition, similar sponsorship has been much in evidence for students on MSc and PhD studies, and for Post-doctoral Research Fellows. Pioneering co-operation within the EEC was established via a 'link' with the new Université de Technologie de Compiègne, which brought several French students into the Sound and Vibration MSc course each year.

The evident success of the ISVR, with its growth from five academic staff in 1963



Directors of the ISVR, L to R: Professors E J Richards (Founder, 1963-67), R G White (1982-present), J B Large (1978-82) and B L Clarkson (1967-78)

Twenty-Five Years

to over twenty-five today, with its now three established MSc courses (Audiology, Automotive Engineering and Sound and Vibration), with its wide-ranging consultancy unit activities, with its large doctoral and post-doctoral research programmes, all now underpinned by an established undergraduate honours course in Engineering Acoustics and Vibration, can be attributed to adherence through the years to Richards's essential concept: a partnership of academic, industrial and governmental engineering interests.

ISVR, in keeping with this concept, has moved with the times and is perhaps now a model of what a university department should be with a total staff of over 300 and an annual budget of about £4 million, 80 per cent of which comes from external sources. Current major research and consultancy interests, naturally permeating through into the MSc and BSc teaching programmes, include active control of sound and vibration, aero-acoustics, laser/optical instrumentation for sound and vibration, human vibration tolerance, advanced clinical hearing testing, hearing conservation in the factory and the community, structural and machinery dynamics, dynamics of composite materials, automotive noise and vibration, signal processing and automatic control, underwater acoustics and vibration, and, as occasion demands, even 'less commercial' topics such as auditorium and musical acoustics. In union there may be strength, but in diversity there is staying power and growth.

Reinforcing the argument for the ISVR philosophy is the fact that the Faculty of Engineering and Applied Science brings into the University some two-thirds of its non-UGC income and ISVR is responsible for about two-thirds of this.

Another strength of ISVR has always been its unique internal ethos of unity through diversity. With the staff, early on, divided formally into 'groups', according roughly to their research interests, there has never been a dearth of friendly internal rivalry nor of compensatory mutual pride in the achievements of any particular group.

Those most adventurous spirits who have passed into and out of ISVR are numerous: the founder and first Director, E J Richards, to become Vice-Chancellor at Loughborough, and his successor, the second Director, Professor B L Clarkson, to become Principal of the University College of Swansea, and currently Vice-Chancellor of the University of Wales as well, are the academic stars. These gentlemen, and many other present and former members of staff, have collected on their ways numerous academic distinctions and medals of various professional institutions. Other even more adventurous spirits have distinguished themselves in industry and/or private/corporate research and consultancy activities all over the globe. There is a long list of ISVR alumni who are now professors in various universities throughout the world.

Another aspect of the birth and growth of ISVR, as an academic institute devoted to the technological aspects of sound and vibration, has been the very active involvement of many of its members in the founding and nurturing of extramural professional organizations and enterprises such as, for example, the Institute of Acoustics and the *Journal of Sound and Vibration*. E J Richards and P E Doak were members of the original *ad hoc* 'national committee' on acoustics formed under the aegis of the Royal Society, which, in a series of metamorphoses in the 1960s, established itself as the first Council of the British Acoustical Society, which in turn eventually absorbed the Physical Society's Acoustics Group to become the IOA. This involvement continues: the current President of the IOA is C G Rice, the ISVR's Deputy Director; the current *JSV* Editorial address is again ISVR, which it was when *JSV* began as a quarterly in 1964 – P E Doak (now Emeritus Professor) is even still Editor(!).

ISVR persons, past and present, are a fairly convivial lot, and on the evening of 16 July 1988 a 25th Anniversary Celebration Party was held, organized by Dr F J Fahy, presided over by the present Director, Professor R G White, and honoured by the presence of the Vice-Chancellor, Dr Gordon Higginson and Mrs Higginson. Needless to say, a very good time was had by all the many attendees coming from far and wide, and not least by old buffers such as your correspondent, who particularly enjoyed the Glen Miller 'belted out' for dancing by an enthusiastic 'big band' of youngsters from Poole, Dorset – incidentally, the Director comes from Dorset and has played jazz trombone in his off moments (is there some connection here?).

P E Doak

Chartered Status

This seems an opportune moment to inform members of the progress IOA has made in formulating routes for Chartered and Incorporated Engineer Status.

An Engineering Division Committee has been set up, under Professor P. Lord as Chairman, which will run the Engineering Division. This Division comprises those members who are already registered as Chartered or Incorporated Engineers, and in time will also comprise those who are registered as being in training to become so.

The Engineering Division Committee held its first meeting on 21 July 1988. These initial efforts were directed at forming two sub-committees, one cover ing Education and Training, whose task will be to receive, assess and process CEng and IEng applications from members of the IOA. The other subcommittee is for Joint IOA/IMechE Registration whose principal responsibilities will be to assess and process applications for Chartered Status to the IMechE Membership Committee for consideration and to ensure that successful applications are passed to the Engineering Council for registration by the Board of Engineering Register (BER).

An important facet of progress towards becoming a Chartered Engineer, particularly for young academically qualified candidates, will be a requirement for their work to be continuously monitored by a Principal Industrial Tutor who is a Chartered Engineer. The Institute is asking anyone interested in taking on this responsibility to contact the Secretariat.

The Institute has to hand a list of those members who have shown an interest in applying for Chartered Status and it is sincerely hoped that we shall see the first selected names going forward to the Joint IOA/IMechE BER Registration Committee before Christmas 1988.

Peter Lord,
Department of Applied Acoustics
University of Salford

New Institute of Physics President

At the AGM of the Institute of Physics held on 5 July 1988, Professor Cyril Hilsum, FInstP, FEng, FRS, was elected President for a two-year term starting on 1 October 1988. Professor Hilsum is Director of Research at the GEC Hirst Research Laboratories, Wembley.

Letters to the Editor

'Quiet' road surface trial

Your readers might be interested to know that the Government of Hong Kong has conducted a HK$1 million (£75 000) experiment to overlay a 300 m section of brushed concrete surface of an elevated dual four-lane carriageway, the Hong Kong Island Eastern Corridor (IEC), with new open-textured asphaltic material in an effort to determine the effectiveness of the road-tyre noise reduction. The location and length of the trial were determined by this department taking into consideration the practicality of a controlled measurement (that is, finding two locations having identical physical configurations and traffic patterns that will single out the road-tyre noise reduction effect) and also the number of people who would benefit from the anticipated noise reduction. The section of road runs at a distance of about 10–20 m from major high rise residential buildings and generates façade noise levels of up to 81 dB(A) L10 (peak hour).

Immediately after the overlay was completed, this department conducted measurements concurrently at two locations to determine the noise reduction effect. The results were encouraging – it was found that an average reduction of 5 dB(A) L10 was obtained from the trial overlay. Consistent results were also obtained from recent measurements approximately six months since the first survey.

Opinions gathered from local residents also indicated that a significant noise reduction was noticed subjectively. We are in the process of identifying similar stretches of road with a view to alleviating the noise problems being posed by heavily trafficked roads in Hong Kong, by the application of this surface.

From Raymond Chan, Principal Environmental Protection Officer, for Director of Environmental Protection, Hong Kong Government.

Hearing aid research

I write in answer to the letter from Judith Cohen which was published in the July 1988 issue of *Acoustics Bulletin* (Vol 13 No 3) regarding hearing aid research in the UK.

As she correctly infers there is a limited amount of help that can currently be given to the sensorineural hearing impaired person who uses a hearing aid with conventional electronic amplification. However, the technological advances to which she refers do in fact considerably improve performance as well as miniaturization, and should not be discouraged as they are usually accompanied by increases in battery life and also improve the cosmetic element which is so important to many users. Manufacturers are, in fact, spending considerable resources on hearing aid research and development and this should be encouraged particularly as financial support is regularly given to research teams in independent institutions.

The major advances which everyone concerned with these problems is seeking are most likely to come from advances in real-time digital signal processing. These techniques are being increasingly applied to the problems of the hearing impaired, although information relating to such progress is not being widely disseminated in public due to the difficulty in achieving the breakthrough that is required. Unfortunately nothing short of a miracle will enable most sensorineural hearing impairments to be completely restored, and progress will have to be made slowly, and with considerable patience and application from all those concerned with the rehabilitation process.

The subject is not totally neglected, however, and hearing aid research is being taken seriously at the highest levels. For example, the MRC Hearing Research Committee recently held a Tenth Symposium on 'Signal Processing Hearing Aids'. In addition its Advisory Sub-committee on Sensory Aids for the Hearing Impaired has prepared two important documents. The first is *Guidelines for Research Workers Performing Hearing Aid Studies* and the second, which attempts to prioritize research, *Needs in Hearing Aid Research*.

At the present time there is only a limited amount of financial support being placed with hearing aid research, and whilst the level of this support is not ideal, it is nevertheless adequate to ensure some continuity in the development of these new ideas. Additional sources of funding are always welcome of course, and researchers are continually seeking new sponsors.

Those institutions currently involved in such research include the MRC Institute of Hearing Research in Nottingham, the Royal National Institute for the Deaf in London, the Department of Phonetics and Linguistics at University College London, the Department of Experimental Psychology at the University of Cambridge and the ISVR at the University of Southampton. I am sure that each of these would be only too pleased to discuss their research with any interested party.

The issues raised in Judith Cohen's letter are most important and the Institute of Acoustics (IOA) is indeed willing to co-operate with the British Association of the Hard of Hearing in any way that will improve the hardships encountered by the hearing impaired. Whilst the IOA does occasionally hold joint meetings with the Institution of Electrical Engineers and the British Society of Audiology on topics relating to hearing aid research, it is really the BSA which co-ordinates the interest. Further information can be obtained from the Hearing Aid Audiology Group, British Society of Audiology, 80 Brighton Road, Reading RG6 1PS, telephone (0734) 660662.

The more interaction that takes place can only be to the benefit of all concerned.

From C G Rice, President of the Institute of Acoustics.

Hearing aid research

The letter from Ms Judith Cohen in the last issue was very welcome to anyone working in the area of hearing aids who wishes to attract into the area the talent and funds that are required to make substantial progress. However, it may have created the impression that the Medical Research Council does not care about the area and is not putting any funding into it. This would be unfortunate, not least because the impression would be totally incorrect. For the last nine years the Council has had a standing advisory subcommittee concerned with research and development in the area of hearing aids. For the last three of those I have been Chairman of this committee. I would be the first to recognize that some fields of research, important for the delivery of an effective hearing aid service, such as the acoustics of earmoulds, have received scant discussion during this time. However, the committee has done its best to address ways in which talent and funds could be brought into the area, and ways in which research directly on hearing aids, or on related problems, could be validly funded. By validly I mean by going through the peer review system in competition with submissions from all other areas making a call upon the medical portion of the nation's science budget, including submissions in other areas of direct concern to hearing-impaired people.

I am not quite sure what is meant by the suggestion that the Medical Re-

(continued on p.35)

Underwater Acoustics

Say 'Underwater Acoustics' to the man in the street and he will give you a blank stare. Try it on a practitioner of some other branch of acoustics and he will give his friends a knowing look and think thoughts of black magic and strange rituals – in fact the reaction will be the same from someone actually involved in the underwater arts. But systems and devices employing underwater acoustics are in daily use in practically all maritime activities. Only sound waves propagate in water over useful distances, and are used by all kinds of telemetry, communications, detection, and remote sensing within the water.

However, the acoustical parts of underwater systems are generally assembled using 'suck it and see' engineering (but you won't get anyone to admit it) and it is well known that theoretical predictions of sound propagation in the sea are sometimes almost right and sometimes altogether wrong. The physics governing underwater acoustics is the same as that in any other sort of acoustics, but the environment makes it special. Acoustical oceanography is in its infancy and, although many aspects are well understood, many are not. In either case, the vastness of the ocean and the fact that it changes continually in both space and time means that the empirical data needed to confirm theories about the behaviour of the sea as a propagation medium, or simply to predict propagation paths, signals levels and other parameters of interest, are often just not available.

This group of articles is intended to convey an impression of the nature of this special environment and the way it governs propagation and influences the performance of acoustic systems. The first three pieces talk about the general ocean environment, the noise background and acoustic propagation modelling, while the next two are more specific, dealing with shallow water and the effect of the seabed. The last two describe specialized and more complex situations where propagation is influenced by random fluctuations of the medium and by the presence of an ice canopy.

The authors are among the more eminent members of the underwater acoustics community. Their names will be familiar to many *Bulletin* readers:

Robert J Urick has contributed over the years to all phases of underwater sound research, and has literally hundreds of publications to his credit, including the well known *Principles of Underwater Sound*; **Geoff Kirby** started life with UKAEA at Winfrith in Dorset but moved to the MOD at Portland where he now runs the Ocean Science Division; **Roy Levers** made the long trek to Edmonton, Canada, to obtain a PhD in high energy physics and digging cars out of snowdrifts, but is now at ARE Portland working on sonar and underwater environmental acoustics; **David Weston** will be known to all as a Past President of the IOA: he has wide interests in underwater acoustics, but particularly in sonar and underwater propagation; **David Chapman** was A B Wood Medallist for 1986 and is leader of the Shallow Water Acoustics Group at the Defence Research Establishment Atlantic in Nova Scotia; **Barry Uscinski** has been working in Ocean Acoustics since 1977 in the Department of Applied Mathematics and Theoretical Physics at Cambridge, specializing in propagation in random media. His co-author, **John Potter**, joined the SACLANT Undersea Research Centre at La Spezia, Italy, in 1986, having previously been with the British Antarctic Survey; Finally, **Joe Posey** has been engaged in acoustic research for the past 20 years, and is now co-ordinator of high frequency Arctic acoustics at NORDA, Mississippi, while his co-author **Paul Bucca** is Head of the Acoustic Environmental Modelling Branch at NORDA and has been working in oceanography for the US Navy since 1967.

It is perhaps of interest to note that both Geoff Kirby and David Chapman are keen amateur astronomers whilst Barry Uscinski began his professional life with the Radio Astronomy Group in the Cavendish Laboratory, Cambridge. Is there a non-obvious link between astronomy and underwater acoustics?

These authors are to be congratulated for their contributions to a special issue that will be found readable, interesting and informative, and, hopefully, will go some way to dispelling the mystique that seems to have attached itself to underwater acoustics.

Peter F Dobbins
British Aerospace, Dynamics Division

The Noisy Sea

Robert J Urick

The Catholic University of America, Washington, DC

Introduction

Just as in the air above and in the earth below, there is noise in the sea. Indeed there is so much noise in the sea that there is never a problem in designing sensitive hydrophones to convert noise into an electrical voltage – except sometimes under a stationary solid ice cover.

Strange to say, this noisy environment appears not to have been described in the scientific literature until the years of World War II. Since then, it has acquired a sizeable literature – stimulated by the needs of passive sonars – and may now be said to be reasonably, but not entirely, well understood. A recent summary[1] has listed over 200 literature references, and these are only those references that are unclassified, meaningful and available, that is, not buried in some laboratory's dusty files – if they can be found at all.

When the noise is persistent and typical of a spot in the sea, it is said to be the *ambient* background of noise at that spot. Transient sounds, such as the noise of a passing ship or the apparent noise made by a crab crawling over the hydrophone are excluded, unless they are persistent or long-continuing. Ambient noise is partly of natural and partly of man-made origin, and when the latter, constitutes noise pollution of the otherwise quiet sea.

This paper is a review of the sources and some of the properties of ambient noise as they appear to be at the present time, and concludes with a mention of some of its aspects that are now, or need to be, under research investigation.

Sources of noise in deep water

If you were to take a broad band calibrated hydrophone to sea and make noise recordings, and analyse them in one-cycle frequency bands, you would get the spectrum of noise at the time and place where the recordings were made. You would find that the spectrum has portions of greater or lesser slope in different frequency bands, even reversing in one. From this you would conclude – correctly – that the sources of noise are different in different bands. A typical deep water spectrum may be seen in Figure 1, where it is divided into five frequency regions.

Starting at the left, in Band I below 1 Hz, little is known. This is a difficult region to work in and has had, so far, little practical application. In this band, an ordinary pressure-sensitive hydrophone is plagued by a large variety of noises of non-acoustic origin, such as the hydrostatic pressures of tides and waves and the hydrodynamic effects of water flow. This band includes the noise made by microseisms[2] and must contain tonal components in the pressure spectrum like those of the tides and a regular swell.

Going to the next band, here labelled II, the noise is clearly of sea-surface origin because it increases with increasing sea state or wind speed. The most likely process operating here is the hydrodynamic interaction of waves and swell travelling in opposite directions, producing, according to theory, a pressure un-attenuating with depth at twice the frequency of the waves. The spectral slope in this band is steep, but flattens out or even reverses somewhat at its upper end.

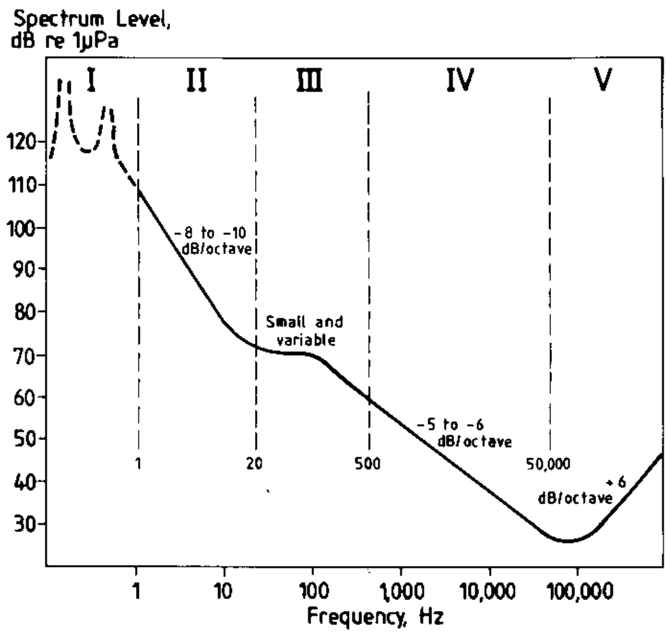


Fig. 1. A typical spectrum of deep water noise, divided into 5 frequency bands

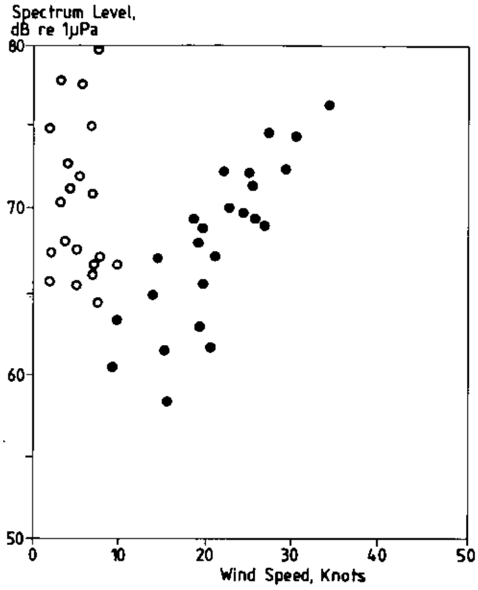


Fig. 2. Measurements of noise level vs. wind speed at 12.5 Hz at 4 locations. The open circles are at 1 location far from a shipping lane, and the solid circles at 3 locations near a shipping lane[3]

In Band III, starting around 10 to 20 Hz, the ambient background is dominated by the noise of distant shipping in the busy shipping regions of the world's oceans. This is illustrated by Figure 2, where one out of four locations was in a shipping lane, and at 12.5 Hz the noise was independent of wind speed, while at the other three locations, remote from shipping, the level depended on wind speed. In the North Atlantic and North Pacific, where shipping is prevalent, this form of noise pollution is obviously a deterrent to the long-range passive detection of submarines.

In the next band, IV, beginning at a few hundred Hz, the ambient spectrum is clearly dependent on wind speed; indeed, you can measure wind speed tolerably well with a deep bottom-mounted hydrophone by measuring the noise level at one or more frequencies. Figure 3 shows noise level vs. wind speed as observed at a deep site north of St Croix, Virgin Islands, where ship traffic was prevalent. Note here the close dependence on the wind at high frequencies and its absence at low. The first systematic study of ambient noise in this important sonar band was made during World War II[4] and the resulting spectra with wind speed or sea state as a parameter have long been called 'Knudsen curves' from the eminent acoustician, V O Knudsen, who directed the pioneering work.

Band V, with a reversed slope, consists of the noise made by the im-

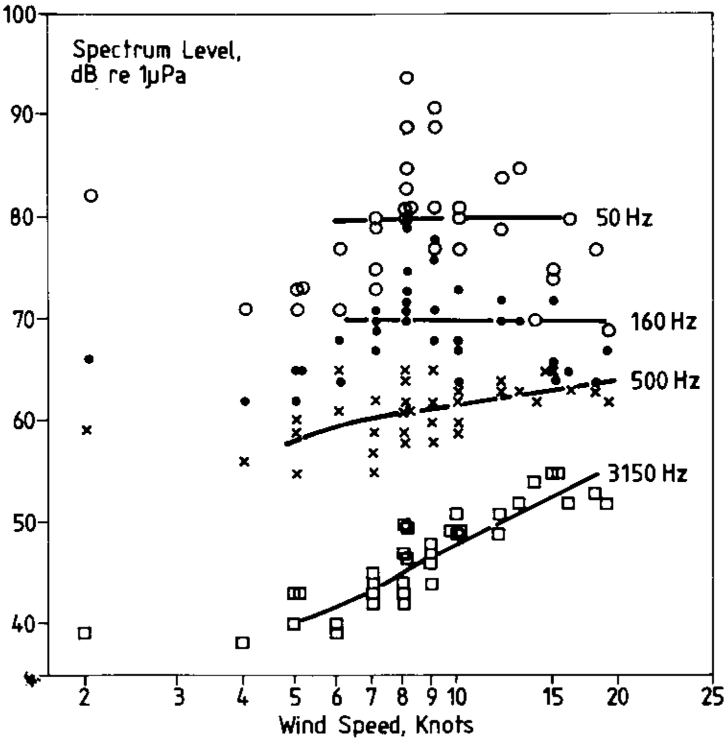


Fig. 3. Noise vs. wind speed north of St Croix, Virgin Islands (see ref. 1, fig. 2-12)

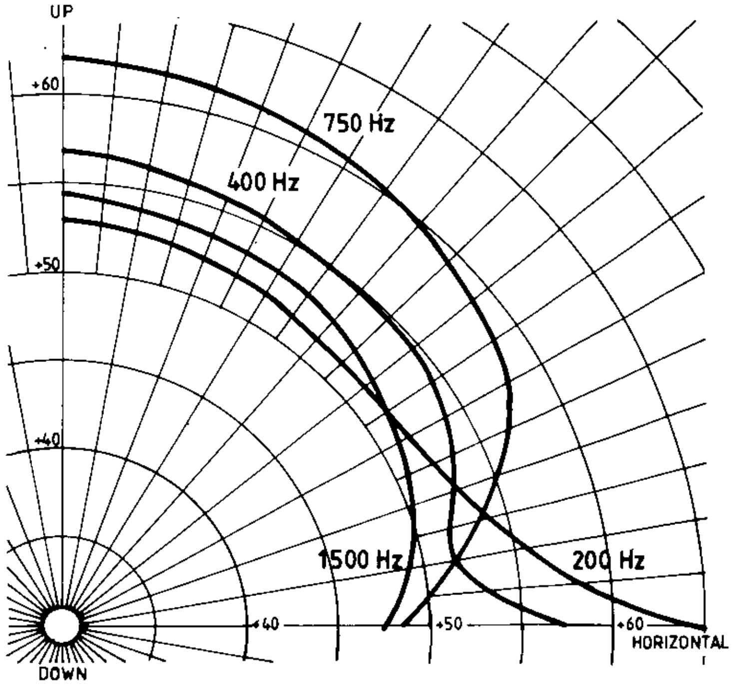


Fig. 4. Vertical directional patterns at four frequencies in sea state 3. The scale is in dB re 1 μPa per steradian[5]

pingement, or bombardment, of water molecules on the sensitive face of the hydrophone. Like the electrical noise measurements in the resistance of an antenna, it forms a floor to noise measurements at high kilohertz frequencies.

Except at extreme frequencies, deep sea noise can be thought of as consisting of two components. Component A comes from ships and storms at long ranges and travels via deep essentially horizontal paths. Component B originates locally at sea surface by the interaction of opposing waves at low frequencies and the stress of the wind on the rough surface at high frequencies.

Properties of ambient noise

With this model in mind, we can understand many of the characteristics of the deep sea ambient. First, it is directional and is not isotropic as it was carelessly imagined to be for many years. In Band IV where Component B is dominant, the noise arrives preferentially from above, and the 'beam pattern' of noise is oriented upward (Figure 4). At lower frequencies, in the region of dominance of Component A, the vertical pattern is oriented horizontally. There is directionality in the horizontal as well as in the vertical, as illustrated in Figure 5 which shows measurements taken in the Pacific about 800 miles east of San Francisco. Here, there was a greater amount of noise coming from the northwest and from the east. This was attributed to the ship traffic travelling along the great circle track from the west coast of the United States to the Far East, giving more noise in these two directions as a result of the so-called 'downslope conversion' effect, whereby noise originating on the Continental Shelf or on the Continental slope is 'converted' into noise propagating down the deep sound channel with low loss out to great distances.

Another property of deep water noise is its variation with depth. The noise level falls off gradually with depth below the surface duct, if one is present. The surface duct is exceptionally noisy at frequencies where ducting occurs. The quietest depth of all is at the seabed especially in a valley or depression where there is bathymetric shielding of distant noise sources.

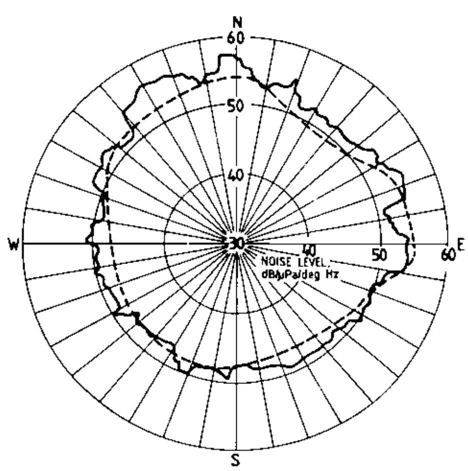
Finally, we point to the correlation properties of noise that are so important for the design of low-noise arrays. If the cross correlation between band-limited signals from two vertically separated hydrophones is plotted, the correlogram will show a peak correlation at zero time delay at low frequencies, indicating the horizontal arrival of Component A. At higher frequencies, however, the correlation peak will occur at a delay corresponding roughly to the propagation time between the hydrophones, indicating the vertical arrival of Component B. Thus, this property, too, confirms our two-component model of noise.

Shallow water

Shallow water noise differs in several ways from that of deep water. It is highly variable with time because shallow water is a dynamic, changing noise environment. At all frequencies there occurs a variation with wind speed when local shipping noise and biological noise are absent. Indeed, shallow water can be very quiet compared with deep water because of its often poor propagation conditions and the absence of favourable deep paths and convergence zones. A location in shallow water can be very noisy at times, but at other times it can be very quiet when the wind is the only source of noise.

Soniferous marine animals love shallow water. The noise of marine life came as a surprise in the early testing of acoustic mines in World War II – where the Chesapeake Bay Croaker was the

Fig. 5. Horizontal directionality of noise in the Pacific 800 miles east of San Francisco. The patterns were obtained by towing a horizontal array in different directions; the end-fire beam is shown dashed and broadside beam solid[6]



noisy culprit – and in sonar operations later in the war in shallow tropical water, where Snapping Shrimp (not edible!) were found to be obnoxious. Still later, when deep low frequency hydrophones began to be explored for long range sonar detection, a peculiar pulsing noise was heard at 20 Hz. This noise was first suspected to be of enemy origin and its discovery was kept highly classified for a number of years, when it was found to be produced by a species of whale. These unimaginatively termed '20-cycle pulses' have since been observed in many of the world's oceans. But by what mechanism, and for what purpose – other than that it must be pleasurable – whales make this peculiar sound is not entirely clear.

The Arctic

The ice-covered Arctic Ocean presents a unique noise environment. When the ice is continuous and short-fast (that is, not moving), when the wind is calm, and when the air temperature is not falling, the ambient level under the ice is extremely low – so much so that low-noise high-gain amplifiers are needed to reach it. On the other hand, when moving ice blocks with high winds are present, the level can be high. Even with a solid ice cover, decreasing air temperatures can cause tensile cracking of the ice, raising the level by as much as 30 dB. Nevertheless, the water beneath a solid ice cover in the Arctic seldom is as noisy as the ice-free sea at the same wind speed, for the ice cover acts as a smoothing, partially insulating, blanket.

Concluding remarks

In spite of its relatively great literature and the considerable understanding that has resulted from it, the subject of the ambient noise background of the sea is by no means a dead one. For example, the six issues of the *Journal of the Acoustical Society of America* for the period July–December 1987 contain some ten papers on the subject, and more were presented at the November 1987 meeting of the Society.

Some topics of current interest are: computer modelling of noise, the process or processes by which the wind makes noise, the noise of rain, snow and hail, seismic noise in the sea and generally the noise in the sub-sonic bands where occur the blade rate frequencies of propeller-driven vessels. In short, because of its many-faceted aspects, the noise of the sea is still a lively subject of current research.

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Some Range Dependent Effects in Sonar Performance

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Introduction

Oceanography has a long history of service to mankind. Polynesian navigators used an intimate knowledge of ocean currents and wave characteristics to cross the Pacific. Whalers used the Gulf Stream to hunt prey and merchantmen used it to cut down journey times across the Atlantic. In a modern military context, the detection and tracking of submarines and ships relies on sound, and the performance of sonars is dominated by environmental effects. These, in turn, are dependent on an understanding of oceanography. For the navy, acoustics and oceanography are inseparable.

For decades those striving to understand environmental effects on sonar performance concentrated on range independent situations. Recently, the emphasis has shifted towards range dependent effects since these give much greater scope for tactical exploitation, thereby giving a tactical advantage to the submariner with superior understanding of the oceans around him. This shift has been partially prompted by the ability to run computer programs which can predict propagation loss in environments where both the water column and the seabed topography are not constant around a sonar. The submariner now has the option to predict the detection performance of his sonars in all directions around his boat and to investigate changes in performance that would result from moving his vantage point relative to, for example, seamounts, fronts and eddies.

Figure 1 illustrates the power of recent developments in the solution of the acoustic wave equation for complex environments. Propagation loss was measured[1] over topography consisting of a steep Continental shelf edge and a seamount. Signal enhancements as large as 15 dB occur in the vicinity of the shelf edge and the seamount which can increase detection ranges by as much as a factor of three relative to the flat seabed case. The ability to predict and exploit such effects can be crucial in the detection of targets or the avoidance of counter-detection.

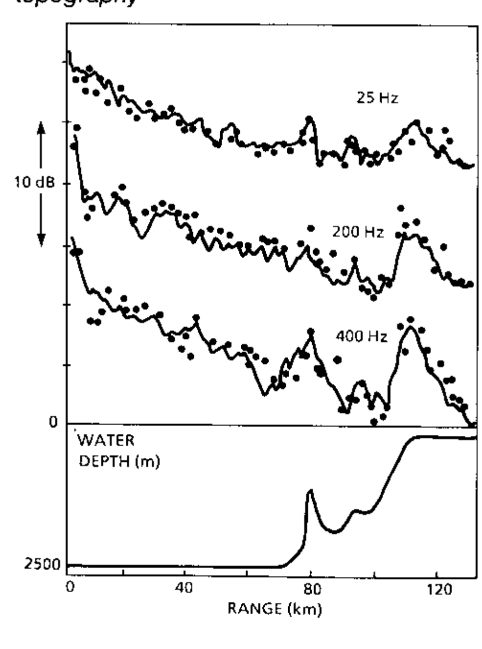
Propagation loss predictions – the continuous curves, computed using a wide-angle version of the PE code, agree extremely well with the data. Such comparisons now give users confidence that the effects of features in the environment on sonar performance can be predicted and exploited.

Three environmental features will be discussed briefly here to give a flavour for tactical exploitation of the oceans for military purposes.

Sea bed absorption

Rock can support shear waves and thereby efficiently attenuate sound at low frequencies. Sediments, on the other hand, are less supportive of shear waves and can refract sound upwards

Fig. 1. Comparison of experimental and predicted propagation loss over a complex topography[1]



and back into the ocean. Indeed, so efficient is sediment in the transmission and returning of sound to the water column that the dominant path between source and receiver may be via the sea bed rather than the ocean overlying it.

Experimental results have demonstrated that at low frequencies over a distance of about 50 km an increase in transmission loss as great as 35 dB can be found when the seabed is predominantly rock rather than deep sediments. This shows that areas of exposed rock or thin sediment may be good hiding places for submarines.

Fig. 2. Infrared image of the East Iceland ocean front

Ocean fronts

Figure 2 shows an infrared image of the sea between Iceland and the Faroe Islands taken from a NOAA (National Oceanic and Atmospheric Administration) satellite. The boundary between the warm and saline water to the south and the cold fresher water to the north is an oceanic front. Frontal structures in the oceans are similar to their atmospheric counterparts. A sloping boundary forms which is approximately stabilized by density gradients and the earth's rotation. The frontal zone still has a local instability, however, which causes it to cast off eddies. The sharp changes in density, temperature and salinity which occur at the boundary of the contrasting water masses may have severe effects on sound propagation.

Figure 3 shows a ray trace through the Maltese Front[2]. Initially the sound is split at the source by the vertical, undisturbed thermal structure in such a way that some is trapped in a near-surface duct and some is refracted down into the deep ocean. As the frontal zone is approached, at around 10 km range, the sound trapped in the surface duct leaks out and is dispersed over the whole water column. The deeply penetrating sound meanwhile is refracted back towards the surface but it does not quite reach it before being refracted back to the Stygian depths once more.

This diagram suggests several potential ways in which a combined knowledge of oceanography and acoustics can be used to advantage in the cat-and-mouse world of submarine warfare. For example, conventional wisdom states that the optimum location for the detection of targets in a surface duct is within that duct. Whilst true in general it is precisely *not* the place to search when a frontal system like that illustrated intervenes. The optimum is on the broad band of rays which dive to 800 m and return to approach the surface at a range of 30 km. Data collected across this front[2] show that propagation loss between shallow target and receiver is reduced by as much as 20 dB by the presence of the front.

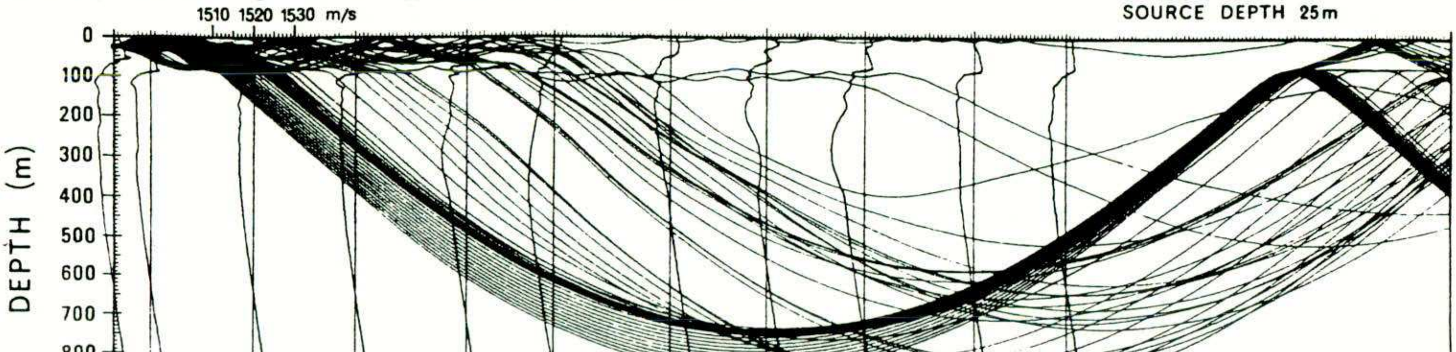
Internal waves

Internal waves are propagated on vertical density gradients in the oceans. Figure 4 shows 50 hours of vertical temperature profile data collected in the deep Atlantic with a static thermistor chain developed and operated by the Admiralty Research Establishment, Portland. The vertical scale covers the top 120 m of the sea. The oscillations of the thermocline can reach an amplitude of 80 m in a surface duct scarcely larger than 100 m. This can have a severely disruptive effect on sound propagation in surface ducts.

Fluctuations are induced into the signals received and the temporal and spatial characteristics of N E Atlantic internal waves correspond closely to the integration times and lengths of modern sonar arrays, thereby making internal waves the dominant source of environmentally induced fluctuations in low frequency sonars. Such fluctuations are not necessarily bad. Most disruptive influences in life can be turned to good use and internal wave fluctuations are no exception. They give the potential to make fleeting detections at significantly longer ranges than would be achieved in a steady environment.

The regular large pulses of internal waves on Figure 4 occur at tidal frequency and are due to internal wave solitons generated at the Continental shelf break by tidal currents. The ability to predict the occurrence of these

Fig.3. Ray trace showing sound energy paths across the Maltese Front[2]



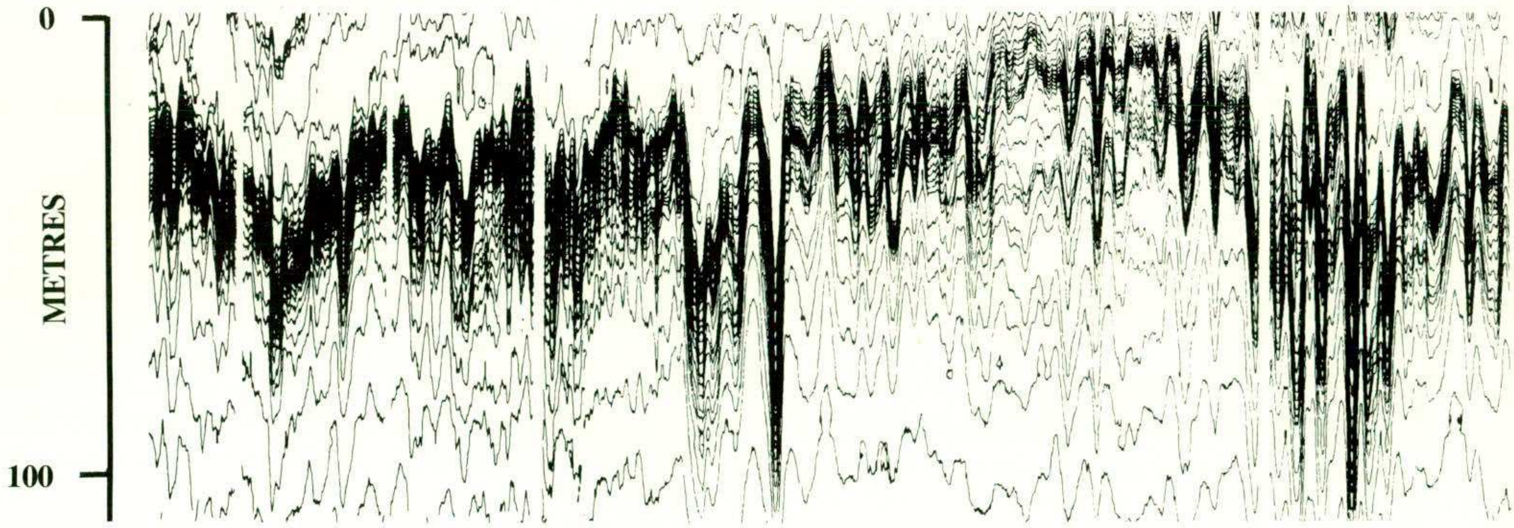


Fig. 4. Fifty hours of thermal profiling with the ARE thermistor chain

occasional large amplitude waves and to be able to exploit their beneficial effects on sonar performance is obviously highly desirable.

Internal waves also cause sound energy to be refracted out, leading to insonification of sub-thermocline regions which would otherwise be in a shadow zone. Thus the mean levels of propagation loss are affected as well as the fluctuating levels. Theoretical work by the author has shown that the effective depth of a surface duct is shallower than the true depth by about 2.1σ, where σ is the standard deviation of the thermocline displacement.

The surface slicks of internal waves are detectable on synthetic aperture radars from space. Thus, there is the potential to inform ships and submarines of their presence and allow them to exploit their acoustic effects. This can be either for increasing detection range by fluctuations or for avoid-

Ocean Acoustic and Atmospheric Microwave Propagation – Comparisons and Modelling

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The propagation of sound in the oceans has an important deterministic component which is more profoundly influenced by the acoustic refractive index than microwaves are by the electromagnetic refractive index in the atmosphere. Unlike radar, where absorption windows occur at a number of frequencies, sonar is confronted with an ever increasing volume absorption loss with increasing frequency. The physics of both types of wave propagation may, however, be studied with the aid of ray, mode, and parabolic equation methods.

The models considered here are not only the main ones utilized in unravelling the physics of acoustic transmission loss from a single frequency source in the ocean environment, but serve to describe microwave propagation in the atmosphere too. Problems of pulse transmission, target strength, coherence, ambient noise, reverberation, clutter, fluctuations etc. have been ignored, although a list of relevant books is included.

Inputs to the model, such as actual source position, refractive index throughout the ocean volume of interest, sub-seafloor geoacoustic parameters, sea-surface roughness, bubble distribution, biological scatterers etc. are often unavailable, approximate or fluctuating! Thus, although many models attempt to map such parameters into meaningful acoustic transmission loss outputs, they can be somewhat proscribed by this less than perfect input data.

The underwater enrivonment may be conveniently divided into deep water and shallow water zones with average ocean depths being typically thirty times greater than the world's continental shelves. This leads to two immediate consequences. Firstly, at a given range from an underwater sound source transmitting frequencies at which volume absorption loss is not large (below a few kHz), frequent interaction with the seabed of the shallower waters can lend credence to the concept of average energy stripping loss with range. Secondly, in deep waters (average depth around 4 km) there is a much greater variation of refractive index both with depth due to wider pressure and temperature ranges and with range due to 'ocean weather' systems such as fronts and eddies, in extent similar to but an order of magnitude smaller than atmospheric weather of everyday concern.

Sound velocity and ocean waveguides

It is the velocity of sound or, more precisely, its spatial and temporal changes, which generally has such a profound influence on sound propagation in the oceans. It may be regarded as consisting of three major components i.e. C_0, C_1, and C_2.

C_0 is deterministic in nature, varies with depth only, and has a value around 1500 m/s. C_1 introduces large scale spatial variability effects, typically of the order of 10 m/s, due to mesoscale

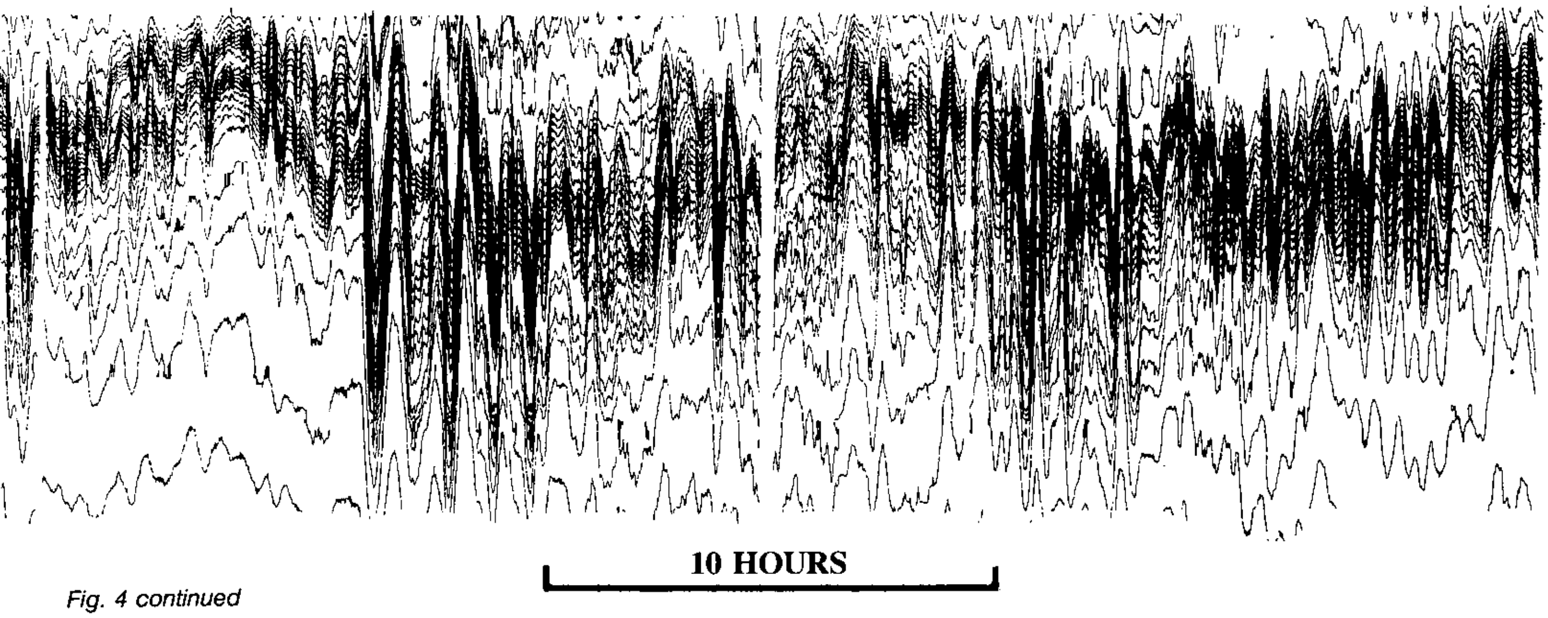

Fig. 4 continued

ing detection by operating in a surface duct rendered thinner and more highly attenuating by internal waves.

Summary

Only a very few examples of oceanic features have been cited but each offers the potential for exploitation by an informed sonar user. The gains – and losses – can often amount to 10 or 20 dB which can change detection range by a factor of three or more. Range dependent effects are the key to this improved awareness of the importance of the ocean environment to sonar performance.

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Ocean Acoustics *(continued)*

phenomena such as eddies and fronts. C_2 accounts for finer scale temporal (hours or less) and spatial variability, on a scale of about 10 cm/s, such as internal waves.

C_0 increases with pressure (and therefore depth (z)), salinity (S) and temperature (T) and may approximately be written as

$$C_0 = 1500 + f(S,T) + 0.017z,$$

with z in metres and C_0 in metres/sec. The function f increases with S and T. For water around 10°C and salinity of 35 ppt (parts per thousand) the same increase of velocity (of about 3.5 m/s) would be obtained from an increase of 1°C in temperature, 3 ppt salinity, or 200 m depth.

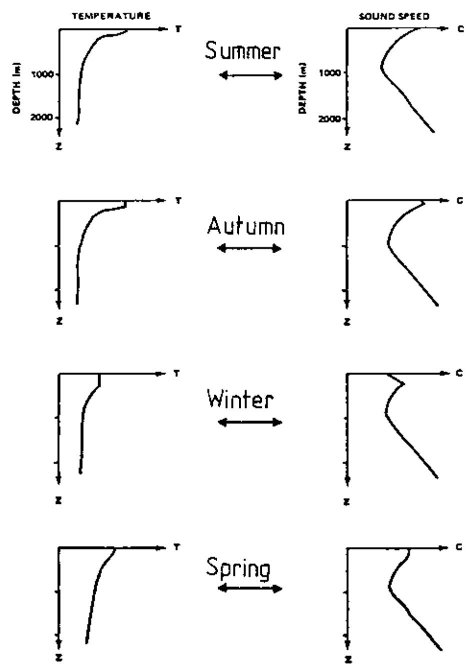
In contrast the velocity of microwave radiation in the environment above the sea-surface increases slowly with temperature but decreases more rapidly with barometric and water vapour pressure. The 0.03 per cent increase in microwave velocity from sea-level to free space compares with the typical 5 per cent increase of sound velocity from the sea-surface to average ocean depths, i.e., two orders of magnitude greater. In the absence of microwave ducts (see later) the average behaviour of temperature, barometric and water vapour pressure generally ensures that microwaves are bent towards the earth (superrefractive). The bending is not great enough to overcome earth curvature – this would require a four-fold increase in the velocity gradient i.e. about 0.12 per cent change. Sound velocity changes are typically forty times greater than this, implying more dramatic effects essentially unaffected by earth curvature.

Figure 1 indicates a seasonal variation of temperature and sound velocity with depth, typical of the North Atlantic, in an area where salinity changes are unimportant. In summer the temperature drops away fairly rapidly (the thermocline) with depth below the warm surface until it becomes isothermal. In autumn, increasing winds mix up the water to a depth of a few tens of metres, creating an isothermal layer (the mixed-layer). This deepens in winter and may reach a few hundred metres. In spring lower turbulence and increased surface heating decreases and weakens this mixed-layer.

An immediate effect of the rapid increase of velocity at the greater depths is the presence of convergence zones, in which sound energy penetrating to great depths due to downward refraction is re-focused near the sea-surface every 60 km or so.

Two other noticeable features of sound velocity are (i) the minimum

Fig. 1. Typical North Atlantic seasonal variation of temperature and sound velocity with depth



velocity at around 1000 m, giving rise to the deep sound channel, where the decreasing negative temperature gradient is finally compensated by the increasing pressure, and (ii) the surface-duct created in the mixed layer by the increasing pressure, without compensating decreasing temperature. Salinity effects, such as the warm saline Mediterranean outflow, can create additional depressed sound channels.

Sound channels and surface ducts behave as acoustic waveguides, whose channelling capability is a function of the sound velocity gradient around the sound source and the channel width (in wavelengths). Surface ducts are similar to the well known microwave evaporation ducts over the sea, which are due to the relatively rapid decrease in water vapour pressure away from the surface, yielding a microwave velocity increase over a height of a few metres.

Channelling capability improves with increasing frequency until such time as absorption and rough surface scattering losses become dominant. At low frequencies diffraction losses may be important, although absorption and scattering losses decrease significantly. At low enough frequencies the whole ocean between the surface and the seafloor (and below) behaves as a waveguide. Compressional velocity gradients in sediments are typically a couple of orders of magnitude greater than deep ocean water column gradients. In principle they are able to refract sound back relatively rapidly into the water column, although energy losses are naturally higher than in water.

Volume losses

Sound absorption in sea water at sonar frequencies is an order of magnitude greater than fresh water. The pH of the alkaline oceans, together with the three relaxation processes associated with boric acid, magnesium carbonate and magnesium sulphate, appear to control sound losses in the ocean. A satisfactory three component global model formula for this absorption A in dB/km seems to be

$$A = A_1\,(MgSO_4) + A_2\,(B(OH)_3) + A_3\,(MgCO_3),$$

with

$$A_n = (S/35)a_n f^2 f_n/(f^2 + f_n^2),$$

f denoting the frequency in kHz. The relaxation frequencies f_n depend on temperature only, i.e., $f_1 = 50 \times 10^{T/60}$, $f_2 = 0.9 \times 10^{T/70}$, $f_3 = 4.5 \times 10^{T/30}$, whereas individual absorption coefficients depend on either depth i.e., $a_1 = 0.5 \times 10^{-50z}$, or pH, i.e., $a_2 = 0.1 \times 10^{(pH-8)}$, $a_3 = 0.03 \times 10^{(pH-8)}$.

Figure 2 shows the important effect of pH on absorption loss (dB/km) per kHz, at a temperature of 4° and salinity 35 ppt for typical oceanic pH values of 7.7 (North Pacific) and 8.3 (Eastern Mediterranean); North Atlantic values are between these (around 8.0). Absorption loss has been divided by frequency to reduce the dynamic range. This relentless increase of absorption loss with frequency contrasts strongly with microwave propagation in the atmosphere, where absorption losses due to rotational energy-level transitions in water vapour or oxygen occur in quite narrow resonance bands in the tens to hundreds of GHz regime. There appears to be no absorption frequency window for optimum propagation in the underwater scenario.

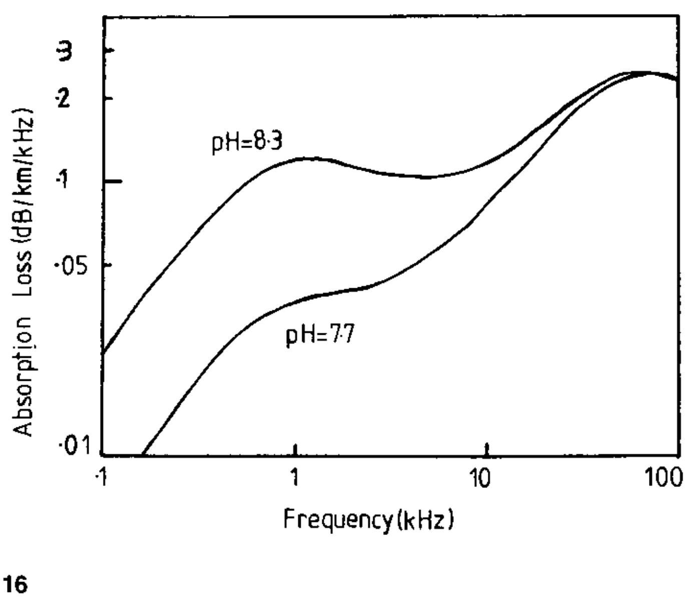


Fig.2. Effect of pH on volume absorption loss

CW propagation loss models

The pressure p(r,z) created by a cw source of angular frequency ω in a velocity field c(r,z) satisfies the acoustic wave equation

$$\frac{\partial^2 p}{\partial r^2} + \frac{1}{r}\frac{\partial p}{\partial r} + \frac{\partial^2 p}{\partial z^2} + k^2 p = 0$$

where the range and depth dependent wavenumber $k(r,z) = \omega/c(r,z)$. The coupling of energy into azimuthal directions has been neglected; although adequate in many situations it obviously depends on having a refractive index, scattering, and bathymetric structure which doesn't bend too much energy out of the range/depth plane.

The well known high frequency ray theory approximation reduces the wave equation to a much simpler one in which energy flows along rays perpendicular to wavefronts, and has strong visual appeal. This simple concept is not easily turned into a (ray) flux-density one required for the determination of intensity. To be computationally tractable a number of further approximations have to be made concerning acceptable ray densities at a given range–depth point. It can be very time consuming to trace an acceptably dense ray-set through the ocean in which convergence can be convincingly demonstrated. Ray tracing techniques lead to (unphysical) infinities at caustics due to the (unphysical) infinite frequency approximations. There is a considerable literature which attempts to regain this lost ground by various diffractive corrections.

At lower frequencies the two main techniques in use to take account of diffraction are (i) normal modes and (ii) parabolic approximations to the wave equation. These methods, together with ray-tracing, are also used for microwave calculations.

Normal mode techniques assume, unlike parabolic methods, that the refractive index varies with depth only (horizontal stratification) and that boundaries are flat, often referred to as a range-independent environment. The wave equation becomes separable and leads to the pressure field being composed of a sum of normal modes, not unlike the fourier components of a signal. Each normal mode (or eigenfunction) is a 'standing-wave' in depth, similar to the modes of a vibrating string fixed at both ends, in this case the sea surface and seabed. The mode amplitude determines the pressure field for that mode for each depth point; these depth (eigen) functions are each multiplied by their own appropriate 'range-decay' function, whose decay rate is determined by the 'range-decay parameter' (eigenvalue) associated with that particular mode. Higher order modes have more oscillations in depth and larger eigenvalues; the latter imply faster decay rates. At those frequencies and water depths which support a number of modes the pressure field variation with range consists of interfering modes. Increasing range progressively damps out higher order modes (mode stripping), leading to smoother behaviour. One variant of a normal mode model, known as the adiabatic approximation, introduces a slight range-dependence, another deals with more severe changes in a coupled mode theory.

More sophisticated mode models calculate those 'near-field' evanescent modes which decay rapidly with range and depth utilizing the Hankel transform of the wave equation, thereby mapping the problem into the wavenumber domain. The numerical problem becomes one of ensuring that a sufficient amount of this space is adequately sampled, generally involving a great deal of care. Practical difficulties in normal mode calculations are concerned with accurate and speedy determination of eigenfunctions and eigenvalues, and the large number of modes which may have to be calculated for higher frequencies and deeper waters.

Parabolic methods partially overcome these problems by removing cylindrical spreading from the Helmholtz equation using $p(r,z) = r^{-1/2}u(r,z)$, which for $kr \gg 1$ yields

$$\frac{\partial u^2}{\partial r^2} + \frac{\partial u^2}{\partial z^2} + k^2u = 0.$$

By taking the formal square root (in an operator sense) of this equation and neglecting the (generally small) backscattered waves then

$$\frac{\partial u}{\partial r} = ik_o\,(n^2 - \sin^2\theta)^{1/2}u$$

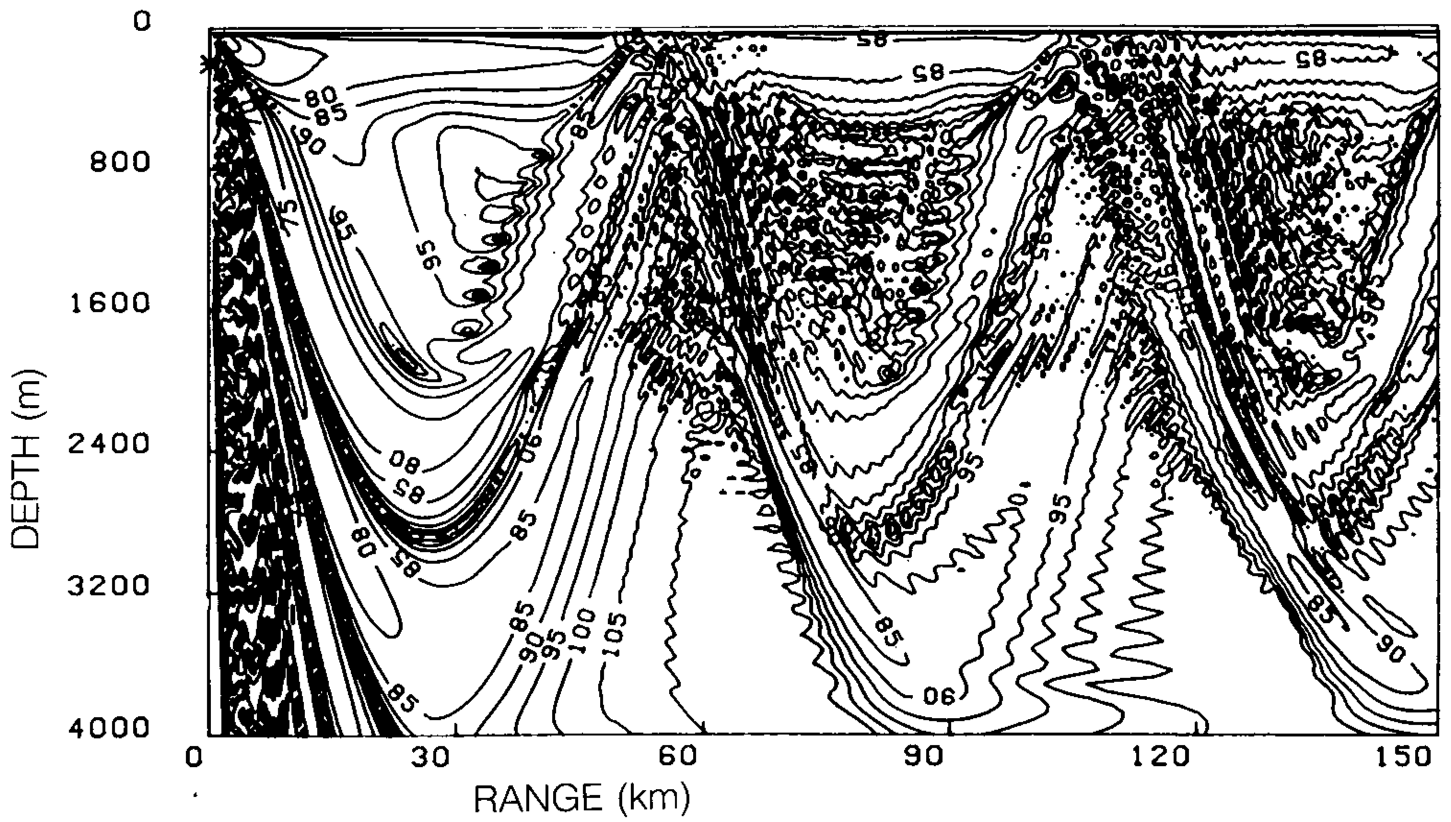
where $k\,(r,z) = k_o n\,(r,z)$, $k_o = \omega/c_o$ is a fixed reference wavenumber, c_o a fixed reference sound speed and $n(r,z)$ the varying refractive index. The angle θ between the horizontal direction and the wave travel direction is defined formally by $(\sin\theta)u = (i/k_o)\,\partial u/\partial z$. The final step is now to approximate the square root operator for various values of θ. The standard method, associated with the name of Tappert, is to take the formal Taylor expansion for small angles θ below about a third of a radian to yield

$$\frac{\partial u}{\partial r} = ik_o\,(1 + \tfrac{1}{2}\epsilon + \tfrac{1}{2}\sin^2\theta)u$$

where $\epsilon = n^2(r,z) - 1$. There are many other formal expansions possible, an important class being those formed from rational functions involving $\sin^2\theta$ which give wider angles of validity. Note that the expansions are formal as $(n^2 - \sin^2\theta)^{1/2}$ is a non-local operator which requires a more careful mathematical treatment (Weyl Calculus) than that given here. Unlike modal methods, parabolic ones cope well with range-dependent environments, if horizontal sound gradients and bottom slopes are not so great as to violate the propagation angle limits.

The equations can be solved by simple methods in which the pressure distribution with depth at a given range is determined from that at a range nearer to the source. The calculated pressure distribution is then used to determine that at the next range step; this 'marching forward in range' is not unlike the use of Huygens wavelets in determining the progression of wavefronts. Two popular methods at this time are the split-step FFT technique and finite-difference methods. Although diffraction is automatically included, parabolic methods are not without difficulties. Problem areas include (i) long computational times for adequate range and depth sampling (although generally much shorter than the equivalent mode calculation), (ii) angle limitations, (iii) limits to sound speed gradients and bottom slopes, (iv) difficulties in examining incoherence, (v) incorporating rough-surface scattering and a full geoacoustic sub-seafloor description, (vi)

Fig. 3. Propagation loss contours from a parabolic equation



determining a meaningful reference sound speed to avoid major phase errors.

Some of the flavour of the parabolic equation solutions is shown in Figure 3, where a 50 Hz source has been placed approximately half-way down a deep mixed layer in deep water. The dB (relative to one metre from the source) loss contours may be likened to equipotential surfaces orthogonal to field lines (electrostatic) or streamlines (fluid flow) or 'rays'. Notable effects are the waves sweeping along the duct, which eventually interfere with convergence zone contributions. Parabolic Equation methods are the subject of intense research activity at the present time.

Summary

Channelling of acoustic energy due to refractive index changes in the ocean is much more dramatic than in the equivalent atmospheric microwave situation. The inexorable rise with frequency in the volume absorption of ocean sound due to boric acid, magnesium carbonate, magnesium sulphate and pH value contrasts strongly with the microwave case at similar wavelengths, where absorption 'windows' occur. This paper has been mostly concerned with acoustic propagation. Nevertheless, in both the acoustic and microwave case, ray, normal mode and parabolic equation methods form a fruitful basis for deterministic propagation modelling.

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The Shallow-Water Acoustic Environment

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Introduction

For our purposes the only sensible definition of shallow water is that it corresponds to the Continental Shelf. This is the broad plateau surrounding most land masses, extending out to the Shelf Edge at a depth of some 200 m, where the seabed shelves suddenly and steeply toward the abyss. A typical depth is 100 m. Shallow water constitutes only about 10 per cent of the ocean area, but it is where most of the action takes place. It has much more than its fair share of the shipping, with virtually all the fishing and marine exploitation of oil, gas and minerals. It is at least of comparable importance to deep water.

Ocean acoustics may be compared with atmospheric acoustics and with atmospheric electromagnetic propagation, noting of course that everything is upside down. Thus for deep water we may look downwards from the sea surface, and find very close parallels with *both* atmospheric cases where we look upwards from the surface of the earth. But for shallow water we can find no atmospheric equivalent that has a lid 100 m up.

The most useful comparison is that between shallow and deep water. To a first order we expect similar behaviour if everything scales according to the water depth, which we illustrate here for a ratio of 40. Shallow 100 m water for the audio-frequency range 20 Hz–20 kHz and distance 100 km corresponds to 4000 m water with frequency range 0.5 Hz–500 Hz and distance 4000 km! In practice we are more likely to want to compare for a fixed frequency, when it is immediately apparent that for shallow water the sea-bottom must play a much larger part. There are many other environmental differences, and some of the acoustic consequences will be spelt out in the remainder of this article.

Propagation

We start by thinking of shallow-water propagation from the point of view of energy flux, where the sound leaving the source is soon contained or channelled in the water column between surface and bottom. This is possible because we have a gross acoustic impedance mismatch at the sea surface, and, for the rays of smaller grazing angle, total internal reflection at most sea-bottoms. But the channelling is not all that efficient and the attenuation can be relatively high. In contrast, for deep water the containment effect is much less, since the main sound channel is so much wider. The attenuation is also much less, since refraction within the main sound channel can virtually rule out interactions with both surface and bottom. In the result, for modest ranges of a few tens of km, we may actually do better in shallow water. However, for the really long ranges there is no competition with deep water, where 10 000 km can be achieved, with a reasonable transmission loss.

We have already hinted that the shallow water attenuation is associated with the sea-bottom. For a sediment bottom this is due to the lossy nature of mud and sand as a propagation medium, noting that energy travels in the bottom material as well as in the water. An alternative and equivalent description merely refers to a reflection loss at the bottom. In addition for a rock bottom the longitudinal wave energy in the water can couple into transverse or shear wave energy in the bottom, which is subsequently lost. (In passing we point out that rigidity in the bottom allows the possibility of Scholte waves at the interface, similar to Rayleigh waves, and that other types of interface waves are permitted when there is free gas at or near the sea bed.)

The sea surface also contributes to the shallow-water attenuation, since a rough surface scatters the sound into higher grazing angles, when it is lost into the bottom. And the water medium itself also plays a part. The chief mechanism in the low kHz region is a boric acid relaxation, the loss magnitude rises with the pH, the pH in shallow water is higher than in the depths of the ocean, and so shallow water is saddled with a bulk absorption that is significantly higher. In some areas at some times, notably the Bristol Channel in the summer, the bulk absorption can be orders of magnitude higher (2 dB/km) due to the presence of large numbers of dispersed clupeoid fish bearing swim bladders. Note that *all* the attenuation effects we have described are worse for shallow than for deep water.

For deep water, high frequencies, and short ranges it is useful to think of the propagation in terms of ray paths: direct and singly or multiply reflected at the boundaries. For shallow water, low frequencies and long ranges it is better to think in terms of the various waveguide modes. A convenient change-over range is

$R_1 = H^2/\lambda$

where H is depth and λ is wavelength. For example, for 100 m water and 250 Hz we have $R_1 = 1.7$ km. It will be seen that wave effects are more important for shallow water, in fact some people will virtually equate shallow-water propagation with normal-mode propagation.

The modal nature of the shallow-water transmission means that grazing angle at the bottom will increase as the frequency falls, with an associated increase in bottom reflection loss. For this and other reasons there is an optimum frequency for propagation, dependent on depth, range, layering etc., but typically around 100 Hz.

The theoretical plot in Figure 1 shows a more complicated and more surprising wave effect. For isovelocity water the interference field of the modes shows a series of focal points through which all the trapped energy must pass, occurring at range intervals of

$R_2 = 4\ H^2/\lambda$.

Figure 1 shows the first of these at 7 km, with lesser foci at other ranges and depths. This effect has been observed experimentally, as have related electromagnetic effects in fibre optics and in metal waveguides.

This spatial variability is converted to a temporal variability for a sensor traversing the field, and is just one of the many types of fluctuation encountered in shallow water.

Reverberation

In shallow water the reverberation can be high due to the sound scattered back from the bottom plus that scattered back from the surface, that is, the effects are higher than the corresponding ones for deep water. It is not quite so widely realized that the volume reverberation is often higher too, since this is mainly due to fish swimming either singly or in shoals, and fish are more abundant in shallow water. Figure 2 illustrates returns from fish on a long-range sonar record. When the fish are in shoals, which is the usual daytime case, we get a series of discrete echoes which may be referred to as false targets – that is, targets which may be confused with some other target, perhaps of military significance, for which we are really looking.

Ambient noise

Wind-generated surface noise and distant shipping are the two chief sources of ambient noise, with levels and other characteristics that are different for shallow and deep water. But we wish to point out here that there are many sorts of biological noise, due to fish, crustaceans and others, which are only

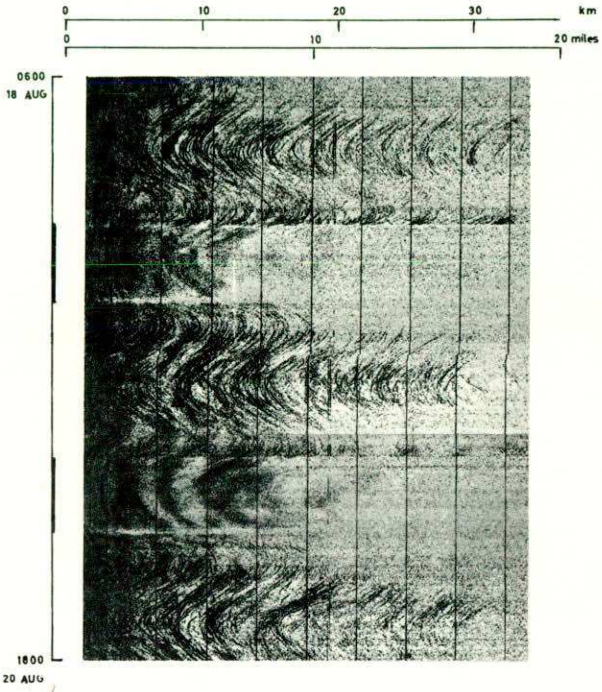
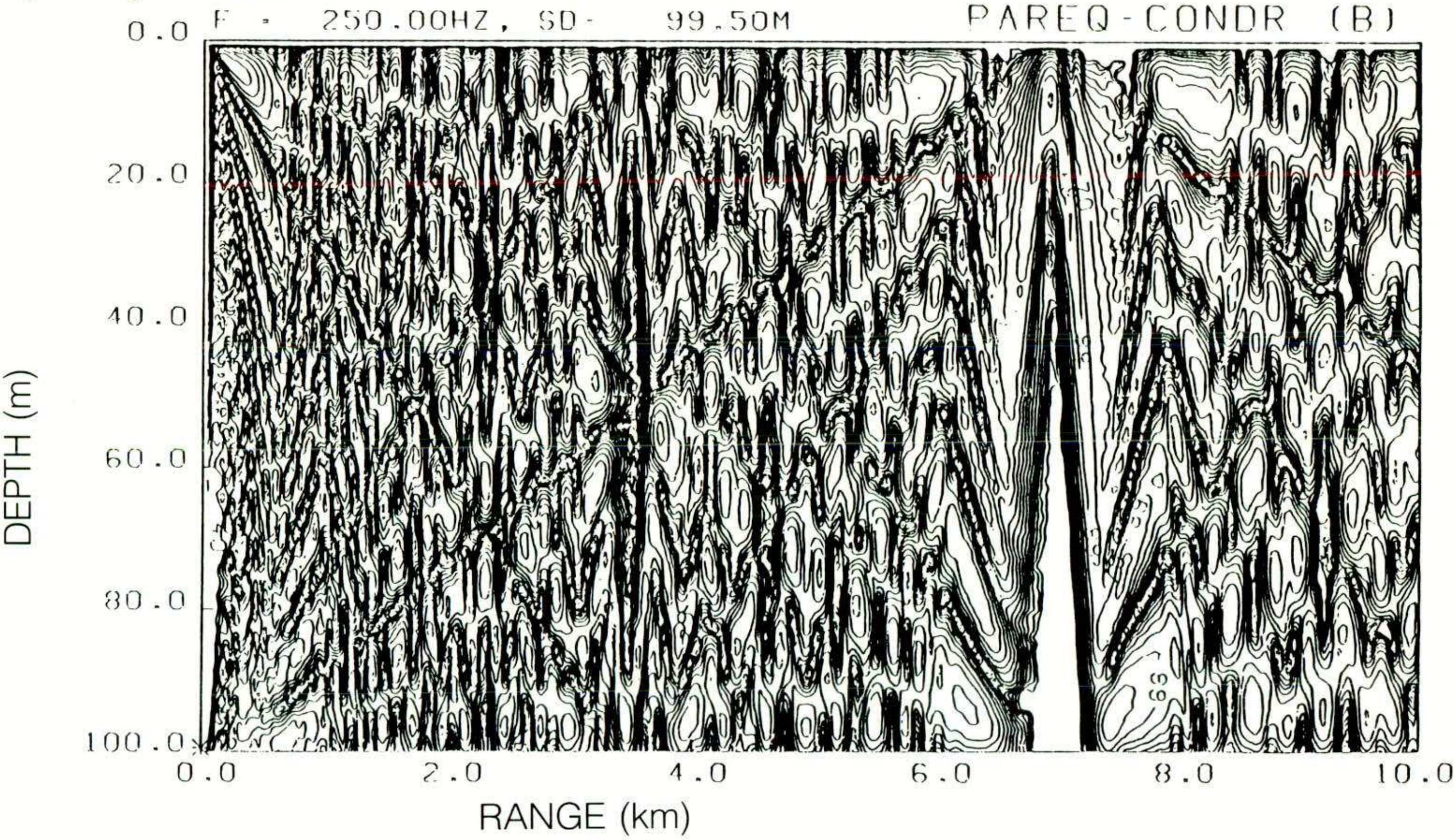


Fig. 2. Sample echo-ranging record showing tracks due to shoals of pilchard

Fig.1. Waveguide interference



encountered on the Continental Shelf. And in Figure 3 we show another special shallow-water feature, which is only seen when the wind blows hard enough for the associated noise to predominate even at very low frequencies. We can be sure that the noise source is local, and find that the quasi-resonances, associated with near-vertical sound in the water column, modulate or colour the noise spectrum. The water here is about 40 m deep, which leads to resonances of about 10, 30, 50 Hz and so on, both the water depth and the resonant frequencies varying through the tidal cycle.

Conclusions

Shallow-water acoustics tends to have a bad reputation. Perhaps this is a defensible viewpoint if the concern is with understanding and prediction, because it can indeed be tricky, though even here it is possible to think of interest and challenge rather than headache. But we would argue strongly that it is not a reasonable view if the concern is with general performance of underwater systems, since in both theory and practice the propagation characteristics allow this to be very good out to moderate ranges. In any case the United Kingdom has to deal with a Continental Shelf varying from about 60 to 300 km in width, covering an area greater than that of the land.

Acknowledgements

Finally I must acknowledge the contributions of many colleagues, specifically for the illustrations.

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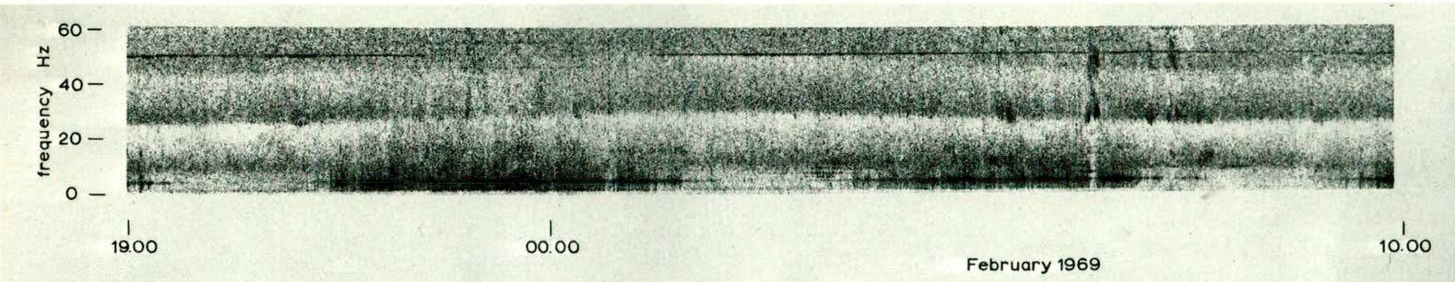
Fig. 3. Sample analyser record showing frequency peaks in ambient noise



The Role of the Seabed in Ocean Acoustics

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Introduction

It would be unusual to transmit and receive an acoustic signal in the ocean without having the sound interact with the seabed in some way, en route. To interpret ocean acoustic data or to predict the performance of acoustic systems in the ocean, we not only need to know how sound propagates within the body of the ocean, we also need to understand the effects of acoustic reflection, scattering, and propagation at the seabed. The extent to which the seabed influences ocean acoustic propagation and ambient noise will of course depend upon other factors, such as the source–receiver geometry, the water depth, and the sound speed profile in the ocean. These issues are addressed by David Weston and Roy Levers in their contributions to this special issue of the *Bulletin*. As a general rule, the acoustic properties of the seabed are more important in shallow water than in the deep ocean, but not exclusively so. In this article I would like to present some of the principles of seabed acoustics, emphasizing those that are important to environmental ocean acoustics. I will not say much about marine sediment acoustics or marine seismic techniques, although these subjects are obviously related. Perhaps a more serious omission is that I have excluded any discussion of acoustic scattering at the seabed. The bibliography at the end should provide the interested reader with adequate source material on these subjects and on what is to follow.

First, I present some experimental results that demonstrate the sensitivity of acoustic transmission loss and ambient noise to seabed type. Then I propose a fairly simple model of acoustic reflection at the seabed that helps explain this sensitivity. Finally, I describe some special propagation phenomena at the ocean/seabed boundary.

I hope the presentation does not appear to be over-simplified. The seabed is a complex acoustic environment, as is the ocean itself, and the key to understanding many ocean acoustic phenomena is to develop models that are as simple as possible, yet do not sacrifice the essential physics of the problem. Due to the complexity and variability of the environment, we may never be in a position to predict ocean acoustic conditions reliably; we may have to be content with an imperfect understanding of ocean acoustics that contains only the most important elements.

Experimental evidence

There are two important types of environmental measurements that ocean acousticians undertake at any given location: the transmission loss to the receiver from sources at various ranges and bearings, and the levels of ambient noise at the receiver. These are usually measured over a wide range of frequencies from as low as 2 Hz up to several kilohertz. In shallow water especially, these measurements vary considerably from one site to another. A large part of this variation can be attributed to the change in the acoustic properties of the seabed.

As part of an ongoing programme of environmental acoustics data collection in both deep and shallow water, the Defence Research Establishment Atlantic participated in some experiments at two particularly interesting areas in Continental Shelf waters. The two sites turned out to have quite different seabed types, and the acoustic data provided correspondingly different results. One site had a seabed made up of several tens of metres of sand overlying sedimentary bedrock; let's call it site S. The other site had a seabed of chalk with a thin veneer (less than 1m) of soft sediment; we'll call it site C. At both sites, the water depth was about 100 m.

**On leave from the Defence Research Establishment Atlantic, Dartmouth, Nova Scotia.*

Transmission loss

Figure 1 shows curves of transmission loss versus frequency measured at both sites at a source–receiver range of 30 km in each case. We used explosive charges as acoustic sources and the data are averaged over ⅓-octave bands. In the frequency range above 300 Hz, the transmission loss does not seem to differ much between the two sites. Below 300 Hz, however, site C shows progressively more transmission loss than site S as the frequency is lowered.

Our initial attempts to explain this difference using acoustic propagation models on the computer were only partially successful. Using a model that treated the seabed as a layered fluid (with appropriate densities, sound speeds and attenuations in the layers) we reproduced the site S results reasonably well. Using the same fluid seabed model (again with appropriate inputs) we failed to reproduce the site C results. In particular, the computer model would not generate the very high transmission loss in the low frequency range.

Following the lead of other ocean acoustic modellers, we considered the possibility that the excitation of shear waves in the seabed may be a loss mechanism. As a fluid cannot admit such an effect, we developed a simple propagation model that treated the seabed as an elastic solid that could support both acoustic shear waves and acoustic compressional waves. Without going into details, this model gave us the high low-frequency losses that we were looking for, although the agreement between theory and experiment was not perfect. Using the modelling process, we had convinced ourselves that the principal difference between the two sites was seabed type, that the acoustic properties of the seabed seemed to be governing the transmission loss at each site, and that shear waves were an important element of these acoustic properties, at least for a chalk seabed.

Ambient noise

The ambient noise background in the ocean arises from a multitude of sources: the action of wind, waves and precipitation at the sea surface; local and distant shipping; marine life (as small as shrimp and as big as whales); seismic activity; and so on. Regardless of the actual sources and their relative importance in differing frequency ranges, the noise must propagate through the ocean from the sources to the measurement point, so it should not surprise us to learn that acoustic propagation conditions, including seabed type, influence received ambient noise levels.

Figure 2 shows 'snapshots' of ambient noise spectra measured at site S and site C at about the same time as the transmission loss measurements. Like the transmission loss curves, these curves display large differences between the two sites. At site S there is a large, broad peak in the noise spectrum that is conventionally associated with shipping noise propagating from a wide area surrounding the receiver; such a peak is absent from the site C data. As we have already established the poor low-frequency propagation conditions at site C, it is satisfying that the noise levels are correspondingly low. Current ambient noise models have difficulty matching spectra such as in Figure 2, because the distribution of the sources and their spectra are uncertain. However, these models do support the observation that difference of seabed type is correlated with site to site noise level differences.

In summary of this section, the experimental data suggest that both transmission loss and ambient noise in the ocean are sensitive to seabed type. This view is supported by acoustic propagation models and by ambient noise models. The generation of shear acoustic waves in the seabed has been proposed as an important loss mechanism. In the next section, I will try to explain how.

Acoustic reflection at the seabed

A realistic geo-acoustic model of the seabed would probably consist of a sandwich of many sediment layers having different acoustic properties – densities, sound speeds, and attenuations – or perhaps even continuously varying depth profiles of these characteristics. We could complicate matters further by allowing the boundaries between layers to be irregular. On the principle that one should learn to walk before attempting to run, let us consider a simple model of acoustic reflection at the seabed, by assuming that the seabed is an infinite body of material with uniform properties forming a smooth boundary with the ocean. We shall see how far this simple model can carry us. In many circumstances, if the acoustic field does not penetrate very far into the seabed, then the acoustic properties of the surficial sediments will be most important and those of the deeper sediments

Fig. 1. Transmission loss in shallow water over two different seabeds. Source-receiver range is 30 km

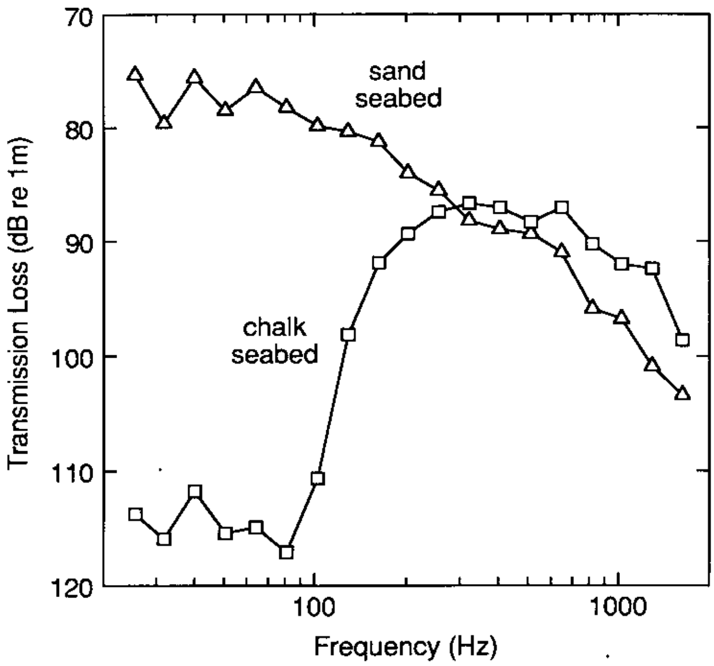
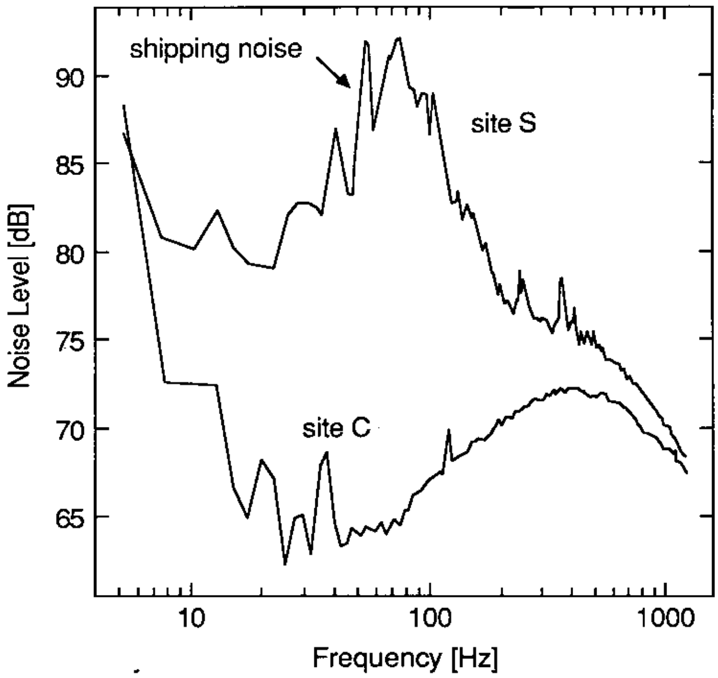


Fig. 2. Ambient noise at the same two sites as in Figure 1. The units are dB re 1 uPa² Hz



will be of little consequence, so the simple model may suffice.

In ocean acoustics, we are primarily interested in the acoustic field in the water itself, and less interested in the acoustic field within the seabed. From this point of view what is important about the ocean/seabed boundary is contained within the acoustic plane–wave reflection coefficient $R(\theta)$. This complex quantity is the ratio of the reflected and incident pressure of a plane wave incident upon the boundary at grazing angle θ. [We ocean acousticians are most interested in near-horizontal directions of propagation, so we measure angles with respect to the boundary plane, not with respect to the normal.] The modulus $|R|$ is the ratio of the amplitudes of the plane waves; the reflection loss in decibels is then $-20\log|R|$. The phase of R is the phase change of the wave upon reflection.

Some general characteristics of the reflection coefficient can be deduced without calculation by applying Snell's Law of Refraction. When an acoustic ray crosses from a lower-speed medium (water) into a higher-speed medium (the seabed), the transmitted ray refracts towards the boundary, as shown in Figure 3a. Because the transmitted ray carries energy away from the boundary, the amplitude reflection coefficient $|R|$ must be less than one: the reflected wave suffers reflection loss. As we decrease the grazing angle θ, we eventually reach a critical angle θ_c at which the transmitted wave is refracted parallel to the boundary. If we decrease θ further, there cannot be a transmitted ray in the conventional sense, although there is an evanescent wave that decays exponentially away from the boundary, shown in Figure 3b. This evanescent wave has several interesting properties, but the most important for this discussion is that it does not carry energy away from the boundary. As a consequence, the reflected and incident waves must have the same amplitude for $\theta<\theta_c$, i.e., $|R|$ must be exactly equal to 1; this condition is known as total reflection.

The previous discussion must be altered if we consider the effects of acoustic absorption within the seabed. If the sediment absorbs energy from the evanescent wave, the deficit must be made up by the acoustic field on the water side, so the reflected wave must suffer a small reflection loss in the range $\theta<\theta_c$. Thus, the principal loss mechanism in the range $\theta>\theta_c$ is the energy carried away by the transmitted ray, whereas the principal loss mechanism in the range $\theta<\theta_c$ is the acoustic absorption of the evanescent wave.

We have implicitly assumed that the seabed is a fluid medium, but in the last section we presented evidence that this assumption may not suffice to explain all acoustic losses. Now imagine how we must modify our simple reflection model if we view the seabed as an elastic solid, supporting low-speed shear waves as well as high-speed compressional waves. [In this context, we mean low- and high-speed in relation to the sound speed in water.] Snell's Law tells us that the low-speed shear wave generated at the boundary refracts away from the boundary, as in Figure 3c. Moreover, in this case there is no critical angle for shear waves as there is for compressional waves. For all angles of incidence, shear waves are generated at the boundary and – in principle – may carry energy away from the boundary. Snell's Law cannot tell us how strong this coupling is, but it does suggest this third mechanism that can contribute to reflection loss, even at angles $\theta<\theta_c$.

The correct theoretical treatment of plane wave reflection at a fluid/solid boundary accounts for the generation of both compressional and shear waves in the solid at all angles of incidence and can also accommodate effects due to absorption of both these waves within the medium. Figure 4 shows calculated reflection loss curves for three dissimilar sediments (silt, sand, and chalk) modelled as elastic solid media having the acoustic properties shown in Table 1. The values chosen are not definitive, but may be regarded as typical.

Perhaps the most important feature of these curves is their strong dependence upon grazing angle. In the range $\theta>\theta_c$ (which includes normal incidence) the reflectivity of the different materials seems to follow a natural progression, 'softer' materials showing higher losses than 'harder' materials. In the range $\theta<\theta_c$, particularly at near-grazing angles, the ordering is different, as the 'hardest' material has the highest loss. Playing with such theoretical curves can tell us a lot about the sensitivity of reflection loss to the different model parameters. In this case, the high low-angle loss of the chalk seabed is due to generation of shear waves. The intermediate loss of the silt seabed is insensitive to shear speed and is almost entirely due to absorption of the evanescent compressional waves. The low reflection loss of the sand seabed arises from a combination of these two mechanisms: there is a little shear wave generation and a little compressional wave absorption, but not too much of either.

Studying curves such as those in Figure 4 helps us to understand why

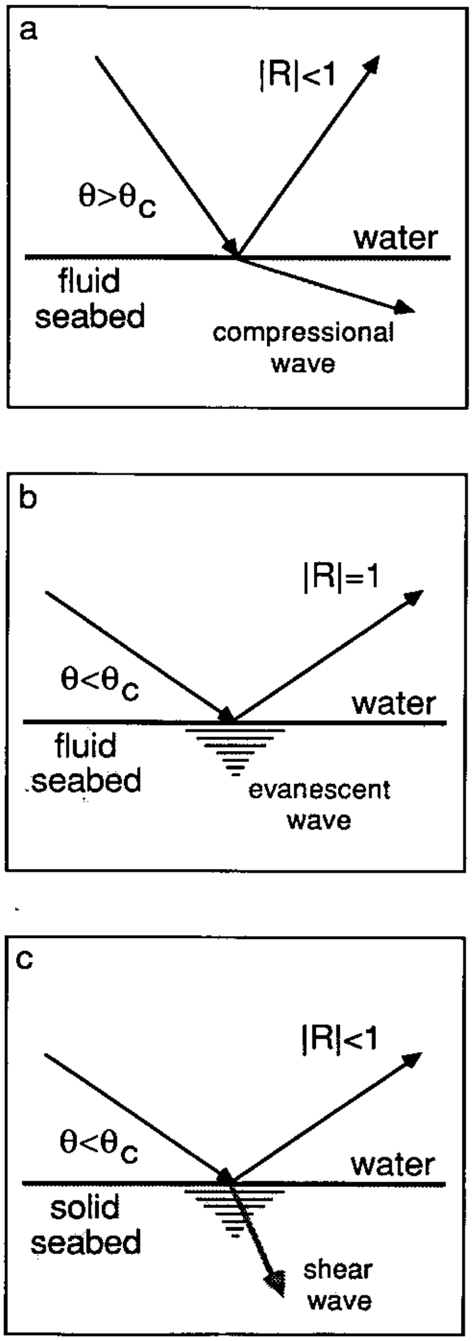


Fig. 3. Plane wave reflection at fluid and solid seabeds. $|R|$ is the reflection coefficient, θ is the grazing angle, and θ_c is the critical angle.

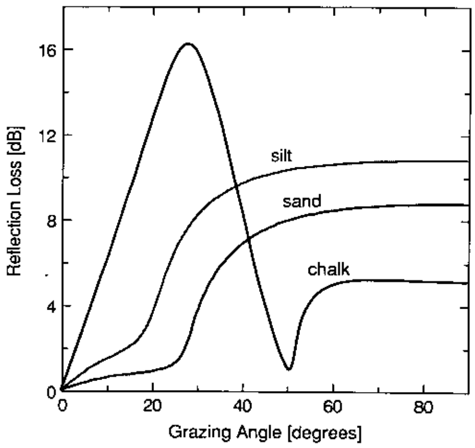


Fig. 4. Plane wave reflection loss for the three seabeds of Table 1

Table 1. Seabed Acoustic Properties

Seabed Type	Density[a]	Sound Speed(m/s) Compressional	Sound Speed(m/s) Shear	Attenuation (dB/m–kHz)[b] Compressional	Attenuation (dB/m–kHz)[b] Shear	Critical Angle (deg)
Silt	1.7	1600	150	0.6	15	20.4
Sand	1.9	1700	200	0.5	10	28.1
Chalk	2.2	2400	1000	0.1	1	51.3

Relative to water
To convert to units of dB/wavelength, divide by sound speed in km/s

near-horizontal propagation directions are so important in shallow water acoustics. If we try to transmit a signal over a horizontal range of tens or hundreds of water depths, acoustic rays travelling at steep angles not only suffer large reflection losses at the seabed, but also reflect from the seabed many times. Near-horizontal rays suffer much lower reflection loss and undergo fewer bottom reflections. For long range propagation, seabed interaction effectively filters out all rays but those with the smallest grazing angles. Even at these low-loss angles, however, Figure 4 shows that the reflection loss is quite sensitive to seabed type.

I believe that these simple arguments go a long way towards explaining the experimental data of the previous section that demonstrate the sensitivity of both ocean acoustic transmission loss and ocean ambient noise to seabed type. It is clear that in some circumstances the seabed must be modelled as an elastic solid rather than as a fluid, and that generation of shear waves can be important. Of course, this is not the full story of acoustic reflection at the seabed. For example, recent efforts by the Defence Research Establishment Atlantic (DREA) to model transmission loss data collected over a granite seabed required inclusion of a thin sediment layer over the rock in order to match the observed low frequency losses. In this case, no single uniform layer of material would lead to the required agreement between theory and experiment.

Special boundary effects

Although the plane-wave reflection coefficient is a useful theoretical tool, it is difficult in practice to generate an acoustic plane wave for experimental work. The simple sources we use in ocean acoustics, such as explosives or low-frequency transducers, behave very much like point sources radiating spherical waves. When such sources are placed near the seabed and the signals are received by a hydrophone also near the seabed, we often observe strong acoustic signals associated with propagation along the boundary. I will briefly discuss two important boundary waves: the head wave or lateral wave, and the interface wave or Scholte wave.

The head wave

When a transient acoustic wave couples into the seabed from the water, the disturbance can 'run ahead' in the seabed, as it has a higher sound speed. This wave then re-radiates back into the water layer. A theoretical analysis of this phenomenon shows that the ray associated with the head wave leaves the source at the critical angle θ_c (determined by the seabed), refracts horizontally along the boundary, and then leaves the seabed at the critical angle θ_c to arrive at the receiver. This ray path is in fact the path of minimum travel time, and the head wave arrives at the receiver before the direct wave in the water. Furthermore, because it travels along the boundary at the speed of sound in the seabed, observations of the head wave prove to be a useful remote acoustic measurement of that speed. In the seismic world, this technique is called seismic refraction.

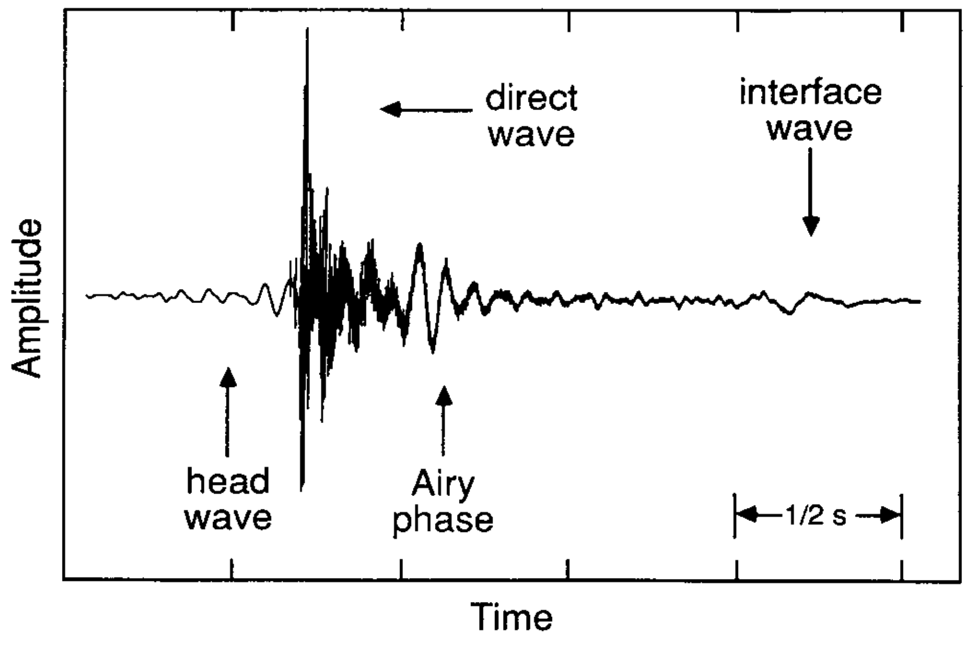
Figure 5 shows the acoustic pressure signal received at a hydrophone on the seabed at Site C, generated by an underwater explosion 5 km away. The direct wave through the water is clearly visible as the sudden onset of strong high frequency oscillations. Just before this, there is a weaker low-frequency precursor; this is the head wave. The high-frequency components of this signal have been filtered out by acoustic absorption in the seabed.

The multiple ray paths of this shallow water experiment, each having a different travel time, stretch and distort the received waveform over several seconds. In fact, it is sometimes more convenient to regard the shallow water environment as an acoustic waveguide and to imagine the signal as propagating in several normal modes rather than along multiple ray paths. At the end of the water wave there is a strong well-defined waveform called the 'Airy phase' which corresponds to the slowest group speed of the first normal mode.

The interface wave

In recent years, the study of ocean acoustics has encompassed phenomena at lower and lower frequencies, to the extent that we now perform experi-

Fig. 5. Signal received at a bottom-mounted hydrophone at site C, 5km from an explosive source



ments at 'infrasonic' frequencies, that is, frequencies below the normal range of human hearing (less than 20 Hz). Infrasonic ocean acoustics has begun to overlap with the study of seismic phenomena in the earth's crust, giving rise to a new speciality: ocean seismo-acoustics. The focus of much of the recent work has been on acoustic interface waves at the seabed, which are related to Rayleigh waves and Love waves in earthquake signatures.

An interface wave at the seabed is a combination of a sound wave in the water, a compressional wave in the seabed, and a shear wave in the seabed. It travels along the boundary at a unique speed determined by all the parameters of the acoustic environment. In fact, there would be no interface wave if the seabed did not support shear waves. The speed is determined by a complicated expression, but is typically about 90 per cent of the shear speed for low-shear-speed materials. Referring back to Figure 5, note the small wavelet that has arrived much later than the other waves, at the far right of the trace. This is the interface wave generated by the same explosion. We used the relative arrival times of this wave and the water wave to estimate the shear speed in the chalk seabed.

The weak signature of the interface wave in this case may give the impression that such waves are difficult to detect. In this instance, the wave has been attenuated by the acoustic absorption in the seabed. In harder materials with lower absorption, such as granite, the interface wave has been observed to propagate well out to several tens of kilometres.

Conclusions

Using a combination of experimental data and simple theoretical argument, I hope that I have convincingly argued that the seabed plays a key role in ocean acoustics, particularly in shallow water. Not only can the acoustic properties of the seabed govern transmission loss of a signal from source to receiver, they can also govern the ambient noise levels within which the desired signal is embedded. Modelling the seabed simply as a uniform elastic solid (with absorption) seems to explain much of the site-to-site variation of acoustic conditions and shows that the ability of the seabed to support shear waves cannot be ignored. Finally, at very low frequencies, there are boundary wave phenomena at the ocean/seabed interface. Apart from being a possible mechanism of acoustic propagation in their own right, these waves provide sensible means of probing the surficial sediments to determine their acoustic properties.

It would be misleading to give the impression that all is known and understood regarding the role of the seabed in ocean acoustics. Despite the progress of recent years, the ocean and its seabed continually conspire to present ocean acousticians with experimental data that defy explanation, challenging our preconceived notions and models.

Acknowledgements

I am most grateful to my colleague P R Staal for providing the experimental data for this article, and to DREA for permitting its release. The article was written with the financial support of the Royal Aerospace Establishment, Farnborough (Agreement No. 2040/431/XR/RN).

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Sound Ribbons in the Sea

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Introduction

The standard way of modelling sound propagation in the ocean has been to assume a sound speed profile that can vary with depth and range, and then to compute the field resulting from a point source either using ray tracing or by solving the parabolic wave equation numerically. Integration of the wave equation gives the acoustic field showing not only convergence zones but also the fine details resulting from diffraction effects. The process requires a very large amount of computation and, as a result, it is both slow and expensive. Unfortunately the detailed structure of the field, computed at such expense, often turns out to be useless because in practice these features are almost always swamped by stochastic intensity fluctuations due to scattering by internal waves, turbulence, layering effects and other irregular structures that always exist in the ocean.

In recent years much effort has gone into understanding these stochastic intensity fluctuations, and there now exist accurate analytical expressions describing their variance and spectra in terms of the properties of the irregular ocean structures responsible for the scattering. In addition, fast and economical methods have been devised for computing the acoustic field propagating in the presence of these inhomogeneities. This means that realistic computer modelling of an acoustic field propagating through the ocean can be carried out without having to use the large amounts of computer time previously required. Moreover, the stochastic fluctuations produced by the numerical model now possess the correct statistical properties, a fact which has been checked by comparison with ocean acoustic experiments.

The advances described above are very significant. They mean that numerical simulations of ocean acoustic propagation can be performed rapidly and economically. Such simulations can yield insight into features of the acoustic field whose existence was previously unsuspected. We shall describe the new numerical approach to intensity fluctuations together with some of the theory on which it is based. One of the new features revealed by the new approach, ribbons of high acoustic intensity, will be described in detail. Finally, some preliminary results of an experiment to test for the presence of these ribbons will be presented.

Acoustic intensity fluctuations: simulations and theory

As a first step towards building up our picture of acoustic intensity fluctuations of the type outlined in the introduction we shall consider the numerical simulation of a sound wave propagating in a stretch of ocean containing internal waves. Naturally, both surface and bottom do play an important part but these, as well as the large scale sound channel, have long been studied by ocean acousticians, and their overall effect, in the absence of statistical fluctuations, is well understood. Here we shall deal mainly with acoustic intensity fluctuations produced by the most common random structure present in the ocean, internal waves. There are, of course, other types of non-internal wave structures present at different times and places, and the effect of these can be included in a similar manner.

(a) Internal waves

The numerical simulations of propagation are done by sub-dividing the ocean into a set of slabs transverse to the direction of wave propagation and allowing the total scattering effect of such a layer to occur in a plane at the exit of the slab. The ocean thus becomes a set of a large number of phase modulating screens whose space–time autocorrelation function is that of the internal waves summed within the slab. When standard models of the internal wave field are used this has the form

$$\rho(\zeta,\tau) = \sigma(\zeta)\psi(\tau), \qquad (1)$$

where ζ is a separation in the vertical, and τ is a time separation. The spectrum corresponding to (1) is

$$F(\beta,\omega) = \qquad (2)$$

$$\frac{C}{(\beta_0^2 + \beta^2)\beta} \quad \frac{(n^2 - \omega^2)^{1/2}}{\omega^3},$$

where β,ω are the vertical spatial frequency and time frequency respectively, β_0 is the inverse of L_V the vertical scale size of the internal waves, n is the buoyancy frequency, and C is a normalizing constant.

(b) Spatial intensity fluctuations

The simulation technique allows us to produce a picture of the intensity fluctuations as they appear in space when sound propagates through an internal wave field. Time variation is

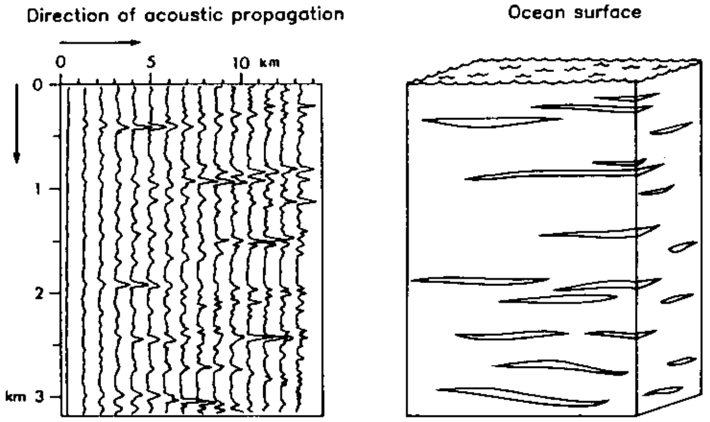


Fig. 1. Simulated acoustic intensity fluctuations and a contour diagram of the high intensity ribbons

suppressed for the moment. Each slab or screen introduces an additional phase modulation on the acoustic wavefront with an autocorrelation function $\sigma(\zeta)$. The wave is treated as composed of a spectrum of plane waves with spatial frequencies ν, and each component is given a phase advance of exp $\{i\nu^2\Delta Z/2k\}$, where ΔZ is the distance to the next screen, and k is the acoustic wavenumber. Repetition of the process produces the complex acoustic field throughout the medium.

The spatial pattern of intensity fluctuations produced when a 3.5 kHz acoustic wave propagates through an ocean internal wave field at a depth of 1000 m is shown on the left in Figure 1 as given by numerical simulation. Only part of the ocean volume is shown. The dimensions are given, and we note that the most striking features are the strong spikes of intensity that arise and extend over large distances in the direction of sound propagation. Enclosing these high intensity regions by contours produces a new picture, that of the patches where the sound has been concentrated. A contour picture of this type corresponding to the simulation is given on the right of Figure 1, with the dimension transverse to the direction of propagation added. Since the internal wave irregularities have horizontal and vertical scales that are in the ratio of about ten to one, so also the intensity fluctuations exhibit a similar anisotropy. However, the longitudinal scale of the sound patches in the direction of propagation is even greater.

Simple analysis shows that in the region of well developed intensity fluctuations the vertical, transverse, and longitudinal scales of the high intensity sound patches are respectively

$$\zeta_0 = \frac{L_V}{\sqrt{2\Gamma X}},\ \eta_0 = \frac{L_H}{\sqrt{2\Gamma X}},\ \xi_0 = \frac{kL^2_V}{2\Gamma X}, \qquad (3)$$

where L_V and L_H are the vertical and horizontal scales of the internal wave irregularities,

$$X = \frac{x}{kL^2_V} \qquad (4)$$

x being the distance in the direction of propagation, and Γ is a parameter characterizing the strength of the scattering regime involved. In the 3.5 kHz case illustrated in Figure 1 the quantities turn out to be, when the range x is about 10 km,

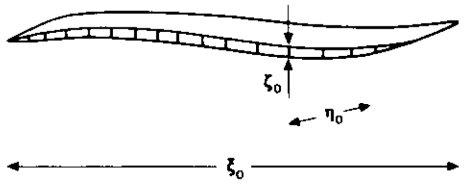
$$\zeta_0 \approx 20\,m, \quad \eta_0 \approx 317\,m, \quad \xi_0 \approx 5.8\,m \qquad (5)$$

The high intensity patches appear as flat ribbons of concentrated sound, greatly extended in the direction of propagation. They tend to lie at small angles above and below the horizontal and to be separated one from the other by some characteristic distance in the vertical. A typical ribbon is shown in Figure 2 for the 3.5 kHz example under discussion.

(c) Time behaviour of the intensity fluctuations

It is a relatively simple matter to introduce time variation into the simulations, and when this is done the ribbons of high intensity tend to undulate irregularly, with some ribbons gradually disappearing and others appearing elsewhere, but they do not drift forward in the direction of sound propagation. An observer at a fixed depth will, from time to time, experience a high acoustic intensity as one of these ribbons passes over him. The time during which he experiences a high intensity depends both upon the rate at which the ribbon

Fig. 2. Typical ribbon of high acoustic intensity



undulates and passes him by and on the life-time of the particular ribbon. The time fluctuating intensity that he observes has a characteristic time scale

$$\tau_0 = \tau_{IW}/\sqrt{2\Gamma X} \qquad (6)$$

where τ_{IW} is the lifetime of internal wave irregularities. In the 3.5 kHz example

$$\tau_0 \approx 2.5\,\text{h}. \qquad (7)$$

The actual lifetime of a ribbon as seen by itself is, of course, greater than τ_0.

(d) Spatial frequency spectrum of intensity fluctuations. Transverse spectrum

A quantity frequently employed to give a quantitative description of the intensity fluctuations in a randomly inhomogeneous medium is the spectrum of spatial frequencies ν present in the fluctuating intensity measured transverse to the direction of propagation at a fixed range x and time t. We shall denote this spectrum by $\Phi_I(\nu,x)$. In terms of Figure 1 this would be the spatial frequency content of one of the irregular intensity traces at a fixed range x as the depth z changes.

The transverse spatial frequency spectrum $\Phi_I(\nu,x)$ is important because analytical expressions can be derived for it that depend only on the autocorrelation of the scattering irregularities and the wavelength of the acoustic wave. One of these theoretical expressions will be discussed in detail below, and some examples of such spectra will be given. The Fourier transform of Φ_I gives the transverse autocorrelation function of the intensity fluctuations

$$\rho_I(\zeta,x) = \int \Phi_I(\nu,x)e^{i\nu\zeta}d\nu, \qquad (8)$$

and it is ρ_I that has the characteristic scale ζ_0 given by Equation (3).

Longitudinal spectrum

The longitudinal spectrum of the intensity fluctuations is a less familiar quantity. It allows us to estimate the scale of the intensity fluctuations in the direction of propagation. If we return to Figure 1 and replot the intensity on a line of constant depth we again obtain a fluctuating quantity and the spectral content of this is the longitudinal spectrum. An approximate but useful expression can be derived for the combined longitudinal–transverse autocorrelation function of the intensity fluctuations based on the fact that the acoustic field can be synthesized as a set or spectrum of plane waves. Thus in an acoustic field of wavenumber k a single spatial frequency ν behaves like

$$\exp\left\{i\left(\nu z + \frac{\nu^2}{2k}x\right)\right\} \qquad (9)$$

when the phase reference e^{ikx} has been removed. Making the assumption that $\Phi_I(\nu)$ is slowly changing in the direction of propagation the obvious extension of (8) is

$$\rho_I(\zeta,\xi) = \int \Phi_I(\nu,x)e^{i(\nu\zeta + \nu^2\xi/4k)}d\nu. \qquad (10)$$

The longitudinal correlation function is obtained by setting ζ equal to zero. Its characteristic scale is ξ_0 as given by Equation (3).

Two cross-sections of the correlation function $\rho_I(\zeta,\xi)$ obtained from simulated acoustic intensity fluctuations like those in Figure 1 are shown in Figure 3. The cross-sections $\rho_I(\zeta,0)$, the vertical transverse autocorrelation, and $\rho_I(0,\xi)$, the longitudinal autocorrelation, are shown in Figure 3. The large longitudinal scale of the intensity fluctuations compared with the vertical transverse scale is clear. In this case the ratio of the two scales is of the order of 100 : 1.

Fig. 3. Vertical and longitudinal autocorrelations of the acoustic intensity fluctuations at 3.5 kHz as in Figure 1

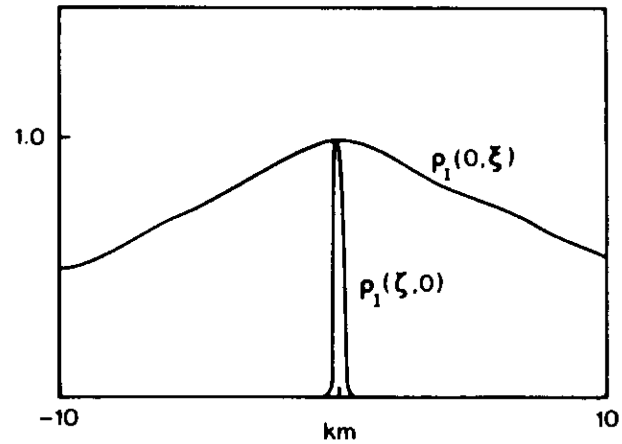
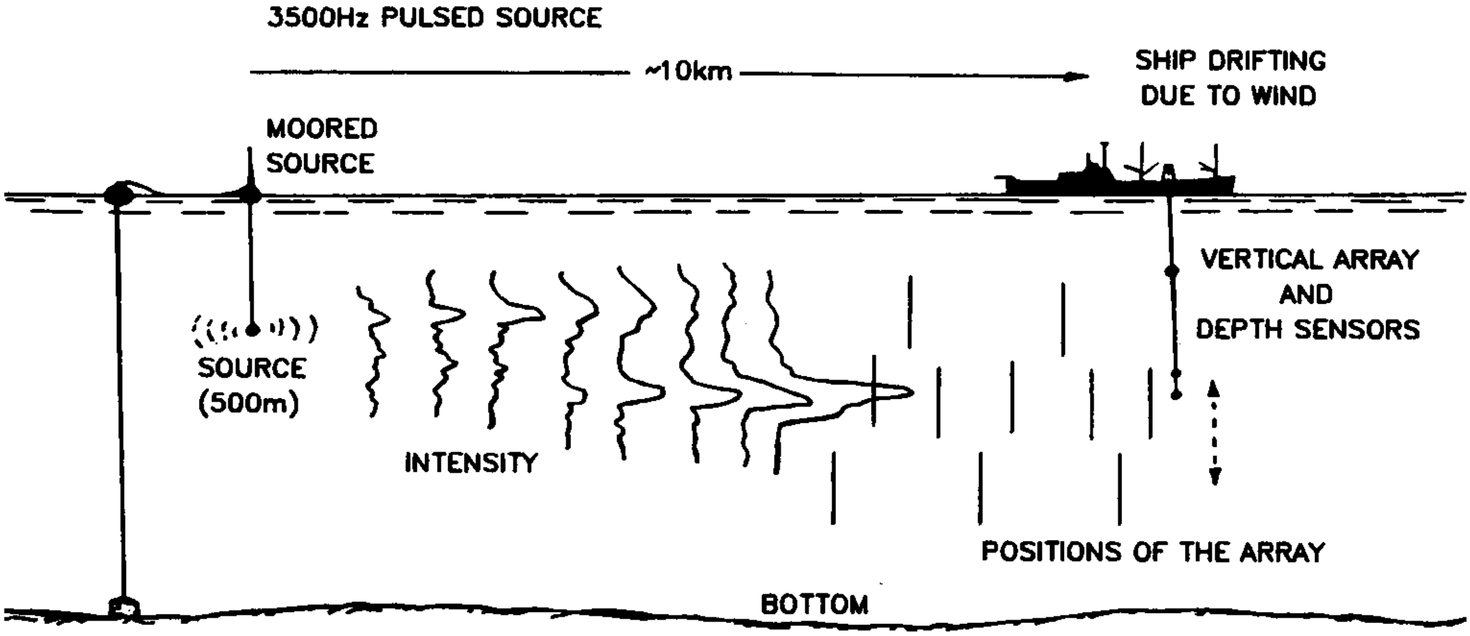


Fig. 4. Experiment to map the sound ribbons. The source transmits pulses at a carrier frequency of 3.5 kHz. The broken lines indicate successive positions of the array. The ship drifted at about 3 km/h with wind and current



Experimental observations of the high intensity ribbons

In 1986 an experiment was carried out in the eastern Mediterranean by the Saclant Undersea Research Center and the Ocean Acoustics Group, Cambridge University, to map the predicted intensity ribbons in the ocean. A moored acoustic source transmitted pulses with a 3.5 kHz carrier frequency over a distance of 10 km. The resulting irregular acoustic field was recorded by a 64 m vertical array consisting of 32 hydrophones deployed from the research vessel *Maria Paolina* (Figure 4). The intensity, averaged over ten pulses, was recorded as a function of distance down the array. The array was then lowered by a distance equal to its own length and the process was repeated until a depth of several hundred metres had been covered. The array was then raised and the procedure continued in the same manner. At the same time the ship drifted with wind and current at a constant rate of about 3 km/h, so that the acoustic intensity structure could be mapped in a strip several hundred metres deep and several kilometres in length in a time comparable to τ_0, the lifetime of the high intensity ribbons. Naturally, there is some change of the structure during this time and the resulting pattern exhibits the characteristics of both space and time changes. However, we see from Figure 5 that the predicted high intensity acoustic ribbons are actually observed. Figure 5 shows an intensity plot resulting from one of the drifting sequences described above. The predicted scales of 20 m in the vertical and over five kilometres in the direction of propagation are seen to be close to the characteristics of the measured ribbons. Also the quasi-regular spacing between the ribbons and their overall appearance agrees well with the picture

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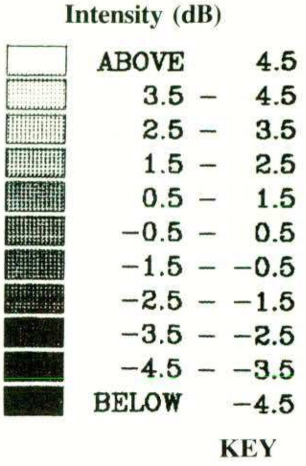
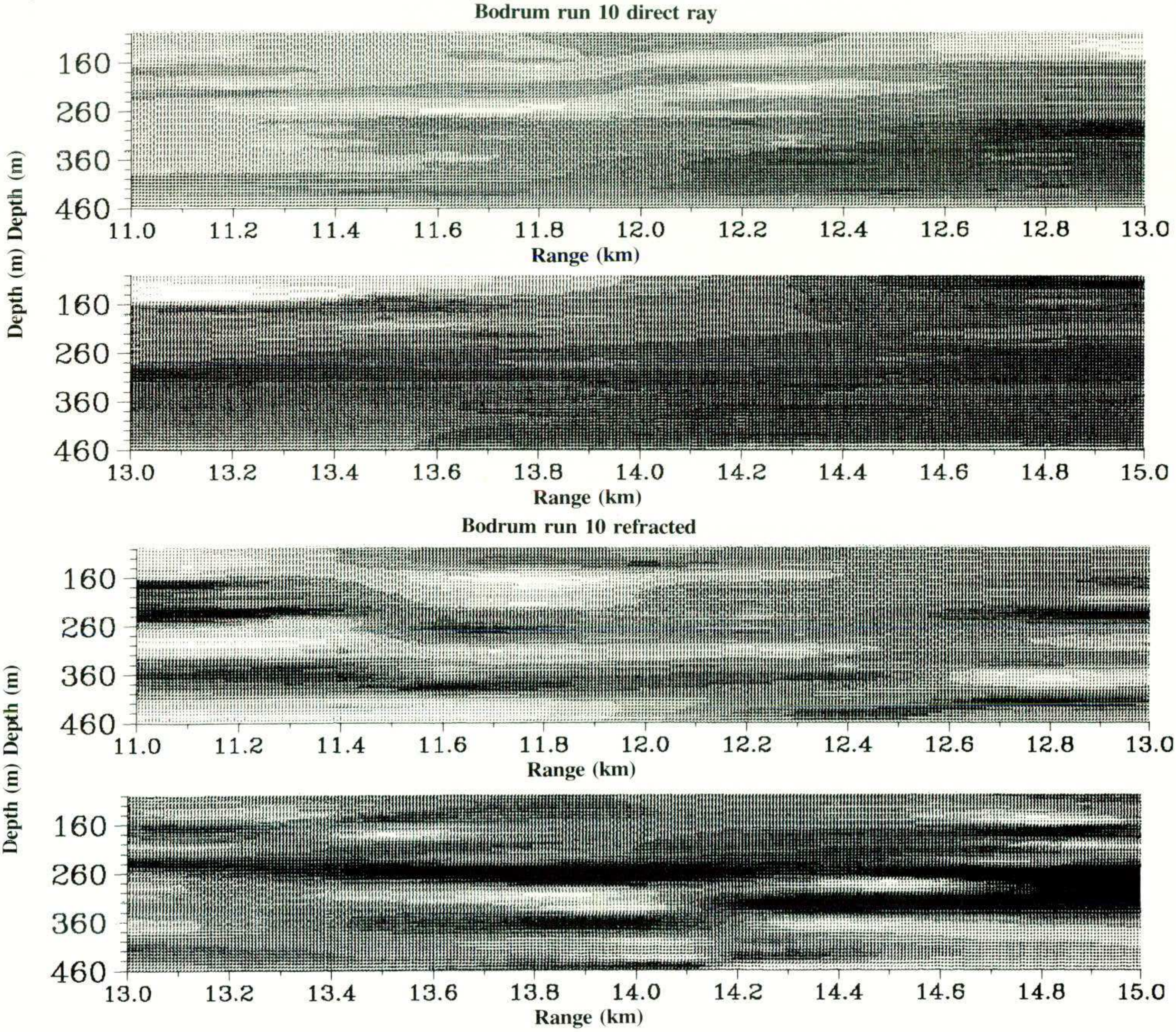


Fig. 5. The acoustic intensity as measured experimentally for 3.5 kHz pulsed source. The long high intensity ribbons can be clearly seen



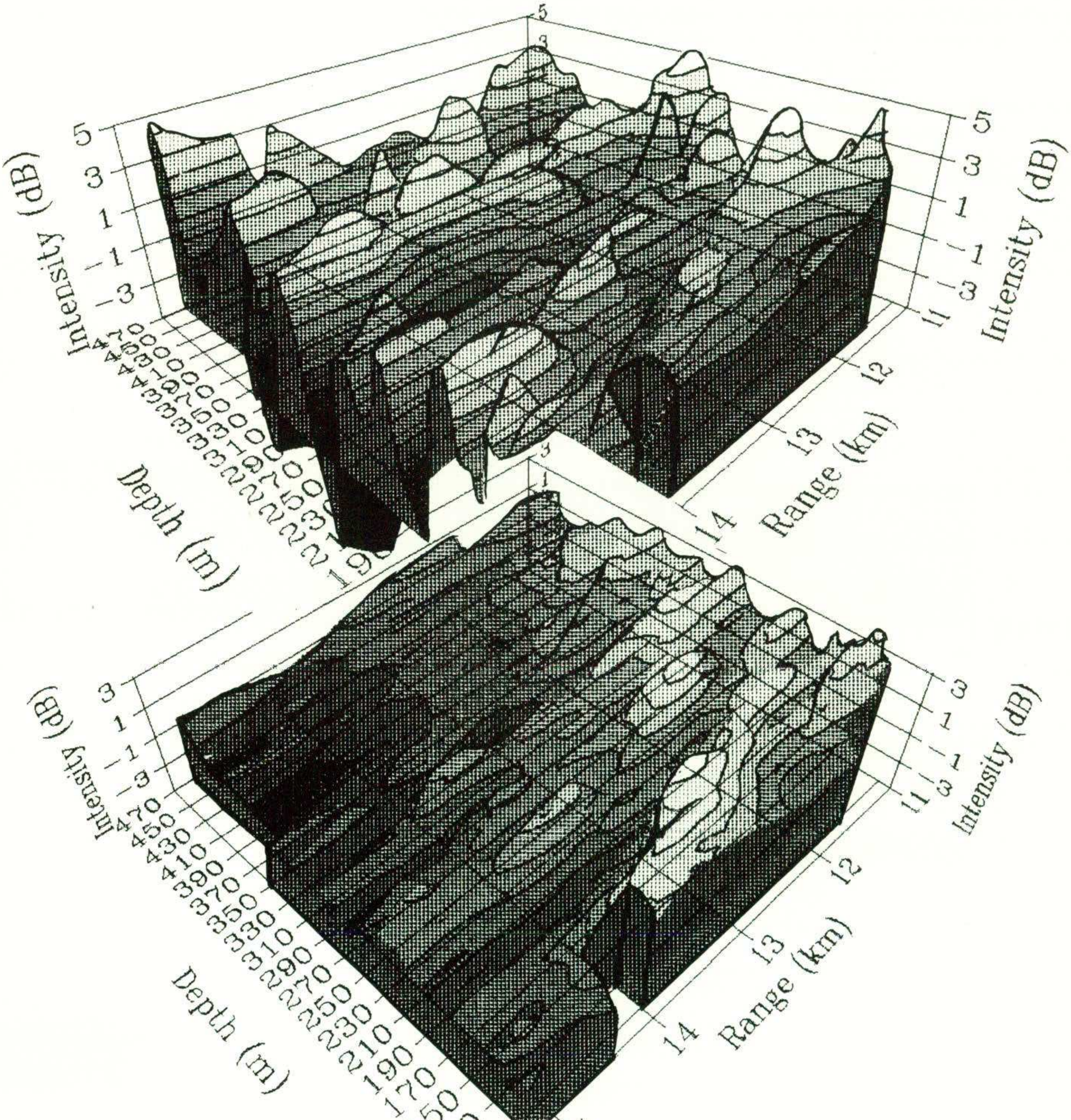
obtained from the numerical simulations.

Finally, Figure 6 shows the same intensity ribbons presented in a different manner. The intensities are plotted like hills and valleys in perspective from above and the longitudinal scale is much compressed. The ribbons now appear like irregular mountain ranges stretching in the direction of propagation and separated by valleys that run in between. This experimental verification of the high intensity ribbons predicted by numerical simulation techniques gives us confidence in the method. Undoubtedly it will continue to be used to reveal and study many more interesting and important features of propagation in randomly irregular media.

Acknowledgements

Dr B J Uscinski was supported by the Ministry of Defence (Procurement Executive).

Fig. 6. The acoustic intensity ribbons of Figure 5 presented as a contour plot in perspective. The scale in the direction of propagation is now much compressed



The Acoustical Environment in Arctic Waters

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Introduction

The most striking difference between arctic waters and temperate waters is the presence of sea ice. During winter months, all of the Central Arctic Basin, as well as much of the neighbouring water, is covered by a nearly complete layer of ice. This pack ice acts as a buffer between the water and the atmosphere, thus maintaining a relatively stable and quiet environment in the water. Warmer weather melts the southern extremities of the pack ice, but most of the Arctic Basin remains ice-covered year-round.

This discussion of the acoustical environment in arctic waters addresses the nature of the ice cover, oceanography, propagation and scattering, and ambient noise. A section on acoustic data collection in the Arctic is also included.

Sea ice

Generally, if arctic ice is not affected by external mechanical processes, it achieves a maximum thickness of about 3.5 metres and is uniformly smooth on the top and bottom surfaces. However, both the wind field and ocean currents play major roles in deforming the ice pack, resulting in a highly inhomogeneous medium. Since these forces are not uniform in time or space, extremely large and relatively independent masses of sea ice, or floes, are driven into one another at times and torn apart at other times. When two floes are pushed together, either rafting or ridging usually results. Rafting is the phenomenon of the edge of one ice floe riding up on top of the edge of an adjacent floe. Ice ridges are the surface expression of collisions in which large blocks of ice are uplifted along the colliding edges of both floes. A small, newly formed ridge is shown in Figure 1. These ridges may attain heights of over 9 metres and can extend for many kilometres. Figure 2 is an aerial view of first year ice showing the random pattern of ridge formation. Of greater acoustic importance is the subsurface deformation of the floes. At the same time a ridge is formed, ice is also thrust downward, creating protrusions of ice slabs below the sea surface. These projections, or ice keels, may extend to depths of over 50 metres. Evidence indicates the subsurface of multiyear ice is much rougher than is its surface since weathering of ice ridges by the atmosphere is much more rapid than is erosion of ice keels by a relatively stable oceanographic environment. Figure 3 is an under-ice profile which shows roughness typical of a multiyear ice floe. The top of the multiyear floe shown in Figure 4 (not the same floe represented in Figure 3) exhibits a maximum relief of about two metres, but under-ice features in this area were measured at depths of almost twenty metres. In fact, there is often no topside manifestation of an under-ice feature on a multiyear floe.

A factor which further complicates the arctic acoustic environment is the presence of areas of open water. Leads and polynyas are the two major types of open water areas found in the Arctic. Leads are formed when wind stress and ocean currents crack and separate the ice. Lead formation may expose either small or very large bodies of relatively warm water (approximately −1.7 °C) to the colder atmosphere and extend for many kilometres. Throughout many

Fig.1. Newly formed ice ridge in the Beaufort Sea, April 1987. A lead between two multiyear floes had frozen to a thickness of about 0.2m when the floes moved toward each other, creating this ridge. Here, the lead has opened again on the right and new ice is forming

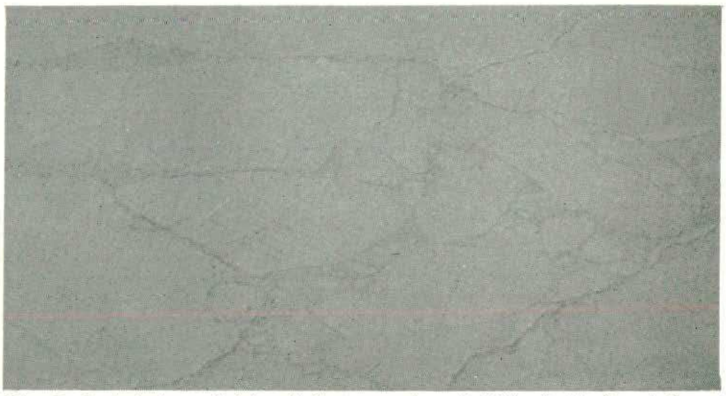

Fig. 2. Aerial view of ridged, first year ice. Rubble fields (top left and bottom centre) as well as randomly oriented ice ridges are evident. The area pictured is about 6 km wide

Fig. 3. Topography of a multiyear ice floe

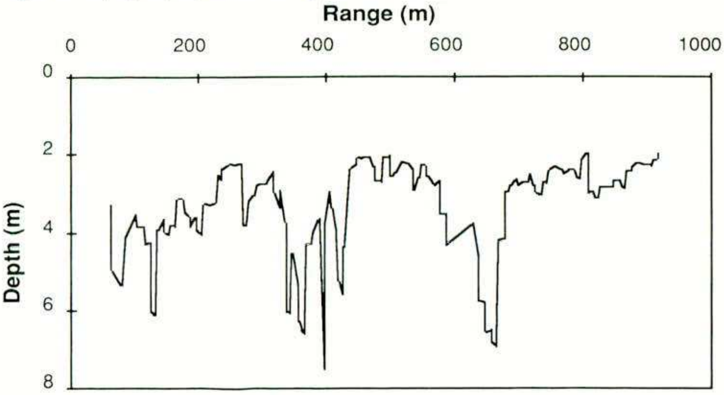

Fig. 4. Top side of a multiyear ice floe in the Beaufort Sea, April 1987. The plywood hut in the distance is about 2.5 m high, and the nominal thickness of the floe is 2 m. This location is less than 0.5 km from that shown in Figure 1

areas of the Arctic, lead formation is sporadic and seems to proceed in almost random directions, traversing thin ice areas as well as thick pressure ridges. While leads in pack ice usually either freeze over or close up within hours or days, polynyas are semipermanent areas of open water which occur in roughly the same geographical positions from year to year. Polynya formation and maintenance is thought to be primarily due to the upwelling of relatively warm subsurface waters.

The presence of large areas of open water in the Arctic Basin is the exception to the rule. A special case is the Marginal Ice Zone (MIZ) where the transition from pack ice to ice-free water occurs. In winter months, the MIZ is limited in the Pacific Ocean to the northern portion of the Bering Sea between Alaska and the Soviet Union and to the marginal seas of eastern Siberia. In the Atlantic Ocean, the MIZ extends to the east and west coasts of Greenland and east to Novya Zemlya. Figure 5 shows summer and winter ice limits for the Arctic. As the ice recedes during summer months, the occurrence of marginal ice is common in many locations throughout the Arctic. Sea ice in the MIZ exists in varying concentrations, sizes and types; factors which greatly complicate the range dependent determination and prediction of acoustic propagation.

Water column characteristics
An understanding of the ocean in which sound propagation occurs is necessary for proper interpretation of acoustic results. Stratification of sound speed in the water column causes acoustic refraction in accordance with Snell's law. That is, sound rays are bent toward a relative minimum in sound speed. The sound speed structure in the water column is dependent on the physical parameters of seawater temperature, salinity, and pressure (depth).

Generally, there are three large water masses in the Arctic Ocean which significantly affect sound propagation. Resident arctic water is found over the entire Arctic Ocean from the surface to approximately 200 m depth and is characterized by cold temperatures (near the freezing point) and low salinity values. Below this water mass, nominally located between 200 and 500 metres, is a lens of warmer, more saline water of Atlantic Ocean origin. This water mass enters the Arctic Basin through the Fram Strait between Greenland and Spitzbergen and circulates counterclockwise at intermediate depths. Atlantic water exerts a decreasingly significant role in affecting the sound speed structure in the Alaskan and Canadian Arctic as a result of convective mixing during its journey. Below approximately 900 metres, homogeneous arctic bottom water is found throughout the Arctic Ocean.

Figure 6 shows two sound speed vs. depth profiles which demonstrate the variability possible in the Arctic basins. One profile is greatly influenced by the Atlantic water, and the other profile has only a minimal amount of Atlantic water influence. Seasonal near surface sound speed variability is absent in the continually ice covered regions since this cover insulates the water from meteorological changes. But in areas where a seasonal ice cover exists, surface warming can occur during the summer, creating a shallow sub-surface propagation duct. The dashed line in Figure 6 depicts a near surface increase in sound speed which has formed such a duct.

In addition to the MIZ having both summer and winter sound speed characteristics as described above, strong oceanographic fronts are present. These fronts, created at the confluence of cold, low saline arctic water masses and warm, saline subarctic water masses, are typified by strong horizontal and vertical sound speed gradients which often serve to diffuse acoustic energy in the water column. In some MIZ areas, the frontal boundaries are nonstationary and erratic in shape. Oceanographic rings, or parcels of water from one side of the front which have been pinched off and completely encircled by the water mass on the opposite side of the front, are often present.

Propagation and scattering
Propagation characteristics in any body of water are dictated by boundary conditions and sound speed structure. The single most important characteristic of a typical arctic sound speed profile is that sound speed increases monotonically with depth, which causes all acoustic energy to be refracted toward the ice canopy. Figure 7 is a ray diagram for a sound source at zero depth in an ocean with the typical arctic profile of Figure 6. Notice that all rays which leave the source within less than 10° of horizontal bounce off a flat ice canopy at least three times every 20 km. Repeated interaction of acoustic energy with an unpredictable under ice surface produces even more complex propagation characteristics. Also, the surface half-duct would be even stronger in areas which have more Atlantic water influence since higher sound speed gradients produce more ray bending.

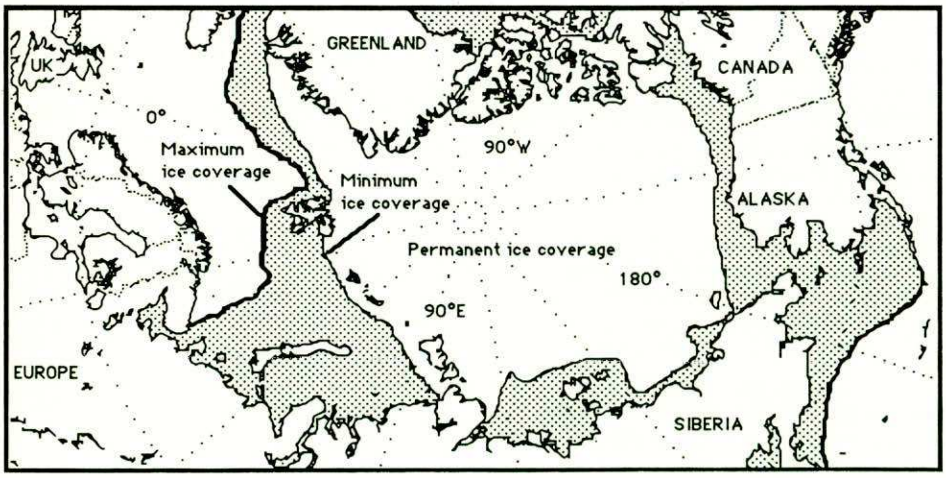

Fig. 5. Average seasonal ice limits in the Arctic Ocean. The limits shown correspond to the total area having local ice concentrations greater than one-eighth.

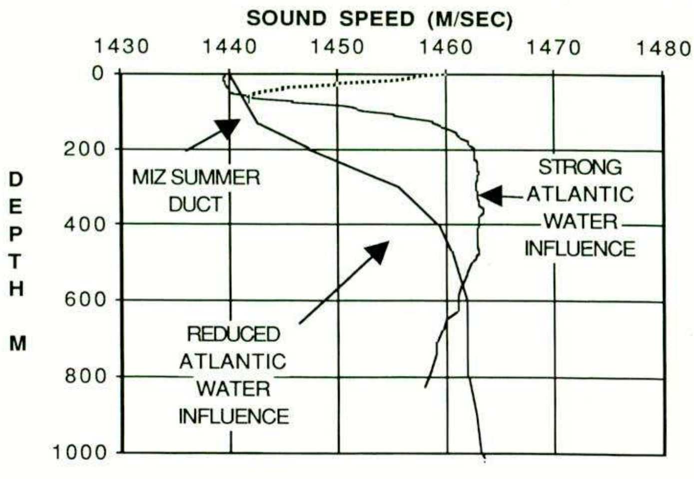

Fig. 6 Generic arctic sound speed structure. Sound speed profiles are shown with and without strong Atlantic water influence. Dashed line indicates the effect of summer warming in areas of reduced ice coverage.

Slightly steeper rays in Figure 7 (10° and 12° rays) are widely dispersed, and still steeper rays (not shown) bounce between the bottom and the ice. All three of these ray types (surface ducted, deep dispersed, or bottom-surface bounce) lead to low sound levels at long range.

The boundary of primary interest in arctic acoustics is ice cover, since it is peculiar to polar regions and since typical sound speed profiles are upward refracting. The minimum size of relevant boundary features decreases as frequency of interest increases; therefore, acoustic propagation and scattering models must become increasingly complicated as the frequency of interest increases. At very low frequencies (1 Hz and less), where ice cover thickness is an extremely small fraction of a wavelength, the presence of ice can be ignored. At slightly higher frequencies, pack ice responds to incident sound as a thin elastic plate. As keel depths become a significant fraction of a wavelength, scattering from ice keels becomes important. When ice plate thickness becomes a significant fraction of a wavelength, stratification of ice properties within the canopy must be considered. Relevant properties include, as a minimum, the shear and compressional wave speeds and attenuations plus ice density. At the same frequencies, geometric and acoustic properties of individual blocks which make up keels should not be ignored. Other factors to consider are ice properties on the level of crystals, including detailed specification of the transition layer found on the bottom of growing sea ice. This transition layer is typically about 0.1 m thick with a highly porous skeletal structure next to the water. Rigidity increases with distance from the water as ice becomes consolidated. Ice interaction of water-borne acoustic waves with frequencies as low as 4000 Hz is affected by the presence of the transition layer.

Noise

The Arctic Basin is generally much quieter than ice-free waters. Less noise is put into the water, and propagation conditions are less favourable because of the upward refracting nature of typical sound speed profiles. Dominant arctic noise sources are wind and ice events. Naturally, shipping and breaking waves, common noise sources in temperate waters, are essentially nonexistent. Also, biological noise is believed to be at a minimum.

Wind generates noise as it blows across the ridges and rubble fields of the pack ice, and this sound is transmitted through the ice and radiated into the water. Even high frequency noise is generated as loose snow is blown about, but little of this enters the water due to high attenuation in the ice at high frequencies.

Ice events can radiate sound at all frequencies. High frequencies are easily heard as leads are formed or as floes push or rub against each other. Low frequency noise is produced when a large piece of ice undergoes sudden vertical displacement. Such displacement occurs when stress-induced vertical ice deformations are suddenly relieved by cracking and when large blocks of ice are broken off a floe due to rafting.

Data collection

An acoustic field experiment in the Arctic usually requires the establishment of an ice camp, which must be on a relatively stable piece of ice. A camp, or station, which is to be inhabited year-round must be on an ice island rather than on sea ice. An ice island is a large tabular ice sheet with a thickness of 20 to 50 metres which has broken off an ice shelf. An ice island may circulate in the Central Arctic Basin for several years before being ejected through the Fram Strait. Unfortunately, ice islands are relatively rare and usually not where a particular experiment must be done. Therefore, a multiyear floe, the next most stable ice formation, is more often used, and habitation is limited to a few weeks. Spring is the most popular season for these camps, because fall and winter are too dark, and the ice is breaking up during the summer. Primary logistical support can be via icebreaker, fixed-wing aircraft, or helicopters, depending on location and size.

Once a camp has been established, the ice canopy must be penetrated in order to get hydrophones, acoustical sources, and oceanographic instrumentation in the water. Figure 8 shows an ice plug being removed from a one metre square hole cut through the ice by a thermal drill. This plug was 3.6 m thick and had to be cut into small pieces by chain saw in order to clear the hole. Holes up to 0.4 m in diameter can be drilled with a gasoline powered auger, and holes up to 0.1 metre are easily drilled with a hand powered auger.

Working through an ice hole inside a heated shelter to collect acoustical and oceanographic data has definite advantages over working from a ship in the open ocean. A large ice floe does not pitch or roll noticeably, and one seldom gets wet. Also, the floe provides a large, stable platform from which sound sources and large vertical or horizontal hydrophone arrays can be moored, using multiple, widely separated suspension points if necessary.

Concluding remarks

The Arctic Ocean is remote and the environment is harsh, making arctic experimentation expensive and time consuming. Therefore, even though arctic acoustic research has been pursued for at least four decades, data are still sparse compared with the world's more accessible waters. Research has been concentrated in the spring and in areas

Fig. 7. Ray trace diagram for the typical arctic sound speed profile (with reduced Atlantic water influence) shown in Figure 6. The sound source is at a depth of 0 m. The 6 rays shown leave the source at 2° intervals from 2° to 12° below the horizontal, inclusive

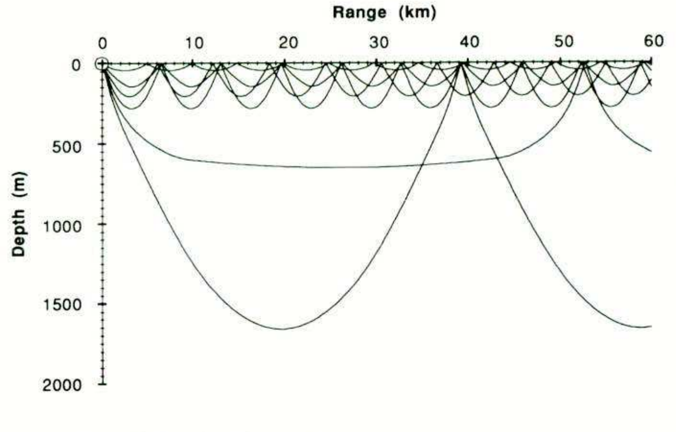

Fig. 8. Core being removed from a thermally drilled ice hole. The active element of the thermal drill was a 1 m square copper tube, through which hot antifreeze was circulated. One of the authors (PJB) is shown with a chain saw preparing to cut the 3.6m long plug into manageable pieces to clear the hole

close to permanent supply bases such as those in the USSR, Alaska, Greenland, and the Canadian archipelago.

Active areas of research include the effect on acoustic propagation of varying ice concentrations between the ice pack and open water; spatial coherence of signals propagated under and reflected from pack ice; ambient noise directivity, patchiness, and seasonal dependence; ice backscattering; and volume reverberation. In order to collect data necessary to fill in the seasonal and spatial gaps in existing data sets, more sophisticated autonomous data collection systems are being developed for air or surface deployment. These systems will lessen the requirement for ice camps and reduce the cost of experimentation.

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OBITUARY

Hugh Creighton MA (Cantab), RIBA

Hugh Creighton died on June 2nd at the age of 68.

Hugh was one of the architect/acousticians in a tradition almost unique to Britain. The late Hope Bagenal, an Hon. Fellow of this Institute, was the first of these and the world doyen of consultants from the 1930s through to the 1950s. Hugh was a family friend and a disciple of Hope's who shared his abiding concern for the beauty of musical sounds and the spoken voice.

His acoustic practice developed from the 1960s onward. Among his consultancies were the Queen Elizabeth Hall in London, the Barbican (which was attended by sad difficulties), the Royal College of Music, the Crucible Theatre in Nottingham, the Queen's Hall in Edinburgh, the Guildhall School of Music, the Music School in Cambridge, and the Royal Scottish Academy of Music and Drama. He was one of a small group of acousticians drawn together by Yehudi Menuhin, as he then was, to discuss acoustics at one of the latter's Bath Festivals. Not the least interesting of Hugh's acoustic projects was a ritual cave in Burma.

Hugh practised as an architect as well, chiefly dealing with historic buildings for the National Trust, the Landmark Trust, and for Stowe School to which he was consulting architect.

He was a quietly delightful, considerate and erudite companion and a competent musician. He was blessed with a clear mind, a light touch and a nice sense of the absurd. Those who knew him well would not be surprised that from military service during the war he was soon moved to intelligence work at Bletchley. His integrity was self-evident.

He was educated at Marlborough, Cambridge and the Architectural Association.

He has left us much too soon.

William Allen

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cel INSTRUMENTS

Proceedings of the Institute of Acoustics – Abstracts

Prosody in Speech Recognition and Production

Speech Group Meeting, Cambridge, 11 March, 1988 (reported in the July 1988 issue of the *Bulletin*)

PROSODY IN SPEECH RECOGNITION

Lexical stress recognition using Hidden Markov Models

Ghassan Freij
Cambridge University Engineering Department

A probabilistic algorithm is described for the estimation of the lexical stress pattern of English words from the acoustic signal using hidden Markov models (HMMs) with continuous asymmetric Gaussian probability density functions. Adopting a binary stressed-unstressed syllable classification strategy, two 5-state HMMs of the left-to-right type were generated, one for each stress value. Training observation vectors were extracted from a corpus of bi-syllabic stress-minimal word pairs and consisted of nine acoustic measurements based on fundamental frequency, syllabic energy and coarse linear prediction spectra. Evaluation of both models using a new set of recordings of the same word pairs yielded an average stress recognition rate of 94%.

Automatic syllable and stress detection in continuous speech recognition

Briony Williams and Jonathan Dalby
CSTR, Edinburgh

Syllable structure and stress level are important conditioning factors in segmental temporal and spectral variability, and in lexical access. This makes automatic syllabification and stress estimation a key part of continuous speech recognition research. A feature-based system has been implemented for locating syllable peaks in continuous speech and for estimating stress. Location of syllable peaks and rough estimation of syllable boundaries is performed using a smoothed mid-frequency 'sonorant' energy contour and a frication detector. The classification of syllables as stressed, unstressed, or uncertain, is based on the relative energy levels and durations in a three-syllable window. Preliminary evaluation of the system's current performance over data from two speakers yielded 77% correct location and stress classification of syllables. Some suggestions are made for extension of the algorithm, including the use of phonotactic knowledge to guide syllable boundary decisions, and the use of fundamental frequency information to guide stress classification.

Voice fundamental frequency for lip-reading in Cantonese

Teresa Ching
Department of Phonetics and Linguistics, University College London

This contribution is concerned with the possibility of presenting tonal and prosodically contrasting information to hearing-impaired listeners to facilitate speech communication in Cantonese. The approach is based on the use of the isolated auditory speech pattern relating to the voice of the speaker, and the presentation of this pattern in a modified and simplified manner to enhance lip-reading. Results obtained with Cantonese listeners indicate an increase of communication rate by 129% to 278% when lip-reading is complemented by voice pitch information.

Categorical perception and the reality of targets in intonation

Jo Verhoeven
Department of Linguistics, Edinburgh University

In this paper, the results of two discrimination experiments on Dutch intonation are presented.

The first experiment aims at establishing whether the initial rise of a flat-hat pattern is perceived categorically, when shifted through an accented syllable. The results show that location of a pitch rise with respect to an accented syllable is perceived categorically: listeners only perceive a difference between an EARLY and LATE rise. It will be hypothesized that this categorical distinction is to be explained in terms of whether the syllable is phonologically associated with a HIGH or a LOW tone.

In the second discrimination experiment, the onsets and offsets of EARLY and LATE rises were systematically varied. Discrimination results show that listeners can only discriminate accurately between stimuli if the assumed TARGET is varied (i.e., in the case of early rises – with an assumed H-target – listeners discriminate between the FO-offsets only, whereas a variation in the FO-onset is not perceived). In late rises (with an assumed L-target), the reverse is observed: subjects discriminate between variation in FO-onset and not in FO-offset.

Therefore, it will be argued that an account of intonation in terms of TARGETS is more appropriate than one in terms of PITCH MOVEMENTS.

PROSODY IN SPEECH PRODUCTION

Speech rate variability in sports commentary

Catherine Johns Lewis
Department of Modern Languages, Aston University

Radio tennis commentary provided by one male speaker is analysed first in terms of three typical recurrent phases: action, post-action and general commentary. Speech characteristics are then examined in relation to these three discourse phases. Figures for speech to silence ratio; speech burst duration; silence duration; silence frequency; words per speech burst; and speech rate are reported.

The results indicate that action phases have significantly longer speech bursts and shorter silences than the other two phases. As expected, speech rate is fastest in the action phase. The post-action phase is distinguished from the commentary phase by its slower speech rate. Commentary phases typically have twice as many words per speech burst, as compared with post-action phases. Thus, the prosodic dimensions that distinguish the three phases in tennis commentary involve distinctive combinations rather than one-to-one association.

Local speech-rate measurement in a real-speech corpus

Nick Campbell
IBM UK Scientific Centre, Winchester

Speech rate is generally acknowledged to be a variable affecting the duration of segments in spoken English, but is difficult to quantify except in the most general terms. A method is proposed whereby local variation in speech rate can be measured by comparing the predicted output from a set of duration rules against observed syllable durations. Research is in progress to examine the factors that govern such variations so that speech rate can be predicted as a variable for input to a computerized text-to-speech system.

Intonational phonology in the Edinburgh text-to-speech system

Alex Monaghan
Centre for Speech Technology Research, Edinburgh

It is well known that natural intonation is determined largely by semantic and pragmatic factors, neither of which is currently susceptible to automatic analysis. The Edinburgh text-to-speech system under development at CSTR, like most linguistics-based text-to-speech systems, relies entirely on lexical and syntactic information to generate Fo contours: nevertheless, it is capable of producing highly natural-sounding intonation. The strategies employed by the intonation module in this system are essentially as follows:

(1) Preservation of an abstract, phonological representation as far down as possible.
(2) Generation of maximally naturalistic output from minimum input.
(3) Specifying basic default rules for neutral intonation and gradually refining these as exceptions are identified.
(4) Concentration on ACCEPTABILITY of output rather than correspondence to human Fo traces.
(5) Multidimensional representation of the levels involved in generating intonation.

Our intonation module consists of four stages: INTERFIX, the syntax–intonation interface; the accent rules, including rhythm rules; the abstract phonetic model; and the mapping algorithm. This paper deals mainly with the first two stages, although their effects on later stages are mentioned.

INTERFIX is responsible for producing a regular phonological structure from the syntactic analysis: this is done by purely left-to-right processing with no reference to metrical hierarchies. The burden of the 'intelligent' processing falls on INTERFIX.

The accent rules include accent-assignment rules based on lexical information, domain general rhythm rules, and a set of WFCs. All rules in this and the following stages are entirely regular.

The emphasis in our system is on efficient, regular symbolic (abstract) processing at the phonological level. The success of this approach is both gratifying and promising for future development.

continued on p. 34

More about Noise Control in Factory Buildings

One-day Meeting held at the Newton Building, University of Salford, 27 June 1988 (Meeting Organizer, R J Orlowski)

(A report of this Meeting will be published in the January, 1989, issue of the Bulletin)

A strategy for noise control
Graham Custard
Salford University Business Services Limited

When the proposed Noise Regulations become law, noise consultants will need to adopt a more systematic and quantifiable approach to noise hazard control. A strategy based on value judgements is needed to ensure not only compliance with the law but, if necessary as justification for recommendations to management, inspectors and even in civil litigation decades later.

An initial assessment should be made to identify whether the Action Levels are *likely* to be exceeded, where and which people are affected. But yardsticks or criteria are needed to arrive at the optimum noise control solution.

Detailed cost–benefit analysis is not recommended because of the difficulty of assessing benefits in monetary terms, but this paper offers two simple models for estimating the priorities as a spur to further discussion.

Noise control – precautions at the design stage
Ernie Hill
Department of Applied Acoustics, University of Salford

Noise control costs money and must be allowed for when costing a project; failure to do so inevitably leads to (a) over-expenditure or (b) excessive noise levels. Noise control applied after commissioning inevitably costs more and in some cases becomes impractical or uneconomic.

Works design staff should make provision for noise control at the design stage. Design staff should have a basic knowledge of noise control and an appreciation of the precautions necessary to prevent noise problems arising at new installations.

Faults found at the commissioning stages of recent installations, arising through default at the design stage, are discussed.

Noise levels in factories: prediction methods and measurement results
R J Orlowski
University of Salford

The first part of this paper outlines the characteristics of sound fields in factories and the factors which influence them. The main factors are considered to be: enclosure shape, absorption of enclosure surfaces, density and size of machinery and fittings, and absorption of machinery and fittings. The effect of these factors on the sound field is described.

The second part discusses the various methods that have been proposed for predicting noise levels in factories. These fall into three groups, namely empirical equations, physical scale modelling, and theoretical predictions. In the case of empirical equations, a comparison is made between the method proposed by Friberg and measurements in UK factories.

A computer model for the prediction of noise levels in factories
C J Jones and B M Shield
Institute of Environmental Engineering, South Bank Polytechnic

A model was written several years ago for the prediction of factory noise, and tested in workshops and factories of varying sizes. Good agreement was obtained between predicted and measured noise levels. The model has been updated and various modifications in the calculation procedures have been made in an attempt to improve its accuracy. The model has been tested using new data recently collected in workshops and an empty factory space. The attenuation of sound throughout a large space has also been investigated and compared with previously published data.

Sound absorbing layers: a simple prediction model for calculating absorption and the effect on sound transmission
T E Vigran
University of Salford

The acoustical performance of a sound absorbing layer or facing added to a wall or ceiling can be of interest not only in terms of sound absorption but also because the transmission loss is increased. A wide range of computational schemes at various levels of sophistication are available in the literature, mostly concerning either the absorption or the transmission characteristics. Owing to the complex nature of the problem any single model is not able to cover all practical cases with the desired accuracy. It is believed, however, that the model presented here gives estimates suitable for design purposes in a wide range of cases.

The model evaluates the absorption and the transmission characteristics of multiple layers including limp panels, limp perforated panels, porous sound absorbents and air spaces. It is based on four-pole theory using partly theoretical, partly empirical data for the impedance of the various layers.

A series of experimental results are presented showing good agreement with prediction. The transmission loss data are obtained from conventional diffuse field transmission loss measurements, whereas a new free field method is used to measure the input, impedance and the absorption coefficient of the facing.

Measurements of sound absorption and transmission of corrugated steel plates
Nicola J H Alexander
University of Salford

In order to accurately predict noise levels experienced at positions both within and around a factory, the acoustic absorption and sound reduction index of its structural materials are required. Corrugated lightweight metal claddings form an integral part of many industrial buildings. Their extensive use presents the need to measure the sound absorption and transmission of cladding structures and to investigate possible methods for predicting these characteristics.

A programme of absorption and SRI measurements on corrugated single-skin, double-skin and composite claddings has been instigated at Salford University. Complementary to these measurements, orthotropic plate theories are being developed to predict the sound absorption and transmission loss of corrugated single- and double-skin panels. The results will be valuable for use with computer models which predict noise levels inside and around factory buildings.

The directivity of orthotropic factory cladding panels
M A Rowell and D J Oldham
University of Sheffield

Recent work by Shen and Oldham has demonstrated that above the critical frequency homogeneous panels excited by a reverberant sound field radiated with a pronounced directivity. Cladding panels applied to industrial buildings are often profiled and as a result their stiffness properties are orthotropic and they are generally reckoned to have two critical frequencies. One of these critical frequencies is typically two orders of magnitude less than that of the panel material when employed as a thin plate and as a result pronounced directivity effects may be observed at very low frequencies. A further problem associated with predicting the radiation from cladding panels is that the existing field is not clasically reverberant. In this paper these effects are considered and their affect on radiation from factory buildings is assessed.

Predicted effect of ground on sound radiation from factories
K Attenborough, N W Heap, K M Li
Faculty of Technology, The Open University
P S Nagra
GEC Avionics, Rochester

The feasibility of modelling propagation from an extended source in terms of propagation from an array of coherent point sources is demonstrated by comparison between prediction and measurements near to a large four engined aircraft. The ground effect is predicted to be most sensitive to the array height. To a lesser extent the array depth is found important and the ground effect is predicted to be relatively insensitive to the transverse length of the array. Excess attenuation from a hypothetical point source array intended to represent a radiating industrial building is predicted for various distances and various surrounding ground surfaces, the acoustical properties of which are modelled by two parameters.

Prosody in Speech Recognition cont'd

Linguistic stress, intonation and the right hemisphere
Susan J Behrens
Department of Experimental Psychology, Cambridge University

Recent claims have been made of a general prosodic processor lateralized in the right hemisphere, thus paralleling the left hemisphere language processing system. These claims, however, are largely based on prosody used to convey non-propositional, affective information. Data from both normal populations and neurologically-impaired individuals, concentrating on prosody of a linguistic nature, however, challenge this view of a right dominance for the suprasegmental component of speech.

Institute Prizes awarded at the University of Surrey

The passing of the Physics with Modern Acoustics course in its present form from the Physics Department of the University of Surrey has been marked by the award of prizes from the Institute to the best student in the last cohort in each of their years. Last year, the Board of Examiners decided not to award a prize to that Final Year because it felt that the calibre of students was not sufficiently high, so there were two Final Year prizes for this, the last, Final Year. In the event, the Examiners decided that there was one student clearly deserving a prize and two further students who were equally meritorious and both were awarded prizes for Highly Commendable Performance.

On 24 June 1988 Dr A E Brown in his capacity as External Examiner to the Physics with Modern Acoustics Course, awarded the Institute of Acoustics Prize for the best student in the Final Year to Nicole Porter. Two years ago, Nicole had won the prize for the best student in the Second Year and, a year before, had shared the prize awarded for the best student in the First Year. The new prizes for Highly Commendable Performance in the Final Year were awarded to Douglas Manvell (who had shared the First Year Prize with Nicole), and to Christopher James.

So a popular and interesting Degree Course has come to an end. In two years' time, the first award of a new Institute of Acoustics prize, to be sponsored by Bruel and Kjær, will be made to the best student in the Final Year of the New Physics with Modern Acoustics course at the University of Surrey. Students succeeding in this course will also be awarded the Diploma of the Institute as they will be taking the Diploma course and examinations at the North East Surrey College of Technology as part of their Industrial and Professional Training Year.

J M Bowsher

Nicole Porter receiving her Degree from the Chancellor of the University of Surrey, HRH the Duke of Kent

CALLS FOR PAPERS – NON-INSTITUTE MEETINGS

Noise and Vibration '89

The First International Conference on Noise and Vibration, 16–18 August 1989, to be held in Singapore

The working language of the Conference will be English, and Proceedings will be published. The programme will contain invited papers, contributed papers, and a technical exhibition. Topics will include: noise sources; effects of noise and vibration; noise control elements; noise and vibration analysis; vibration isolation and reduction; machinery diagnostics; environmental noise; modal analysis; noise legislation and regulations; structural vibration; computational methods.

Abstracts of proposed papers (about 300 words), together with a brief biography of the author, should reach the Secretariat by 15 November 1988: Dr Lim Mong King, School of Mechanical and Production Engineering, Nanyang Technological Institute, Nanyang Avenue, Singapore 2263.

* * * * *

Internoise '89 — Engineering for Environmental Noise Control

18th International Conference on Noise Control Engineering, 4–6 December 1989, at the Newport Beach Marriott Hotel near Los Angeles, California, USA

The conference is sponsored by the International Institute of Noise Control Engineering and organized by INCE/USA, and the following technical areas among others will be of interest: acoustical materials for noise control; active noise control systems; aircraft propeller noise; noise barriers and highway noise prediction; noise-induced hearing loss; noise control at the workplace; sound intensity and power determination; standards for noise control; structural propagation and damping; traffic and transportation noise control.

Abstracts of proposed papers must reach the Conference Secretariat (from whom further information may be obtained), PO Box 2469 Arlington Branch, Poughkeepsie, NY 12603, USA, by 27 February 1989.

Letters to the Editor *(cont'd)*

search Council only funds 'the medical sciences' – perhaps this is meant to indicate anatomy and physiology. If so, then the suggestion is misplaced because a high proportion of grants and programmes in the hearing area that have been funded recently by the MRC have a very strong applied element to them. Two of the largest, namely that to Professor A J Fourcin at University College and that to Dr Brian Moore at the University of Cambridge, while including some basic work, have a very heavy orientation towards hearing aids that represent significant advances from today's medium- and high-power amplifiers, but could still be on the market within the next five years.

This correction should make it clear that there is sufficient commitment, or at least openness, at the policy level and sufficient interest and active talent at the personnel level in this country to provide a secure basis for future hearing aid research and development. That assurance should provide an encouraging basis for a rational person to further invest their own talent or funds in the field. If there were no such basis, as Ms Cohen's letter seems wrongly to suggest, then the rational person would not be wise and probably not willing to make such an investment. There is much to be done but at least current events suggest that the United Kingdom may be successful in doing some of it.

From Professor M P Haggard, MRC Institute of Hearing Research, Nottingham.

Judith Cohen replies:

I am sorry if my letter in the July issue of *Acoustics Bulletin* seemed to criticize the Medical Research Council or current research workers. The British Association of the Hard of Hearing is very concerned that the present poor performance of hearing aids should be improved as soon as possible. The BAHOH Technical Committee intends to continue to campaign for this in a spirit of co-operation with all concerned.

(Member of the BAHOH Technical Committee)

BRANCH AND GROUP NEWS

North West Branch

August evening meeting

Although it was the height of the holiday season the branch met at the Manchester Office of Bruel & Kjær for an excellent presentation and demonstration on Medical Ultrasonics. This was given by Keith White, manager of the Bruel and Kjær Medical Department. Keith introduced the physical principles and limitations involved in this modern technology and went on to discuss the range of transducer design used for various applications. He then showed a series of very interesting slides illustrating ultrasonic images of various views of the human anatomy. These ranged from the development of the foetus in the womb to the very latest techniques that showed the flow of blood to and from the chambers of the heart. These non-invasive techniques allow a wide range of accurate diagnoses to be made from the early detection of problems in the foetus to the malfunction of the valves of the heart. Following the talk Keith applied the probe to himself and explained the images of his kidney, liver and heart. Discussions followed over refreshments kindly provided by Bruel & Kjær whom I thank once again for their kind hospitality.

I have been asked on several occasions if members can bring friends, colleagues, and partners to our meetings. The North West branch welcomes all to our meetings. Sometimes there are restrictions, due to limited numbers, for visits; if this happens I will refer to it in the meeting notices but we will still try our best to accommodate everyone. If you have any suggestions for future meetings or visits or would like more social events please let me or one of the NW branch committee members know.

Chris Waites

London Branch

Meeting held at British Aerospace, Dynamics Division, Hatfield

Twenty-seven delegates arrived at Hatfield for this meeting which had a slightly delayed start as Professor Ffowcs Williams, who had planned to chair the meeting, was unavoidably delayed overseas. A last minute rearrangement resulted in John Simson, chairman of the London Branch, taking over and the meeting organizer is grateful for his doing so at such short notice.

Delegates were welcomed to the Hatfield site by Frank Cooper, Head of Development Support Engineering (DSE), who explained the DSE organization and put the Hatfield (Dynamics) acoustic activities into perspective.

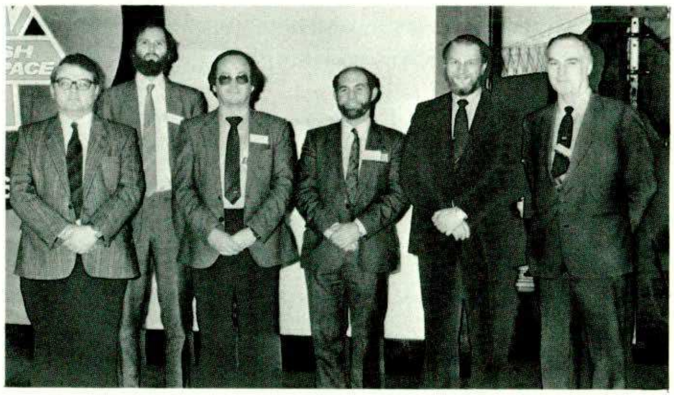
The first speaker was Alan Mortlock from the Civil Aircraft Division at Hatfield. He gave an account of the noise certification programme for the BAe 146 and ATP aircraft. These involved the use of both tripod mounted and ground plane microphones. Data analysis procedures to establish the certification levels and 90% confidence intervals for the two aircraft were described and comparisons made between the noise levels of these and other aircraft in the same categories.

The next author, Steve Rogers, was from the same Division but was unfortunately away on business. His paper was presented by Paul Brereton and gave an account of current research related to the advanced propeller being carried out in both the UK and USA. British Aerospace were examining three areas of cabin noise, namely, flight measurements, ground tests on a full scale section of the BAe 146 fuselage and the development of a theoretical prediction model. Each of these was described in some detail.

After a short coffee break the subject noise level was increased for a presentation on the acoustic effects on spacecraft by John Bennett from the Space and Communications Division at Stevenage. He gave a resumé of two problem areas arising from acoustic excitation of space structures: structural fatigue and vibration of electronic units. One difficulty in the space field is that there is little opportunity for extensive development work if the objective is to produce a 'one-off'.

A further increase in subject noise

continued opposite



Some of the speakers at the Hatfield Acoustic Facility. From the left, David James, Paul Brereton, Alan Mortlock, John Simson, Frank Cooper and Derek Sims

Letter from the Vice-President Groups and Branches

About this time last year, being a little concerned about the inactivity within the Building Acoustics Group, I dropped a strong hint in the committee's direction that they might just be letting the side down. It was of course met with the usual apathy! Well that's what I thought at the time, but slowly the gears began to grind and the cogs mesh, and with a little help from members of Meetings Committee the format for the forthcoming Autumn Conference emerged. I wish them luck with what promises to be an extremely interesting event.

All Groups are now actively engaged in a programme of meetings which should interest and help their various members. Speech Group recently spread their wings a little and produced a survey of workers and laboratories involved in speech research which is being distributed to group members. I wonder whether other Group committees would consider expanding their activities in this way. I am sure that there are many young members willing to help with the spade work.

Members will have seen the recent Secretariat Notes which included the outcome of a recent discussion in Council about membership of Branches. In future all UK and HK members will automatically become members of a branch and will be asked to indicate their choice on the annual membership return. If no choice is made they will be allocated to the branch appropriate to their geographical address. This should give committees access to a wider membership and better potential for support at meetings.

Geoff Kerry

Book Review

Transportation Noise Reference Book

Edited by P M Nelson

Published by Butterworths, in hardback, 1987; £65; ISBN 0-408-01446-6.

This book sets out to provide a comprehensive and up-to-date review of transportation noise and vibration, its impact on man and structures and the methods of control that are available. It is set out as a reference work to provide the essential facts and interpretations that have emerged from research and other areas of development and to provide leads to further sources of information. The Editor states that the book is aimed at both students and teachers in colleges and universities and is intended to provide a research and consultancy aid for the wide range of vocational groups who work in this field.

The book is arranged in six parts which deal with the following subject areas. (In addition there is a set of Appendices containing useful general information.) Part 1 is an introduction to transportation noise as a whole with brief summaries of the following sections together with a basic introduction to the fundamentals of noise propagation in the open, the units used in the evaluation of transportation noise and the measurement methods available.

Part 2 deals with the effects of transportation noise on man including annoyance and other reactions to noise, attitude surveys, health effects and a detailed consideration of sleep disturbance.

Parts 3, 4 and 5 are concerned with road traffic noise, train noise and aircraft noise respectively. Each part gives a detailed consideration of the nature of the noise source, considers how this noise can be reduced, sets out the methods of prediction of the noise level and considers how the impact can be controlled. There is inevitably some difficulty in separating these topics completely. For example, sound insulation is dealt with in detail in the traffic noise chapter but applies almost equally to the other sources.

Part 6 considers the environmental appraisal of the various types of transportation noise and shows how this can be used for decision making in the planning process. It also addresses the difficult problem of attaching some sort of financial value to the noise impact.

These six parts are subdivided into a total of 24 chapters that have been written by 26 contributors in addition to the Editor. Space does not allow them all to be listed here so I will not single out individuals for mention but they are all respected contributors to research in their particular fields from various parts of the world. The international theme of the various sections adds much to the usefulness of the book. I do, however, feel that in some chapters there is variability in the balance between the information pertinent to the UK compared with the international scene. It may well be that this is a reflection of the variation between countries in the amount of research activity in the particular topics covered rather than the personal selection of individual authors.

This general arrangement works extremely well and the resulting book contains an enormous quantity of useful information. It runs to over 500 pages and is generously provided with supporting illustrations. The quality of production is very high although I found the small print rather wearing after long periods. The line drawings are all clear but variable in size and the amount of detail they contain, and a few are rather more diagrammatic than accurate. In general the photographs, although not numerous, are all rather dark with poor contrast and are perhaps the weakest feature.

As one must expect in a work of this size there are some errors but I did not find enough to detract from my enjoyment of the book. I did notice that rather than spelling mistakes the faults were generally omitted or incorrect words. This caused me to muse that computer spelling checkers are no substitute for good sub-editing if the wrong word is typeset!

Overall I found this an excellent book that fulfilled most of the aims that the Editor set out to achieve. I do, however, have one significant criticism. The title presents it as a reference work and this is what it will be for most people. I certainly expect to return to it frequently, but I have already discovered that it is not easy to find one's way around it. There is a general contents list at the start of the book, a detailed contents list at the beginning of each chapter, a glossary of acoustic terminology and an index but there is very little cross referencing between these pointers. To add to the problems the book is not conventionally page numbered and the references are included at the end of each chapter whether or not they are specific to that topic or of general interest. I believe that if more effort had been put into the index then a significant improvement could have been achieved. By way of example, it appears to me that keywords in the subheadings within particular chapters have not necessarily been included in the index. I started to check for entries in the index and found many occasions where I felt that additional entries would have been helpful to a person trying to use the book as a source of reference. This is, however, a point of detail that will irritate the user rather than detract from the book's usefulness.

At £65 this is not a book that every student will go out and buy as a matter of course but I would recommend that anyone who is researching or working in this field should do their best to obtain a copy or at least make sure that they have regular access to it in a library. They will find, I am sure, that they will keep going back to it.

Robert Hill

Branch and Group News *continued*

level and Derek Sims, from the Dynamics Division at Hatfield, presented the noise environment of the aircraft-carried missile. It was noted that, apart from some low frequency input from the parent aircraft, the major source of vibration was the turbulent boundary layer. The need to reproduce this environment and the means of doing this, in combination with temperature, were described.

The final paper related to work currently being carried out by the Military Aircraft Division at Warton and was presented by David James. This work involved the long-term thermal and acoustic fatigue evaluation of new materials for high performance aircraft including titanium and carbon fibre constructions with joints and with direct loading.

After a break for lunch 23 delegates toured the Acoustic Test Facilities, Vibration Laboratory and Data Centre where they were able to discuss the techniques used with the engineers in these areas. Over tea it was generally concluded that the meeting had been useful and enjoyed by all participants.

Derek Sims

Contributions and information for the January 1989 issue of ***Acoustics Bulletin*** should reach the Executive Editor, Marjorie Winterbottom, at 14 Witney Road, Long Hanborough, Oxon OX7 2BJ, no later than 22 November, 1988.

NON-INSTITUTE MEETINGS

1988	
20–24 October	*World Conference on Ergonomics, Occupational Safety and Health,* in Beijing, China, organized by the Chinese Society of Metals and the Darling Downs Institute of Advanced Education, Australia.
24–27 October	*55th NSCA Conference* to be held in Llandudno, North Wales. Information from: National Society for Clean Air, 136 North Street, Brighton BN1 1RG.
26–28 October	*Undersea Defence Technology 1988.* Conference and Exhibition, supported by IEE and IOA Underwater Acoustics Group. Contact: Microwave Exhibitions and Publishers Ltd., 90 Calverley Road, Tunbridge Wells, Kent TN1 2UN.
2–4 November	*Westpac III,* The 3rd Western Pacific Regional Acoustics Conference, to be held in Shanghai, China. Details: Secretariat of Westpac III, c/o Institute of Acoustics, Academia Sinica, 17 Zongguancun Street, PO Box 2712, Beijing, China.
7–11 November	Acoustical Society, China.
14–15 November	*IOSH '88 Exhibition* (Institution of Occupational Safety and Health) at the Moat House International Hotel, Harrogate, Yorks.
14–18 November	Second Joint Meeting of the Acoustical Society of America and the Acoustical Society of Japan, Honolulu, Hawaii, USA.
15–18 November	Short course: *Control of Industrial Noise and Hearing Loss Protection.* Details from Pat Stenhouse, Course Secretary, Centre for Extension Studies, University of Technology, Loughborough, Leics. LE11 2TU. Tel: 0509 222161.
24–25 November	*Noise into the Nineties,* Annual Conference of the Australian Acoustical Society, to be held in Victor Harbour, South Australia. Details from: R. A. Piesse, Gen. Sec., Australian Acoustical Society, Science Centre Foundation, 35-43 Clarence St., Sydney, NSW 2000.
28 November–2 December	*POLMET '88* – Pollution in the Urban Environment, with emphasis on the Asian and the Pacific regions. Technical exhibition and site visits. Enquiries: Polmet 88 Secretariat, c/o Hong Kong Institution of Engineers, 9/F, Island Centre, Causeway Bay, Hong Kong.
6–8 December	British Medical Ultrasound Society, *Annual Scientific Meeting and Ultrasound Equipment Exhibtion,* Scottish Exhibition and Conference Centre, Glasgow. Contact: Mrs L Blench, BMUS, 36 Portland Place, London W1N 3DG, Tel 01-636 3714.
1989	
27 February–3 March	*1989 SAE International Congress and Exposition,* in Cobo Hall, Detroit, Michigan, USA. Topics include: Engine Noise Control at Source and at Response; Engine Redesign for Low Noise; Vehicle/Engine Noise and Vibration. Organizer: Prof. Sam D Haddad, FIMechE, Dept. of Mech. and Aerospace Engineering, 2005 Engineering Complex, University of Missouri-Columbia, Columbia, Missouri 65211, USA.
7–10 March	*86th AES Convention* to be held in Hamburg, FRG. Information from: H A O Wilms, Exh. Director, Zevenbunderslaan 142/9, B-1190 Brussels, Belgium.
14–16 March	*STRESS AND VIBRATION: Recent Developments in Measurement and Analysis,* incorporating the Third International Conference on Stress Analysis by Thermoelastic Techniques, to be held in London. Information from: Conference Office, SIRA Ltd., South Hill, Chislehurst, Kent BR7 5EH.
15–17 March	*DOI 89* (Defence Oceanology International), at the Brighton Metropole, Brighton, UK. The twentieth anniversary of the Oceanology International series: The Gap between Civil and Military in Oceanology.
3–5 April	Modern Practice in Stress and Vibration Analysis, University of Liverpool. Organized by the Stress Analysis Group of the Institute of Physics.
10–12 April	*AIAA 12th Aeroacoustics Conference* at the Hilton Palacio del Rio, San Antonio, Texas, USA. Topics include: Unsteady loads on hypersonic vehicles; computational aeroacoustics; control of acoustic/fluid dynamic phenomena; duct acoustics; helicopter and V/STOL noise; jet aeroacoustics; sonic fatigue; turbomachinery and core noise. Information from: Dr James F Unruh, Southwest Research Institute, 6220 Culebra Road, San Antonio, TX 78284, (512) 522-2344.
24 April (week of)	*8th Fase Symposium on Environmental Acoustics,* in Zaragoza, Spain. Details from Secretariat Viajes el Corte Ingles, Dpto. Congresos, Avda-César Augusto, 14, 2.ª planta, 50004 Zaragoza (Spain).
25–29 April	International Conference on *Acoustics, Speech and Signal Processing,* in Glasgow. Details from: Institute of Electrical and Electronics Engineers, Inc., Conference Co-ordination, 345 E. 47th St., New York, NY 10017.
26–28 April	*Sixth Symposium on Maritime Electronics,* Rostock, DGR. Details from: Wilhelm-Pieck-Universität Rostock, Sektion Technische Elektronik, Albert-Einstein-Str.2, Rostock 1 2500.
22–26 May	Meeting of the Acoustical Society of America, New York. Details from: Murray Strasberg, 500 Sunnyside Blvd, Woodbury, NY 11797.
7–10 June	*6th Seminar and Exhibition on Noise Control,* to be held in Pécs, Hungary. Details from: The organizers, Optical, Acoustical and Film Technical Society, Föu.68. H-1027, Budapest II, Hungary.
16–18 August	*Noise and Vibration '89,* to be held in Singapore. Abstracts by 15th November, 1988. Details from: The Secretariat, International Conference Noise and Vibration 1989, c/o School of Mech. and Production Engineering, Nanyang Technological Institute, Nanyang Avenue, Singapore 2263.
24–31 August	*13th ICA Congress,* International Commission on Acoustics, Belgrade, Yugoslavia.
4–6 September	*Symposia:* Dubrovnik on *Sea Acoustics*; Zagreb on *Electroacoustics.* Details: Secretariat, Sava Centar, 11076, Belgrade, Yugoslavia.
October	28th Acoustical Conference on Physiological Acoustics: *Acoustics of Speech and Music.* Details: Secretariat, House of Technology, Eng. L. Goralikova, Škultétyho ul.1, 832 27 Bratislava, Czechoslovakia.
4–6 October	IEEE/UFFCS Ultrasonics Symposium, Montreal, Canada. Details: Allied-Signal Inc., Attn. H van de Vaart, PO Box 10221R, Morristown, NJ 07980, USA.
6–10 November	Meeting of Acoustical Society of America, St. Louis, USA. Details: Murray Strasberg, (see above).
6–10 November	Meeting of Acoustical Society of America, New York. Details from Murray Strasberg (see above).
4–6 December	Inter-Noise 89, Newport Beach, CA, USA. Details from: Internoise '89, Institute of Noise Control Engineering, PO Box 3206, Poughkeepsie, NY 12603.
December	European Symposium on Transportation Noise, Braunschweig, FGR. Details from: Deutsche Gesellschaft für Luft- und Raumfahrt e. V., Godesberger Allee 70, D-5300 Bonn 2.
1990	
February	*Fourth Conference on Hydro- and Geophysical Acoustics,* Rostock, E Germany.
21–25 May	Meeting of the Acoustical Society of America.
October	*29th Acoustical Conference on Room and Building Acoustics* – Czechoslovakia.
26–30 November	Meeting of the Acoustical Society of America – San Diego, California.

Information relating to meetings of possible interest to readers should be with the Editor at the address on page 1 no later than four months before the date of the meeting.

New Products

Submissions for inclusion in this section should be sent direct to J W Sargent, Building Research Establishment, Garston, Watford WD2 7JR.

Vibration calibrator B&K 4294
The type 4294 Calibration Exciter is a self-contained handheld unit for calibrating vibration measurement and monitoring systems using piezoelectric accelerometers and other vibration transducers with a maximum mass of 70 grams. The unit calibrates the system taking into account the influence of connecting cables on the sensitivity of the transducer.

The 4294 embodies an electromagnetic exciter driven by a stabilized oscillator at a frequency of 159.2 Hz. Servo-stabilization of vibration amplitude is provided by an integral reference accelerometer which is placed on the underside of the vibration table. The straightforward calibration procedure involves push-button actuation of the exciter and adjustment of the measuring instrumentation to indicate an acceleration level of 10 m s^{-2}, velocity level 10 mm s^{-1}, or displacement reading of 10 μm.

Intensity probe B&K 3545
The Type 3545 is a new single-cable sound intensity probe for use with the 2133 realtime frequency analyser. A Remote Control Unit can be attached to the probe for full remote-controlled intensity measurements.

The kit comes in a carrying case and comprises probe, one pair of ½-in microphones, one matched pair of ¼-in microphones for high-frequency work, a range of spacers and a telescopic handle.

Further information from Bruel & Kjær (UK) Ltd, 92 Uxbridge Road, Harrow HA3 6NZ. Tel: 01-954 2366.

VIBAS – Multichannel modal analysis
VIBAS is a new Vibration Modal Analysis software system from Anthony Best Dynamics Ltd., which was written specifically to run on IBM AT computers (or equivalent) and the Cambridge Electronic Design 1401 intelligent interface.

Applications are for structural testing on vehicles, machines, civil engineering structures, bridges, cranes, etc. The entry level software consists of three modules: (1) set up and data acquisition; (2) modal parameter estimation and curve fitting; (3) mode shape plotting in two- and three-dimensional views. Module 1 provides, in addition, many of the frequency analysis facilities of a four channel analyser.

The software is particularly user friendly and requires no computing expertise to use it. Additional modules can be added to the VIBAS software for vibrator excitation, alternative analysis modes and animation of mode shapes. Using a portable computer the whole system can easily be carried on site by one person.

Anthony Best Dynamics also supply the CAARM family of software and systems for noise and vibration testing of rotating machinery, such as gearboxes, at the end of a production line; HYCAARM for hydraulic machine testing; EXCAARM for vehicle exhaust system development; CARDS for spring damper and elastomer testing. All these systems use the same basic hardware.

Further details from Anthony Best Dynamics Ltd., Holt Road, Bradford on Avon, Wiltshire BA15 1AJ. Tel: 02216 7575.

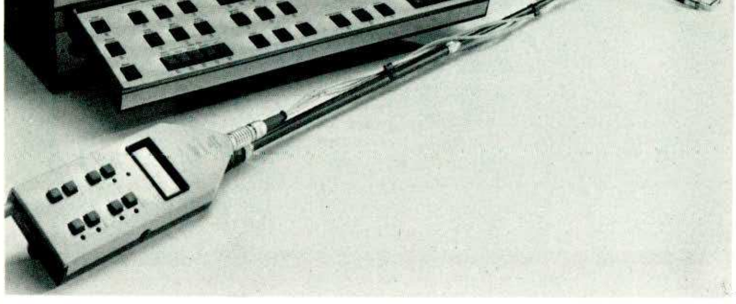
Portable FFT spectrum analyser SD385 'NOMAD'
The NOMAD has been designed with portability and ruggedness as a prime objective to meet the requirements of engineers needing a compact, lightweight instrument suitable for use outside the laboratory. It is available either with one or two input channels. Expansion from one to two channels involves a simple upgrade. Other options include: (a) a flat-screen display; (b) octave and third octave analysis; (c) signature ratio adapter for order tracking rotating equipment; (d) 1 Mbyte 3.5 in floppy disc drives for data storage.

The NOMAD has a versatile 200 Spectra Waterfall Display ideal for the analysis of rotating machinery, structural mode shapes, damping estimates, human speech and a large range of other applications. The NOMAD has selectable frequency ranges from 20 kHz to 100 Hz in a 1,2,5 sequence with resolutions of 100, 200, 400 and 800 FFT lines and also real time zoom analysis. The instrument has a digital

continued on p. 40

A typical hardware set-up for use with VIBAS system. A single channel of force measurement and a single accelerometer are shown

The Bruel & Kjær Intensity probe 3545



New Products *continued*

input memory of 32K samples/channel to enable post processing of time history data.

The NOMAD is fully programmable via the GPIB Interface and has a direct output to both line printers and HPGL compatible plotters.

Further details from Scientific-Atlanta Ltd., Home Park Estate, King's Langley, Herts. WD4 8LZ. Tel: 09277 66133.

Data logging sound level meter CRL 2.36

The CRL 2.36 is a new concept in sound level meters. It can read a new Leq 8 times each second and store each one in its memory, which can hold 114000 Leq values. Each noise source can be coded at acquisition time to identify the source during later analysis.

The data in the meter memory cannot be destroyed or erased accidentally and at any time after acquisition the CRL 2.36 can be connected to a host computer and all the separate Leq read by the software to recreate a noise profile. The computer can be programmed to provide percentile levels or the overall Leq between any specified times. While the CRL 2.36 is acquiring data it can also display normal Leq, Max Leq or the number of Leq already in the memory.

Further details from Cirrus Research Ltd., Acoustic House, Bridlington Road, Hunmanby, North Yorkshire Y014 0PH. Tel: 0723 891655.

Sound level analyser NEAS Type 110

Norwegian Electronics announce a new battery operated precision environmental and multifunction sound and vibration meter. The NEAS 110 weighs only 5 lb and will fit in a briefcase. Among the features of this instrument are:

(1) Simultaneous measurement of Fast, Slow, Impulse and Peak levels with separate Max and Min Hold functions for all of them. In one measurement all the level parameters are stored, over a 90 dB dynamic range.
(2) Simultaneous time-averaging of Leq, Leq(I), Leq(4 dB), Leq(5 dB), Leq(6 dB), SEL.
(3) A,B,C, and Lin networks plus optional built-in digital filters for measurement of 1/3 or 1/1 octave levels from 1 Hz to 20 kHz with automatic scanning.
(4) 64 × 240 dot LCD screen for numerical and graphical presentation of results.
(5) L1 – L99 percentiles in 0.2 dB classes – Probability and Cumulative Distribution.
(6) Extended trigger facilities and real time clock, for transient capture, etc.
(7) Outputs for computers, printers, etc.
(8) Large internal memory, stores up to 10,000 results.

Further details from Gracey & Associates, High Street, Chelveston, Northants. NN9 6AS. Tel: 0933 624 212.

Diploma in Acoustics and Noise Control 1988 – Project Titles

Space restrictions have prevented the publication this month of the list of titles of Projects for the Diploma in Acoustics and Noise Control, 1988. We assure readers that they will appear in the January, 1989 issue.

Technical Articles

The editorial board would welcome offers of technical articles on Acoustics and related subjects likely to be of general interest. Please contact the Editor, John Tyler, at Pooh Corner, Chalkhouse Green, Reading RG4 9AG.

No Noise...

can escape precise detection with the CEL-493/2 Precision Integrating Impulse Sound Level Meter. A 100dB single measurement span covering the most common sound level range ensures simplicity of use, whilst the custom designed display conveys results with crystal clarity.

The pocket-sized meter is further enhanced with a versatile digital computer interface for connection to the CEL-238 Digital Printer and to suitable microcomputers. A comprehensive range of filter sets and other accessories is available for virtually any application.

CEL-493

Precision Impulse Integrating Sound Level Meter

For further information or a free demonstration contact:

Lucas CEL Instruments Ltd
35/37 Bury Mead Road
Hitchin, Herts, SG5 1RT.
Tel: Hitchin (0462) 422411
Telex: 826615 CEL G
Fax: (0462) 422511

cel INSTRUMENTS

Institute of Acoustics

Meetings

1988			
26-28 October	UAG	Undersea Defence Technology (co-sponsors with IEE)	Novotel, London
3-6 November	M	**Fourth Annual Conference: Reproduced Sound 4**	Windermere
16 November	LB	Sounds generated by the Ear and its Application in Hearing Testing	6 p.m. County Hall, London
25-27 November	M	**Autumn Conference: Noise in and Around Buildings**	Windermere
14 December	LB	Clay pigeon shooting	6 p.m. County Hall, London
7 December	SB	Inaudibility in the Assessment of Noise Nuisance	Reading
14 December	UAG	Finite Elements Applied to Sonar Transducers	Birmingham
14 December	M	The Acoustic Consultant — Professional Responsibility and Risk	London
1989			
Early '89	M	Noise and Vibration from the Channel Project	To be announced
Early '89	M	New Methods for Measurement and Assessment of Environmental Noise	To be announced
Early '89	M	PC Programmes in Acoustics	London
21-22 March	UAG	Progress in Fisheries Acoustics	Fisheries Lab., Lowestoft
3-6 April	M	**Acoustics '89**	University College, Oxford
11-13 December	UAG	Digital Sonar Processing	Loughborough

Key

M = Meetings Committee Programme
BAG = Building Acoustics Group
ING = Industrial Noise Group
MAG = Musical Acoustics Group
PAG = Physical Acoustics Group
SG = Speech Group
UAG = Underwater Acoustics Group
LB = London Branch

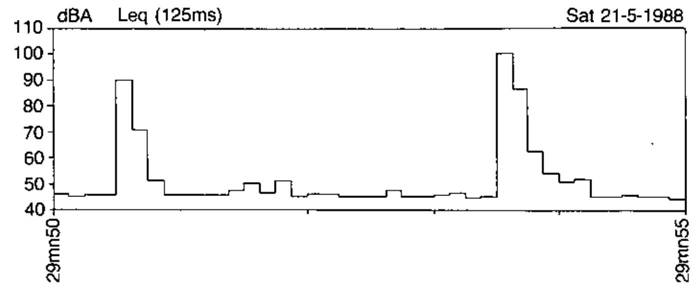
EMB = East Midlands Branch
NEB = North East Branch
NWB = North West Branch
SB = Southern Branch
ScB = Scottish Branch
SWB = South West Branch
YHB = Yorkshire and Humberside Branch

Further details from:

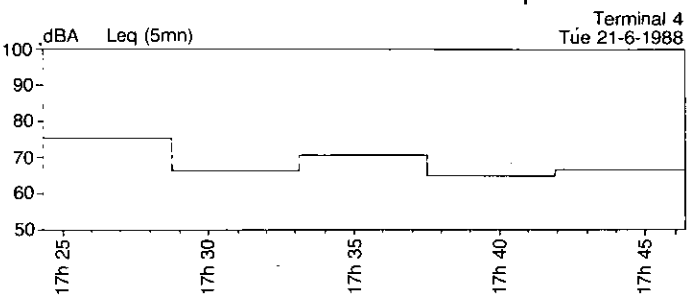
Institute of Acoustics
25 Chambers Street
Edinburgh EH1 1HU
Tel: 031-225 2143

ADVERTISEMENT

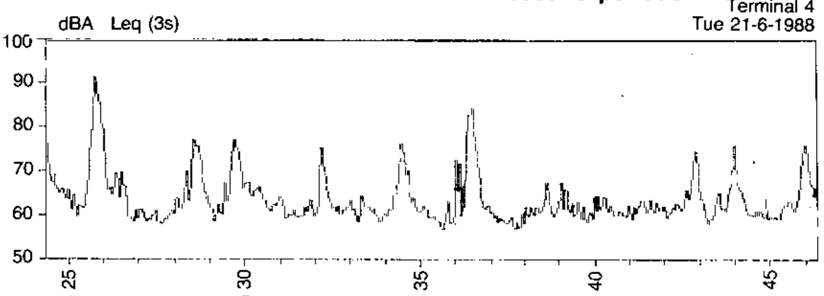
Two shots fired within a 5 second period.



22 minutes of aircraft noise in 5 minute periods.



22 minutes of aircraft noise in 3 second periods.



L10 L50 and L90 every 200 seconds.

Place: Terminal 4
from 17h 24mn 20s
till 17h 46mn 18s Tue 21-06-1988
Elementary duration: 0.125s dBA
Sub-period 200s

Period	Leq	L1	L19	L50	L90	L95
24mn 20s	76.9	91.0	77.6	64.2	58.9	58.4
27mn 40s	69.0	77.9	73.8	64.1	60.2	59.2
31mn 00s	64.1	73.7	65.0	61.3	59.5	59.1
34mn 20s	72.2	85.0	75.1	61.1	58.2	57.6
37mn 40s	62.4	69.7	64.6	60.8	58.3	57.5
41mn 00s	66.0	76.0	68.2	62.4	59.9	59.3
44mn 20s	66.9	77.3	69.9	61.6	59.4	59.1

Overall: 71.1 dBA

TEN QUESTIONS ON SHORT Leq

1. What does it offer?

The new technique of Short Leq has revolutionised the taking of acoustic data. Now, all that has to be done on site is to simply place the meter in the correct place and ALL the noise data will be captured. The CIRRUS CRL 2.36 has a 120dB dynamic range, extending from 20 to 140dB and thus there are very few practical noise levels that it cannot capture. In principle, the technique is to take a series of ⅛th second integrals one after the other with no break between them and store these in the internal memory of the hand held meter.

2. How is it used?

First the data is captured. This is often an unattended operation, but naturally there will always be measurements where unattended operation is not sensible or even desirable. Any time of acquisition from 1 second up to 30 hours can be stored in the internal memory of the CRL 2.36 with a new Leq being taken every second. Thus for a full 24 hour period, every change of level, every impulse, every event is faithfully recorded into the memory.

3. How long is the data safe?

After the acquisition is over, the data can be kept inside the CRL 2.36 as long as desired, up to a year or more. When the information is needed, the Leqs are transferred to the disk of a personal computer for permanent storage. Now, you have the full and exact Time History of the original noise with a ⅛ second resolution in a permanent form.

4. What can you now do?

A better question is in reality what CAN'T you do? Any acoustical index can be produced from the data, automatically by the CIRRUS software. Not only the data for the whole file, but also any part of the data can be zoomed in and inspected in the minutest detail. Figure 1 shows a 5 second plot taken out of the middle of a 2 hour file. Two shots are recorded, with some reverberation present. In figure 2 the Leq Time History using 5 minutes as the data base is plotted. This is the typical type of data that a community noise analyser would give. Fig 3 by contrast, shows the same data using 3 seconds Leq. In fig 4, some Ln values are listed every 200 sec. With the CIRRUS system, it could just as well have been every 180 seconds. You only need to choose the period of data presentation AFTER you have seen the data.

5. How can such a system save money?

To start with it is very inexpensive. Including a computer, the whole system costs less than comparable meters. The low price is achieved by making the Leq meter as accurate and simple as possible but doing as many calculations as possible in the external computer, thus using the economies of scale. With the high production volume of personal computers they are much cheaper and a scale order more powerful than the simple computer chip used in even the very best Sound Level Meter. Naturally, the sound level meter circuit could be put inside the computer, but this is generally not so convenient as the CRL 2.36 which looks and functions like a conventional Sound Level Meter.

6. What are the applications?

While almost any measurement is simplified with Short Leq, the measurement of highly impulsive or level varying noise shows the most savings. For example, in measurement of noise complaints, two meters are used, one near the complainant and one near the noise source. The programme can AUTOMATICALLY identify when the source is active and how much it is contributing to the overall noise climate. For projects such as Civil Engineering or the Extraction Industry, this is a Godsend. Now you can positively demonstrate that you are not the offending source.

7. Can it be used in Environmental noise?

With its range starting at 20dBA and with no range switching, the CRL 2.36 is ideal for Environmental Health Officers. In its waterproof box and outdoor microphone, the CRL 2.36 can be left out for long periods, acquiring ALL the noise data, no matter how impulsive or how rapidly changing the noise. The CRL 2.36 will capture everything. At any time later, the Environmental Health Officer can make a measurement of the noise based on the form of the data itself. For example, if traffic was a significant contributor, perhaps L10 and L90 may be needed. If it was for a specific regulation, simple Leq values each 5 minutes may be better, perhaps even both. With the CRL 2.36 it simply doesn't matter. All these decisions are taken at replay time, not when the data is acquired.

8. What indices can't it produce?

Unless the true peak value is involved, NONE. It can reproduce ANY conventional acoustic index.

9. How does it compare with a conventional programmable Leq meter?

A really good conventional computerised Leq meter can perform any measurement that can be done with the CRL 2.36. However, if the form and structure of the data is unknown, the CRL 2.36 has a huge advantage. It acquires all the data, and subsequently you the user can decide what you want to measure. You need take no decision before acquisition. Clearly, there are many occasions where the required measurement indices are known in advance. In these cases, the instant readout of a conventional meter will outperform the CRL 2.36 in the time to obtain results. However, in the 'difficult' cases where the required indices are not known in advance, the CRL 2.36 will show advantages of economy and security. An analogy would be the wedding photograph, there is only one chance. With the CRL 2.36 you are SURE you have the data, all the data, with no chance that you have chosen the wrong programme module. There are no modules, the CRL 2.36 captures ALL the data within its 120dB dynamic range. Also of course, the CRL 2.36 transfers ALL its data to the computer disk, not a processed version of the data, thus it can reconstitute the whole noise climate, something no other hand held meter can do.

10. What does it cost?

The CRL 2.36 complete with a fast 80286 desktop computer costs less than a meter alone from the market leader. In terms of cost to performance ratio, the CRL 2.36 has no peer. Why not call Cirrus and ask for a FREE copy of the process programme and see for yourself!

Cirrus Research Ltd, Acoustic House, Bridlington Road, Hunmanby, North Yorks. Tel: 0723 891655