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contents

The Institute of Acoustics was formed in 1974 through the amalgamation of the Acoustics Group of the Institute of Physics and the British Acoustical Society and is the premier organisation in the United Kingdom concerned with acoustics. The present membership is in excess of two thousand and since 1977 it has been a fully professional Institute. The Institute has representation in many major research, educational, planning and industrial establishments covering all aspects of acoustics including aerodynamic noise, environmental, industrial and architectural acoustics, audiology, building acoustics, hearing, electroacoustics, infrasonics, ultrasonics, noise, physical acoustics, speech, transportation noise, underwater acoustics and vibration. The Institute is a Registered Charity no. 267026.

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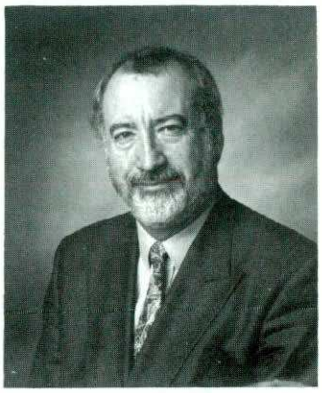

Dear Fellow Member

At the Institute's Annual Dinner in April when I formally took over from Alex Burd, I thanked him on behalf of all the membership for his calm and assured leadership over the last two years. I would like to start my first President's letter by restating those thanks.

It is customary for the incoming President to set out his aims for the coming years. I have two particular strategic objectives: (i) to raise the profile of the Institute within the general scientific community in the UK and also to increase the general public awareness of the role of the Institute and (ii) to develop a more systematic approach to the interaction between the Institute and related professional societies and other organisations in the UK, such as the British Society of Audiology.

Members of the Institute come from a wide range of scientific and engineering backgrounds and work in a subject – acoustics – which has widespread significance in people's daily lives, from the effects of aircraft noise to the safe use of ultrasound in medicine. But how often does the Institute receive the publicity it deserves? We aim to use the fact that more than 1000 of the world's leading specialists, from 46 countries will be coming to the UK in July for Internoise '96 to spread the word about the Institute but this must just be the start of a concerted effort.

We are continuing to arrange joint meetings with other societies but other forms of interaction need to be planned for. I was personally very honoured recently to be asked to join the Scientific Advisory Committee of the Institute of Sound and Vibration Research. The letter of invitation made specific reference to the benefits of increasing links between ISVR and our Institute, and I look forward to taking up this opportunity.

It is a great honour to have been asked to be President of this Institute and I look forward to the challenges it brings. It is a job which is only possible with teamwork and the support and encouragement of others. I would like to conclude by thanking in particular my colleague Dr Graham Torr, Head of Acoustics at NPL, for his continued support for my work for the Institute over the years, and NPL Management Ltd, for an allowance of working time to spend on my presidential duties.

Sincerely yours

Bernard Berry

ACOUSTIC BUBBLE SIZING: FROM THE LABORATORY TO SURF ZONE TRIALS

Timothy G Leighton MIOA, Andy D Phelps & David G Ramble

Introduction

The ability to detect bubbles has a range of industrial, medical and environmental applications [1]. Historically interest concentrated on characterising violent cavitation and its effects (eg erosive [2], biological [3] and chemical [4]), brought about when the local pressure around a small bubble nucleus changes in such a way as to bring about sudden bubble growth, followed by a rapid collapse. Reasons for detection of stable bubbles have progressed from a need to characterise the nuclei in order to predict the likelihood of cavitation, to an understanding of the importance of such stable bubbles in their own right. This includes monitoring the near-surface oceanic bubble population to gain information of the atmosphere/ocean transfer of momentum and mass [5].

There is a wide range of techniques which can characterise cavitation [6] and stable bubbles [7]. Acoustic techniques have many advantages, including the abilities to directly infer the size of the bubbles and discriminate between gas and solid particles. However, all techniques individually have limitations. This report starts with a description of the different techniques, illustrated with experimental results taken in the laboratory, and discusses how their individual advantages and limitations may be exploited to best effect. Following this, one of these techniques is exploited in a preliminary deployment in the surf zone to measure the oceanic population.

Laboratory Study: A Comparison of Acoustic Techniques

The combined use of several acoustic techniques not only reveals, and to some extent compensates for, the limitations of each [8], but also might be used to give additional information. An example of this is a comparison of the bubble population measured through 'active' techniques with that obtained from the passive emissions which are excited from bubbles when they are entrained. Since the passive emissions decay over millisecond timescales, they reflect the population characteristics at the time of entrainment (eg by a breaking wave). Active techniques must be used to measure the population at a later time. A comparison of these two estimates might yield information on the way dissolution, buoyancy and liquid flow can remove bubble gas from the population, and so may be relevant to the atmosphere/ocean transfer studies outlined above. An experimental comparison of these acoustic techniques has been the focus of recent work, and a description of the apparatus and calibration is given elsewhere [8]. In this article each of the signals will be introduced and the advantages and disadvantages of its application to in situ bubble sizing discussed.

A pulsating gas bubble in a liquid is a lightly-damped oscillator, the stiffness being invested in the gas and the inertia in the surrounding liquid [1]. As such, if an air bubble (roughly resembling a sphere of radius R_0) is injected into water at around atmospheric pressure, a nearby hydrophone will detect an acoustic pressure fluctuation resembling an exponentially decaying sinusoid at the natural frequency $\nu_0 \approx 3.3/R_0$ (using SI units). The detected frequency gives the bubble size (Figure 1a). A few milliseconds later, these passive emissions have effectively ceased, and as the bubble rises under buoyancy it must be detected by an active technique. The bubble can be sized from its resonance, found for example through the scattering of a 'pump' signal, which may be broadband, a chirp, or a sequence of tones at a pump frequency of $\omega_p/2\pi$ Hz. The closer the pump signal comes to exciting a bubble at its resonance, the greater the pulsation amplitude and the more strongly it backscatters the insonifying signal. However, strong scattering at a particular frequency might also be obtained from a bubble which is much larger than resonance size, which though it does not pulsate significantly, presents to the incident field a large target [7]. Although this represents an ambiguity when using the signal as an indicator of resonant bubbles, such geometrical scattering can be exploited by insonifying the bubble with an ultrasonic beam whose frequency is much higher than the bubble resonance. This is demonstrated in Figure 1b, and typical results taken using a 3.5 MHz clinical diagnostic scanner are presented in Figure 2.

However, the bubble is a nonlinear oscillator (the stiffness is nonlinear [1], and the wall motion must clearly be asymmetric since it can theoretically expand without limit, but cannot contract beyond zero radius). This nonlinear behaviour is demonstrated in the sequence of pictures given in Figure 3, where an air bubble in glycerol is being driven at its resonance frequency of 100 Hz, and its volume is clearly not simply varying sinusoidally about equilibrium. In general, as the pump frequency approaches a bubble resonance, the amplitude of oscillation of the bubble wall becomes greater, and these nonlinear characteristics become more manifest: the resonant bubble generates harmonics, subharmonics, and ultraharmonics at $2\omega_p$, $3\omega_p$ ...; $\omega_p/2$; and $3\omega_p/2$, $5\omega_p/2$ etc. Therefore, though when the pump signal is far from the bubble resonance, the detected signal should contain only the transmitted frequency ω_p; when it approaches the bubble resonance, one expects a harmonic spectrum about ω_p (Figure 1c). To be an unambiguous indicator of bubble size, these spectral components must be excited only when the pump frequency is close to the bubble resonance. The off-resonance fall off of these various signals

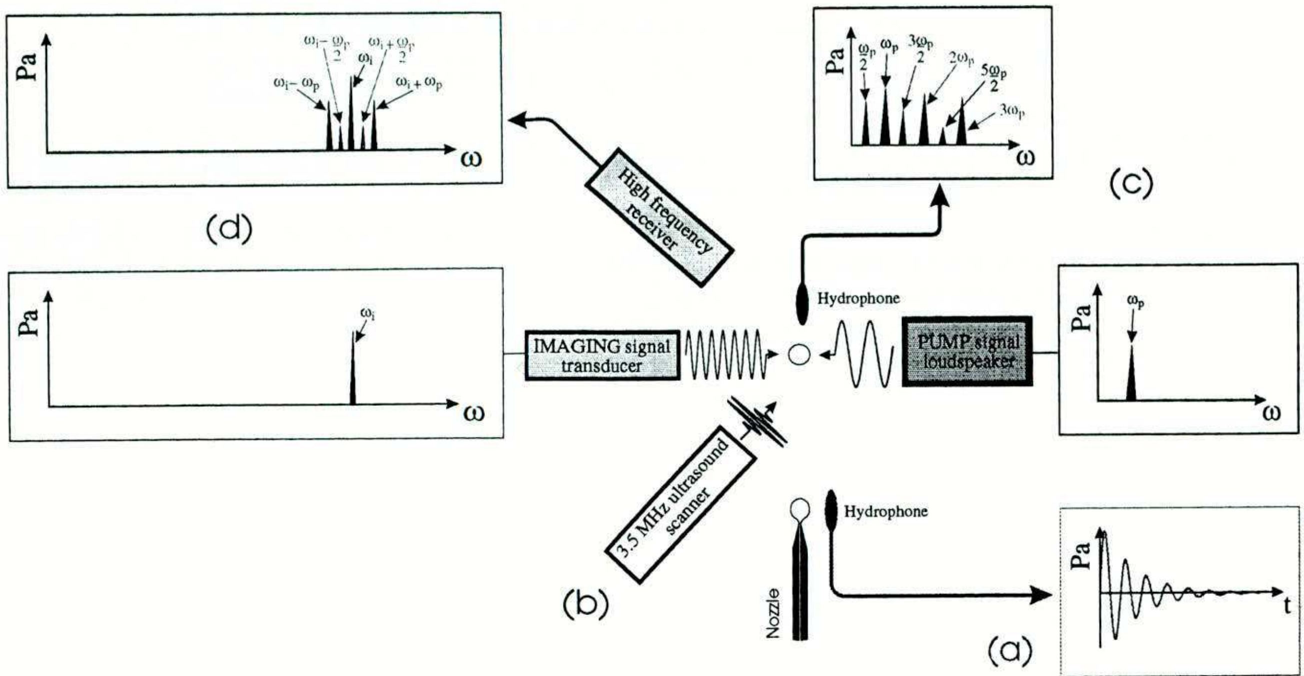

Fig. 1. Schematic of the apparatus required to implement the various acoustic detection techniques, a simultaneous deployment of which has been realised [8]. In (a) the bubble is shown, injected from a nozzle, where a hydrophone detects its short duration passive emissions. In contrast, all the active techniques are schematically shown interrogating a bubble which has risen under buoyancy. In (b) a medical diagnostic ultrasound scanner is deployed to produce an image of the bubble (shown in Figure 2). In (c) the underwater loudspeaker generates a series of tonal pump signals, and a second hydrophone detects structure in the spectrum corresponding to $2\omega_p$, $3\omega_p$, $\omega_p/2$, $3\omega_p/2$ and $5\omega_p/2$ in the presence of a resonant bubble. In (d) a high frequency imaging signal is projected onto the bubble, and the scattered signal is detected by a high frequency receiver. Whilst in the absence of the bubble, ideally only ω_p and ω_i can be should be present, a resonant bubble will produce structure in the spectrum around ω_i. The various peaks have been colour coded to facilitate their identification in later results (Figs. 4, 5 and 10)

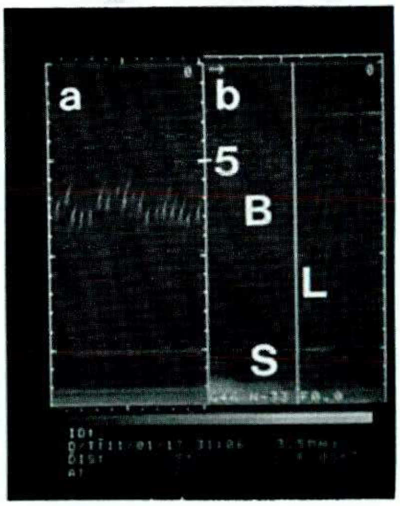

Fig. 2. This output shows both the a) M- and b) B-mode images obtained using a medical ultrasound scanner, the section shown being a slice at 45° to vertical [8].
Bubbles, rising under buoyancy, pass through the beam section. The bubble (labelled B) can be located in Fig. 2b (near-field is at top of image), which also images the underwater loudspeaker (S). Images which intersect the vertical line (L) in 1 s are plotted in Fig. 2a: almost 19 bubbles pass through the beam in that time, with rise speed (from the image, assuming local rectilinear bubble motion in the 45° beam orientation) of 20 ± 2 cm/s, covering an implied 0.87 – 1.13 mm radii range [8]

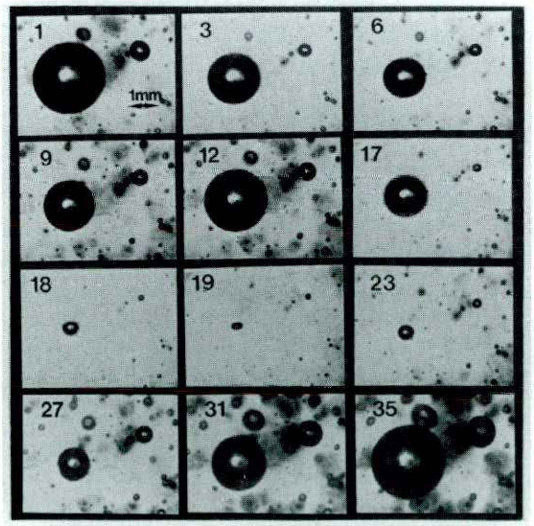

Fig. 3. Selected frames taken from a sequence of photographs of a 100 Hz air bubble in glycerol being driven at its resonance frequency, with a pump amplitude of 3900 Pa. The 35 frame sequence contains the periodic repeating cycle of oscillation, and the figure shows selected frames from this sequence. They show the bubble contracting from a maximum size in frame 1 to a minimum in frame 6, expanding to a second maximum (frame 12), then collapsing to a second minimum (frame 19) before expanding to the initial size. The second collapse is gradual up to frame 17, but then becomes very rapid.
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can be seen from Figure 4a, where a single bubble resonant at 1950 Hz was tethered to a horizontal wire and was then insonified at discrete tones from $\omega_p/2\pi$ = 1700 Hz to 2200 Hz in 25 Hz steps. The harmonically related signals at $2\omega_p$ and $3\omega_p$ are excited off-resonance, and in fact are excited when no bubble is present (Figure 4b) as a result of nonlinear processes in the apparatus and propagation through the water. The non-integer harmonic signals at $\omega_p/2$, $3\omega_p/2$ and $5\omega_p/2$ initially appear to be better indicators of the bubble presence and resonance. However, these signals do not propagate well into the medium, as the nonlinearities do not arise from monopole volumetric pulsations in the bubble motion. For example, the subharmonic oscillation at $\omega_p/2$ (at the low pump signal amplitudes required to be minimally invasive [9]) is generated only when the pump signal amplitude exceeds the threshold required to excite Faraday waves on the bubble wall [10], and the pressur fluctuations resulting from such oscillations do not propagate to distance.

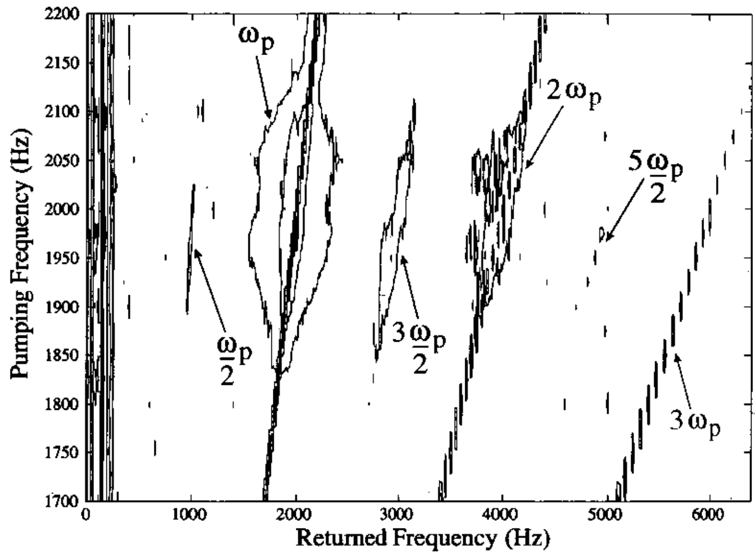

Fig. 4a. Contour plot showing the through resonance response for a 1950 Hz resonant bubble, tethered to a horizontal wire at a distance of approximately 1 mm from the active element of a hydrophone to allow any non-monopole bubble emissions to be detected. The frequency step size was 25 Hz and the insonification amplitude was 150 Pa (0 – pk).

Many of these drawbacks can be overcome with the use of a combination frequency technique [11]. With this technique the bubble is driven at its resonance using the pump signal described earlier, and simultaneously with an 'imaging' signal at a much higher frequency ω_i, typically of the order of a few MHz (Figure 1d). The scattered high frequency sound from the bubble is then detected by a high-frequency receiver. Consider a bubble which is only pulsating volumetrically (ie without surface waves). The strength of the target which the bubble presents to the imaging beam varies periodically as the bubble pulsates, and so the scattered imaging beam is amplitude modulated by the bubble, generating frequency sidebands at $\omega_i \pm \omega_p$. The further the pump frequency is from resonance, the smaller the displacement amplitude of the pulsation, so that the energy invested in these sidebands is reduced. Thus the technique allows the exploitation of the first-order resonant behaviour of a bubble, but without the ambiguity caused when a large bubble can be mistaken for a small resonant bubble. Additionally, the use of combination frequency measurements allows very specific spatial localisation of the bubble, and the process translates only bubble mediated information from the noisy frequency window around their resonance up to the comparatively quieter frequency window around the imaging signal.

Although any bubble wall effects which do not give rise to a volumetric pulsation do not themselves produce acoustic signals which propagate to distance in the medium, they too can be used to modulate the imaging beam, which does propagate. In the case of the subharmonic oscillation generated by Faraday waves on the bubble wall at half the driving frequency, these provide a modulation of the acoustic cross-sectional target area presented to the high frequency signal, and this manifests itself in the returned frequency plots as signals at $\omega_i \pm \omega_p/2$ [12].

These combination frequency signals are demonstrated in the data shown in Figure 5. A uniform stream of bubbles was injected to rise through the common focus of the high frequency transmitter and receiver transducers. The imaging sound field was set at a constant 1.135 MHz, and the pump sound field incremented from 2500 Hz to 3500 Hz in 25 Hz steps, at a pressure amplitude of 160 Pa (0-pk). The returned signal from the high frequency receiver was then heterodyned before data acquisition: this procedure involves multiplying the analogue signal returned from the high frequency preamplifier with a second signal

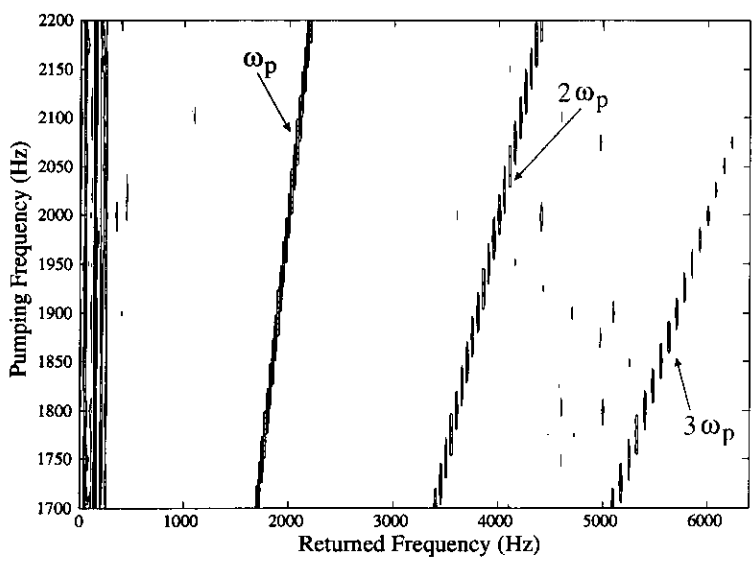

Fig. 4b. Experiment repeated in the absence of a bubble

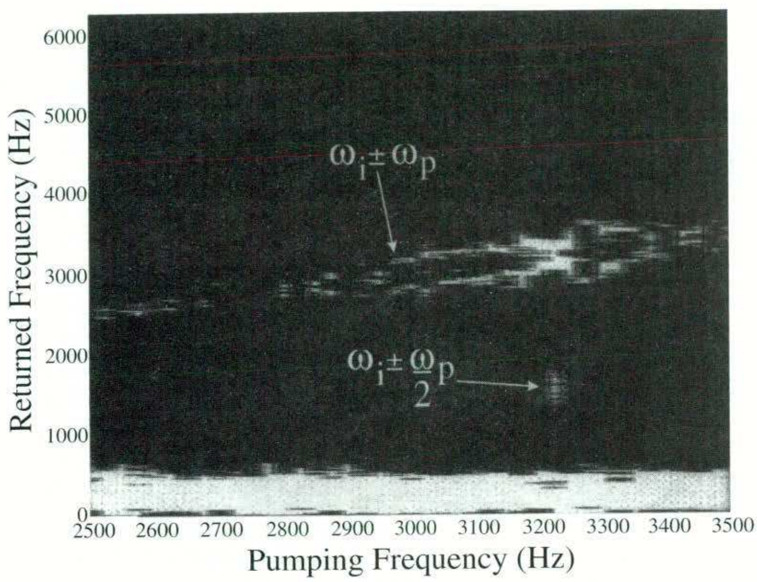

Fig. 5. Grey-scale map of the returned signal strength through resonance for bubbles of one size rising through the focus of the two high frequency transducers in the combination frequency tests. The bubbles were insonified at 160 Pa (0 – pk), and the pumping frequency was incremented in 25 Hz steps.

from the imaging frequency signal generator. As a result the useful information contained just above the imaging frequency is reproduced at just above dc, and the information just below the imaging frequency is also reproduced above dc but in anti-phase. This enables much lower sampling rates and data storage.

At each setting of the pump frequency, the returned signal was heterodyned and the spectrum obtained. These spectra are illustrated as a grey-scale plot over the range of pump frequencies used. In the plot, the signals at $\omega_i \pm \omega_p$ and $\omega_i \pm \omega_p/2$ are clearly visible. As expected, though the signal at $\omega_i \pm \omega_p$ reaches a maximum value at the bubble resonance, the off-resonance pulsation causes it to extend over a wide frequency range. Clear confirmation that the resonance of the bubbles in the stream occurs at a pump frequency setting of 3225 Hz is given when structure in the heterodyned spectrum at the subharmonic of the driving frequency is also evident. Each of the heterodyned $\omega_i \pm \omega_p$ and $\omega_i \pm \omega_p/2$ signals, where they occur, are themselves separated into their two peaks, corresponding to $\omega_i + \omega_p$ and $\omega_i - \omega_p$, and to $\omega_i + \omega_p/2$ and $\omega_i - \omega_p/2$, respectively. After heterodyning, the difference information is reproduced overlaid on the sum information, but owing to the Doppler shift from the moving bubbles the centre frequency of the returned signal is no longer exactly at the imaging frequency.

Discussion on the Laboratory Tests

The laboratory tests indicate that if only one driving frequency (ω_p) is employed to characterise a single bubble, the clearest indication of the bubble resonance, and therefore its size, is given by the presence of non-integer harmonics of the driving sound field, and especially a subharmonic at $\omega_p/2$. However, these signals are caused by surface phenomena and do not propagate into the medium. This limitation is overcome through the use of a combination frequency insonification technique, which results in emissions at frequencies of $\omega_i \pm \omega_p/2$ as well as at $\omega_i \pm \omega_p$. It has been demonstrated [12,13], however, that although the combination frequency signal involving the subharmonic of the driving sound field can give an accurate and unambiguous indicator of a resonant bubble, it is a particularly difficult emission to stimulate and analyse. Because the Faraday waves on the bubble surface are parametric in nature, it is necessary to drive the bubbles at exactly the right amplitude to maximise the accuracy of the technique – too low and the signal will not be stimulated, too high and the pump frequency span over which the emission occurs increases and much of the accuracy benefit is lost. To date in experiments, the amplitude of the signal scattered at $\omega_i \pm \omega_p/2$ from a single bubble has not been sufficiently reproducible to warrant relating the amplitude to the number of bubbles in a population resonant at that frequency [14]: reliable counting can only be achieved if no two bubbles are so close as emit $\omega_i \pm \omega_p/2$ signals at any given pump frequency. Additionally, the surface waves themselves are very lightly damped, so that ideally a period of insonification before the data are collected is required to allow for any transient effects to decay. The signal at $\omega_i \pm \omega_p$, however, is attributable to the volumetric pulsations of the bubble, and therefore behaves much more predictably. At present the $\omega_i \pm \omega_p/2$ signal content can unambiguously detect a resonance whilst simultaneous observation of the $\omega_i \pm \omega_p$ signal could give the bubble count [8]. In this test study the oceanic data concentrated on analysing these $\omega_i \pm \omega_p$ signals. Although these combination frequency com-

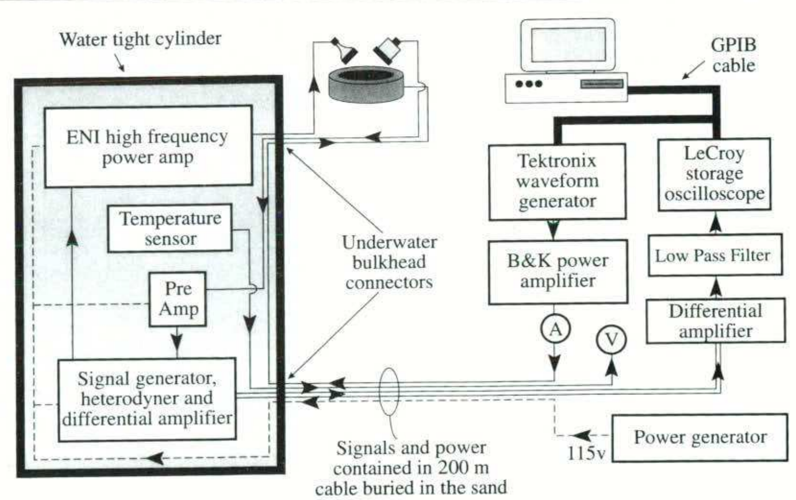

Fig. 6. Schematic of the apparatus used in the oceanic measurements

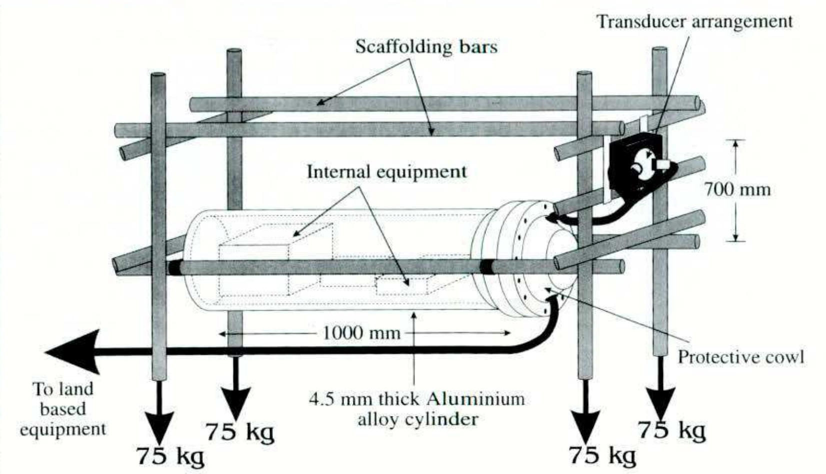

Fig. 7. Deployment details of the watertight canister and scaffolding

ponents will occur whenever the bubble pulsates, and so can be detected far from resonance, the $\omega_i \pm \omega_p$ signals reach a maximum amplitude when the pump sound field becomes coincident with a bubble resonance, and thus can be used to get a statistical measure of the oceanic population.

Oceanic Data Collection

Oceanic tests were performed in the North Sea between 26th and 30th November 1995, on a beach in Tunstall in East Yorkshire. The aim was to measure the bubble population at a point in the shallow water surf zone. This was performed in tandem with sonar measurements of the surf zone bubble cloud profiles taken by the Southampton Oceanography Department. The beach was chosen because of its slight gradient, which allowed the equipment to be set up at low tide and anchored to the sand, such that as the tide came in it would eventually cover the rig enabling measurements to be taken. The data collection was performed at four spot frequencies: 28 kHz, 50 kHz, 60 kHz and 88 kHz. This was so that the data could be directly compared with earlier oceanic bubble measurements [15] which relied on measuring the direct acoustic backscatter from individual sonar transducers. The current tests used a 3 kPa pump signal amplitude, and 25 four frequency samples were taken over a 3.5 minute period every half hour that the transducers were immersed. As the signals were broadcast consecutively with no gap, each measurement lasted only 0.4 s.

The equipment set up used in the sea trials is shown in the schematic in Figure 6, and a complete description of the apparatus and calibration techniques can be found elsewhere [16]. The figure shows a remote equipment canister which was placed in the sea, containing a high frequency power amplifier, the imaging signal generator and heterodyner equipment, the returned signal pre-amplifier, and a temperature sensor to ensure that the equipment did not overheat. The canister comprised a 1000 mm long x 355 mm diameter watertight aluminium alloy cylinder with a shell thickness of 4.5 mm, which was painted to minimise corrosion and clamped to a rigid scaffold structure as shown in Figure 7. A photograph of the equipment set-up on the beach at low tide before immersion is included in Figure 8, and a picture of the rig becoming uncovered after the measurements as the tide went out in Figure 9.

A typical spectrum from the sea trials is presented in Figure 10, taken from a 28 kHz insonification. The particular data were collected at 22.30 on the 29th November 1995, when the wind speed was 11 m/s, and the transducers were immersed at a depth of 1.5 m in water approximately 3 m deep. The data shows the heterodyned signal from the high frequency receiver, in which the imaging signal is visible at 1 kHz (not at dc owing to the Doppler shift from the moving bubble targets). The sum frequency spectral information contained just above the imaging signal is also shown, at approximately 29 kHz, and the difference data shown at 27 kHz. Between the two combination frequency peaks is a single spike at 28 kHz. This is caused by the nonlinear combination of the pump and imaging signals by turbulence in the detection zone, and can be therefore distinguished from the actual bubble mediated information.

The data collected over these 25 time intervals were analysed to get the individual heights of the heterodyned sum signals, and time averaged so that comparisons with

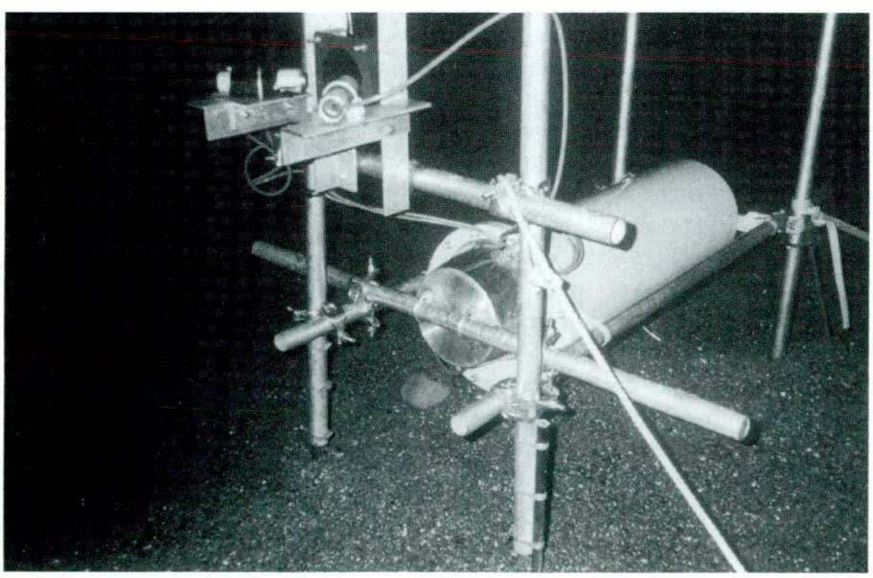

Fig. 8. Photograph of the canister and remote equipment set-up on the beach at low tide, taken at night before the oceanic measurements were taken

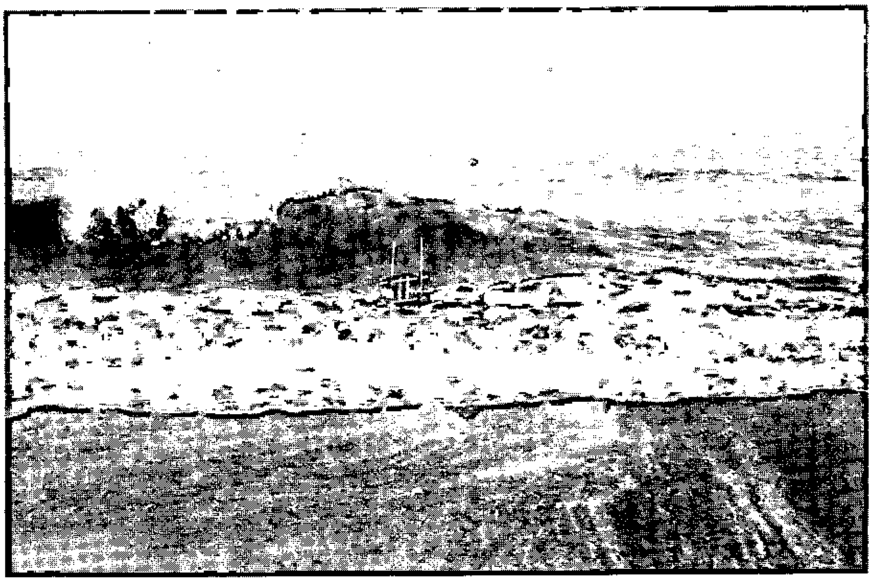

Fig. 9. Photograph of the canister becoming uncovered the morning afterwards with the tide going out

existing bubble data is possible. These data were taken from Farmer and Vagle [15], Breitz and Medwin [17] and Johnson and Cooke [18] who have all previously applied different bubble estimators to measure the oceanic distributions. The traditional method of presenting the data is in numbers of bubbles per m^3 per micrometer radius range, and Figure 11 shows the three sets of data superposed with the time averaged population measured using the two frequency technique. The radius range over which these signals existed was numerically calculated from linear theory of the behaviour of a range of bubble radii to the four frequencies employed [1], defined by where the individual contributory sound pressure level was 3 dB down on the maximum resonant level. The effective insonification volume was theoretically estimated as 0.20 m^3 by performing a Rayleigh integral over the surface of the two high frequency transducers.

The data shown in Figure 11 show that the bubble population measured using the two-frequency technique exceeds the other estimates over the whole radius range. This is to be expected as the data were collected in the surf zone where, because of the continual wave action, a high concentration of bubbles is created. Farmer and Vagle collected their data in a 12 – 14 m/s wind speed from bubble scatter in a 4 km deep channel using upwards-facing sonar designed to monitor the linear backscatter from the bubble population. Johnson and Cooke used photographic estimates in 20 – 30 m deep water, of which the population estimate at 0.7 m depth and 11 – 13 m/s wind speed is included. Breitz and Medwin collected their oceanic data with a flat plate resonator, which again exploits the linear resonance of bubbles. They measured in water 120 m deep in 12 – 15 m/s wind speeds and at a depth of 25 cm. Thus, although the weather conditions were similar over the four sets of collected data, the local sea dynamics were very different for the Tunstall measurements because of the presence of surging breakers.

Summary

This article has examined the various signals produced when a gas bubble in water interacts with an insonifying sound field. The geometric scattering from the impedance mismatch at the bubble surface was demonstrated, and the individual signals generated by a resonant bubble were also identified. Then the ability of the combination frequency technique to detect and estimate the resonance frequency of individual bubbles in the laboratory was discussed, and it was demonstrated how this overcame earlier ambiguities and inaccuracies. These combination frequency signals occur when a bubble is insonified at resonance, and a second high frequency sound field is simultaneously applied: the strength of the high frequency signal scattered from the bubble is thereby amplitude modulated as the bubble's acoustic cross-section varies periodically. Two potential combination frequency signals were identified, at $\omega_i \pm \omega_p$ and $\omega_i \pm \omega_p/2$. It was shown that the signals involving the subharmonic stimulated at the bubble's resonance were more accurate and less ambiguous indicators of the

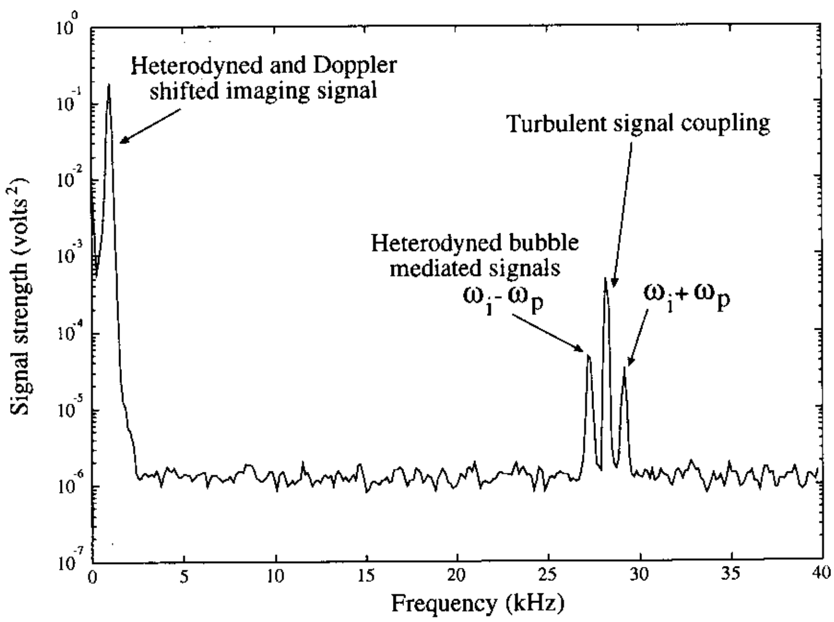

Fig. 10. Typical results from the oceanic tests, showing the heterodyned frequency content for a 28 kHz insonification signal

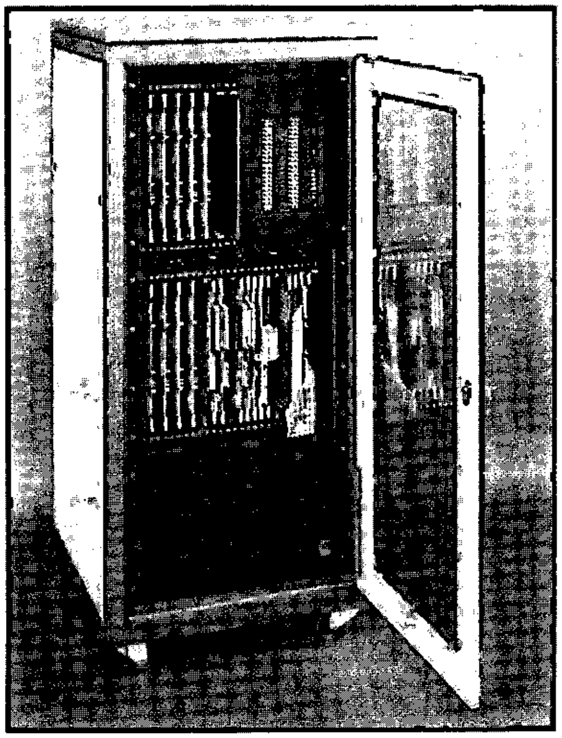

Fig. 2. Talon

deployed, the development of TouchTone and digital recording alone were sufficient to herald in a whole range of applications including

Voice messaging	**Telemarketing** *promotions* *market research*
Finance *telephone banking* *stocks & shares information* *credit card transactions*	**Menu driven teleshopping/ reservations** *theatres*
Entertainment *betting* *horoscopes* *games* *competitions*	**Field operation** *data entry & retrieval* *field personnel* *job dispatch*
Information services *timetables* *arrivals information*	**Automatic operator services** *call forwarding* *auto-attendant*

Table 1

BT's Early Speech Recognition Products and Drivers

None of the above applications necessarily required speech recognition as they could all be accomplished, albeit somewhat tediously, using TouchTone. However the roll-out of Touchtone would take time and speech recognition was seen to be one way in which advanced applications could be made rapidly available to all customers. This was one of the major reasons for re-examining the technology. However, the situation was that the speech recognition technology to do this was not yet viable. The state of the art was such that virtually all commercially available speech recognisers were 'speaker dependent' (ie they had to be trained by each speaker) and although they could be coaxed into giving impressive results in a laboratory environment were far from robust enough for general telephony based applications.

If speech recognition was to be successful, it would only be in those applications where the recognition error rates could be tolerated, and few of the applications listed in Table 1 fell into that category. Indeed there were only two areas which were likely to be successful: games and 'voice-dialling'. Voice dialling was attractive because not only was there no simple alternative, but failure was easily corrected – the user simply had to set down the handset and try again or resort to old fashioned button pushing. 'Speech games' were even more appealing because the recogniser weaknesses could be masked by turning them into a 'competitor challenge' and these application areas were targeted. The voice dialling telephone was known as 'ASCOT' and the first game was 'Penny Green'.

ASCOT (A Speech Controlled Telephone)

By 1983 there were quite a number of speech recogniser suppliers on the market and the approach was to evaluate what was available to 'Buy and Apply' speech technology rather than attempt to develop it in-house. Almost invariably the available products were 'stand alone' boxes which were linked to a computer via an RS232 link and it was with one of these recognisers – a Vecsys R80 – that ASCOT 1 was constructed. The great virtue of the Vecsys recogniser was that it was much smaller than any others on the market, and along with a similarly sized microprocessor control board the whole system could be housed in a 'stretched' GTE phone which had been modified to accept a display (Figure 3).

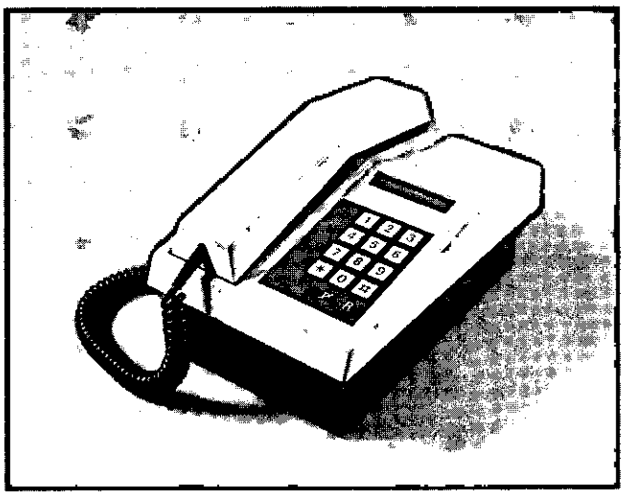

Fig. 3. ASCOT I

Alpha characters were input using the numeric keypad by simply 'scrolling' through the alphabet: for example to select the letter 'E' the number '2' which spanned the three letters 'CED' was pressed twice followed by '*' to select it. The input was terminated using the '#' key.

Although seemingly complicated this turned out to be a very effective and easily mastered way of entering the necessary alphanumeric data.

Although they were not a commercial proposition and only four were constructed, they served to demonstrate that it was now feasible to incorporate a speech recogniser inside a telephone instrument. To be commercial a much simpler and much more cost effective solution was required. This was achieved by designing a completely integrated recogniser/telephone instrument from scratch. A single 68000 processor combined the roles of controller and recogniser and concatenated speech output. Fully programmed in assembler, this was capable of supporting fully specified versions of the algorithms which were state of the art for speaker dependent recognition at the time.

Although, as before, only a small number were assembled, there were sufficient to undertake trials. These confirmed that the functionality of the device was acceptable and it was particularly encouraging that some users were reluctant to let the unit go at the end of the trial period. However, the production cost – although a fraction of that previously – demanded a price well above that which could be expected to sell as a normal telephone. ASCOT would probably never have gone further as a product but for a major new development. Almost overnight a new market in cellular telephony had opened up and its cost structure was very different.

In 1985 a basic cellular telephone typically cost around £2000 – without extras. With this base cost, our recogniser would not increase the cost significantly – especially as many of the components (particularly the high cost display) were already part of the instrument. ASCOT was re-engineered into BT's 'flagship' cellular telephone – TOPAZ – the world's first hands-free speech controlled cellular telephone [3]. It provided speaker dependent recognition of up to 100 words and the speech recogniser, speech feedback module, dialogue controller and interface to the cellular telephone were integrated into a single module using surface mount technology. The production version of the speech recogniser used in Topaz was contained on two small circuit boards – see Figure 4.

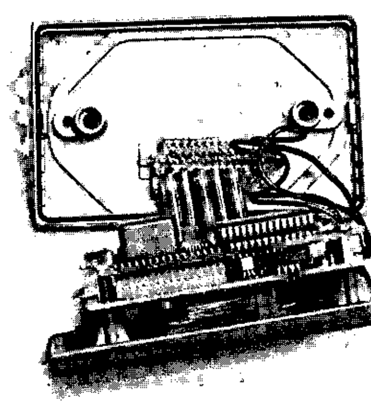

Fig 4. Topaz recogniser

Such was the 'buzz' surrounding the launch of Topaz (at the 1986 motor show) that the Daily Telegraph reported on 31st October that 'The BT Hi Tech phone......today raised the share price of BT by 7p.'

Topaz and Topaz II (a lower cost successor) remained in BT's portfolio until it was replaced by 'Azure' in 1989.

The First BT 'Network Based' Speech Recognition Service

While ASCOT and TOPAZ had been developed for the 'stand alone' market, a parallel activity had been taking place on the network side with a theme based upon the immensely popular 'adventure' games which were available on the new breed of personal computers. The telephone replaced the screen/keyboard interface allowing a fully interactive 'Speech Game' to be played. The first design was based upon a market square in a mythical village called 'Penny Green' and callers were able to move about the countryside using a small vocabulary of words such as 'Yes', 'No', 'North', 'South', 'East', 'West', 'Square', 'Station' etc. As they travelled round they were able to collect objects until they eventually found treasure. At this point they were given a 'code-word' and instructions on how to claim their prize.

Along with one of the earliest versions of ASCOT, 'Penny Green' was first shown at 'Martlesham '84' – one of the major events leading up to the sale of BT. It attracted a great deal of press coverage and its popularity was such that plans were made to launch a small scale service. A number of recognisers were purchased and a multi-channel system designed and built.

The launch just after Christmas in 1984 was hardly spectacular – being little more than a mention in a single line of an article in the Guardian newspaper which said 'If you want to play an interactive speech game ring ..'. The response was such that the game acquired 'cult' status – to the extent that it had to be replaced with a recorded announcement saying that it was no longer available, to prevent congestion on the local exchange.

However, speech games were not to become a product. Although widely viewed as likely to be a commercial winner, it was clear that the main user-base would be teenagers. At a time when the new 'Chat-line' services, which appealed to the same group, were drawing adverse publicity, the service was not pursued.

The PABX Environment

To some extent 'Penny Green' had been a diversion from more 'serious' applications and one of these was the voice controlled PABX. This was a much more demanding scenario than the earlier ones for not only would the system have to be reliable, fast and accurate, but the user population would have higher expectations. The design was based upon a Monarch switch coupled to a number of speaker-dependent VOTAN recognisers: all extensively modified to allow the necessary high speed template swapping as callers came on-line so that each user had their own set of frequently called names. In all, 200 lines were eventually used to share several recognisers. Visual feedback for confirmation was provided via a simple liquid crystal display unit mounted beside a conventional touch-tone telephone, with messages passed to it using multi-frequency tones. The system was trialled extensively within BT with some success. However, a separate decision that Monarch was to be the last PABX fully designed 'in-house' in BT meant that future development was ruled out.

To some extent this development probably confirmed what everyone had known – that speaker-dependent recognition alone was too limiting in a telephony applications environment. A lot had been learnt and there had been a number of commercial successes. But something had to change.

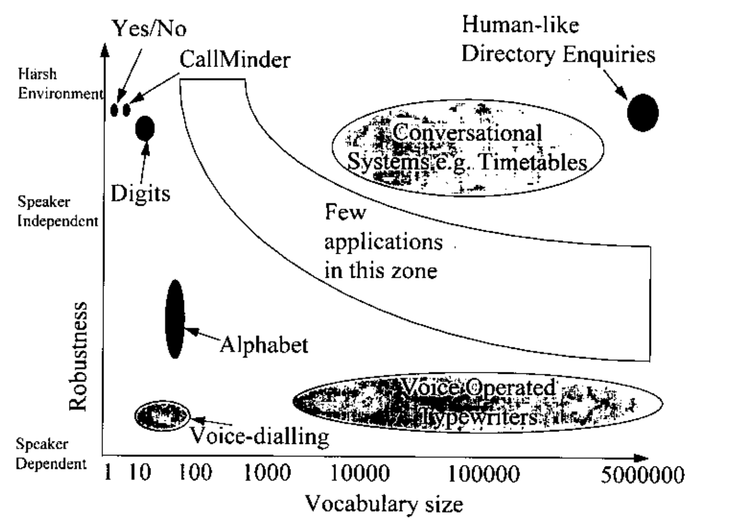

Fig. 5. Linggard Leap/Johnston Jump

A Change in Strategy

The limitations of 'speaker-dependent' recognition were reinforced by our participation in the VODIS project, which had been building a major demonstrator as part of the ALVEY programme. BT had been the prime contractor for this project, which aimed to provide a demonstrator of a natural spoken language interface for a database enquiry system and combined the state of the art in recogniton, synthesis, database access and natural language processing. Much more futuristic in nature than the simple Topaz and 'Penny Green', VODIS was a 'technology integration' project and involved several leading UK companies and universities. Although not specifically focused on 'component' creation, it was taken for granted in VODIS that the necessary speaker-independent recognition technology would have evolved naturally by the end of the project. However, by this time it was clear that the speech recognition technology remained one of the weakest links in the chain. The problem was not just one of system integration – the problem lay with the components.

More than ever, the real need was for speaker independent-recognition which worked reliably over the telephone, for anyone, and in almost any acoustic environment. Research into speaker-independent recognition for use over the telephone network accelerated. Although the ultimate goal was fully fluent natural spoken language input, it was acknowledged that this was still likely to be many years off. If there were to be applications in the near term they would have to be confined to simple and intuitive vocabularies – probably using isolated words.

The situation was summarised in a diagram (illustrating what came to be known locally as the Linggard Leap/Johnston Jump) shown in Figure 5.

The strategy for BT (in common with most telecommunications companies) was to move round the side by first moving upwards along the robustness axis with small and intuitive vocabularies. This contrasted with the 'Voice typewriter' strategy which exploited the fact that the 'captive' user would be in an environment where speaker adaptation, screen feedback and 'clean' speech signals would be the norm.

From this, it seemed clear that in the short term the key enablers would be robust recogniton of vocabularies such as:

- Yes/No
- The digits – preferably connected but not essential if there was a performance penalty
- The alphabet.
- Small 'intuitive' vocabularies – days of the week for example.

All this suggested that a speaker-independent recogniser capable of supporting about 40 speech tokens (tokens could be letters of the alphabet, numerics or words) would be sufficient to cover most of the requirements.

Although we had investigated many techniques, ranging from statistical formant modelling through neural nets (through involvement in the RIPR[2] programme), by 1988 our research into speaker independent algorithms for telephony had shown the best performance was realised using multiple template dynamic programming techniques[3]. However, the computational load was such that it typically took 30 seconds to recognise a single utterance of one second duration from a set of 40 words on a state of the art minicomputer. This had to be speeded up. As an intermediate step towards a real time system the minicomputer system was replicated on a parallel processor – an 80 element transputer array. This served to improve matters to the extent that it now only took 2 seconds for the same task but it was unrealistic to use such a machine for a service.

The solution was simple. The algorithm was re-implemented in hardware on an Uncommitted Logic Array chip. Dedicated solely to the pattern matching 'kernel' of the process, the chip was simple and elegant – and blisteringly fast. Not only could it run the algorithms with time to spare, but had a production cost below £5. Supported by 2 digital signal processing chips – one to perform the feature extraction and the second to undertake a

2 Research into Pattern Recognition. This was a jointly funded project based at the Speech Research Unit of the Defence Research Agency.
3 It was only several years later that Hidden Markov Model methods overtook clustered template performance.

number of tasks including tone detection, line conditioning/echo cancellation and low bit rate speech coding – we had the components of a speech card which supported:

- real time speaker-independent recognition of up to 40 words
- real time speaker-dependent recognition of over 400 words
- low bit rate speech coding at 8, 16, 32 and 64 kbits per second
- high speed data transfer for 'template swapping'
- Touch-Tone detection
- telephone line interfacing
- high speed template (and application) swapping.

These chips were put into a PC-compatible card which also held the necessary telephone line interfaces and the links to the PC for speech storage and backup [4] – see Figure 6.

For several years this speech card was the 'work horse' of the BT Speech Applications Division. The original analogue single card version was re-engineered to accept digital line inputs, and a multi-channel version followed – the Voice Control Platform. These were used primarily for systems trials within the company and some in partnership with others outside. The largest of the external trials was a joint venture with the Royal Bank of Scotland. This not only used speech recognition but incorporated speaker recognition where the system identified users using a combination of spoken PIN and their voice.

People and Machines

One of the first target applications for the speech card was a simple answering machine. This concept had been tested previously and was one of the motivations behind the PC based SpeechCard development. Rather than simply saying 'Please leave your message after the beep...', the system entered into a dialogue with the caller as follows:

Machine: Hello This is the Speech Applications Division

Caller: 'Oh, Can I speak to ....?'

No matter what they said the machine simply detected the end of speech and replied

Machine: I'm sorry they aren't available at present ...

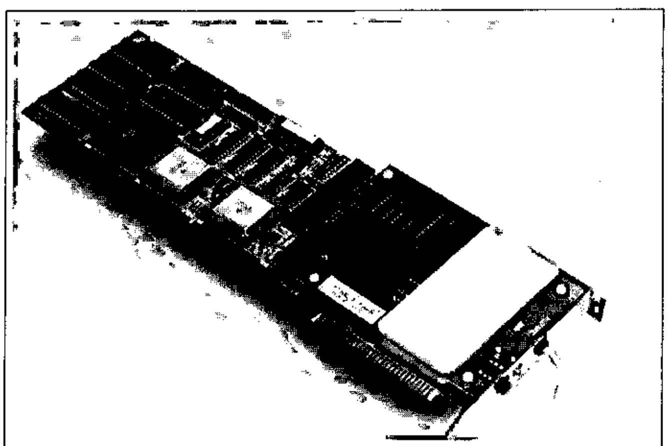

Fig. 6. Speech card

Who is calling please?

Caller : <responds with name>

Machine: and what is your number?

Caller : <responds with number>

Machine: This is an answering machine – would you like to leave a message?

At this stage the machine either recognised 'Yes' or 'No'. If 'No' was recognised it politely terminated the call and if 'Yes' invited the caller to leave a message.

Surprisingly, many users reacted 'spontaneously' without even realising they were talking with a machine. At a time when over 40% of users 'slammed down' the telephone on encountering an answerphone, this system painlessly extracted and stored the name and phone number of the caller, who, even if they did not leave a message could be called back. This simple example served to demonstrate the power of 'dialogues'. Here the recogniser was hardly used at all – indeed the only functionality really required was 'speech detection' – yet users were convinced that they had been speaking with a very sophisticated machine.

One of the first people to install the machine was Chris Wheddon, who was head of the Speech Applications Division at the time, and the voice of his secretary, Anne, was used to make the first recordings. One of the early callers was one of the Speech Division's major customers who only realised that he had been talking to a machine after completing the dialogue. He didn't believe it was real, and thinking that it was Anne 'pretending to be a machine', made a second call – speaking with a 'Dalek' voice – in the hope that this would cause Anne to falter. This event is now believed to be the first instance of a person, pretending to be a machine conversing with a machine pretending to be a person!

The system gave clear benefit to both caller, who found it less inhibiting than the traditional answer-phone, and the recipient who now had sufficient information to return almost every call.

From this concept the BT CallMinder™ service was born.

CALLMINDER™

CallMinder™ is currently the largest single application of speech recognition in the UK – and is available to most o our customers nationwide. Although it may be thought of as an 'answering machine in the network' it offers much more than this. In particular, it answers calls when the customer is already on the telephone or when the line is busy with a fax or data call. A novel feature is the use of speech recognition to allow the user to retrieve messages or to alter the user-specific features of the system – for example the number of 'rings' before CallMinder™ picks up the call may be changed using voice commands.

The architecture for CallMinder™, described more fully in [5], is shown in Figure 7.

CallMinder™ is implemented on a specially designed speech applications platform. Originally designed at BT, this is now produced and supported as the Interactive Speech Applications Platform (ISAP) by Ericsson Ltd. The ISAP equipment (Figure 8) consists of industry standard processing cards with additional special purpose speech

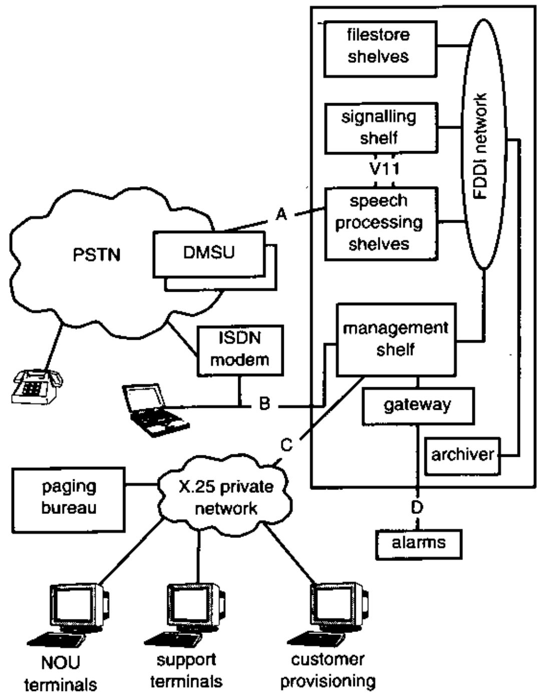

Fig. 7. CallMinder™ architecture

processing cards. Each of these is dynamically configurable to undertake speech coding, speech recognition, tone detection and many other features according to the required service profile at any time.

The service was formally launched in May 1995 and currently supports about 500,000 customers nationwide. Future services including those for fax and paging are under consideration.

Back at the Labs

While CallMinder™ has been rolled out, the momentum of basic research has been maintained. Here the focus has been on two major speaker-independent areas:

- spelt word recognisers
- sub-word recognisers

Spelt word recognisers work by determining what sequence of letters is valid given the constraints of the vocabulary. For example in a directory enquiry system there might be 500,000 different names – but they are all spelt with only 26 letters. What is more, only a small number of all possible letter sequences are valid. To take an example: there are no names spelt 'Gohmfton' (try spelling it out loud), but there is one spelt 'Johnston'. By combining the constraints of possible spellings with the probabilities of individual letter acoustics, a very robust large vocabulary recogniser can be constructed.

Sub-word speech recognisers work in a similar way except that instead of letters the words are assumed to consist of 'sub-word units'. At the simplest level these are 'phonemes', the building blocks of real speech.

The first trial of a directory enquiries system in which both large vocabulary and spelt input was used was undertaken in East Suffolk in 1994 [6]. This worked with a directory of 25,000 names. Today, a similar system is available with BT Laboratories giving access to the telephone numbers of everybody on the site – 5000 people.

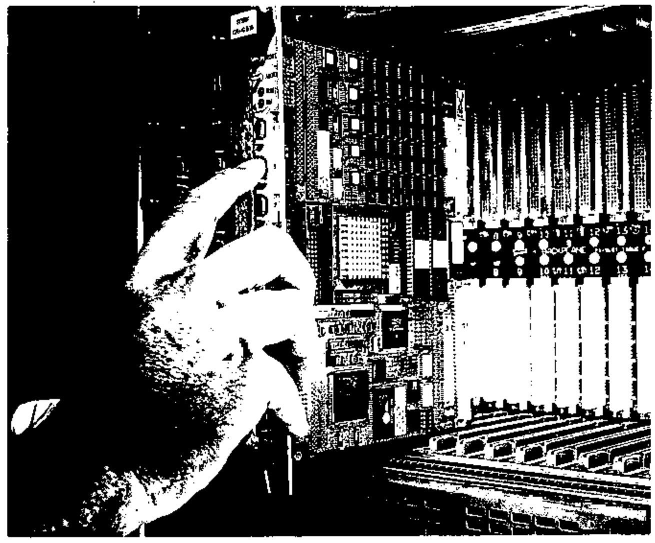

Fig. 8. Speech signal processing card inside ISAP cabinet

The Future

Although the past two decades have shown unprecedented growth in the applications of voice based services, this is probably only the beginning of the end of an an era in which the keyboard and mouse are the main human/machine interfaces. Integrated within multi-media systems and combined with Natural Language Understanding systems and Text to Speech systems, Speech Recognition has the potential to render the keyboard obsolete. Coupled with the telephone network, sources of unlimited information need only be a phone call away.

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[1] B Oakley, & K Owen, 'Alvey: Britain's Strategic Computing Initiative', MIT press, 1989.

[2] S R Hyde, 'Automatic Speech Recogniton: A Critical Survey and Discussion of the Literature', Human Communication: A Unified view (Editors EE David Junior and P B Denes), pp 399–438, McGraw Hill, 1972.

[3] N J A Forse, 'Speech Recognition for Telephony Applications', ProclOA, vol 9 (1987)

[4] P J Hunter & M O Watts, 'A Speech Card for Provision of Interactive Speech Systems';Digital Signal Processing: Components and Applications Seminar, ERA 880386, Nov 1988.

[5] K Beacham and S Barrington,'CallMinder™ – the development of BT's new telephone answering service', British Telecom Technical Journal Vol 14 No 2, April 1996

[6] C Southcott, & S J Whittaker, 'Advanced network based speech applications', AVIOS, 1994.

Further Reading

Readers interested in more detail of the speech applications of BT Laboratories are referred to two recent Editions of the British Telcom Technical Journal: Vol 14 No 1, January 1996 and Vol 14 No 2 April 1996.

Robert D Johnston is at BT Laboratories, Martlesham Heath, Suffolk ❖

CALL FOR PAPERS

One-Day Meeting

How Sound Are Your Measurements?

(Organised by the Measurement and Instrumentation Group)

Strathclyde University, Glasgow

9 October 1996

This is the second in a series of meetings across the country organised by the Measurement and Instrumentation Group; the first was held in London in February. The aim of the Group is to promote best practice in acoustical measurements. Papers addressing this aim are sought.

Examples of relevant subject areas are:

- **precision of measurement instruments**
- **calibration issues**
- **the role of standards**
- **environmental noise measurement methods**
- **new measurement techniques**
- **education of users in the accuracy of their measurements**

The meeting will begin at 10 am, and the papers will be presented in the morning session. Intending authors should be sent a 100-word abstract to the Meeting Organiser at the address below. Abstracts (and any papers for refereeing) should be received by 9 August 1996. The proceedings of the meeting will be published in Volume 18 of the Proceedings of the Institute of Acoustics (1996).

Meeting organiser:
Richard Tyler FIOA, CEL Instruments Ltd, 35–37 Bury Mead Road, Hitchin, Herts SG5 1RT. Tel: 01462 422411, Fax 01462 422511

A buffet lunch and refreshments will be provided. After lunch, two 'workshop' sessions will be held, covering

- **Practical use of sound calibrators (led by Richard Tyler)**
- **Calibration of sound level meters (led by John Shelton)**

The workshops are designed to allow all delegates the opportunity to make 'hands-on' measurements on their own instruments, guided by the workshop leaders. Bring your sound level meter and sound calibrator.

Certificates of attendance will be available for CPD purposes

---

☐ I enclose a cheque for the delegate fee which covers both lunch and the printed Proceedings ☐ Invoice me

☐ Members £70.00 + £12.25 VAT = £82.25 ☐ Others £90.00 + £15.75 VAT = £105.75

☐ I cannot attend. Send a copy of the Proceedings and invoice me for ☐ £20 (members) ☐ £27 (others)

I intend to bring a sound level meter (Model:) nad/or sound calibrator (Model:).
(This will help us to arrange the workshop sessions)

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CALL FOR PAPERS

International Conference

NUMERICAL/ANALYTICAL METHODS FOR FLUID-STRUCTURE INTERACTION PROBLEMS

(Organised by the Underwater Acoustics Group)

Strelley Hall, PAFEC Limited, Nottingham, UK

16–18 December 1996

Computer based analytical methods have been covered at many Institute of Acoustics conferences, primarily for frequency domain applications. The current meeting aims to extend the scope of the discussion by covering both time domain as well as frequency based phenomena. Applications will include transducer design, signature reduction and vulnerability studies as well as entrained fluid problems such as test tank design or inkjet printing. It is intended that both linear and non-linear aspects be covered for fluid and structural responses. Techniques discussed may include finite elements, boundary elements, finite difference, statistical energy analysis and transmission line modelling. It is likely that ray tracing will fall outside the scope of the discussions.

- Radiation
- Scattering
- Entrained Fluids
- Transducer Design
- Signature Reduction
- Vulnerability/Shock
- Cavitation and Bubble Loading
- Periodically Repeating Structures
- Inverse Problems
- Verification/Experimental Comparison

Prospective authors are invited to submit a 200 word abstract as soon as possible. Successful authors will be notified by early September. Complete manuscripts may be up to 10 pages long including diagrams and must be in the hands of the conference organiser by 1 November 1996. The conference proceedings will be published in Volume 18 of the Proceedings of the Institute of Acoustics and copies will be available at the start of the conference.

The conference will be held at Strelley Hall Nottingham, which is situated to the west of the city with excellent access for road, rail and air travellers. The hall is just 4 miles from the historic city centre which is one of England's finest cities for evening entertainment and shopping.

Abstracts and all other communications should be sent to Dr Patrick C Macey, PAFEC Ltd, Strelley Hall, Nottingham NG8 6PE, UK Tel: +44 (0) 115 935 7055 Fax: +44 (0) 115 935 7067 email: pcmfd@pafec.co.uk

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FIRST ANNOUNCEMENT

ISMA '97

INTERNATIONAL SYMPOSIUM ON MUSICAL ACOUSTICS

UNIVERSITY OF EDINBURGH

19–22 August 1997

Following previous international symposia on musical acoustics held in Mittenwald (1989), Tokyo (1992), Stockholm (1993) and Dourdan (1995), the next meeting in the series will take place in Edinburgh in 1997.

The meeting is being organised in association with the Catgut Acoustical Society and the Institute of Acoustics (UK).

Accommodation is available at very reasonable rates in Pollock Halls, picturesquely set at the foot of Arthur's Seat and Salisbury Crags yet only a ten-minute walk from the Festival Theatre.

The Symposium will take place during the 1997 Edinburgh International Festival, which runs from 10–30 August. On 22–23 August there will be a meeting of the Galpin Society in Edinburgh at which papers on historical musical instruments will be presented.

A call for papers will be issued in summer 1996; the deadline for submission of abstracts will be 1 December 1996.

Further information from: Dr D M Campbell MIOA, Dept, of Physics and Astronomy, University of Edinburgh, James Clerk Maxwell Building, Mayfield Road, Edinburgh EH9 3JZ, Scotland

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Web URL: http://www.music.ed.ac.uk/research/conferences/isma

MEMBERSHIP

The following were elected to the grades shown at the Council meeting on 9 May 1996

Fellow
Woodward, B

Member
Bradshaw, R A
Brewer, P A
Butt, J N
Cook, S M
Doyle, C P
Farren, J M
Hiller, D M
Hopkins, C P
Malpas, P R
McCullagh, R J
Tinsdeall, N J
Young, M P

Associate Member
Burns, R
Charles, D J
Chau, P L
Fattorini, B A
Hung, K W
King, C D
Laidlaw, L M
Lilley, A
Marston, R C
North, D M
Rogers, M A
Sethi, R P S
Shortt, P J
Steadman, G
Wong, C H

Associate
Etheridge, N P
Marsden, M A
Parkin, A J

Student
Leino, M A

INSTITUTE DIARY 1996

1996

1 JUL
Diploma Working Party
St Albans

2 JUL
IOA CofC in Env Noise M'ment Advisory Committee
St Albans

3 JUL
Reproduced Sound Committee
St Albans

19 JUL
Instr/ Measurement Committee
St Albans

23 – 25 JUL
Underwater Group Conference - Arrays and Beam-Forming in Underwater Acoustics (note new date)
Bristol

24 JUL
CEng Interviews
St Albans

30 JUL – 2 AUG
inter·noise 96
Liverpool

4 SEP
Business Review Committee
St Albans

5 SEP
Distance Learning Committee
St Albans

16 SEP
Environmental Noise Group Committee
St Albans

19 SEP
IOA Publications, Meetings Committee
St Albans

25 SEP
Environmental Noise Group - WHO Document: Community Health Workshop
NESCOT

26 SEP
IOA Membership, Education Committee
St Albans

3 OCT
IOA Medals & Awards, Council
St Albans

9 OCT
Instrumentation and Measurement Meeting How Sound Are Your Measurements
University of Strathclyde

11 OCT
IOA CofC in W'place Noise Ass't exam
Accredited Centres

17 OCT
Tutors Meeting
St Albans

21 OCT
Assessment of Workplace Noise Exposure – Workshops
St Albans

24 – 27 OCT
Reproduced Sound 12 Conference
Windermere

1 NOV
IOA CofC in Env Noise M'ment exam
Accredited Centres

8 NOV
IOA CofC in W'place Noise Ass't Advisory Committee
St Albans

14 NOV
IOA Publications, Meetings Committee
St Albans

15 NOV
IOA CPD and Branch Reps Committee
St Albans

21 – 24 NOV
1996 Autumn Conference – Speech & Hearing
Windermere

28 NOV
IOA Membership, Education Committee
St Albans

29 NOV
IOA CofC in Environmental Noise M'ment Advisory Committee
St Albans

5 DEC
IOA Medals & Awards, Council
St Albans

16 – 18 DEC
Underwater Group Conference - Numerical/ Analytical Methods for Fluid-Structure Interaction Problems
Nottingham

THE PREDICTION OF NOISE TRANSMISSION THROUGH PROFILED METAL CLADDING SYSTEMS

Yiu Wai Lam MIOA

Introduction

The widespread use of lightweight metal profiled cladding in modern industrial architecture has tended to exacerbate the problem of noise pollution from industrial premises. The sound insulation properties of these materials can be rather poor. Previous research has shown that the acoustic performance of single-skin cladding can vary significantly for relatively small changes in cladding parameters [1]. The Sound Reduction Index (SRI) is characterized by large 'dips' (Figure 1). A similar deterioration in the acoustic performance of double-skin systems can also occur (Figure 2).

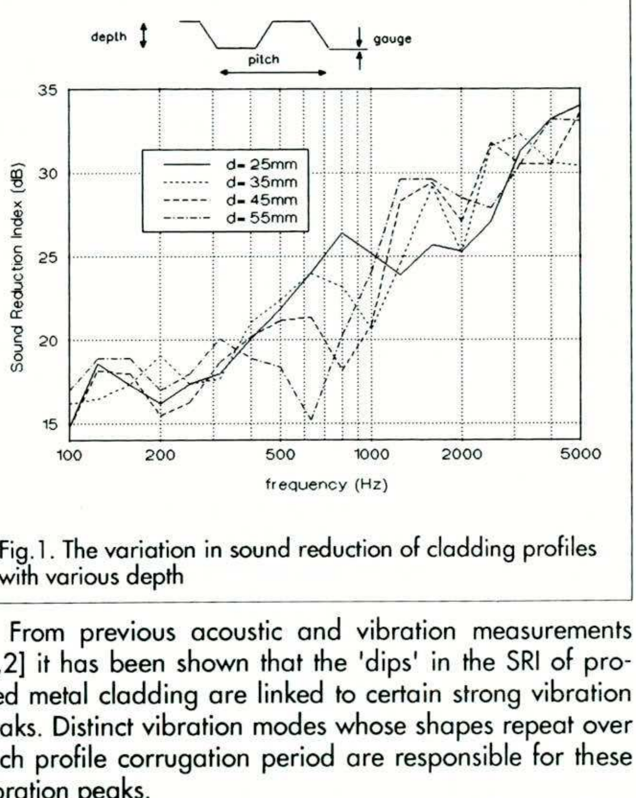

Fig.1. The variation in sound reduction of cladding profiles with various depth

From previous acoustic and vibration measurements [1,2] it has been shown that the 'dips' in the SRI of profiled metal cladding are linked to certain strong vibration peaks. Distinct vibration modes whose shapes repeat over each profile corrugation period are responsible for these vibration peaks.

This article looks at the methods of predicting these sound reduction dips and the methods of predicting the sound reduction index (SRI) of single and double-skin cladding systems [3,4,5].

Prediction of Single-Skin Cladding SRI

The overall sound reduction of cladding is dependent on both 'resonant' and 'non-resonant' (forced) transmission. The mid-frequency 'dips' are related to the 'resonant' path. The 'non-resonant' path can be predicted by existing orthotropic plate theory [6], empirically corrected by comparison to measurements over a wide range of profiles.

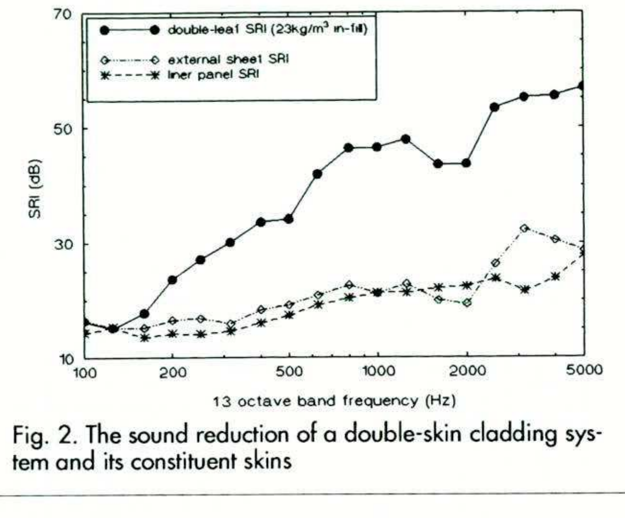

Fig. 2. The sound reduction of a double-skin cladding system and its constituent skins

(A) Global 'Non-resonant' Transmission Path

This part of the transmission is controlled by the global orthotropicity of the plate rather than by the detailed geometry of a corrugation. It can be modelled by the usual orthotropic plate sound reduction theory. The corrugated plate is approximated by an equivalent flat but orthotropic plate, and Heckl's approximate formulae [6] can then be used. However, comparison with the cladding SRI measurements performed in our laboratory over many years showed that Heckl's formula for low frequencies ($f \ll f_{c1}$, where f_{c1} is the lower critical frequency of the panel) underestimates the SRI.

The mid-frequency formula ($f_{c1} < f < f_{c2}$ where f_{c2} is the upper critical frequency of the panel) consistently follows the overall trends in SRI reasonably well (not including SRI 'dips') but again underestimates the SRI. The high frequency formula ($f \gg f_{c2}$) is irrelevant in the case of metal cladding because it is well above the frequency range of interest (usually f_{C2}>10 kHz) The prediction formulae were revised and, for the 'non-resonant' path, are summarised as follows:

$$TL_{non} \approx 10\log_{10}\left(\frac{\pi\omega\mu}{\rho_0 c}\frac{f}{f_{c_1}}\right) - 20\log_{10}\left(\ln\frac{4f}{f_{c_1}}\right) + 3\text{ dB} \qquad f \geq f_{c_1}$$

$$TL_{non} \approx 8.3\log_{10}\left(\frac{f}{f_{c_1}}\right) + 10\log_{10}(\omega\mu) - 19\text{ dB} \qquad f < f_{c_1} \tag{1}$$

where μ is the mass density of the panel. The two critical frequencies, f_{c1} and f_{c2}, are calculated from the equivalent orthotropic bending stiffness of the profiled plate [7].

(B) SRI 'dips' Transmission Path

Profile Vibration Modes The 'dips' in the SRI of profiled metal cladding are linked to certain strong vibrational modes that are dependent on the local geometry of a profile period. These modes can be successfully predicted by means of 2-dimensional finite element analysis (FEA) with a simple periodicity restraint to simulate 'infinite' repeats of the profile. Figure 3 demonstrates the close correlation between the frequency of three FE predicted generic mode shapes and the occurrence of sound reduction 'dips'. In general the 'dip' frequency is consistently overestimated but usually falls within one 1/3

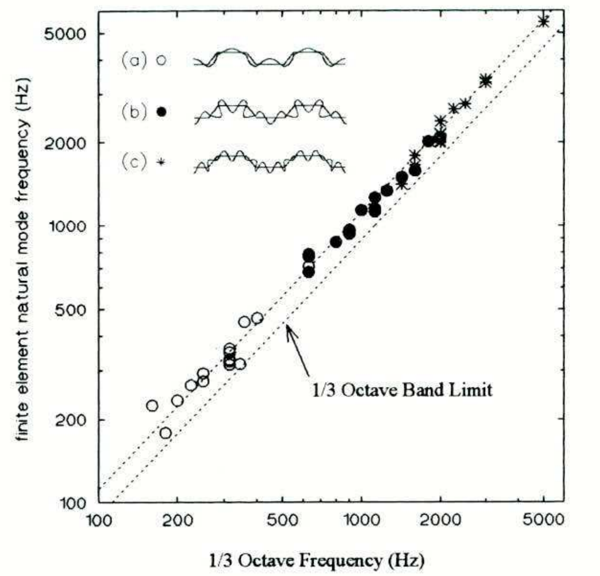

Fig. 3. Correlation between FE predicted mode frequencies and observed SRI 'dip' frequencies for 3 mode shapes in 15 profiled cladding

octave band. Consequently a simple empirical correction factor is used to modify the FE predicted mode frequencies.

Radiation Efficiency of Vibration Modes A 2-dimensional boundary element method (BEM) [8] can be used to calculate accurately the acoustic radiation from pre-defined vibration conditions. This enabled a detailed analysis of the cladding noise radiation, from which it was found that the radiation calculation can be approximated by a much simpler (and speedier) technique – the vibrating cladding can be split up into sections which are treated as sources radiating independently into half-space. This produced results similar to those by BEM (see Figure 4) and provides a fast and reliable way of evaluating the radiation efficiency of the cladding's vibration modes.

As shown in the figure, the radiation efficiency of the vibration modes generally increases above a certain modal frequency. However, the increase generally applies to all modes above that frequency and does not correspond exactly with the frequency band limited nature of the large SRI 'dips'. To explain this, one needs to investigate the excitation mechanism of these modes.

Excitation of Profile Vibration Modes The excitation can be modelled by a simple modal analysis approach using plane waves, and by the BEM. The former technique was

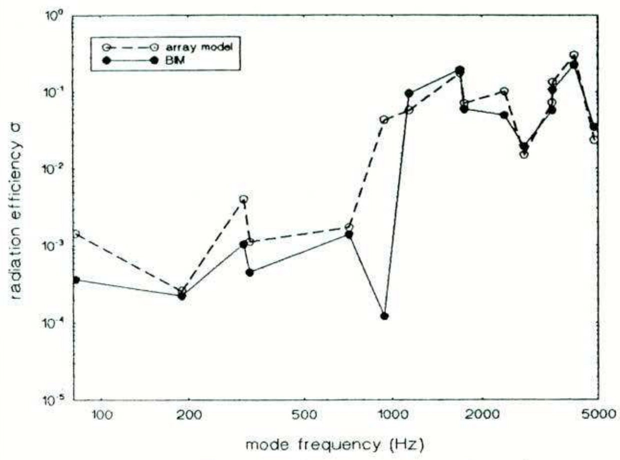

Fig. 4. Radiation efficiency of vibrational modes of a symmetrical trapezoidal profile

found to approximate the BEM very well with an enormous saving in complexity and computation time. Detailed measurement of cladding has showed that when combined with the finite element analysis the excitation model is able to predict the most prominent vibration characteristics of the cladding (Figure 5), which are closely related to the large SRI 'dips'. It can therefore be concluded that the acoustic excitation of the profile dependent vibration modes is the prominent cause of the 'dips' in the sound reduction of profiled cladding.

(C) Single-Skin Cladding Sound Reduction Prediction [4]

Theoretically one can perform the above calculation over a range of incident angles to arrive at the diffuse field sound transmission. However, BEM calculation is computation intensive and is therefore costly to perform over many incident angles. Even with the array model the calculation is cumbersome. The transmission calculation can be dramatically simplified by assuming that the profiled plate can be taken as flat so that the usual flat plate transmission equations can be used. This assumption is valid as long as the profile depth (typically 35 mm) is small compared with the acoustic wavelength. In fact this assumption has already been taken earlier

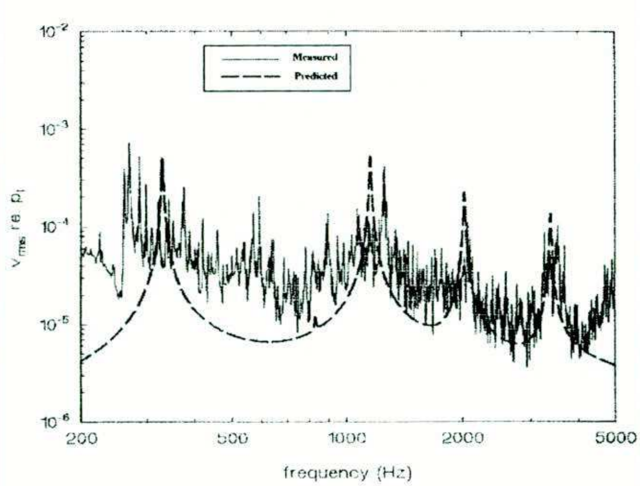

Fig. 5. Predicted and measured root-mean-square velocity on an asymmetrical profile

when Heckl's orthotropic plate formulae were adopted for the calculation of the 'non-resonant' sound reduction.

The bending wavelengths of the modes related to the SRI 'dips' are usually much shorter than the acoustic wavelength. We may further assume that the 'dip' related resonant response of the plate can be characterized by a plate impedance Z_{dip} (θ,ϕ) that is given by the FE predicted average ratio of surface pressure to the normal plate vibration velocity at an oblique incidence characterised by the elevation (from z-axis) and azimuth angles θ and ϕ. Under such assumptions, the reflected wave will be essentially plane and the following equation can be used to calculate the sound reduction associated with the 'dip' related resonant vibration:

$$\bar{\tau} = \frac{2}{\pi}\int_{\phi=0}^{\phi=\frac{\pi}{2}}\int_{\sin^2\theta=0}^{1}\frac{d\left(\sin^2\theta\right)d\phi}{\left|1+\frac{Z_{dip}(\theta,\phi)}{2\rho_0 c}\cos\theta\right|^2} \quad (2)$$

$$TL_{dip} = -10\log_{10}\bar{\tau}$$

The SRI of the profiled cladding is obtained by assuming an incoherent combination of the 'non-resonant' and 'dip' related 'resonant' transmission paths,

$$SRI = -10\log_{10}\left(10^{\frac{-TL_{non}}{10}} + 10^{\frac{-TL_{dip}}{10}}\right) \quad (3)$$

(D) Accuracy

The resulting prediction (labelled 'analytical prediction' in Figure 6) of $^1/_3$ octave band sound reduction is reasonable. The prediction model provides good overall correlation with measurements and gave the sound reduction 'dips' within one $^1/_3$ octave band (Figure 6). This represents an enormous improvement in the understanding of cladding systems and the ability to predict their acoustic performance.

It is also interesting to see that the empirical formulae developed in earlier work [9] also predicted the SRI very well, not surprising because the formulae were developed from this very set of measurements. A proper test of the empirical method is to compare it to commercial profiles which are not part of the data set used to formulate the original algorithms. Figure 7 shows such a comparison. In this case the analytical model has a clear advantage. Nevertheless the empirical formulae are simple and can be used by any design engineers and architects. Their accuracy is good for trapezoidal profiles, and covers a large range of those available commercially.

Prediction of Double-Skin Cladding SRI

Single-skin materials are generally used only for industrial and agricultural storage sheds or peripheral workshops where specifications are less strict. In the great majority of cases industrial buildings are constructed from more complex cladding systems normally containing two layers of profiled metal sheet with some form of cavity filling and structural fixings. Therefore we need to extend the previous study to cover double-skin cladding constructions [5].

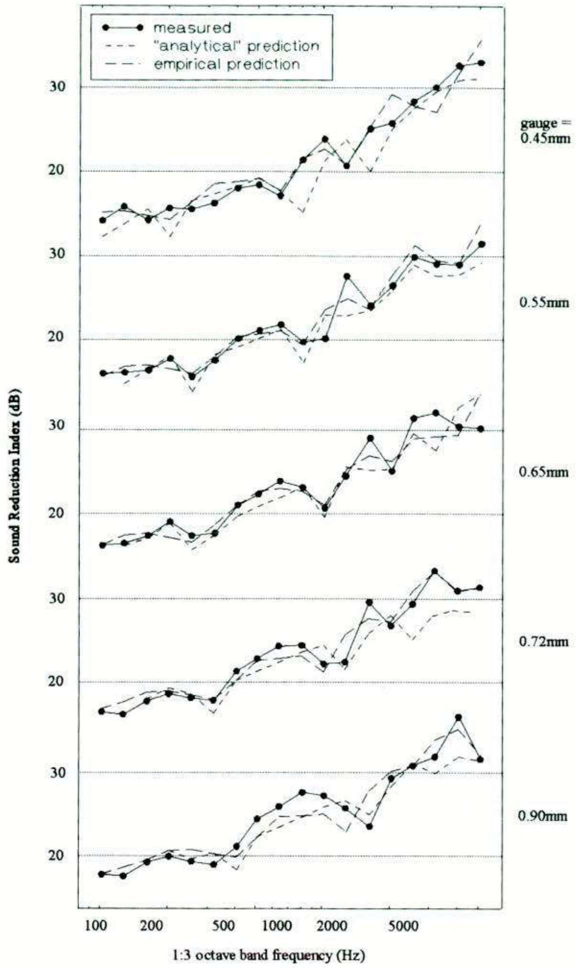

Fig. 6. Empirical and analytical prediction of cladding sound reproduction for symmetrical profiles of various gauge

Without sound bridges between the two constituent sheets, and with sufficient absorption in the cavity to prevent air cavity resonances, the following engineering approximation provides a good prediction of the ideal sound reduction of a double sheet construction [10], where R_1 and R_2 are the individual skins' sound reduction, d the cavity span and $\mu = \mu_1 + \mu_2$ the total surface mass of the skins:

$$\begin{aligned} R_{NB} &= 20\log_{10}\mu f - 47\,dB & f &< f_0 \\ R_{NB} &= R_1 + R_2 + 20\log_{10} fd - 29\text{ dB} & f_0 &< f < f_L \\ R_{NB} &= R_1 + R_2 + 6\text{ dB} & f &< f_L \end{aligned} \quad (4)$$

The mass-air-mass resonance f_0 and limiting frequency f_L are given by:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{1.8\,\rho_0 c^2}{d}\frac{(\mu_1+\mu_2)}{\mu_1\mu_2}} \quad \text{and} \quad f_L = \frac{c}{2\pi d} \quad (5)$$

Equation (4) can be applied to both isotropic and orthotropic sheets. However, the assumption of no sound bridging is rather unrealistic for cladding systems. Figure 8 shows the typical fixing method of standard double-skin cladding systems. The cladding is affixed by screws to the

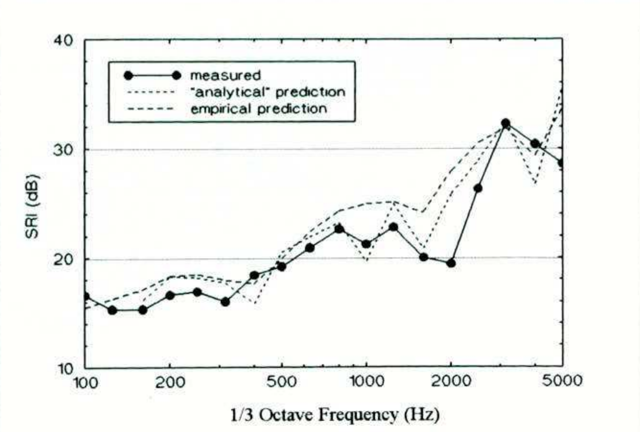

Fig. 7. Prediction on a commercial profiled metal cladding sheet

structural building frame or purlins. In the most common constructions Z-spacer rails are fastened through the liner panel to the purlin and the external sheet is then affixed to the rail. The link between the liner and the external sheet can be considered as point-to-point.

Effect of Sound Bridges in Orthotropic Systems With the presence of sound bridges, the calculation of sound reduction becomes more complicated. For isotropic plates, Sharp's method [10] can be used. For cladding systems, existing methods need to be extended to cover the orthotropic nature of the systems.

From a consideration of the radiation efficiency and impedance matching at each of the point-to-point sound bridges, the total sound reduction through the double-sheet cladding system can be obtained [5]:

$$R = R_{NB} - 10\log_{10}\left[1+\frac{\sigma_{rad}}{S_{B1}}\left|\frac{Z_{B1}}{Z_{B1}\,Z_{B2}}\right|^2\left[2\left(10^{\frac{R_2}{20}}-1\right)\beta\right]^2\right] + TL_{ins} \quad (6)$$

where R_{NB} is the sound reduction in the absence of sound bridges, and

$$\sigma_{rad} = \frac{8}{\pi^3}\lambda_{c1}\lambda_{c2} \qquad f < f_{c1}$$

$$\sigma_{rad} = \frac{2}{\pi^4}\frac{\lambda\lambda_{c2}}{\eta}\left[\ln\left(\frac{4f}{f_{c1}}\right)\right]^2 \qquad f_{c1} < f < f_{c2} \quad (7)$$

$$\sigma_{rad} = \frac{2}{\pi^2}\frac{\lambda_{c1}\lambda}{\eta} \qquad f_{c2} < f$$

$$Z_{Bi} = \frac{4}{\pi}c^2\frac{\mu_i}{\sqrt{f_{c1_i}f_{c2_i}}} \qquad \text{where } i = 1,2 \quad (8)$$

$$\beta = \frac{\omega d}{c} \quad for\ f < f_L \quad \text{and} \quad \beta = 1 \quad for\ f > f_L \quad (9)$$

f_{c1} and f_{c2} are the external plate's lower and upper critical frequencies, λ_{c1} and λ_{c2} are their corresponding wavelengths, η is the loss factor, and R_2 the sound reduction index of the external plate. The subscript i in equation (8) indexes the liner (i=1) and external sheet (i=2). TL_{ins}, is the additional sound reduction through high density insulation, estimated using standard transfer matrix method for fibrous materials with rigid frames [11].

Results Figure 9 shows a comparison between predictions using the above theory with the SRI data measured on a double-skin system with different in-fill density. The 'Complete Prediction' is compared with that using measured single-skin SRI data ('Predicted from measured SRI'). Both predictions show very good accuracy throughout the frequency range of 200 to 5000 Hz. The 'partial' prediction has only slightly better accuracy than the 'Complete Prediction' which serves to show the good accuracy of the single-skin SRI prediction. It is of interest to note that the SRI of the cladding system with the lower in-fill density shown in the figure has a rather large 'dip' at 2000 Hz which is also evident in the SRI of one of the constituent skins. This 'dip' has also been successfully predicted. Note that the magnitude of the 'dip' at 2000 Hz was reduced by the higher density insulation.

In Situ Performance

A programme of on-site measurements was undertaken to check the laboratory test results. Measurements were carried out on five double-skin systems and two single-skin systems. The SRI of the cladding was determined from the difference between the incident sound intensity on the internal face of the cladding (liner panel) and the intensity radiated out from the external face of the cladding. The radiated intensity was measured directly by means of an intensity probe. Inside the building a 'local' diffuse field near (but not too close) to the cladding wall was assumed.

Figure 10 shows a comparison of the SRI of a single-skin cladding measured (i) using the standard transmission suite method, (ii) by the intensity method in the laboratory, and (iii) by the intensity method on-site. The intensity measurements were repeated twice in each case. The site building was a purpose built factory construction in a rural area at Silsoe. The background noise was low, and a reasonably diffused sound field could also be generated inside the building. Consequently the on-site measurements were reliable over a wide frequency range. In this case the in situ SRI agrees very well with the laboratory measured SRI. Figure 11 shows a comparison of the SRI of a double-skin cladding. The in situ measurement was taken in an industrial estate with a noisy background, which affected the mid and high frequency results. Otherwise the in situ SRI again agrees well with the laboratory values.

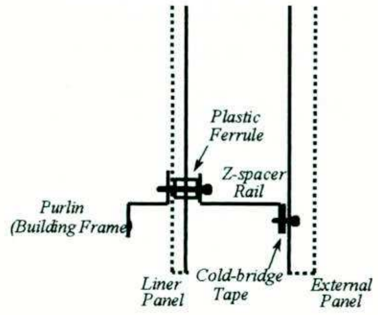

Fig. 8. Representation of the build-up of a typical double-skin cladding system

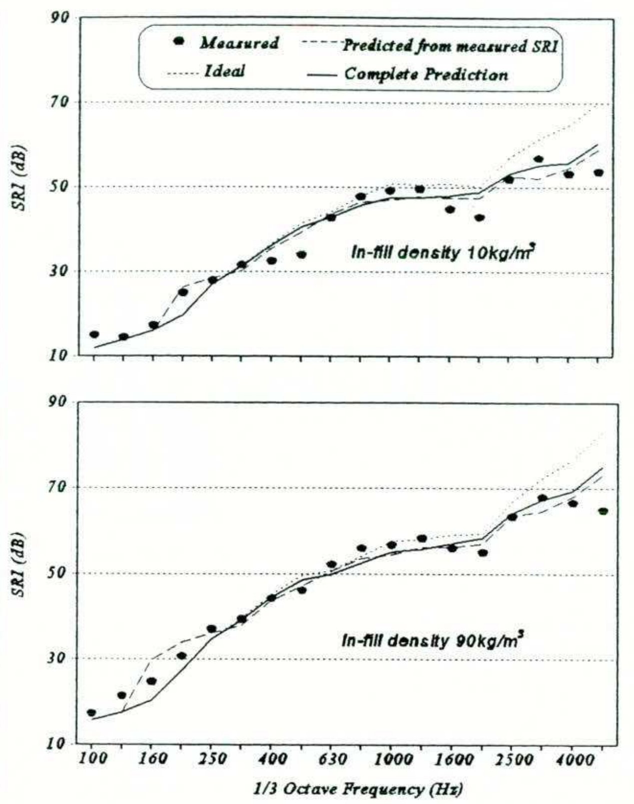

Fig. 9. SRI prediction on a double-skin profiled metal cladding system with different in-fill density

Conclusions

The methods described here have been shown to predict the SRI of single and double-skin profiled metal cladding systems well. Although not shown here, predictions by these methods have been compared with the SRI measured on 24 double-skin profiled metal cladding systems of various constructions. The root-mean-square error on the weighted index R_w and on the individual $^1/_3$ octave frequency band SRI over the frequency range of 200 to 3150 Hz were found to be 2.1 dB and 2.9 dB, respectively, which should be acceptable for preliminary

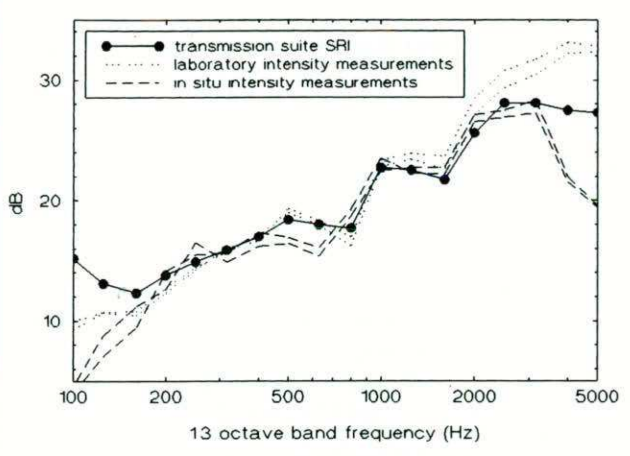

Fig. 10. Comparison of laboratory and in situ measurements of SRI on a single-skin cladding

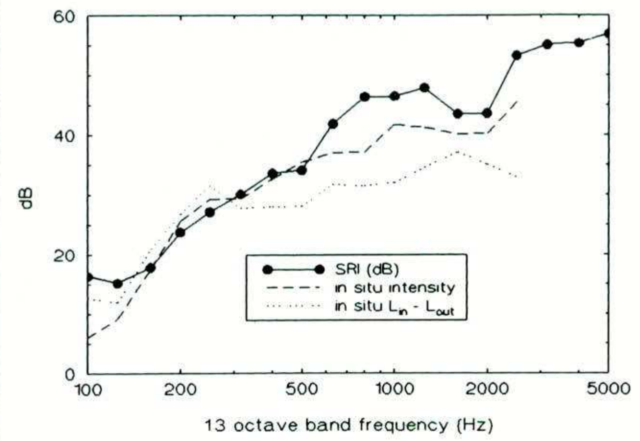

Fig. 11. Comparison of laboratory and in situ measurements of SRI on a double-skin cladding

design purposes. The prediction methods have now been implemented under a contract with the Metal Cladding and Roofing Manufacturers' Association into a user-friendly computer model which can be used for assessing double-skin metal cladding designs.

Acknowledgements

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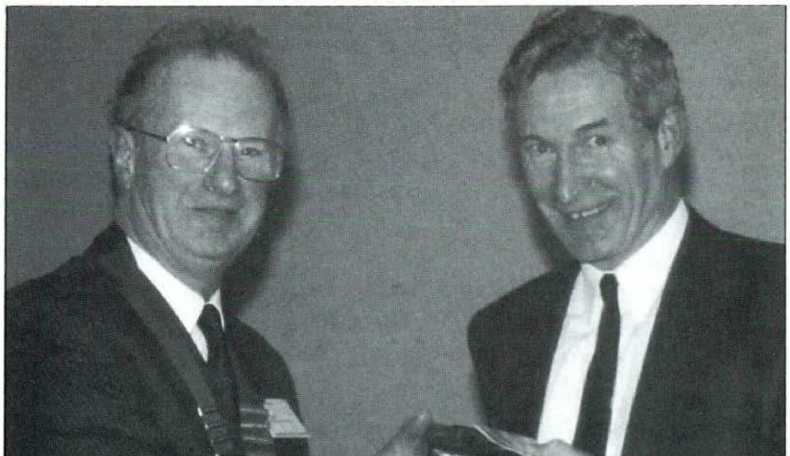
PLANNING & NOISE

Church House, Westminster London, 17 April 1996


The President hands over the chain of office to the President Elect


Left to right: John Holmes, Bernard Berry, Derek Sugden and Alex Burd


Presentation to John Tyler

Some 85 delegates arrived at Church House, Westminster for the annual London Branch One Day Meeting on Planning & Noise. It was run this year in collaboration with the Environmental Noise Group of the Institute, and unusually, comprised both technical presentations and a workshop session.

Following an introduction from the chairman, John Simson, the background to the current DOE research contract looking at the application of PPG 24 was described by Bernard Berry. We then heard four papers covering different aspects of the PPG from Steve Goswell, Catherine Day, Chris Manning and David Watts. They all raised points which struck a chord with the audience, with the hypothetical situation painted by David being both entertaining and yet uncannily realistic!

After lunch, Rupert Taylor introduced the workshop session by outlining the sort of responses he had already received as part of the DOE research and asking delegates to consider several points in some detail. It was stressed that this was not an opportunity to rewrite the definition of the NEC categories, but instead to seek further advice and guidance in the application of the PPG which is currently lacking. Four workshop groupings were established and wide ranging discussions occurred. The moderators of each workshop then reported the outcome of their group's deliberations to the conference, before Rupert summarised the results.

This type of intensive study of an issue meant that we all came away having clarified a little more our understanding of this important subject. The mixture of presentations and workshop also seemed to be well received by the delegates and might well be a format that could be repeated when there is a distinct issue to be discussed.

The Institute's 1996 Annual General Meeting and Annual Dinner took place following the meeting. During the Dinner, Honorary Fellowships were conferred on Derek Sugden and John Holmes. The office of President of the Institute was passed to Bernard F Berry of the National Physical Laboratory. John Tyler received an award to mark his retirement from the post of Bulletin Editor after a tenure of ten years.

Stephen Turner

22nd ANNUAL REPORT OF THE COUNCIL 1995

Summary

The Institute is the professional body representing acoustics in the UK. A range of services is provided for members. This includes publishing six editions per year of Acoustics Bulletin, organising meetings and conferences, and providing courses for the Diploma in Acoustics and Noise Control, the Certificate of Competence in Workplace Noise Assessment and the Certificate of Competence in Environmental Noise Assessment. International activities include the organisation of conferences and participation in the European Acoustics Association and the Federation of Acoustical Societies of Europe. During the year, many members have registered as Chartered or Incorporated Engineers via the Institute, which is an affiliated/nominated body of the Engineering Council. A Continuing Professional Development (CPD) Scheme has been prepared during 1995 for implementation in 1996. Thanks are due to the Secretary, Cathy Mackenzie, and her staff at the Headquarters in St Albans for their commitment and enthusiasm which has ensured the efficient organisation of Institute activities.

Standing Committees

The operation of the Institute is guided by Council through Standing Committees concerned with Membership, Meetings, Publications, Education, and Medals and Awards. There is also a Committee of the Engineering Division.

Membership Committee

Over the year the overall number of members has shown a net increase of 3.9%. A substantial increase in Associate Members of 15.6% has been largely at the expense of Associates whose numbers have decreased by 15%. The remaining small increases in Members and Students account for the overall increase. The current membership statistics are shown in Table 1, and an analysis of the employment categories of members is shown in Table 2. Agreement has been reached with the Open University over Course Profiles which will satisfy the Institute's requirements for educational standards leading to membership of the Institute. During the year Hong Kong acousticians formed their own Institute which may lead to a reduction in the number of HK members in our Institute. We are seeking to attract further applications for membership by writing to non-members who attend our conferences.

Grade	1994	1995	Applied	Elected
Hon Fellow	13	14	—	2
Fellow	228	224	6	5
Member	1193	1225	98	87
Associate Member	472	546	150	148
Associate	208	177	11	11
Student	42	54	20	20
Totals	**2156**	**2240**	**285**	**273**
Key Sponsor	3	3	0	0
Sponsor	21	20	2	2

Table 1. Institute Membership

Employment Category	1994	1995
Architectural Practice	17	18
Consultancy	523	528
Industry/Commerce	320	314
Education	224	224
Public Authority	454	477
Research & Development	217	214
Other	66	72
Retired	67	66

Table 2. Details of Employment

Meetings Committee

During the year 14 workshops and meetings were held, including 4 major conferences, see Table 3. The international conference on Opera & Concert Hall Acoustics was well attended, with speakers from Italy, Canada, Sweden, France, the Netherlands, UK and USA, and included a unique listening session at the new Glyndebourne Opera House. The Spring Conference, Acoustics '95 at Liverpool, was attended by 190 delegates. The Autumn Conference, held at Windermere as usual, included the novel format of a Noise & Vibration School, which included many practical tutorials, and was well received by the 113 delegates. Reproduced Sound 11 also took place at Windermere. The workshop form of meeting was pursued by the Environmental Noise Group and it was particularly pleasing to note the successful workshop in Belfast. Organisation of Inter-Noise '96 proceeded as planned.

Topic, Date & Venue	Attendance
Links between Speech Technology, Speech Science and Hearing, *5 January, University of Sheffield*	70
Opera & Concert Hall Acoustics, *10/12 February, Gatwick*	**94**
Building Services Noise *15 March, Church House, London*	43
Integrating Speech Recognition and National Language *23 March, University of Durham*	29
Sonar Transducers 1995 *3/5 April, University of Birmingham*	56
Workshop: Environmental Noise Assessment *11 April, University of Strathclyde*	51
Acoustics 95 Environmental Noise & Vibration *9 May, Adelphi Hotel, Liverpool*	**190**
PC Programs in Acoustics *31 May, South Bank University, London*	29
Speech Systems for the Handicapped *8 June, University of Durham*	33
Workshop on Environmental Noise *22 September, University of Ulster*	25

Workshop on Environmental Impact Assessments *12 October, NPL*	60
Autumn Conference, Standards & Measurements in Acoustics ***26/29 October, Windermere***	113
Reproduced Sound 11 ***16/19 November, Windermere***	95
Sonar Signal Processing ***18/20 December, Univ. of Loughborough***	67

Table 3 Meetings Attendance in 1995

Publications Committee
Acoustics Bulletin has continued to be published as a bi-monthly journal with a balance of news, technical contributions and regular features. Our thanks go to John Tyler, editor for nine years, who retired from the position at the end of 1995. Roger Higginson has agreed to edit the first edition in 1996. The 1995/6 Institute Register was published and circulated to members in the middle of the year. The procedure for refereeing papers has been monitored and as a consequence more time has been allowed for authors to respond to referees' comments. The reference library is now well established and the books catalogued on a computer data base, as are the authors and titles of papers in the Institute's Proceedings.

Education Committee
In 1995, 194 candidates studied at 10 centres for the award of the Institute's Diploma in Acoustics and Noise Control, including 20 students for the Institute's Tutored Distance Learning Programme. At the three examinations held in February, May and October, 120 candidates were awarded the Certificate of Competence in Workplace Noise Assessment; this makes the total awarded so far 1,121. Following examinations in March, June and November, 92 candidates were awarded the Certificate of Competence in Environmental Noise Measurement. This makes a total of 246. A working group of the Committee has finalised a scheme of Continuing Professional Development to commence in January 1996 and to be run mainly through the Branches. The working group is now established formally as a sub-committee of the Education Committee.

Medals and Awards Committee
The Rayleigh Medal for 1995 was presented at the Spring Conference to Prof R H Lyon for outstanding contributions to original research in engineering acoustics and noise control. The R W B Stephens lecture, Generalised Impedance Concept: Analysis and Acoustic Applications, was given at the same meeting by Prof A Lara-Saenz, President of the Spanish Acoustical Society. Also at the Spring Conference, an Honorary Fellowship was presented to Dr John Bowsher for his contribution to musical acoustics. Dr John Holmes was awarded an Honorary Fellowship for his contribution to speech research and technology; this was presented at the 1996 AGM. The 1991 A B Wood Medal was received by Dr Michael Porter at the Sonar Transducers meeting at Birmingham University and the 1994 A B Wood Medal was presented to Dr Timothy Leighton at the Sonar Signal Processing Conference at Loughborough University, for their outstanding contributions to underwater acoustics.

Engineering Division
In 1995, members of the Engineering Division and Officers of the Institute played an active role in the development of the reformed Engineering Council, for launch early in 1996. Dr Susan Boyle CEng MIOA was elected to the Senate of the new Engineering Council. The Diploma in Acoustics and Noise Control has been accepted by the Engineering Council as meeting the requirements for registration at Stage 1 Incorporated Engineer, in conjunction with various non-specialist HND/HNC qualifications and degrees. Five candidates have been granted Incorporated Engineer status, 35 candidates (2 via the Mature Candidate route) granted Chartered Engineer status, and 24 new acoustics graduates have registered at Stage 1 for Chartered Engineer.

Specialist Groups

The Institute reflects the broad spectrum of the science and application of acoustics. Several Groups have been formed to foster closer contacts between members of the various specialisms. Group membership numbers are shown in Table 4.

Building Acoustics Group
The Group held a very successful meeting at Glyndebourne on Opera & Concert Hall Acoustics which attracted a number of international delegates. The Group also strongly supported the Windermere Autumn Conference with both formal sessions and a series of workshops.

Electroacoustics Group
There was no activity during 1995. Anyone wishing to revive the Group should contact Dr J A S Angus at the University of York, or contact Headquarters.

Environmental Noise Group
1995 was a very busy year for the Group. We continued our series of half day workshops and visited the University of Strathclyde in April and the University of Ulster in September. At both events, the subject matter was Environmental Noise Assessment. We were also closely involved with the organisation of the Spring Conference in Liverpool and we ran a workshop session on entertainments noise at the Autumn Conference. The Group also responded on behalf of the Institute to the DoE consultation document on neighbour noise, and formalised the liaison with the Institute of Environmental Assessment with the formation of the Noise Impact Assessment Working Party, following an open meeting in October.

Industrial Noise Group
The Group organised a session of papers at the Autumn Conference, where the Group AGM was also held. A meeting on Health Risks from Noise and Vibration is planned for 1996. Suggestions for future activities and meetings of the Industrial Noise Group, and for volunteers to join the Committee would be welcomed.

Measurement and Instrumentation Group
The Group was founded during 1995. The first informal meeting was held in June and an ad-hoc Committee was established chaired by Richard Tyler of CEL Instruments, with Peter Hanes of the NPL as secretary. The Group assisted in the organisation and preparation of 2 sessions at the Autumn Conference and held its first AGM at which the ad-hoc Committee was officially elected. At a Committee meeting in December, arrangements were made for the Group's first one-day meeting, held in London during February 1996 with the title 'Roughly how loud is that? - Current issues in measurement'. A feature of the meeting was calibration workshops.

Musical Acoustics Group
Although the Group has been dormant for some time, it has experienced a mild revival over the past year. This began with a joint evening meeting with the SW Branch on 'Strings Ancient and Modern', which was followed by an AGM. There are now plans for an increased level of activity in the near future.

Physical Acoustics Group
The Group held a successful symposium at the Autumn Conference at Windermere, which attracted eight interesting papers related to ultrasonics.

Speech Group
The Group held three one-day technical meetings. The first, in January, was on the theme of 'Links between speech technology, speech science and hearing', and was held at the University of Sheffield. The second, in March, was on the subject of 'Integrating speech recognition and natural language processing systems', and was held at the University of Durham. The third, in June, was entitled 'Speech systems for the handicapped', and was held at the University of Edinburgh. All events were well attended and stimulated much interest.

Underwater Acoustics Group
Two major conferences were organised in 1995. In April, the eighth meeting in the series on Sonar Transducers to be held at the University of Birmingham attracted 24 papers and was the venue for Dr Michael B Porter's 1991 A B Wood medal presentation. The conference on Sonar Signal Processing at Loughborough University in December was another regular event, being the fourth in the series established by Prof Roy Griffiths. Sadly Prof Griffiths died in May, so the conference organisation was taken over by Profs Hugh Griffiths and Colin Cowan. The A B Wood medal for 1994 was presented to Dr Timothy Leighton at the December conference.

Group	1994	1995
Building Acoustics	514	499
Electroacoustics	138	134
Environmental Noise	582	653
Industrial Noise	556	531
Measurement & Instrumentation		new group
Musical Acoustics	130	123
Physical Acoustics	89	86
Speech	108	111
Underwater Acoustics	150	143

Table 4. Group Membership

Regional Branches

The Regional Branches of the Institute of Acoustics have been established to further the technical and social activities of the Institute at local level. Branch membership numbers are shown in Table 5.

Eastern Branch
The Branch was very active during 1995, holding several meetings and a dinner, with venues across the area to give everyone a fair chance of attending. The meetings were successful, and included Noise from mineral extraction by Angus Walker, Noise and the law by Philip Barnes (joint with CIEH), Engineering of the ear by Ted Evans, Long distance sound propagation by Howard Sandford/Chris Hood, Train noise and vibration by Brian Hemsworth, Acoustic modelling and loudspeakers by Celestion, and Measuring human hearing by David Baguley. The dinner was held at Dedham Hall, Essex with Derek Sugden as guest speaker.

Hong Kong Branch
During 1995 the Branch was replaced by the newly formed Hong Kong Institute of Acoustics.

London Branch
Evening meetings remained the backbone of the regular technical programme. Venues outside central London proved successful, having attracted new attendees, which averaged 23 per meeting. The wide range of topics included transportation, noise at work, statutory nuisance, sound transmission, and new ideas in measurement techniques. A half-day visit to Browns Organ Builders gave an unusual insight into the practical application of basic acoustic principles. The annual dinner was enjoyable and our one-day conference provided a good exchange of ideas on noise control in buildings. Special thanks go to John Miller who, after years as our hard working secretary, will not be seeking re-election.

Midlands Branch
It was an encouraging inaugural year, following the formation of the Branch in December 1994. In April, at Coventry University, the Branch learnt about recent research into low frequency environmental noise from John Sargent of the Building Research Establishment (BRE). At the July meeting at Aston Science Park, Sue Bird briefed the Branch on the Institute's CPD proposals followed by a talk from Henry Cleary of the Department of the Environment concerning the Neighbour Noise Working Party report. In November, the Branch returned to Coventry University for its first AGM, at which the ad-hoc committee of John Hinton and John Magrath were formally elected to the new committee. After the formalities, Colin Grimwood and Nick Antonio of BRE discussed sound insulation between dwellings.

North West Branch
After a period of inactivity, the AGM was held in September when Bernard Berry gave a presentation on the proposed changes to BS 4142:1990. In November, a well attended meeting was held at BDP's premises where Brian Hemsworth of British Rail Research talked about the principal elements of The Noise Insulation (Railways and Other Guided Transport Systems) Regulations 1995 and

the background to noise prediction methods for railway vehicles.

Scottish Branch

In April the Environmental Noise Group held its Workshop on Environmental Noise Assessment at the University of Strathclyde, and the event was well supported by the members of the Branch. In June we visited Glasgow Airport where Ian McMahon of the BAA gave the members an interesting talk on the airport noise monitoring system. This was followed by the AGM at which Bill Frame and Ron McLaughlin were re-elected to the Branch committee to join the current Chairman Patrick Corbishley, Treasurer Andy Watson, John Nicol, Dr Bernadette McKell and Ricky Burnett. Following the AGM, Susan Bird spoke about CPD which generated a useful discussion on how CPD might be operated.

Southern Branch

The Branch was very active, largely due to the efforts of new committee members who brought fresh ideas and abundant enthusiasm. The Branch held four meetings which included very good speakers and excellent venues. All the meetings were well attended, averaging 30 members and guests. The consensus was that the topics, namely noise barriers, instrumentation, theatre acoustics and PPG24, were of great interest to many members of the Branch. Dawn Langdown (Basingstoke and Deane DC) has kindly agreed to be the Branch representative for CPD issues.

South West Branch

The AGM in March agreed to continue to operate the Branch with the same informal structure based at UWE Bristol. The meeting continued with a lively session on 'Aspects of Instrumentation' with contributions from Roger Rodwell, Gracey & Associates, Mike Squires, Exeter City Council, Martin Williams, Brüel & Kjær, Norman Pittams and Stan Simpson, UWE Bristol. The established tradition of a long informal session completed the evening. The joint meeting with the Musical Acoustics Group "Strings Ancient and Modern" organised by Peter Dobbins, BAeSEMA, was highly successful, the Hurdy Gurdy music being most popular, with Peter modestly resorting to recorded music.

Yorkshire and Humberside Branch

The Branch was resurrected at its AGM in February when the new committee was formed. Four meetings were held during the period of April to November. The topics were Predicting the Performance of Noise Barriers by David Hothersall, Properties of Absorbent Materials by Kiril Horoshenkov, Vibration Standards and Assessment Criteria by Richard Greer, Legislation on Noise and Vibration by Frank Irvine, Environmental Noise and the Steel Industry by Richard Scott, and a Planning and Noise Forum. The discussions were lively and members were appreciative of the interesting papers. A membership survey was undertaken and all respondents expressed an interest in attending meetings and some offered to present papers. CPD was discussed several times and concern was expressed about the cost to participants and employers. There was, however, general support for the scheme and the Branch decided to issue CPD certificates for attendance at meetings.

Branch	1994	1995
Eastern	171	177
London	469	464
Midlands	210	217
North East	51	48
North West	234	231
Scottish	85	86
South West	146	148
Southern	308	316
Yorks/Humberside	104	103
Hong Kong	143	146
Overseas	140	138

Table 5. Branch Membership

COUNCIL

Officers

President: Mr A N Burd FIOA
President Elect: Mr B F Berry FIOA
Immediate Past President: Prof P D Wheeler FIOA
Honorary Secretary: Dr A J Jones FIOA
Honorary Treasurer: Mr G Kerry FIOA
Vice President (Groups & Branches): Dr R J Peters FIOA

Ordinary Members

Mr S C Bennett FIOA
Mr K Broughton MIOA
Mr J G Charles FIOA
Dr R C Chivers FIOA
Prof R J M Craik FIOA
Dr P F Dobbins FIOA
Dr C A Hill FIOA
Prof P A Nelson MIOA
Prof M A A Tatham FIOA

Chairmen of Standing Committees of Council and Sub-committees

EDUCATION: Dr R C Chivers FIOA

Diploma in Acoustics and Noise Control, Board of Examiners: Chairman: Dr J M Bowsher HonFIOA, Deputy Chairman: Mr J G Charles

Certificate of Competence in Environmental Noise Measurement Advisory Board: Dr M E Fillery MIOA

Certificate of Competence in Workplace Noise Assessment Advisory Board: Dr R J Peters FIOA

Continuing Professional Development: Ms S M Bird MIOA

ENGINEERING DIVISION: Prof P D Wheeler FIOA
MEDALS & AWARDS: Mr A N Burd FIOA
MEETINGS: Mr J G Charles FIOA
MEMBERSHIP: Mr A N Burd FIOA
PUBLICATIONS: Mr J W Sargent MIOA

Specialist Groups

BUILDING ACOUSTICS: Chairman Prof R J M Craik FIOA, Hon Secretary Mr N Antonio MIOA
ELECTROACOUSTICS: Hon Secretary Dr J A S Angus FIOA
ENVIRONMENTAL NOISE: Chairman Mr S W Turner FIOA, Hon Secretary Ms D G Langdown MIOA
INDUSTRIAL NOISE: Chairman Dr R J Peters FIOA, Hon Secretary Mr D G Bull FIOA
MEASUREMENT & INSTRUMENTATION: Chairman Mr R G Tyler FIOA, Hon Secretary Mr P Hanes MIOA
MUSICAL ACOUSTICS: Chairman Dr B E Richardson MIOA, Hon Secretary Dr P F Dobbins FIOA
PHYSICAL ACOUSTICS (Joint with the Institute of Physics): Chairman Dr D Almond, Hon Secretary Dr C Langton
SPEECH: Chairman Prof S J Young FIOA, Hon Secretary Dr B J Williams MIOA
UNDERWATER ACOUSTICS: Chairman Dr P F Dobbins FIOA, Hon Secretary Dr P D Thorne FIOA

Regional Branches

EASTERN: Chairman Mr D G Bull FIOA, Hon Secretary Mr J M Hustwick MIOA
MIDLANDS: Chairman Mr J F Hinton MIOA, Hon Secretary Dr M E Fillery MIOA
LONDON: Chairman Mr J Simson MIOA, Hon Secretary Mr J G Miller MIOA
NORTH WEST: Chairman Mr P E Sacre MIOA, Hon Secretary Ms N Alexander MIOA
SCOTTISH: Chairman Mr P J Corbishley MIOA, Hon Secretary Mr R B McLaughlin MIOA
SOUTHERN: Chairman Mr G A Parry MIOA, Hon Secretary Dr I H Flindell MIOA
SOUTH WEST: Chairman Mr N J Pittams MIOA
YORKSHIRE & HUMBERSIDE: Chairman Mr R F Scott MIOA, Hon Secretary Mr J Bickerdike FIOA

Table 6. Institute Personnel at 31 December 1995

Honorary Fellowship

Citation: Professor Derek Sugden

Professor Derek Sugden studied Civil and Structural Engineering at Westminster Technical College prior to joining Ove Arup and Partners in 1953, becoming a founder Partner of Arup Associates in 1963 and a founder Principal of Arup Acoustics in 1980.

The design of the Maltings Concert Hall, Snape, for the composer Benjamin Britten, provided the opportunity for Derek to combine his engineering skills with his love of music and architecture and led to his specialising in the acoustic design and analysis of auditoria. Since then, his opinions and design expertise have been sought in respect of many major existing and proposed concert halls, opera houses, recital rooms and recording studios both in the UK and worldwide.

In recent years, he has worked with his colleagues at Arup Acoustics to advance the understanding of good acoustic design, by analysing existing auditoria and employing computer aided design and physical scale modelling techniques. This has led to such successes as the Britten Opera Theatre and the new Glyndebourne Opera House. A successful outcome is anticipated too, for the Hallé Orchestra's new hall in Manchester which will soon be completed.

Derek has lectured in the UK, Europe and America, and has published many papers on the subject of structures with particular reference to aesthetics, design and historical development as well as the acoustics of auditoria. He is visiting Professor at the Bartlett School of Architecture, Company of Designers Professor at the School of Architecture, Polytechnic of the South-West, and is Chairman of the Building Centre Trust.

Derek is a Chartered Engineer, a Member of the Institution of Civil Engineers, the Institution of Structural Engineers, the Institute of Acoustics, and the Institute of Welding, and an Honorary Fellow of the Royal Institute of British Architects.

The Institute of Acoustics is pleased to award an Honorary Fellowship to Derek Sugden for his contributions to the understanding, design and teaching of architectural acoustics.

Report

NATO/CCMS Pilot Study on the Effects of Public Works Projects on the Environment

This study has brought together environmental experts from the USA, Spain, Portugal, Greece and the United Kingdom to consider the best environmental restoration methods available for mitigating the effects of major construction projects ranging from new roads and railways, dams and reservoirs to military training grounds. The study was headed up by the Spanish delegation and has taken four years of regular meetings prior to publication of the final report which is 130 pages long. It includes advice on preventive and recovery measures, institutional measures for environmental stewardship, characteristics of the physical environment, measures and actions for habitat restoration, tools of environmental restoration etc. The study also includes chapters on legal and policy aspects as well as seven practical case studies.

For those interested in copies of the report or discussing any particular aspects of the work he can be contacted on 01235 821888.

Journals

Journals from Russia

Two journals, until recently published only in Russian, and produced by leading experts in the field of acoustics, are now available in English.

'Technical Acoustics', published by the East European Acoustical Association, is designed to keep scientists and engineers abreast of the latest developments in the field. It will interest anyone connected with aircraft, vehicles, ships, industry or buildings.

The topics covered include architectural and building acoustics, hydroacoustics, medical and musical acoustics, ultrasonic techniques, as well as industrial and transportation noise and vibration, There are four issues a year.

'Noise Abstracts and Reviews' is the cooperative effort of several groups including the Noise and Vibration Control Society of St Petersburg and the Russian Institute of Scientific and Technical Information, Moscow. This journal deals with both theoretical and applied noise control topics. Each issue includes a feature article, news of major developments in noise and vibration control, and also abstracts of a wide range of papers from all over the world. There are six issues a year.

The Russian scientists concerned are keen to make contacts with their colleagues in Europe, and in the longer term they would like to develop editorial connections as well.

If you are interested in more information, please contact Imogen Bright, 21 Weedon Lane, Amersham, Bucks HP6 5QT. Tel and Fax 01494 726069.

New Products

CEL INSTRUMENTS LTD

WindowsTM Software for RTA's

CEL Instruments have announced a series of WindowsTM software programs for their range of Real-Time Sound Analysers.

The 'Soundtrack Software Library' contains four software titles (dB1 to dB4) to enable data from the analysers' applications to be downloaded to a computer.

The dB1 Control program carries out two functions; it enables a CEL analyser to be controlled via a computer and stored data to be downloaded. The control function allows the selection of mode, bandwidth, user set-up, measurement range and the measurement start and stop facility.

Download includes an option to export data files in standard Lotus 1-2-3 (.wk1) file format for further processing.

Each of the other three are used to download and manipulate data from particular applications. dB2 will enable data saved for the analysers' Sound Level Meter, Environmental and Event modes to be downloaded to a computer. The software produces level versus time graphs or spectra and is provided with two cursors and a zoom function.

dB3 carries out a similar role for the analysers' 'Faststore' application. 'Faststore' provides very fast data capture; down to 5ms in Broad band and 10 ms in Octave or $1/3$ Octave band mode.

dB4 will download and manipulate data from the Building Acoustics application. This will display reverberation time profiles of selected decays and recalculates selected reverberation time using the least squares or first point methods. Calculation of the single number rating values to ISO and ASTM standards are included.

All of the programs incorporate a facility to enable graphs and alpha-numeric data to be exported or cut and pasted into other WindowsTM software programs and a full word processing facility is included for the creation of customised reports.

A 'Soundtrack' demonstration disk (3.5 inch HD format) is available that illustrates the features and user friendliness of the programs. Individual disks are also available for each of the four software programs.

Copies of the disks and a data sheet are available from CEL.

New CEL Noise Dosimeters

The 1996 edition of the CEL Instruments catalogue contains details of noise and vibration measurement instruments for industry, environmental issues and for product development.

This issue introduces the new CEL 'Millennium' product range. This is a series of instruments that have been designed to meet the needs of noise measurement legislation into the next century.

Heading the introduction of the 'Millennium' series are two new dosimeters. The CEL-420 and 460 dosimeters employ a 'Quick Measurement Start' formula which means that a preset range of measurement criteria (European or US) can be selected for a measurement sequence with the minimum of button pushing. The instruments also have on-board memories which automatically store and arrange the data in a set format enabling comprehensive, hard copy reports to be generated by connecting the dosimeters to printers and selecting the 'PRINT' instruction. The same data can also be downloaded to computers using CEL's WindowsTM based software, for the preparation of customised reports.

Copies of the catalogue can be obtained by contacting:

CEL Instruments Ltd, 35 – 37 Bury Mead Road, Hitchin, Herts SG5 1RT Tel: 01462 422411 Fax: 01462 422511.

CEL Instruments is a Key Sponsor of the Institute

PLYGLASS plc

WHISPERPLY

WHISPERPLY is a new safety glass to combat environmental noise.

Plyglass has invested in new technology and plant at its Derbyshire manufacturing centre to make this noise reducing safety laminated glass. Because Whisperply is a safety glass it can be installed in virtually any external window or internal glazing where the protection of people and property are regulated by health and safety standards.

Whisperply has a specially formulated sound-deadening membrane bonded between two plates of glass. Where even higher levels of noise control are required a heavier gauge Whisperply is available. The new glass can also be used in the company's ISOPLY insulating glass units ('double glazing'), which can be filled with special inert gas to provide even further noise reducing performance.

For further information contact Paul Doyne-Ditmas at Pyglass plc, Cotes Park, Somercotes, Derbyshire DE55 4PL Tel: 01773 520000 Fax: 01773 520052/3/4.

CASTLE GROUP LTD

GA 111 Personal Exposure Meter and Integrating Sound Level Meter

The Castle GA111 Combined Personal Exposure Meter and Integrating Sound Level Meter is encased in a small and lightweight, yet very tough body designed to fit neatly into your pocket or clip easily onto a belt. It is a sophisticated, yet easy to use data-logging instrument which can store up to 5 sets of logged data. These include daily personal exposure ($L_{EP,d}$), time average (L_{eq}), daily percentage exposure (DOSE) as well as hourly DOSE and projected 8 hour $L_{EP,d}$ and DOSE. It also records the Maximum noise level (L_{max}), any peak noise above the legislated peak action level (L_{peak}), along with a 115dB RMS trigger, and Pa^2/hr. These results can then simply be output directly to a printer or downloaded into a PC for further analysis. The GA111 will also log all the results as either an Integrating Sound Level Meter or a Personal Noise Exposure Meter.

Simply by unplugging the Sound Level Meter Microphone and plugging in a Dosimeter microphone the conversion is made. This means that you can use the one meter for 2 different jobs.

A full kit, the FK017, is available that includes the GA111, the Dosimeter microphone cable, a GA602 calibrator, the GA503 printer and cable and a very tough kit case with a pen and screwdriver, everything you would need in one useful case.

For further information contact: Simon Bull or Stephen Cavanagh, Castle Group Ltd, Salter Road, Scarborough, North Yorkshire, YO11 3UZ. Tel: 01723 584250 Fax: 01723 583728.

ILLBRUCK LTD

illtecFM

illbruck Ltd, suppliers of room acoustic and industrial sound protection products, have introduced a new sound absorptive material. illtecFM is the result of considerable investigation into market demands for fibre-free sound absorptive materials. The new self coloured illtecFM in mid or charcoal grey, is both lightweight and fire resistant. Being completely fibre free it overcomes the traditional fibre migration problems associated with more recognised products which require facing or encapsulation.

Cut into sheet form and lain on the back of perforated metal ceilings, illtecFM achieves equivalent absorption to that obtained by traditional materials 2.5 times thicker with a saving in weight of over 30%.

When produced in thicker sections it may be used as a liner for air handling or attenuator/silencer systems. As a suspended absorber it has an ingenious inverted 'T' cut into its upper edge into which a conventional suspended ceiling T bar is inserted for speedy and labour saving suspension.

Further information from Paul Durham UK Technical Sales Manager, illbruck Ltd, Croesfoel Industrial Park, Rhostyllen, Wrexham, Clwyd LL14 4BJ Tel: 01978 264444 Fax: 01978 291333.

BSD STEEL SERVICES CENTRE

Sontech composite panels

Following extensive research and development into noise reducing composite panels, BSD, the steel services centres arm of British Steel, is now marketing sound deadened steels for a wide range of manufacturing applications.

The company's interest in sound damping for metal structures, and its investment in plant and equipment for production of its new material Sontech, arose from close manufacturing partnerships with customers in the automotive and other industries where vibration and noise control has long been a concern.

Supported by British Steel's Welsh and Swindon Technology Centres, BSD's Sontech is produced with two skins of steel separated by a thin layer of visco-elastic polymer, which can provide maximum damping at specific temperatures. Its properties allow it to absorb noise-producing energy by converting shear strain to negligible heat. The higher the strain which is transferred to the polymer, the higher the energy dissipation.

Shear strain is generated by vibration of the composite producing relative movement between the top and bottom sheets causing energy absorption in the layer.

Comparison tests with undamped steel have shown fewer and lower broad-based resonance peaks for Sontech which indicates a higher level of damping over a wide range of frequencies – noise reductions of up to 30 dB have been achieved.

Technical information on engineering properties, fabrication, forming, drawing and welding can be obtained from BSD Steel Service Centres, Product Development, Walker Industrial Estate, Walker Road, Guide, Blackburn BB1 2IJ. Tel: 01254 55161 Fax: 01254 678263.

PROSIG COMPUTER CONSULTANTS LTD

P4400 data acquisition system

Prosig are pleased to announce the availability of their new P4400 data acquisition system which they believe to be the most versatile and cost effective true parallel processing system available today.

The P4400 is equally at home in a vehicle or on the workbench. It has advanced acquisition, analysis and report generation software which provides engineers with an extremely effective solution for a wide variety of testing applications.

Each channel of the P4400 has its own dedicated analogue to digital converter allowing true simultaneous sampling at rates of up to 100,000 samples a second per channel.

The portable version of the P4400 comes in a strong compact enclosure housing up to 32 channels of complete acquisition electronics. It operates from a nominal 12 volt DC power supply with internal battery backup to cover short power outages and more importantly to complete and save data acquisitions until power is restored. There are no fans so that the system is ideal for noise work involving microphones.

Another unique feature of the P4400 is that it is able to recognise individual transducers and where available interrogate a database to provide full QA control of testing.

Signal conditioning for most types of resistive and ICP transducers is included. Software programmable amplifiers, filters, offset control, transducer excitation and calibration facilities are all standard features.

The P4400 is further enhanced by a very comprehensive software suite for acquisition, analysis and display and includes industry specific packages for bio-mechanics, noise, vibration and harshness and rotating machinery analysis.

The P4400 is supplied with a smart carry case and is compact enough to be carried on board an aircraft as hand luggage.

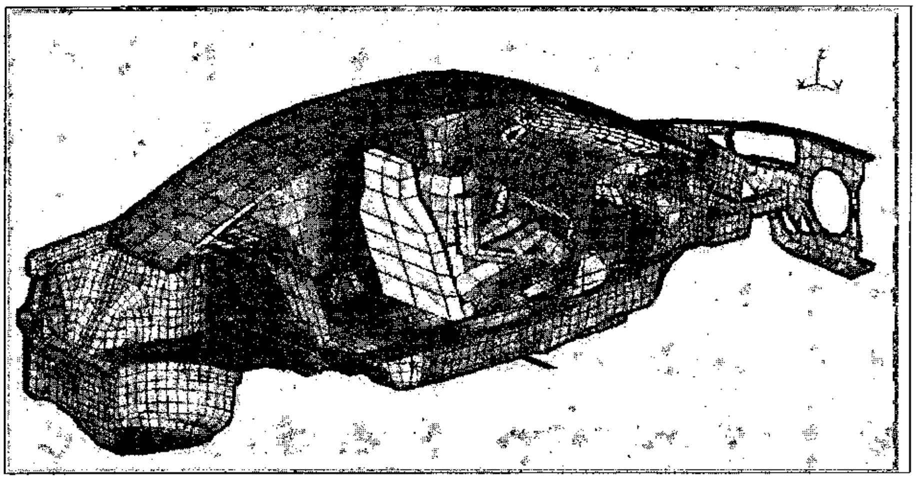
The P4400 is manufactured and marketed by Prosig Computer Consultants Limited, Link House, High Street, Fareham, Hampshire, PO16 7BQ. Tel: 01329 239925 Fax: 01329 239159, email sales@prosig.demon.co.uk

LMS UK

New software for predictive acoustics

Numerical Integration Technologies, an operating company of Leuven Measurement & Systems (LMS) Belgium, has released the latest revision 5.3 of their SYSNOISE software for acoustic modelling, and a new program MOSART (Modelling Of Sound with Advanced Ray-Tracing). SYSNOISE Revision 5.3 includes new features and algorithms, bypasses restrictions found in other formulations and has enhanced solution speed and a flexible model and results database architecture. MOSART embodies a new approach to modelling sound fields at mid and high frequencies and is suitable for interior and exterior noise and transmission between regions such as different compartments in a vehicle.

New features of SYSNOISE include major enhancements to the boundary element acoustics capabilities, a Generalized BE module, which eliminates all restrictions on boundary conditions and allows combinations of conditions such as



vibration and surface impedance (absorption treatment) and transmission through elements. A multi model architecture enables the coupling of finite element and boundary element models of acoustic and structural sub-systems. Infinite elements can be used to model exterior noise radiation as an alternative to BE methods, mean flow of the acoustic fluid can be added in certain cases, and random acoustic excitation can be applied.

MOSART is fully-integrated into the SYSNOISE graphical environment for modelling and presentation of results. It accurately predicts the sound field and acoustic comfort parameters in car compartments, aircraft cabins, railway vehicles and other structures, in the mid- and high-frequency ranges where other numerical methods are ineffective. Even at lower frequencies, MOSART gives good correlation with other methods such as BE models. MOSART allows multiple compartment analyses, with panels with transmission as well as absorption, reflection and diffusion properties.

The new SYSNOISE and MOSART programs take numerical methods for predictive acoustics to a new level of functionality, enabling vehicle NVH engineers, designers and analysts in aerospace, marine, defence, consumer goods and other industries to identify and eliminate noise problems and optimize acoustic performance up-front in the development, prototyping and refinement process.

For further information contact: Colin McCulloch, Manager, Predictive Software LMS UK, Westwood House, Westwood Way, Coventry CV4 8HS. Tel: 01203 474700, Fax: 01203 471554, email: info@lms uk.mhs.compuserve.com

News Items

BRITISH GYPSUM & ISOVER

New force in insulation market

In a move which has major implications for the UK insulation market British Gypsum has established a new joint venture with French company Isover Saint-Gobain to manufacture and supply insulation products to the UK construction industry. The new company will have the benefit of the massive technical, marketing and product development resources of two of the world's leading building products companies.

The new company, to be called British Gypsum-Isover Ltd, will incorporate all of British Gypsum's existing glass wool insulation business. The joint venture company is an equal partnership between British Gypsum and Isover with its management team drawn from both companies. Paul Withers will be appointed managing director of the new company and will also retain his position as deputy managing director of British Gypsum Ltd.

Commenting on the formation of the new company Paul Withers said, 'Our customers will see a stronger company backed by the full commitment of both British Gypsum and Isover. The joint venture will be able to supply the full range of structural as well as industrial insulation products, which will be further improved through a planned investment programme. Customers will see no change in their day-to-day contact, orders will continue to be taken on our freephone system, the current sales representatives will continue to support the same customers and the Technical Services Department at East Leake will continue to resolve technical queries.'

The share capital of British Gypsum-Isover is divided equally between the joint venture partners with a commitment from both for investment funding on a 50–50 basis. In addition British Gypsum will be providing a sales and marketing infrastructure linked to its existing service. Isover will provide new technology under a license agreement to the new company.

It is hoped that the joint venture will start in July following clearance from the European Merger Control Unit.

For further information contact Liam Herbert, Osborne Public Relations, Corbar Hall, Corbar Road, Buxton, Derbyshire SK17 6TF Tel: 01298 26224 Fax: 01298 24870.

SANDY BROWN ASSOCIATES

The Lowry Centre: Britain's Millennium Jewel for Visual and Performing Arts

Sandy Brown Associates have been appointed as the acoustic consultants for The Lowry Centre, one of six national landmark projects, and the first purpose built cultural centre in the UK combining the performing and visual arts. It includes:

- A gallery displaying the world's largest collection of paintings and drawings by L S Lowry and incorporating the Lowry Study Centre.
- A 1650 seat theatre which will be capable of staging world class performances of opera, ballet and drama.
- A 400 seat flexible theatre for community theatre/activity.
- Britain's first children's hands-on gallery enabling young people to learn and experience all aspects of the world of the arts.
- The National Industrial Centre for Virtual Reality, created in partnership with Salford University on an adjacent site.
- A Plaza to provide a welcoming focus to the public.

The extended site will incorporate commercial and leisure development and a new bridge across the Manchester Ship Canal, which forms the waterfront of Salford Quays.

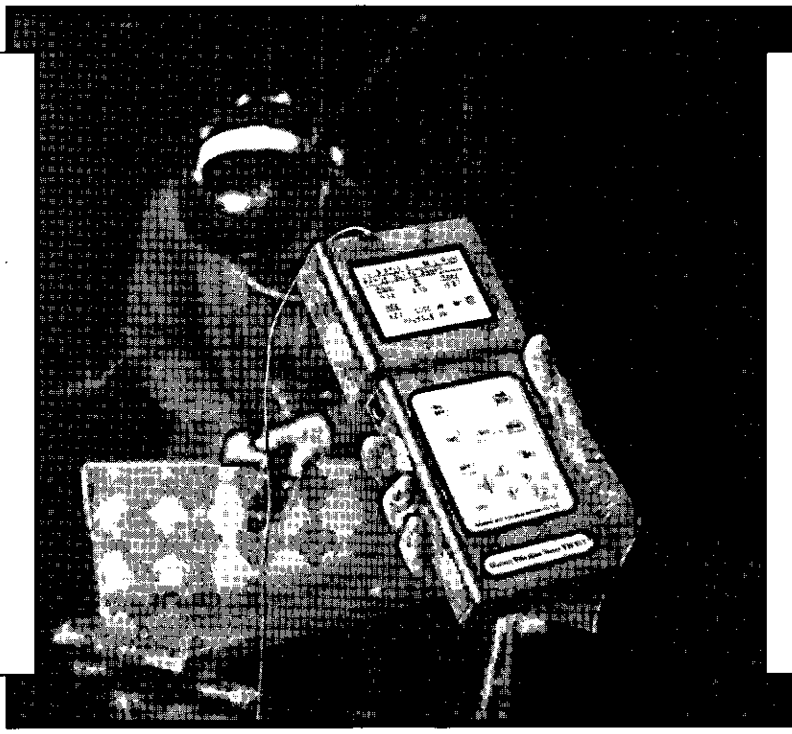
The Lowry Centre, designed by architects Michael Wilford and Partners, will be completed during the year 2000.

Items for this section should be sent to John Sargent at the Building Research Establishment, Garston, Watford, Herts WD2 7JR ❖

The World's First

Dedicated Hand Arm Vibration Meter.

E.P.M. is proud to announce the world's first dedicated Hand Arm Vibration Meter. The VIS-015 is designed specifically to meet the proposed European Union Physical Agents Directive.



Frequency Weightings to the requirements and accuracy of ISO 8041

Displayed in accordance with ISO 5349

Three Measurement Ranges

Designed to measure Hand Arm Vibration levels in accordance with Health and Safety requirements and the E.U.P.A.D., the Human Vibration Meter will give measurement of both instantaneous vibration levels and the equivalent 8 hour exposure.

Includes Real Time Clock and Profile.

Allows 7 separate vibration measurements to be collected in each Run then gives the user options to enter exposure time for all relevant measurements and combine them to give the overall daily exposure in an easy to use program routine.

European Process Management Ltd

Newby House, 309 Chase Road, Southgate, London N14 6JL.

Tel 0181 882 6633 Fax 0181 882 6644