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contents

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Dear Fellow Member

This month the acoustics world lost a distinguished acoustician and the Institute a warmly respected Honorary Fellow with the death of Professor Elfyn Richards. The Institute of Sound and Vibration Research at Southampton owes its formation and early success to the efforts of Professor Richards; an obituary appears in this issue.

The 1995 Autumn Conference incorporates a new and interesting format this year with a Noise and Vibration School. Ten practical exercises have been developed to elucidate problems encountered in field measurements and delegates will be assisted by experts in each of the fields. There will also be workshop discussions and the usual wide-ranging array of papers. I look forward to seeing many of you in Windermere once more.

While on the subject of conferences I might mention the two other major meetings before Christmas. During November Reproduced Sound 11 is set to once again fill the Windermere Hydro Hotel while in December another international conference on Sonar Signal Processing will be held in Loughborough under the auspices of the Underwater Acoustics Group.

However, all these pale into insignificance beside the long-term planning for inter-noise 96. Representatives of the organising committee attended the 1995 congress in Newport Beach, California, to publicise next year's event in Liverpool and our planning committee are already working hard. There is an army of special session organisers already beavering away around the world assembling what I am sure will be an impressive programme, while the detail design of the exhibition and meeting rooms is well in hand. A progress report is given in this issue.

The Institute is well into the final stages of organising our CPD scheme which will start on a voluntary basis next year. It is hoped that Regional Branches will play a major role in support of the scheme. Council is presently reviewing the final draft of the document that sets out the ground rules.

Sincerely yours

Alex Burd

Alex Burd

LARGE VOCABULARY SPEECH RECOGNITION

Steve Young FIOA

Introduction

Considerable progress has been made in speech recognition technology over the last few years and nowhere has this progress been more evident than in the area of Large Vocabulary Recognition (LVR). Current laboratory systems are capable of transcribing continuous speech from any speaker with average word error rates of between 5% and 10%. If speaker adaptation is allowed then after 2 or 3 minutes of speech, the error rate will drop well below 5% for most speakers.

Hitherto, LVR systems have been limited to dictation applications since they were speaker dependent and they required words to be spoken with a short pause between them. The capability to recognise natural continuous speech input from any speaker, however, opens up many more applications and as a result LVR technology appears to be on the brink of widespread deployment across a range of IT systems.

This article will describe the principles and architecture of current LVR systems, particularly the Cambridge University HTK system which is a modern design giving state-of-the-art performance [1, 2].

System Overview

Current LVR systems are firmly based on the principles of statistical pattern recognition. The basic framework for applying these principles to the problem of speech recognition was described by Jelinek and his colleagues from IBM in the 1970s [3, 4] and little has changed since. Figure 1 illustrates the main components of an LVR system.

An unknown speech waveform is converted by a front-end signal processor into a sequence of acoustic vectors, $Y = y_1, y_2, \ldots\ldots y_T$. Each of these vectors is a compact representation of the short-time speech spectrum covering a period of typically 10 ms. Thus, an average ten word utterance might have duration of around 3 seconds and would be represented by a sequence of around T = 300 acoustic vectors.

The utterance consists of a sequence of words $W = w_1, w_2, \ldots\ldots w_n$ and it is the job of the LVR system to determine the most probable word sequence $\hat{W}$ given the observed acoustic signal Y. To do this, Bayes' rule is used to decompose the required probability $P(W|Y)$ into two components, that is,

$$\hat{W} = \arg_W \max P(W|Y) = \arg_W \max \frac{P(W)P(Y|W)}{P(Y)} \quad (1)$$

This equation tells us that to find the most likely word sequence W, we must find the word sequence which maximises the product of $P(W)$ and $P(Y|W)$. The first of these terms represents the *a priori* probability of observing W independent of the observed signal and this probability is determined by a *language model*. The second term represents the probability of observing the vector sequence Y given some specified word sequence W and this probability is determined by an *acoustic model*.

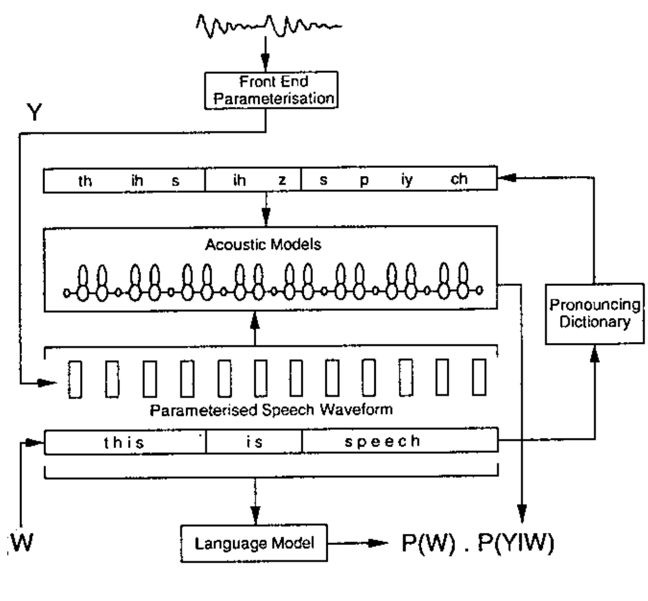

Fig. 1. Overview of Statistical Speech Recognition

Figure 1 shows how these relationships might be computed. A word sequence W = 'This is speech' is postulated and the language model computes its probability $P(W)$. Each word is then converted into a sequence of basic sounds or *phones* using a pronouncing dictionary. For each phone there is a corresponding statistical model called a hidden Markov model (HMM). The sequence of HMMs needed to represent the postulated utterance are concatenated to form a single composite model and the probability of that model generating the observed sequence Y is calculated, this is the required probability $P(Y|W)$. In principle, this process can be repeated for all possible word sequences and the most likely sequence selected as the recogniser output.

To convert the above design philosophy into a practical system requires the solution of a number of challenging problems. Firstly, a front-end parameterisation is needed which can extract from the speech waveform all of the necessary acoustic information in a compact form compatible with the HMM based acoustic models. Secondly, the HMM models themselves must accurately represent the distributions of each sound in each of the many contexts in which it may occur. Furthermore, the HMM parameters must be estimated from data and it will never be possible to obtain sufficient data to cover all possible contexts.

Thirdly, the language model must be designed to give accurate word predictions based on the preceding history. However, as for the HMMs, data sparsity is an ever-present problem and the language model must be able to deal with word sequences for which no examples occur in the training data. Finally, the process outlined above for finding $\hat{W}$ by enumerating all possible word sequences is clearly impractical. Instead, potential word sequences are explored in parallel, discarding hypotheses as soon as they become improbable. This process is called *decoding* and the design of efficient decoders is crucial to the realisation of practical LVR systems capable of fast and accurate operation on today's computing platforms.

The next four sections of this article deal with each of these issues in more detail.

Front-End Parameterisation

A key assumption made in the design of current recognisers is that the speech signal can be regarded as stationary over an interval of a few milliseconds. Thus, the prime function of the front-end parameterisation stage is to divide the input speech into blocks and from each block derive a smoothed spectral estimate. The spacing between blocks is typically 10 ms and blocks are normally overlapped to give a longer analysis window, typically 25 ms. As with all processing of this type, it is usual to apply a tapered window function (eg Hamming) to each block. Also the speech signal is often pre-emphasised to compensate for the attenuation caused by the radiation from the lips.

The required spectral estimates may be computed via Linear Prediction or Fourier analysis and there are a number of additional transformations that can be applied in order to generate the final acoustic vectors. To illustrate one typical arrangement, Figure 2 shows the front-end of the HTK Recogniser which generates Mel-Frequency Cepstral Coefficients (MFCCs) [5].

To compute MFCC coefficients, the Fourier spectrum is smoothed by integrating the spectral coefficients within triangular frequency bins arranged on a non-linear scale called the *Mel-scale*. For 8 kHz bandwidth speech, the HTK Recogniser uses 24 of these triangular frequency bins. The Mel-scale is designed to approximate the frequency resolution of the human ear, but more importantly, its use has been shown empirically to improve recognition accuracy. In order to make the speech power spectrum approximately Gaussian, log compression is applied to the filter-bank output.

The final processing stage is to apply the Discrete Cosine Transform (DCT) to the log filter-bank coefficients. This has the effect of compressing the spectral information into the lower order coefficients and it also decorrelates them allowing the subsequent statistical modelling to use diagonal covariance matrices. In the HTK Recogniser, the signal energy plus the first 12 cepstral coefficients are retained to form a basic 13-element acoustic vector.

As will be discussed in the next section, the acoustic modelling assumes that each acoustic vector is uncorrelated with its neighbours but this is clearly a poor assumption. However, a simple and effective way to mitigate its effects is to append the first and second order differentials to the basic static coefficients. In the HTK Recogniser, these are approximated by fitting a linear regression over a window covering the two preceding and two following vectors. When this is done, the final acoustic vector has 39 components.

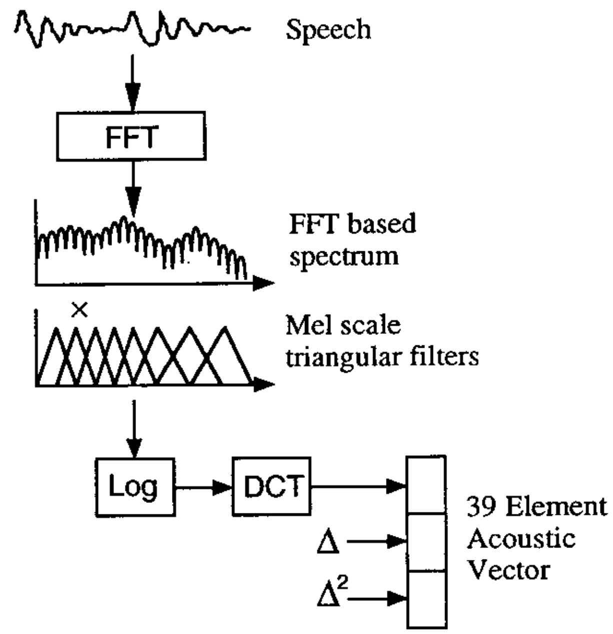

Fig. 2. MFCC-based Front-End Processor

Acoustic Modelling

The purpose of the acoustic models is to provide a method of calculating the likelihood of any vector sequence **Y** given a word *w*. In principle, the required probability distribution could be found by finding many examples of each *w* and collecting the statistics of the corresponding vector sequences. However, this is impractical for large vocabulary systems and instead, word sequences are decomposed into basic sounds called *phones*.

Each individual phone is represented by a hidden Markov model (HMM). A HMM has a number of states connected by arcs. HMM phone models typically have three *emitting* states and a simple left-right topology as illustrated by Figure 3. The entry and exit states are provided to make it easy to join models together. The exit state of one phone model can be merged with the entry state of another to form a composite HMM. This allows phone models to be joined together to form words and words to be joined together to cover complete utterances.

A HMM is most easily understood as a generator of vector sequences. It is a finite state machine which

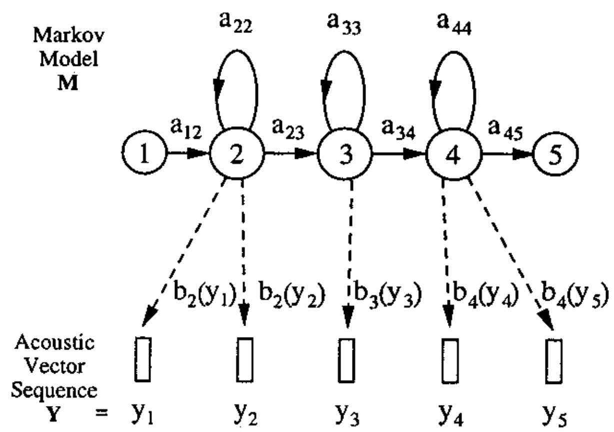

Fig. 3. HMM-based Phone Model

changes state once every time unit and each time t that a state j is entered, an acoustic speech vector $\mathbf{y}_t$ is generated with probability density $b_j(\mathbf{y}_t)$. Furthermore, the transition from state i to state j is also probabilistic and is governed by the discrete probability a_{ij}.

Figure 3 shows an example of this process where the model moves through the state sequence $X = 1, 2, 2, 3, 4, 4, 5$ in order to generate the sequence $\mathbf{y}_1$ to $\mathbf{y}_5$.

The joint probability of a vector sequence $\mathbf{Y}$ and state sequence X given some model M is calculated simply as the product of the transition probabilities and the output probabilities. So for the state sequence X in Figure 3

$$P(\mathbf{Y},X|M) = a_{12}b_2(\mathbf{o}_1)a_{22}b_2(\mathbf{o}_2)a_{23}b_3(\mathbf{o}_3) \ldots \quad (2)$$

In practice, of course, only the observation sequence $\mathbf{Y}$ is known and the underlying state sequence X is hidden. This is why it is called a *Hidden Markov Model*. However, the required probability $P(\mathbf{Y}|M)$ is easily found by summing over all possible state sequences. An efficient recursive method of performing this calculation is available called the *Forward-Backward* algorithm. A crucial feature of this algorithm is that it also allows the probability of being in a specific model state at a specific time to be calculated. This leads to a very simple and efficient procedure called the *Baum-Welch* algorithm for finding Maximum-Likelihood estimates of both the a and b HMM parameter sets. Parameter estimation is beyond the scope of this article but it is important to note that the existence of Baum-Welch has been a key factor in making HMMs the dominant technology in acoustic modelling.

The choice of output probability function is crucial since it must model all of the intrinsic spectral variability in real speech, both within and across speakers. Early HMM systems used discrete output probability functions in conjunction with a vector quantiser. Each incoming acoustic vector was replaced by the index of the closest vector in a precomputed codebook and the output probability functions were just look-up tables containing the probabilities of each possible VQ index. This approach is computationally very efficient but the quantisation introduces noise which limits the precision that can be obtained. Hence, modern systems use parametric continuous density output distributions which model the acoustic vectors directly, the commonest choice of distribution being the multivariate mixture Gaussian [6].

So far there has been an implicit assumption that only one HMM is required per phone, and since approximately 45 phones are needed for English, it may be thought that only 45 phone HMMs need be trained. In practice, however, contextual effects cause large variations in the way that different sounds are produced. Hence, to achieve good phonetic discrimination, different HMMs have to be trained for each different context. The simplest and most common approach is to use *triphones* where every phone has a distinct HMM model for every unique pair of left and right neighbours. For example, suppose that the notation **x – y + z** represents the phone **y** occurring after an **x** and before a **z**. Then the phrase, 'Beat it!' would be represented by the phone sequence **sil b iy t ih t sil**. If triphone HMMs were used then the sequence would be modelled as

sil sil – b + iy b – iy + t iy – t + ih t – ih + t ih – t + sil sil.

Notice that the triphone contexts span word boundaries and the two instances of the phone **t** are represented by different HMMs because their contexts are different. This use of so-called *cross-word triphones* gives the best modelling accuracy but leads to complications in the decoder as discussed later. Simpler systems result from the use of *word-internal triphones* where the above example would become

sil b + iy b – iy + t iy – t ih + t ih – t sil.

Here far fewer distinct models are needed simplifying both the parameter training problem and decoder design. However, the cost is an inability to model contextual effects at word boundaries and in fluent speech these are considerable.

The use of Gaussian mixture output distributions allows each state distribution to be modelled very accurately. However, when triphones are used they result in a system which has too many parameters to train. For example, a large vocabulary cross-word triphone system will typically need around 60,000 triphones[1]. In practice, around 10 mixture components gives good performance in LVR systems. Assuming that the covariances are all diagonal, then the HTK recogniser with its 39 element acoustic vectors would require 790 parameters per state. Hence, 60,000 3-state triphones would have a total of 142 million parameters.

The problem of too many parameters and too little training data is absolutely crucial in the design of a statistical speech recogniser. Early systems dealt with the problem by using conventional statistical smoothing techniques but more recently an alternative approach based on parameter tying, and in particular state-tying has become popular [7, 8]. The idea here is to tie together states which are acoustically indistinguishable. This allows all the data associated with each individual state to be pooled and thereby give more robust estimates for the parameters of the tied-state. This is illustrated in Fig-

ure 4. At the top of the figure, each triphone has its own private output distribution. After tying, several states share distributions.

In the HTK recogniser, the choice of which states to tie is made using *phonetic decision trees.* This involves building a binary tree for each phone and state position. Each tree has a yes/no phonetic question such as 'Is the left context a nasal?' at each node. Initially all states for a given phone state position are placed at the root node of a tree. Depending on each answer, the pool of states is successively split and this continues until the states have trickled down to leaf-nodes. All states in the same leaf node are then tied. For example, Figure 5 illustrates the case of tying the centre states of all triphones of the phone /aw/ (as in 'out'). All of the states trickle down the tree and depending on the answer to the questions, they end up at one of the shaded terminal nodes. For example, in the illustrated case, the centre state of **s – aw + n** would join the second leaf node from the right since its right context is a central consonant, and its right context is a nasal but its left context is not a central stop.

The questions at each node are chosen to maximise the likelihood of the training data given the final set of state tyings. In practice, phonetic decision trees give compact good-quality state clusters which have sufficient associated data to robustly estimate mixture Gaussian output probablity functions. Furthermore, they can be used to synthesise a HMM for any possible context whether it appears in the training data or not, simply by descending the trees and using the state distributions associated with the terminating leaf nodes. Finally, phonetic decision trees can be used to include more than simple triphone contexts. For example, the HTK recogniser can use questions spanning ± 2 phones and can also take account of the presence of word boundaries.

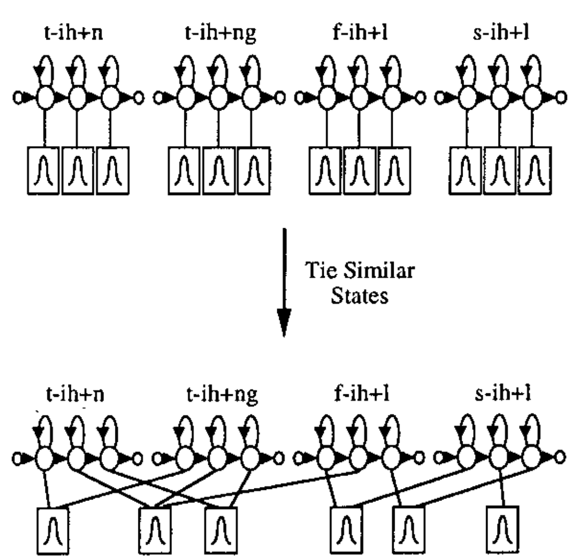

Fig. 4. State Tying

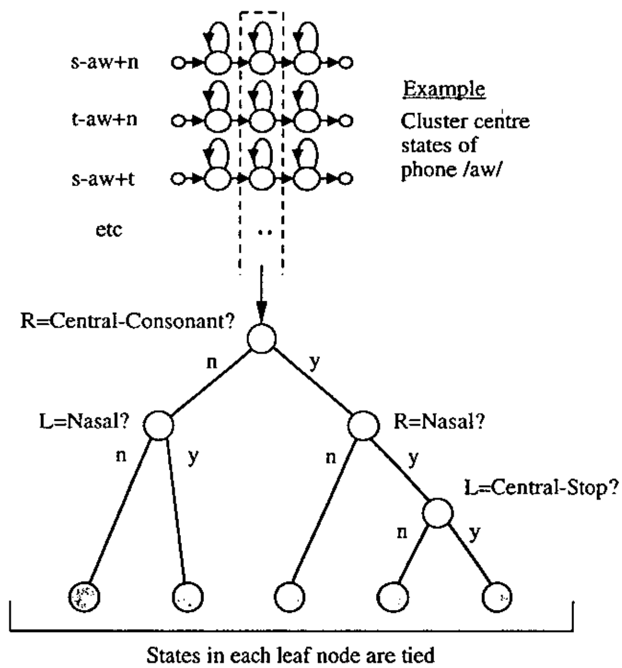

Fig. 5. Decision Tree Clustering

Language Modelling

The purpose of the language model is to provide a mechanism for estimating the probability of some word w_k in an utterance given the preceding words $W_1^{k-1} = w_1 \ldots\ldots w_{k-1}$. A simple but effective way of doing this is to use N-grams in which it is assumed that w_k depends only on the preceding $n - 1$ words, that is

$$P\left(w_k \mid W_1^{k-1}\right) = P\left(w_k \mid W_{k-n+1}^{k-1}\right) \tag{3}$$

N-grams simultaneously encode syntax, semantics and pragmatics and they concentrate on local dependencies. This makes them very effective for languages like English where word order is important and the strongest contextual effects tend to come from near neighbours. Furthermore, N-gram probability distributions can be computed directly from text data and hence there is no requirement to have explicit linguistic rules such as a formal grammar of the language.

In principle, N-grams can be estimated from simple frequency counts and stored in a look-up table. The problem, of course, is that for a vocabulary of V words, there are V^3 potential trigrams. Even for a very modest vocabulary of 10,000 words, this is a very large number. Thus, many trigrams will not appear in the training data and many others will only appear once or twice so there is an acute data sparsity problem.

The solution to training data sparsity is to use a combination of *discounting* and *backing-off* [9]. Discounting means that the trigram counts of the more frequently occurring trigrams are reduced and the resulting excess *probability mass* is redistributed amongst the less frequently occurring trigrams. Backing-off is applied when there are too few trigrams to form any estimate at all (eg just one or two occurrences in the training data). It involves replacing the trigram probability by a scaled bigram probability, that is

$$\hat{P}(w_k \mid w_{k-1}, w_{k-2}) = B(w_{k-1}, w_{k-2}) \hat{P}(w_k \mid w_{k-1}) \quad (4)$$

where B is a back-off function whose function is primarily to ensure that $\hat{P}(w_k \mid w_{k-1}, w_{k-2})$ is properly normalised.

Although robust estimation of trigram probabilities requires considerable care, the problems are soluble and good performance can be obtained. N-grams do have obvious deficiencies resulting from their inability to exploit long-range constraints such as subject-verb agreement. Nevertheless, no significantly better models have been found to date.

Decoding

The preceding sections have described the main components of a large vocabulary system. In order to perform recognition using these components, the sequence of words $\hat{W}$ must be found which maximises equation (1). This is a search problem and its solution is the domain of the decoder.

As with all search problems, there are two main approaches: *depth-first* and *breadth-first*. In depth-first designs, the most promising hypothesis is pursued until the end of the speech is reached. In breadth-first designs, all hypotheses are pursued in parallel. Breadth-first decoding exploits Bellman's optimality principle and is often referred to as *Viterbi decoding*. LVR systems are complex and pruning of the search space is essential, this typically uses a process called *beam search*. The HTK decoder uses beam search and Viterbi decoding [10].

To understand the decoding problem, imagine that a branching tree network is constructed such that at the start there is a branch to every possible start word. All first words are then connected to all possible follow words and so on. This is illustrated in part (a) of Figure 6. Clearly this tree will be very large but if extended deep enough it would in principle represent all possible sequences. At first sight, this representation might seem very extravagant. In small vocabulary systems, it is usually sufficient to put all words in parallel and place a loop around them. This allows all possible word sequences to be represented in a compact way since every vocabulary word appears only once. Unfortunately, however, such an arrangement does not allow a trigram language model to be used since the available history is limited to 1 word. Furthermore, a single loop back prevents cross-word triphones from being used. An explicit branching tree however allows both to be used in a straightforward manner.

Next let each word in this tree be replaced by the sequence of models representing its pronunciation. If there are multiple pronunciations then models can be joined in parallel within the word. Part (b) shows a fragment of the tree expanded into models. Finally, merge all identical phone models in identical contexts which have a common entry point as illustrated in part (c) of Figure 6. Notice here that the use of cross-word triphones significantly limits the amount of sharing of models possible.

The net result of the above is a branching tree of HMM state nodes connected by state transitions and word-end nodes connected by word transitions. Any path from the start node to some point in the tree can be evaluated by adding all the log state transition probabilities, all the log state output probabilities and the log language model probabilities. Such a path can be represented by a movable *token* placed in the node at the end of the path. The token has a *score* which is the total log probability up to that point and a *history* which records the sequence of word-end nodes that the token has passed through. Any path can be extended by moving the token from its current node to an adjoining node and updating its score according to the current state transition probability, state output probability and the language model probability, if any.

The search problem can now be recast in the form of a token passing algorithm. Initially, a single token is

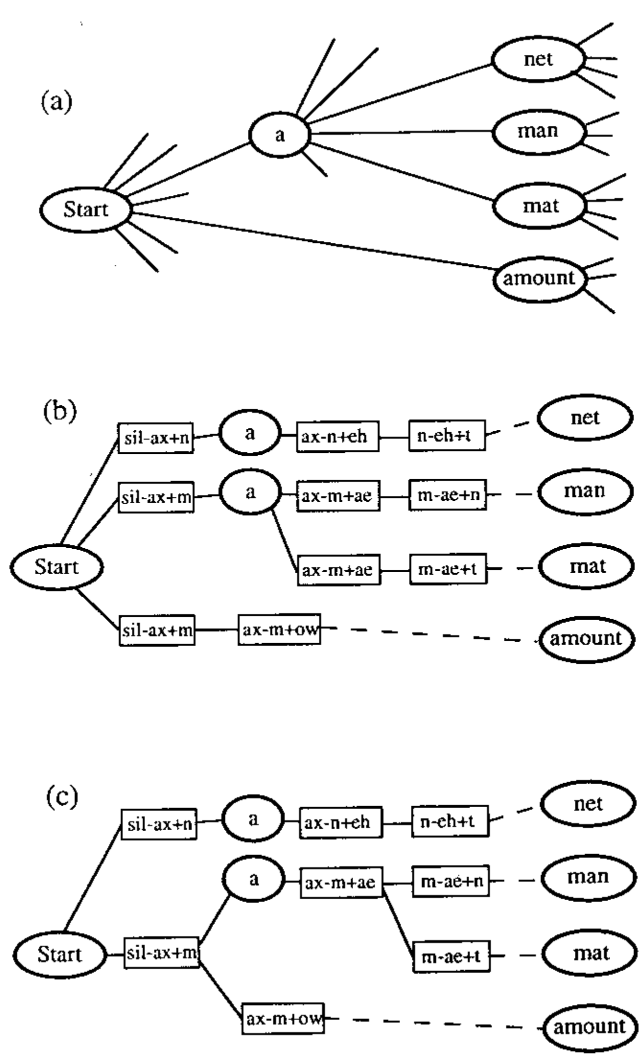

Fig. 6. Fragment of Decoder Network

placed in the start node of the tree. As each acoustic vector is input, every token is copied into all connecting nodes and the scores updated. If more than one token lands in a node only the best scoring token needs to be retained since, by Bellman's Optimality principle, all other tokens must lie on inferior paths. When all of the acoustic vectors have been processed, the word end nodes are scanned and the token with the highest score represents the most likely path and hence the most likely word sequence.

This basic token passing algorithm is guaranteed to find the best possible path but unfortunately, it would take too much time and space to compute. Hence, to make the algorithm tractable, pruning is employed. Every time frame, the best score in any token is noted and any token whose score lies more than a *beam-width* below this best score is destroyed. Since only the active tokens lying within the beam need to be kept in memory, only a fragment of the branching tree described above is ever needed at one time. As tokens move forward, new tree structure is created in front of them and old structure behind is destroyed.

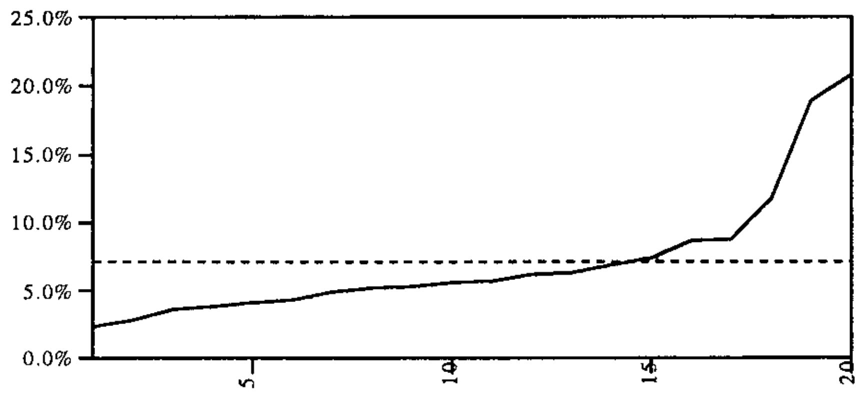

Fig. 7. Word Error Rate Plotted Against Speaker for the H1-P0 System on ARPA CSR November 1994 Evaluation Data (Dashed horizontal is average WER)

This dynamic network approach results in a decoder that can utilise arbitrarily long span language models and HMM phone models that depend on both the previous and succeeding acoustic context. Furthermore, it is simple to extend this decoder to generate a lattice of word hypotheses which can be used as input to more sophisticated processing units such as a natural language parser.

Current State of LVR

The major benchmarks for assessing the performance of LVR systems are the US Advanced Research Project Agency (ARPA) CSR Evaluations. The most recent of these was held in November 1994 [11]. The main focus of this evaluation was the so-called *hub test* H1 on which all 20 participating sites evaluated their systems. This hub test was split into two main parts: H1 – C1 in which the acoustic training data and a 20 k word trigram language model trained on 227 million words of news text were fixed; and H1 – P0 in which any acoustic or language model training data could be used. In H1 – C1 each utterance had to be recognised independently whereas in H1 – P0, each change of speaker was known so that unsupervised adaptation could be used.

Vocab Size	LM N-gram	Adapted	% Word Error
20 k	3	No	10.5*
65 k	3	No	8.2
65 k	4	No	7.9
65 k	4	Yes	7.2**

Table 1. HTK LVR Performance on ARPA CSR November 1994 Evaluation Data (* H1 – C1 test, ** H1 – P0 test)

The HTK LV Recogniser had the lowest error rate of any system tested in the November 1994 evaluation. Performance in terms of the percentage word error rate for a number of conditions (including H1 – C1 and H1 – P0) is shown in Table 1. As can be seen, the best performance achieved was 7.2%, that is, on average 7 words in every 100 were mis-transcribed. Although this figure is somewhat high, it is interesting to look at the error rates on a per speaker basis as shown in Figure 7 where the speakers have been ordered, based on their performance. This figure suggests that, at least for part of the population, useable performance is achievable now. Conversely, it also shows that to cover the majority of the population, better robustness and more effective adaptation is needed[2].

Conclusions

This article has reviewed the main components of a speaker-independent continuous speech large vocabulary recognition system and briefly described the state-of-the-art. Whilst it is clear that much more needs to be done before robust, general-purpose LVR is ubiquitous, the technology is nevertheless on the threshold of usefulness for practical applications. Given a reasonably controlled environment and a well-defined task domain, the technology is useable now. By the end of 1996, off-the-shelf LVR systems will be available running in real-time on high-end PC class machines. LVR systems will then soon appear as remote servers in public telecom systems providing information and personal management services.

If the 1980s was dominated by the rapid development of computer technology, the 1990s will be dominated by the rapid development of communications technology, and speech recognition will play a central role in this.

Acknowledgements

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[1] *With 45 phones, there are 45^3 = 91125 possible triphones but not all can occur due to the phonotactic constraints of the language.*
[2] *Some training of the speakers would also help!*

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REDUCING NOISE FROM MOTORWAYS: THE ACOUSTIC PERFORMANCE OF POROUS ASPHALT ON THE M4 AT CARDIFF

Steve Phillips, Paul Nelson FIOA and Phil Abbott

Introduction

The Transport Research Laboratory (TRL) originally developed porous road surfaces primarily to reduce surface water and spray on high speed roads during periods of heavy rainfall. Following trials in the 1960s it was found that this type of surface also had acoustical benefits. Further research by TRL demonstrated that vehicle noise levels were on average 3 – 5 dB(A) lower than on equivalent non-porous surfaces [1].

The noise reductions achieved by porous road surfaces are often solely attributed to the acoustical absorption characteristics of the surface material. However, this is an oversimplification of a complex generation and propagation mechanism. Research at TRL has examined these mechanisms for vehicles running on Porous Asphalt. Practical trials, backed with theoretical modelling in collaboration with the Open University, have helped to optimise a specification of the surfacing to produce low noise as well as good safety and durability characteristics. The acoustically important aspects of this specification have been incorporated into the Manual of Contract Documents for Highway Works [2].

In 1993 Porous Asphalt was laid on a section of the M4 motorway near Cardiff using a draft version of the Department of Transport (DoT) Specification for Porous Asphalt Surfacing. A further section was laid one year later using the published version of the Specification. TRL was commissioned by the Welsh Office to conduct vehicle noise measurements to confirm the acoustical benefits. Additional funding from the Highway Agency of the DoT also enabled the first significant traffic noise measurements at some distance from a road surfaced with Porous Asphalt to be conducted [3].

This paper reviews the mechanisms of tyre noise generation, the optimised specification obtained from TRL's research and gives the methodology and results of the measurements of vehicle and traffic noise alongside the M4 motorway.

The Generation and Propagation of Tyre/Surface Noise

Vehicles travelling at moderate to high speeds generate noise mainly from the interaction of the tyres rolling on the road surface. The magnitude of the noise depends largely upon the speed of the vehicle, when travelling in excess of 50 km/h the levels generally increase by between 9 – 15 dB(A) for a doubling of speed. The mechanisms governing the generation of tyre/surface noise are complex. The main factors involved are the generation of vibration in the tyre structure resulting from the interaction between the tyre and the road surfaces, and the movement of air in the cavities between the tyre tread and the road surface in the region of the contact patch.

At the leading edge of the tyre/surface contact, vibrations are generated by the impacts of the tread elements with the road surface. To the rear of the contact, radial vibrations can occur as the tread elements abruptly leave the contact patch and return to the undeflected rolling radius of the tyre. This mechanism is often referred to as block 'snap out' and refers to the action of the blocks in the tyre tread as they leave the contact patch. Additional noise is generated by vibrations induced by the frictional forces which develop as a tyre flattens in the contact patch. The continually changing radial deflection produces tangential forces between the tyre rubber and road. These forces are resisted by friction and tyre stiffness and any residual forces are dissipated by slip of the tread material over the road surface. The resulting slip/stick motion generates vibration in the tyre and hence noise.

There are several mechanisms related to the movement of air in the cavities of the tread pattern and road surface. Of these processes the most commonly cited is 'air pumping'. This occurs when air is compressed in the grooves of the tyre tread pattern as the tread elements deform in the contact patch. The provision of air paths in the road surface layer help to dissipate air trapped in the tread grooves

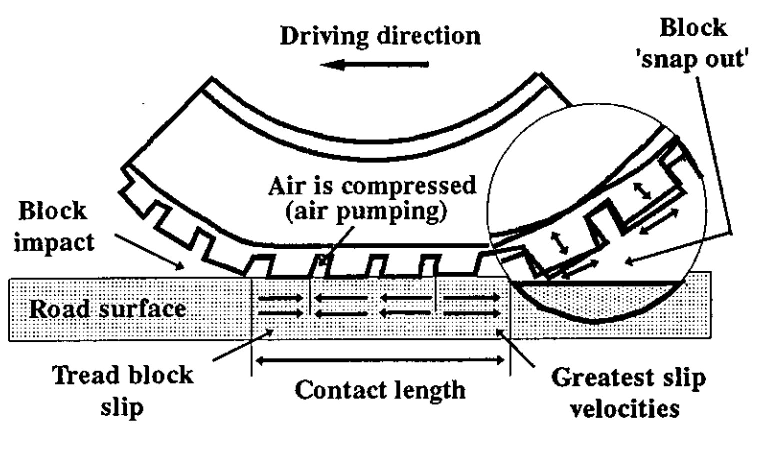

Fig. 1. Tyre/surface noise generation mechanisms

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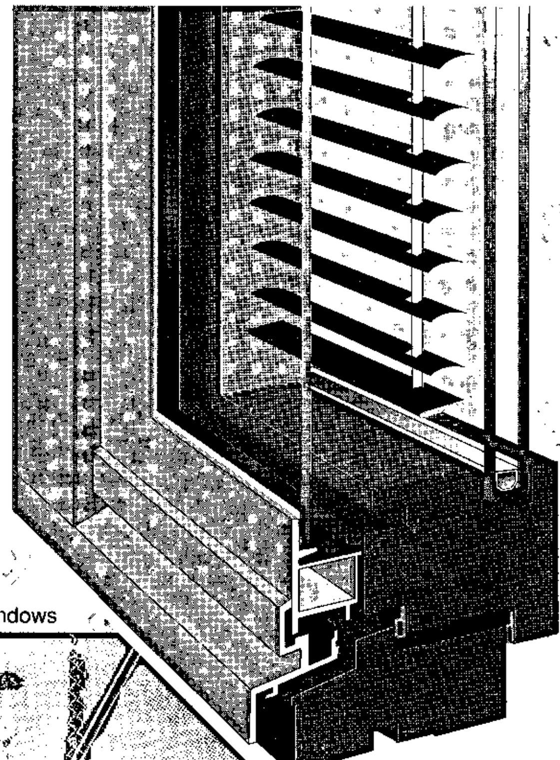

Coupled Sash for superior noise performance

The MODUL coupled-sash configuration permits a technically functional air-gap to be incorporated between the inner and outer glazing units resulting in marked gains in acoustic insulation. Improved thermal efficiency and condensation control are further benefits, and, in addition, the space between the two sashes can be used to accommodate blinds for further light and heat regulation.

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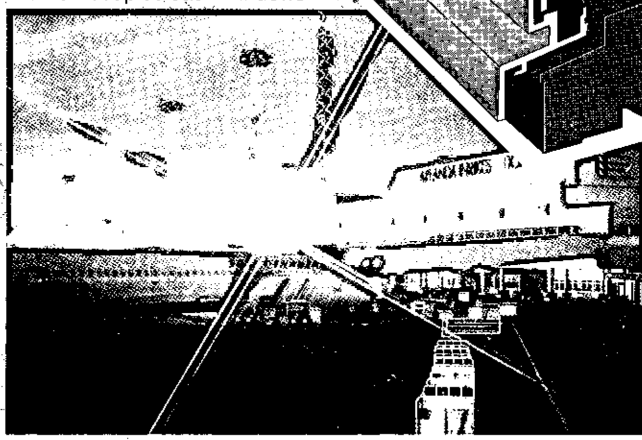

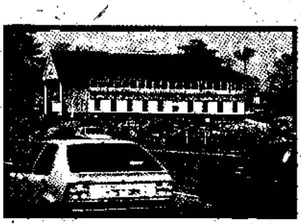

Noise from traffic at Brightwell Court, adjacent to the busy A12 at Martlesham, was controlled using MODUL windows

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and therefore largely prevent air pumping occurring.

Another important mechanism to be considered is the effect of propagation. Sound radiated by a tyre rolling over a road surface can either propagate directly to the receptor located some distance away, or arrive at the receptor via reflection from the road surface. The acoustic field strength at the receptor is then dependent upon the phase and amplitude of the direct and reflected waves which, in turn, depend upon the type of surface, the source and receiver heights and the source-to-receiver distance. When the surface is porous, additional factors need to be taken into account, since the phase of the reflected noise will be further influenced by propagation of sound within the layer itself. Generally, for typical tyre source-to-receiver generations destructive interferences between the direct and reflected waves will occur in the frequency range 250 – 1000 Hz. The frequencies and amplitudes of these important interference effects depend greatly on the acoustical properties of the porous surface layer and the angle of incidence of the reflected wave.

Clearly, the road surface can have an effect on both the generation and propagation of noise from tyres.

Modelling the Acoustical Characteristics of Porous Asphalt

The following section outlines the work jointly undertaken by TRL and the Open University to model the propagation of vehicle noise over porous road surfaces with a view to establishing the relative importance of both the propagation and air pumping mechanisms. The model is based upon the concept that a porous road surface can be approximated by an array of tortuous, arbitrarily shaped capillary pores distributed in a rigid frame or matrix. The loss of energy of an acoustic pressure wave is then modelled as it passes through the matrix.

Research at the Open University has determined appropriate expressions for both the density and stiffness, or compressibility, for acoustic wave propagation through air in capillary pores with a slit shaped cross-section and also for propagation in a matrix consisting of an array of arbitrarily shaped pores [4]. This leads to an expression for the complex surface impedance which can be used as input into a conventional acoustic propagation model, to describe the sound field at any point above a porous surface layer, given the source strength and information about its directivity.

The formulation of the model uses the porosity of interconnecting voids as a parameter, as well as the specific air flow resistivity which is scaled by both the shape and size distribution of the pores. The model requires the input of appropriate parameters such as the tortuosity of interconnecting pores as well as the thickness of the layer.

A primary function of the model is to calculate the excess attenuation (dB) as a function of frequency (Hz) at any point above a porous layer for any combination of surface parameters. Using the model TRL has carried out a comprehensive review and rationalisation of the surface parameters of importance [5]. By running the propagation model for a range of input parameters it has been established that the porosity of the surface layer and the thickness of the layer are the main factors of importance. Varying the thickness affects the frequency where the maximum noise absorption occurs, while increasing the porosity helps to maximise the acoustic benefits at any given frequency.

Normal variations in both the air flow resistivity and tortuosity only appear to have a minor effect on the overall acoustic performance of conventional porous road surfaces. It follows from this analysis that in order to achieve the maximum possible tyre noise reduction from a porous road surface the porosity of a surface should be maximised, consistent with achieving a viable and durable surface, and the thickness of the layer should be chosen so that the reductions achieved occur at frequencies which are dominant in the vehicle tyre noise spectrum. The model has been validated using data independently taken from a range of specially constructed

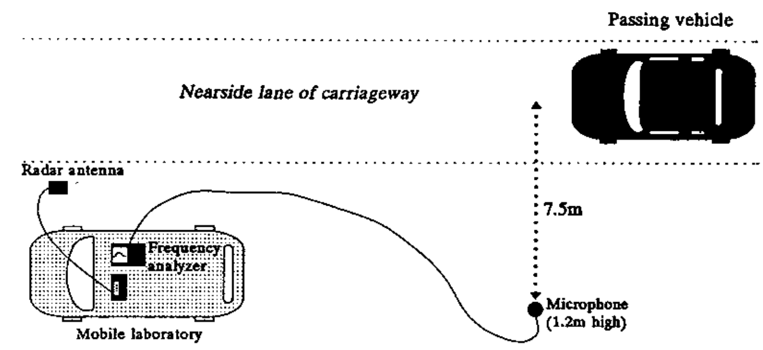

Fig. 2. Schematic diagram of site layout for SPB measurements

porous road surfaces laid on the test track at TRL [5]. Details of the formulation and validation study can be obtained by consulting this paper.

As a result of these considerations it was suggested that porous road surfaces should be made with a large sized aggregate (ie 20 mm maximum aggregate size). By assuming realistic values for the maximum porosity achievable with this specification, and suitable associated values for air resistivity and tortuosity, a layer thickness of between 0.05 m – 0.08 m was indicated to give optimum tyre noise reductions for vehicles operating at moderate to high speeds [5]. These recommendations were incorporated into the DoT's specifications for Porous Asphalt. This specification has been used for the porous surface laid on the M4 near Cardiff which is described in the next section.

Performance of Porous Asphalt at Cardiff

In May 1993 3.2 km of Hot Rolled Asphalt (HRA) surface on M4 Motorway near Cardiff was replaced with a Porous Asphalt made to a draft version of the DoT Specification with a maximum aggregate size of 20 mm and a thickness of 50 mm. A further 4.7 km of Porous Asphalt was subsequently laid adjacent to the first, between junctions 32 and 33, during the summer of 1994 using the published version of the Specification. The specification of the second Porous Asphalt section contained a different grading of stone sizes in the aggregate which resulted in a greater proportion of small stones and hence a lower porosity. TRL took vehicle and traffic noise measurements of the pre-existing HRA surface and the Porous Asphalt surfacings in order to establish the degree of noise reduction obtained. The work was carried out on behalf of the Welsh Office and the Highway Agency.

Three sites were chosen for vehicle noise measurements alongside the 1993 surface (Sites A, B and C) and a further two on the 1994 surface (Sites D and E). Traffic noise surveys were also carried out at Site B, chosen because of the relatively flat area of grassland alongside.

The Statistical Pass-by (SPB) method for determining the noise from vehicles travelling over different types of road surface was used in this study. The SPB method was originally developed by TRL during the early 1970s [6] and has recently been developed as a Draft International Standard by Working Group 33 of the International Standards Organisation (1994) as the standard method of assessing differences in vehicle noise on different road surfaces [7].

The SPB method requires the simultaneous measurement of the maximum noise level and speed of individual vehicles taken from the traffic stream. Measurements of at least 50 vehicles in two categories, 'light' (ie all cars and vans ≤ 1.5t unladen) and 'heavy', are generally required. From this data, a regression of noise against the logarithm of vehicle speed is performed for both vehicle groups. The general relation between the maximum sound level ($L_{A,max}$) and the speed of a passing vehicle for a measurement point located 7.5 m from the centre line of the vehicle path is given by the equation

$$L_{A,max} = A \times \log_{10} V + B$$

where V = speed of the vehicle in km/h, A and B are constants.

The regression lines calculated are used to determine the noise levels at a reference speed of 90 km/h. These noise levels are then used to compare the road surfaces studied.

A schematic diagram of the site layout and equipment used at each measurement site is shown in Figure 2. The measurement microphone was positioned 7.5 metres from the centre of the nearside lane and 1.2 metres above the level of the road surface. The microphone was connected to a real-time frequency analyzer capturing the maximum A-weighted sound level during each selected vehicle pass-by together with the associated one-third octave band spectra levels. A radar device was used to determine the speeds of vehicles under test. The measurements of speed and the type classification of each vehicle (light or heavy) were recorded on a computer.

In the analysis, the acoustic data was merged with the vehicle speed and classification data and the maximum noise levels for each vehicle event were automatically

Site	Year of resurfacing	Average maximum vehicle noise level dB(A)			
		Original HRA	Porous Asphalt Initially	Porous Asphalt 1 year later	Initial reduction
A	1993	85.4	75.6	76.3	9.8
B	1993	86.0	75.0	76.3	11.0
C	1993	84.4	75.6	76.3	8.8
D	1994	85.0	76.1	–	8.9
E	1994	84.4	77.0	–	7.4

Table 1. Light vehicle noise levels (L_{Amax}) after replacing HRA with Porous Asphalt

Distance from edge of carriageway	Average normalised[1] traffic noise level $L_{A10,1h}$			
	Original HRA	Porous Asphalt		Initial reduction
		Initially	1 year later	
10	85.8	77.2	78.0	8.6
20	81.2	73.2	73.7	8.0
40	75.6	67.4	67.8	8.2

[1] Normalised to the average traffic conditions during the study: 3960 vehicles ph at 96.5 km/h, 20.4% heavy vehicles

Table 2. Traffic noise levels alongside the M4

regressed against the logarithm of the vehicle speed using the general relation given earlier. In addition, the regression analysis was carried out for each one-third octave band in the frequency range studied. From the regression lines obtained, the reference levels for a speed of 90 km/h were determined for each frequency band.

At site B, traffic noise measurements were carried out at three positions, located 10, 20 and 40 metres from the nearside edge of the road and at a height of 1.9 metres above the road surface. At each position several separate 15 minute traffic noise measurements were taken using portable noise loggers and the $L_{A10,1h}$ determined according to the method for assessing the noise from road traffic [8].

During each measurement period the traffic flow was determined together with sample measurements of vehicle speed. The hourly traffic flow, percentage of heavy vehicles and the mean traffic speed were then calculated. In addition, the wind speed and direction, and the air temperature were monitored throughout the measurement periods. Initially the vehicle and traffic noise measurements were taken alongside the original HRA surface and were repeated, in July 1993, after the Porous Asphalt surfaces had been laid. The measurements were then repeated approximately 1 year later. At this time further measurements were also taken alongside the new section of Porous Asphalt which was laid to the revised specification as described earlier.

Table 1 gives the 'light' vehicle noise levels obtained alongside the different surfaces using the SPB method. It should be noted that the noise levels in each case were taken at a standard distance of 7.5 m from the centre of the nearside lane and normalized to a reference speed of 90 km/h. It can be seen that for light vehicles, the average maximum noise level was in the range 84.4 to 86.0 dB(A) at sites located alongside the HRA. This can be compared with the noise levels recorded at the same sites for the different specifications of new Porous Asphalt, which were in the range 75.0 to 75.6 dB(A). This gave reductions in light vehicle noise following the resurfacing of between 7.4 and 11.0 dB(A).

The corresponding reductions for the 'heavy' vehicle category were significantly smaller and were found to lie in the range 3.8 to 6.5 dB(A). The average maximum noise level was in the range 89.3 to 89.9 dB(A) at sites alongside the HRA surface compared with 83.4 to 85.5 dB(A) for the Porous Asphalt surface. The lower reductions for heavy vehicles may be a result of the greater contribution of engine noise to the overall levels. In addition, the greater source height that would result from the engine noise contribution for heavy vehicles reduces the effect of propagation across the porous road surface. This, in turn reduces the relative acoustic benefits of Porous Asphalt as the propagation mechanism is then governed mainly by geometric path difference considerations which are identical for the two surface types. A further point to note from the data given in Table 1 is that the noise benefits obtained using the later specification of Porous Asphalt were slightly less than those obtained using the draft specification. This result underlines the importance of maintaining a high degree of porosity in the surface layer if optimum acoustic benefits are to be obtained. However, the newer specification is designed to have greater durability characteristics than the earlier draft.

In order to estimate the change in traffic noise level after replacing the surface with Porous Asphalt it is necessary to normalise the measured traffic noise levels to the same traffic conditions. The prediction method, 'Calculation of Road Traffic Noise' (CRTN), was used for this purpose [8].

The normalised values of traffic noise obtained at site B are shown in Table 2. The final column of the Table shows the reductions in $L_{A10,1h}$ after replacing the surface with Porous Asphalt, at distances of 10, 20 and 40 metres from the nearside edge of the road.

The results show reductions in traffic noise, $L_{A10,1h}$ dB, of between 8.0 and 8.6 dB(A) and with a high degree of consistency at all the distances studied. The average

reduction in traffic noise level of 8.3 dB(A) is equivalent, in acoustic terms, to restricting traffic flow to only 15% of that measured prior to resurfacing. It should be noted that this study compares new Porous Asphalt with well worn HRA.

A new HRA would likely be 3 – 4 dB(A) lower. Consequently when comparing vehicle noise levels on new surfaces, Porous Asphalt would be approximately 4 – 5dB (A) lower than on a new HRA surface.

Conclusions

A mathematical model has been developed to help optimise the specification of Porous Asphalt in order to reduce traffic noise. Using the model it has been possible to rationalise the parameters of importance and to design a surface which, as far as possible, provides low noise characteristics whilst retaining other properties of importance such as durability, safety, spray suppression and resistance to clogging by surface detritus.

A Porous Asphalt surface has been laid on the M4 at Cardiff and the results of monitoring by TRL show a considerable reduction in traffic noise compared with the pre-existing worn non-porous motorway HRA surfacing.

Acknowledgements

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LOW FREQUENCY ACOUSTIC SCATTERING FROM FISH SCHOOLS – A MODELLING APPROACH

Christopher Feuillade FIOA

Introduction

Acoustic scattering from individual fish and fish schools is an important issue in fisheries research and in naval defense applications. Generally, scattering from an individual fish is relatively weak except at swimbladder resonance frequencies, when return signals may be significantly enhanced compared to specular scatter. A swimbladder is essentially just an air bubble within a fish, and this fact led Marshall [1] to examine the possibility that scattering from fish with air-filled swimbladders was the cause of high levels of acoustic volume reverberation within deep scattering layers. The primary mechanism was considered to be swimbladders vibrating in the volume pulsation mode when ensonified at the appropriate monopole resonance frequency. It is now generally accepted that resonance scattering by swimbladder-bearing fish is the major cause of volume reverberation in the ocean at frequencies up to at least 10 kHz [2].

Since the monopole resonance behavior of fish swimbladders bears a close physical similarity to the scattering properties of air bubbles in water, 'bubble-like' models have been a popular method for describing resonant scattering from swimbladder-bearing fish [3]. The swimbladder behaviour is modified from that of an air bubble by the presence of the fish body around it. Acoustically, fish flesh is like soft rubber and can be closely approximated by a viscous fluid. Love [4] has treated fish flesh in this way to develop a spherical swimbladder model which has been successfully used to correlate fisheries data with acoustic measurements of volume reverberation [5]. Studies of the monopole resonances of deformed air bubbles [6] have shown that the azimuthal scattering distribution remains predominantly isotropic even for highly nonspherical bubbles, and further support the use of a spherical swimbladder model to describe resonance scattering from fish.

Schools of fish consist of closely spaced individuals of similar size [7]. At resonance frequencies this causes multiple scattering processes between the fish to become significant and complex. The acoustic wavelength at the monopole resonance frequency of a fish swimbladder is generally many times the length of the fish itself, and, for small schools of similarly sized fish, frequently greater than the dimensions of the school. Since fish in a closely spaced school typically arrange themselves so that they are on the order of a fish length apart, the scattered wave fields from neighbouring fish will interact coherently. This feature, in addition to multiple scattering, must be correctly incorporated to realistically describe resonance scattering from fish schools.

A model is described here for predicting levels of scattering from schools of closely spaced fish. The mathematical formalism used: (a) allows an experimentally verified model for scattering from one object to be introduced (ie the Love spherical swimbladder model); (b) describes scatter from one object to adjacent ones; (c) includes higher order scatter correlations; and (d) exactly accounts for coherent scattering from the aggregate field.

Theory I: Scattering from One Fish Swimbladder

Devin [8] investigated the effects of radiative, viscous and thermal damping processes on air bubbles in water. His equation of motion for the monopole resonance of a spherical bubble is

$$m\ddot{v} + b\dot{v} + kv = -Pe^{i\omega t} \tag{1}$$

where v is the differential bubble volume (ie the difference between the instantaneous and equilibrium volumes). The coefficient m (= $\rho/4\pi a$) is the inertial 'mass' of the bubble, where a is the bubble radius and ρ the water density; and κ (= $3\gamma P_A/4\pi a^3$) is the 'adiabatic stiffness', where γ is the ratio of gas specific heats and P_A the ambient pressure. The coefficient b describes the damping of the motion, while P and ω are the amplitude and frequency respectively of the external pressure field applied to the bubble. If a harmonic steady state solution of (1) of the form $v = \bar{v}e^{i\omega t}$ is assumed, substitution gives the Lorentzian resonance response

$$\bar{v} = \frac{-P}{\kappa - \omega^2 m + i\omega b} = \frac{-\left(P/m\omega^2\right)}{\left[\left(\frac{\omega_0}{\omega}\right)^2 - 1\right] + i\frac{b}{m\omega}} \tag{2}$$

where $\omega_0 = \sqrt{\kappa/m} = \left(\sqrt{3\gamma P_A/\rho}\right)/a$ is the resonance frequency. The imaginary component (b/m ω) in the denominator can be identified with a damping constant δ for the bubble with radiative, viscous and thermal components, ie,

$$\frac{b}{m\omega} = \delta = \delta_r + \delta_v + \delta_t \tag{3}$$

In the theory of resonant acoustic scattering by fish swimbladders developed by Love [4], the quantity δ is replaced by a factor (ω_0/ω H). The frequency dependent parameter H also has three components:

$$\frac{1}{H} = \frac{1}{H_r} + \frac{1}{H_v} + \frac{1}{H_t} \tag{4}$$

In the case of fishes, the damping due to thermal conductivity effects is generally negligible compared to radiin the next section, the target strength is averaged over a set of randomized fish configurations to simulate the swimming motion of an actual fish school. The school target strength for one configuration is given by

$$TS = 10\log_{10}\left(\frac{\sigma_s}{4\pi}\right) = 10\log_{10}\left[\frac{\omega^4 \rho^2 \left|\sum_{n=1}^{N} \bar{v}_n e^{i\phi_n}\right|^2}{(4\pi)^2 P^2}\right] \qquad (9)$$

where σ_s is the scattering cross-section for the school, and the factors $e^{i\phi_n}$ appearing in the numerator of the RHS take into account the different phases of the scattered field from the various swimbladders.

Modelling Results

(a) Simulated schools Schools may be simulated by grouping together individual fish in a way that approximates the formations fish typically adopt when swimming closely together. Here, the fish at any location are assumed to arrange themselves into basic cellular units. Each school unit is a cube with a fish in each corner and one at the centre, all fish having the same size and heading (see Figure 3).

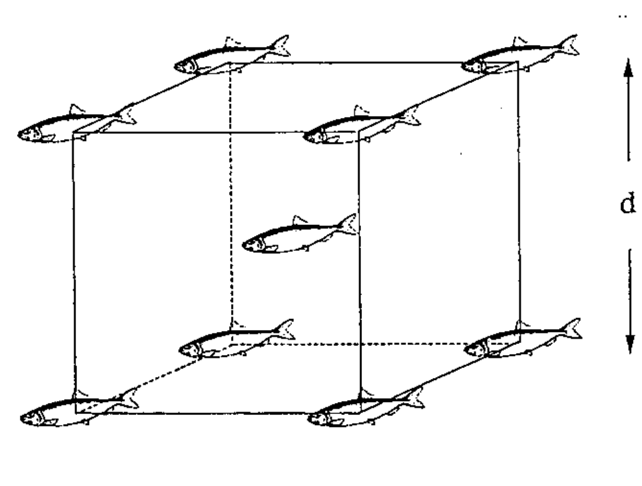

Fig. 3. A basic school unit

The overall ensemble, made from these units, is given a loosely ellipsoidal shape, to again approach the form of actual schools. A school is constructed by starting with a first 'central' fish, and then adding fish sequentially to the corners and centres of the school units, so as to pack the school from the centre outwards. The packing density is parameterized by the mean distance d between any two closest neighbours placed in the corners of the cube. Of course, as the fish swim along, the distances between these neighbours will vary from the value of d. The direction in which the school is swimming may also change in a quite unpredictable manner. These variations are accounted for by averaging the target strength of the school over a series of 'snapshot' simulations. In each snapshot the individual fish locations are varied randomly from their mean positions with a normal distribution of standard deviation σ. The fish school is always ensonified horizontally, but the azimuthal angle of ensonification is varied randomly between 0 deg and 360 deg for each snapshot in order to average over changes of direction. In all the examples considered here, an average over ten snapshots of fish positions and school orientation is taken.

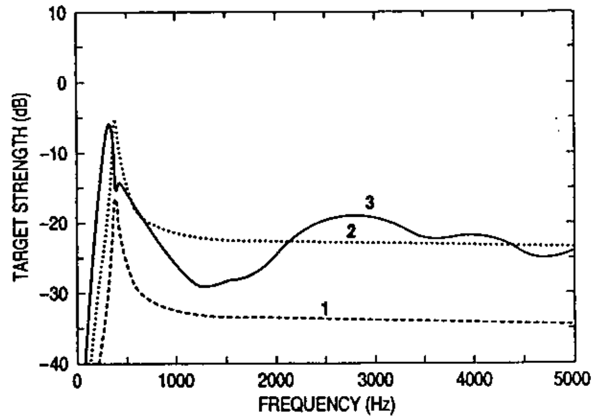

Fig. 4. Scattering from a group of 13 fish

The first example (Figure 4) is a small ensemble of 13 fish, each of length L = 40 cm. This was constructed from a cube of 9 fish with 4 additional single fish placed off the two sides and the front and back. Swimbladder volumes are roughly 4 – 5 % of fish volumes, corresponding to a bladder radius of about a = 0.05 L. Accordingly, for these fish, a swimbladder radius of a = 2 cm is adopted. The fish flesh viscosity is ξ = 500 poise [5]. The value of d is 40 cm and σ is 4 cm. The mean school depth is 50 m. The school target strength is calculated between 0 and 5 kHz. Curve 1 represents the target strength of a single fish placed at the centre point of the school, calculated using the Love model. A peak of approximately −17 dB is seen at about 400 Hz. Curve 2 shows the target strength for the 13 fish calculated by incoherently summing together the scattering cross sections for the individual fish and thereby neglecting multiple scattering and phase difference effects. The values of curve 2 are equal to those of curve 1 plus about $10\log_{10}(13)$ (ie ≈ 11 dB), which is the expected incoherent enhancement. Curve 3, the school model prediction, has several notable features. First, the resonance peak is downshifted below that of the individual fish. This effect has been observed previously for other types of resonators [10, 11]. Second, the peak value of curve 3, while greater than that of curve 1 by about 10 dB, is less than that of curve 2 by about 1 dB. Since the dimensions of this school are much less than the acoustic wavelength at resonance, fully coherent summation of the scattered wave fields should cause the peak of curve 3 to be enhanced by $20\log_{10}(13)$ (≈ 22 dB) over that of curve 1. In fact, the target strengths of individual fish in the school are strongly suppressed by multiple

International Conference

SONAR SIGNAL PROCESSING

(Organised by the Underwater Acoustics Group)

Loughborough University of Technology, Loughborough, UK

18 – 20 December 1995

Monday 18 December

ROY GRIFFITHS MEMORIAL LECTURE

Session 2: Synthetic Aperture Sonar

Recent sea trials of a synthetic aperture sonar • *P T Gough & D W Hawkins* • *University of Canterbury, New Zealand*

3-D high-resolution imaging using interferometric synthetic aperture sonar • *D K Anthony (1), F N Cowan (1), H D Griffiths (2), Z Meng (1), T A Rafik (1), H Shafeeu (2)* • *(1) Loughborough University, (2) University College London*

The application of pixel-based imaging to synthetic aperture sonar • *R McHugh, S Shaw & N Taylor* • *Heriot-Watt University*

Session 3: Image Processing

Inertial sensing for synthetic aperture sonar • *B Haywood* • *University of Sydney, Australia*

MAP side scan sonar image motion distortion correcton using iterative conditional modes and simulated annealing • *R S Beattie, S C Elder* • *Robert Gordon University, Aberdeen*

A multiresolution operator for the segmentation of sidescan sonar images • *D Carmichael (1), L Linnett (2), S Clarke (2)* • *(1) DRA, Bincleaves, (2) Heriot-Watt University*

Ultrasonic imaging improvement by a cooperative approach • *V Murino & A Trucco* • *University of Genoa, Italy*

Intensity coding concepts for sonar images • *F Greiner, G Brecht, J-P Babst & J Ziegenbein* • *FWG, Kiel, Germany*

Spatial interaction models for sonar image data • *B R Calder, L M Linnett & S J Clark* • *Heriot-Watt University*

Tuesday 19 December

Session 4: Sonar Signal Processing

Transducer equalisation: signal representation and filter structure • *M J D Bishop* • *DRA, Bincleaves*

Investigation of the ambiguity function of a special kind of sonar signal • *J Norrmann* • *FWG, Kiel, Germany*

An extensible systolic convolver for signal processing in time and frequency domain • *H G D Gosling* • *BAeSEMA, Filton*

Implementation of digital technology for underwater voice communications • *B Woodward & H Sari* • *Loughborough University*

Multipath detection by frequency domain kurtosis estimation • *L Persson (1), E Lindqvist (2), P Nordstrom* • *(1) & (2) (1) NRDE, Sundbyberg, (2) CelsiusTech AB, Sweden*

A B Wood Memorial Lecture

COMPARISON OF THE ABILITIES OF MULTIPLE ACOUSTIC TECHNIQUES FOR BUBBLE DETECTION • ***T G Leighton*** • ***Institute of Sound and Vibration Research***

Session 5: Posters

Sidescan sonar image restoration using simulated annealing • *R S Beattie & S C Elder* • *Robert Gordon University, Aberdeen*

Architectural and practical issues in sonar system prototyping • *M J D Bishop* • *DRA, Bincleaves*

Influence of area-dependent reverberation on false alarms statistics in shallow water • *D Brecht, F Greiner, J-P Babst & J Ziegenbein* • *FWG, Kiel, Germany*

Matched field parameter subspace methods for selective high resolution estimate with reduced sensitivity to mismatch • *H A Chandler, C Feuillade & G B Smith* • *NRL Stennis Space Center*

Applications of optical and radio aperture synthesis technique to sonar • *G R G Erry & A H Greenaway* • *DRA, Malvern*

Synthetic aperture sonar imaging of moving targets • *H D Griffiths, R Voles, H Shafeeu & T Clamou* • *University College London*

Comparison of the conventional and the multiaspect sidescan sonar concept • *W Jans & J Ziegenbein* • *FWG, Kiel, Germany*

The optimal wave-number estimation • *L G Krasny, V Yu Lapy & S P Antonyuk* • *Inst of Hydromechanics, Ukraine*

A novel time domain beamforming algorithm using an extensible systolic convolver array • *M A Stinchombe* • *BAeSEMA, Filton*

Frequency tracking based on a dynamic programming search of potential tracks • *C R Walters* • *RMCS, Cranfield University*

Underwater acoustic data transmission in shadow zones with pseudorandom waveforms • *Yu Zkharov & V Kodanev* • *Andreev Acoustics Institute, Russia*

A model for the simulation of sidescan sonar images • *J Bell & L Linnett* • *Heriot-Watt University*

Low sidelobes for arbitrary arrays • *I J Clarke (1), A J Fenwick (2)* • *(1) DRA, Malvern, (2) DRA, Farnborough*

Higher order reverberation statistics for non-uniformly distributed scatterers • *A J Fenwick* • *DRA, Farnborough*

On a choice of the optimum sounding signal for time-delay spectrometry • *A Yaremchuk* • *Andreev Acoustics Institute, Russia*

A digital implementation of phased-array beamforming for chirp sources applied to imaging directly in ground coordinates • *G Shippey & T Nordkvist* • *Chalmers University of Technology, Sweden*

Wednesday 20 December

Session 6: Beamforming

Automated transducer array optimisation • *P F Dobbins (1) & G J Heald (2)* • *(1) BAeSEMA, Filton; (2) DRA, Bincleaves*

On the use of array snaking for resolving the rightleft ambiguity of linear arrays in towed array sonars • *P Voen* • *FWG, Kiel, Germany*

Computationally-efficient conventional beamforming via Chinese Remainder Theorem • *K J Jones* • *DRA, Weymouth*

Adaptive beamforming robust to moving jammers • *A B Gershman, U Nickel & J F Bohme* • *Ruhr University, Bochum; FFM, FGAN, Germany*

The importance of stabilization in adaptive sonar signal processing • *D T Hughes & I J Clarke* • *DRA, Malvern*

An FFT-based method for broadband constrained beamforming • *L C Godara & M R Sayyah Jahrmi* • *University of New South Wales*

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CALLS FOR PAPERS

One-day meeting

'Roughly How Loud Is That?'

Current Issues in Measurement

(Organised by the Measurement and Instrumentation Group)

The Royal Society, London SW1
14 February 1996

The meeting is organised by the newly-formed Measurement and Instrumentation Group of the Institute. An aim of this Group is to promote best practice in acoustical and vibration measurements and contributions 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

It is intended that a workshop discussion will also be held during the course of the meeting. Intending authors should send a 100-word abstract to the Meeting Organiser at the address below. Abstracts should be sent to the meeting organiser by 8 December 1995.
The proceedings of the meeting will be published in Volume 18 of the Proceedings of the Institute of Acoustics (1996). Papers for refereeing must be received by 15 December 1995.
Meeting organiser: Richard Tyler CEL Instruments Ltd, 35-37 Bury Mead Road, Hitchin, Herts SG5 1RT Tel: 01462 422411 Fax: 01462 422511

The Auditory Basis Of Speech Perception

Keele University, Staffs
15 - 19 July 1995

Topics will include

- Perceptual cues for speech processing
- Speech processing under adverse acoustic conditions
- Auditory representations of speech
- Auditory processing and speech recognition
- Speech perception by the hearing impaired

Application materials for participation, as well as additional information, can be obtained from Professor William Ainsworth FIOA at the following address ESCA Workshop, Department of Communication & Neuroscience, Keele University, Staffordshire ST5 5BG UK. Tel: 44(0)1782 583055 Fax 44(0)1782 583055 Internet: cob03@keele.ac.uk
Deadline for applications: 15 November 1995. Notification of acceptance: 15 February 1996.
(This is not an IOA meeting)

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IOA CofC in Env Noise M'ment exam
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10 NOV
IOA CofC in W'place Noise Ass't Advisory Committee
St Albans

16–19 NOV
Reproduced Sound 11
Windermere

20 NOV
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21 NOV
Yorks/Humberside Branch mtg: Instrumentation/Rev Chambers
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22 NOV
Eastern Branch mtg Medical Acoustics and Audiology
Cambridge

22 NOV
London Branch mtg: Annual Dinner
London

22 NOV
Southern Branch mtg: Barriers – An Update
Winchester

22 NOV
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23 NOV
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28 NOV
South-west Branch mtg Strings Ancient and Moderns + Musical Acoustics Group AGM
Filton

29 NOV
Midlands Branch mtg Inaugural General Meeting
Coventry

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St Albans

4 – 6 DEC
IOSH 95 Exhibition, *Harrogate*
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7 DEC
IOA Medals & Awards, Council
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7 DEC
Southern Branch mtg: Instruments and PCs – the Great Divide?
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Epsom

18 – 20 DEC
Underwater Group Conference - Sonar Signal Processing
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1996

17 JAN
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1 FEB
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9 FEB
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14 FEB
Measurement & Instrumentation Group 1-Day Mtg
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20 MAR
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St Albans

25 – 28 MAR
Underwater Group Conference - Arrays and Beam-Forming in Underwater Acoustics
Bristol

27 MAR
Environmental Noise Group - Amplified Music Workshop

17 APR
London Branch mtg: 1-Day Meeting
London

17 APR
IOA AGM and Annual Dinner
London

25 APR
IOA Publications, Meetings Committee
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2 MAY
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11 MAY
Eastern Branch Dinner
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17 MAY
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21 – 23 MAY
RoSPA Exhibition, *Birmingham*
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31 MAY
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7 JUN
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13 – 14 JUN
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19 JUN
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30 JUL – 2 AUG
inter•noise 96
Liverpool

19 SEP
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26 SEP
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3 OCT
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11 OCT
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5 DEC
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News of

Members, Research Contracts, Consultancy Contracts, PhD theses, Scholarships, Retirements, etc for inclusion in the Bulletin should be sent to the Editor C/O theInstitute

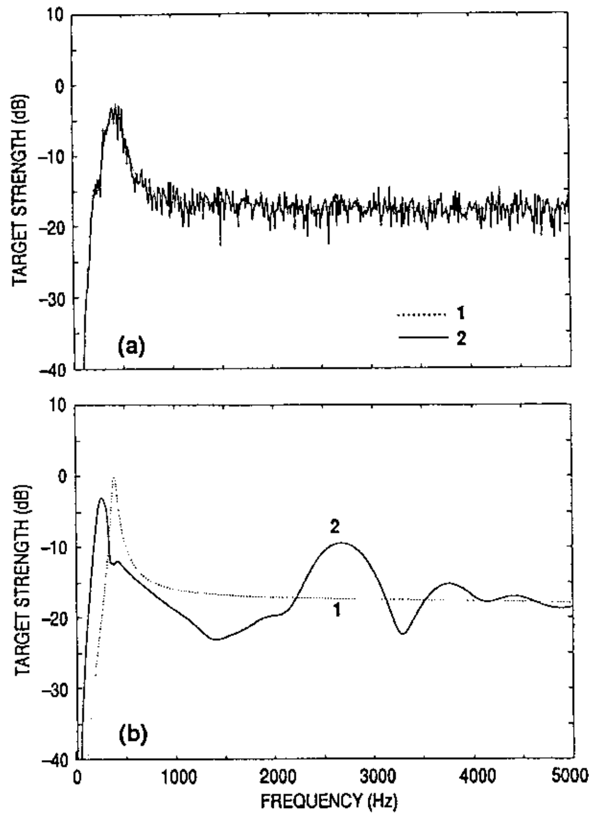

Fig. 5. Target strengths for widely dispersed and closely spaced schools of 47 fish

scattering effects. Finally, above resonance, curve 3 varies alternately below and above curve 2, due to destructive and constructive interference of the scattered wave fields.

The second example (Figure 5a) is a larger school of 47 fish with identical individual characteristics to those of Figure 4. The mean school depth is again 50 m, but now d = 40 m (ie the fish are widely dispersed) and σ = 4 m. The fish are so far apart that multiple scattering effects should play only a minor role in determining the target strength of the school. Also, σ is large enough to ensure that the individual scattered fields should average incoherently and reproduce the result obtained by summing the cross sections together. Curve 1 represents simple summing of the individual fish scattering cross sections. Curve 2 is the school model prediction. Apart from jitter, due to quickly varying interference effects at successive frequencies, the model target strength curve essentially overlays and reproduces the incoherent summation result. In contrast, Figure 5b shows the result of reducing the overall school size of the same group of fish, so that d is 40 cm and σ is 4 cm. Significant differences appear between the school model target strength (ie curve 2) and that obtained from incoherent summation (curve 1), due to increased multiple scattering and interference effects for the (now) closely spaced fish. Multiple scattering hinders the individual resonances so much that the resonance peak is now several dB below the incoherent summation peak and frequency downshifted. Above resonance, the individual scattered wave fields interfere strongly, leading to school target strength values sometimes more than 5 dB above or below the incoherent summation values.

The third example shows the effects of water depth on school scattering behaviour. Many large stocks of commercially important fish such as whiting, hake, cod and rockfish, occur at depths of 100 to 500 m during the day and depths from near the surface to 100 m at night. A length near 40 cm, and other characteristics identical to the previous examples, is reasonable for each of these species [12]. They are modelled here by an ensemble of 123 fish, with d = 40 cm and σ = 4 cm. Figure 6a represents a school placed near the surface at a mean depth of 10 m. Curve 1 shows the incoherently summed target strength. This has a well defined peak with a maximum at 2 dB. The resonance frequency is slightly less than 250 Hz. Curve 2 shows the scattering model prediction. The resonance peak is much sharper, with a marked frequency downshift and a maximum target strength 2 dB greater than curve 1. Above resonance the target strength varies due to interference, with the basic level about the same as curve 1. Figure 6b shows the target strength of an identical school placed at depth 50 m. Curve 1, representing the incoherently summed target strength, has a peak 2 – 3 dB greater than in Figure 6a,

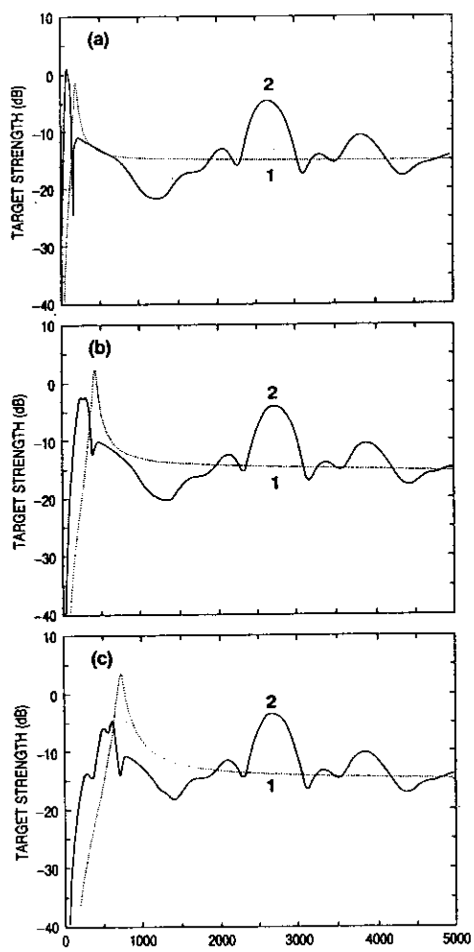

Fig. 6. Effects of depth on the target strength of an ensemble of 123 fish

and the resonance frequency has increased to about 350 Hz. In contrast, the school scattering model prediction (curve 2) has a peak *reduced* by about 4 – 5 dB for the deeper school, and is about 5 dB less than curve 1. However, it is also shifted, due to the depth, to a higher frequency. Comparison of the scattering model predictions for the two cases suggests that, at greater depths, multiple scattering interactions between the fish are more effective in reducing the school target strength close to the resonance frequency. Figure 6c, showing the corresponding result at 200 m, strengthens this conjecture. The peak of curve 1, again representing the incoherently summed target strength, shows another increase to about 6 dB, with the resonance frequency increased to about 700Hz. The scattering model prediction (curve 2) shows the resonance peak has almost completely collapsed. The maximum value is about – 2.5 dB, which is more than 8 dB less than curve 1. The peak is much broader and almost indistinguishable from the variations in target strength above resonance due to interference effects.

Figure 7, showing the effects of increasing school size on the average target strength of a single fish in a school, vividly illustrates the cumulative effects of multiple scattering and interference as the number of fish grows.

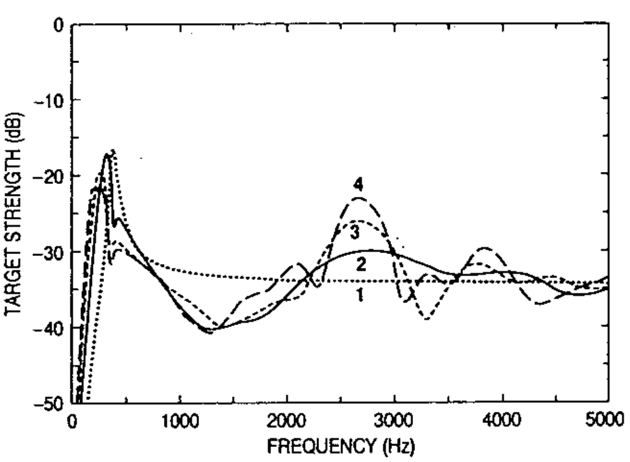

Fig. 7. Normalized target strength for a single fish in schools of increasing size

Again, ensembles of 40 cm fish, with d = 40 cm and σ = 4 cm, placed at mean depth 50 m, are considered. Curve 1 shows the target strength of a single fish, and is identical to curve 1 in Figure 4. Curve 2 shows the target strength of a school of 13 fish, but a factor of $10 \log_{10}(13)$ is *subtracted* to give the average or 'normalized' target strength for a single fish in the school. The familiar frequency downshift of the peak is seen, and the reduction in target strength. Also apparent are the variations above resonance due to interference effects. Curve 3 shows the corresponding normalized target strength of a single fish in a school of 47 fish. Increased multiple scattering effects lead to a further downshift in the peak frequency and reduction in peak value. More target strength fluctuations due to interference appear above resonance. Particularly noticeable is the increasing size of the 'hump' at about 2700 Hz. Essentially the same remarks must be repeated for curve 4, which shows the normalized target strength for a school of 123 fish. Two further general comments may be made about Figure 7. First, the normalized target strength values at frequencies above resonance for all three cases (curves 2, 3, 4) oscillate around the values for a single fish (curve 1) and appear to converge slowly towards them as the frequency increases. Second, as the school size increases, additional interference effects between outlying fish in the school lead to the appearance of shorter period and higher amplitude variations in target strength in the higher frequency region. Overall, Figure 7 seems to show two main trends. One is the steady shift and reduction in amplitude of the main peak. Another seems to be the increasing number of fluctuations in the high frequency region. This seems to happen without, necessarily, a major change in the frequencies of the major lobes.

(b) Application to experimental data The small school model has been used successfully to fit experimental scattering data [13]. The method assumes that the acoustic interactions of fish in a large school are primarily with those fish in locations immediately adjacent to them, and that the target strength of any fish within the school may be represented by the normalized value for a smaller ensemble containing this fish. The spectral distribution for the whole school should then differ only in the overall level from that of the small ensemble. The normalized target strength of an ensemble of (in this analysis) 123 fish is calculated, and the fish spacing d, standard deviation σ and overall scattering level are adjusted to fit the experimental data. Several parameters of the school model are slightly modified to more accurately model the properties of actual schools, based on field experiments [5], particularly the lattice structure and swimbladder radii [13].

Holliday [14] made backscattering measurements from pelagic schools of fish in the Los Angeles Bight from January to June 1971. Three of Holliday's schools (Targets A, B, and D) are considered here. These were observed to be near 20 m, 30 m and 15 m depth respectively, and consisted of anchovy of approximate length L = 12 cm. The swimbladder viscosity was reduced to 300 poise to model these smaller fish, following data suggesting a lower viscosity for small physostomes [4].

Figures 8a, 8b and 8c show data (curve 1 in each case) taken directly from Holliday's figures for Targets A, B, and D, respectively. Deeper targets have higher frequency resonance peaks. To model a primary resonance (curve 2 in each case) near the data for each school, anchovy swimbladders were assumed neutrally buoyant at 1 m depth, and allowed to compress below 1 m. This resulted in progressively higher resonance peaks for the deeper schools, and a good fit to the primary resonance peak for all three targets. The small school model was used (curve 3 in each case), and a best fit was obtained for Target A, with d = 40 cm and σ = 8 cm (Figure 8a). Using the same model parameters, and just changing the depth, reasonable fits were also obtained for Targets B and D (Figures 8b and 8c). This modelling result leads to

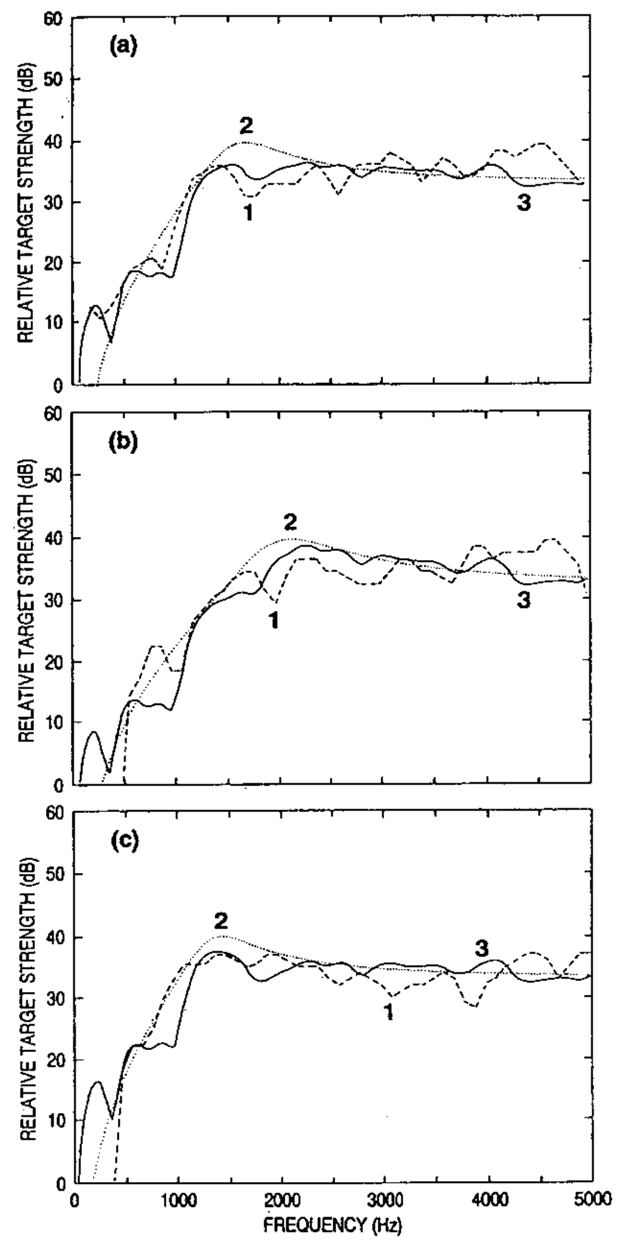

Fig. 8. Model fits to scattering data from schools of anchovy

the inference that the anchovy were not tightly schooled (ie with d = 12 cm = L), but were somewhat loosely schooled (with d = 40 cm ≈ 3.3L).

Conclusions

The low frequency scattering model described here is applicable to small schools of fish. It allows a verified scattering kernel for an individual fish in the school to be incorporated, includes all orders of multiple scattering between the fish, and calculates the aggregate scattering field of the school by coherently summing the contributions from individual fish. The model represents the random motion of fish within the school, and of the school itself, by averaging the scattering over a series of snapshot simulations. Application to simulated ensembles of closely spaced fish predicts anomalous reductions in target strength near the swimbladder resonance from the levels predicted by incoherent scattering, together with downward shifts in the peak resonance frequency. Frequency variations in the target strength due to constructive and destructive interference effects are also observed. When the model is applied to widely dispersed ensembles, it reproduces the results obtained using an incoherent scattering assumption. The model indicates that, for larger schools of commercially important fish in deep water, multiple scattering effects may severely reduce the target strength at frequencies close to the swimbladder resonance. The collective effects on the scattering of a single individual in a school show more fluctuations as the school size increases. The model has been successfully applied to fit experimental scattering data from schools of anchovy.

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This paper was based upon a presentation given at an IOA Underwater Acoustics Group conference on Underwater Acoustic Scattering in Weymouth, December 1994

Dr Christopher Feuillade FIOA is with the Naval Research Laboratory, Stennis Space Center, USA.

A MONTH IN THE COUNTRY – STARTING OFF LIFE AS AN ACOUSTIC CONSULTANT

Andrew J Asbury

On 1st July 1995, my role changed from acoustic student to acoustic consultant. As such, this article has been written to serve two purposes. Firstly, to tell the acoustics students what they can expect to be doing in their working life. Secondly, as we come out of recession and job markets grow, I hope to help the prospective employer get the most out of their new recruits by presenting them with a clearer idea of what the aspiring acoustic consultant may be looking for from a first position.

I have been studying acoustics for nearly four years now. Three of those years have been spent at Salford University, aiming for a degree in Electroacoustics. A fourth year was spent 'out' from university, working at Philips Research, Eindhoven. During this year out I conducted research into the commercial usefulness of loudspeaker arrays for controlling directivity patterns.

As such, I was one of the few students who, on starting the final year at University, had no knowledge of consultancy, or even the acoustics industry in Great Britain. The company I now work for, visited our university department in January of this year. An open-door session was advertised through the Acoustics Department, and around fifteen people attended to hear what the company got up to, and what their future plans were.

It certainly all sounded very appealing. I had found the office-based departmentalised life of research quite frustrating and monotonous at times, and consultancy seemed to offer a good compromise between academic and practical work. And so, after a very detailed interview, I was fortunate enough to be offered a job around March.

My life as a consultant began at 8am on Monday 3rd July. As my company was very busy, this starting date had already been brought forward by one month and my first job was something that I just couldn't miss! I was travelling on this first day to a British Aerospace site to meet a Rolls-Royce engineer/test pilot and discuss the construction of a test facility for the new Rolls-Royce EJ-2000 engine, destined for the European Fighter Aircraft. I would also be seeing the new British Aerospace 'hush-house'. In this facility, jet aircraft such as Harrier and Tornado are wheeled in, clamped to the ground, and the engines worked to full afterburner. As the nearest domestic dwellings are 1 km away, there was obvious work for an acoustic consultant, and my company had been among the design team.

It was perhaps a little overwhelming for my first morning as a consultant, especially when I walked down the silencer tube (I'm 6'4") and had problems touching the top of it. I also knew that when our company was commissioning the facility, one of our consultants measuring outside was not even aware of when the test had been started. The elements were ones I had met before, intake silencers, augmentor tubes, 'pepper-pot' diffusers and acoustic enclosures, but they were on a scale I could never before have imagined.

After seeing this, Rolls-Royce obviously wanted something similar. They had obtained an exhaust silencer from an RAF site, along with three control cabins. We were to investigate this equipment, and model its effectiveness. So, my first day's work involved taking dimensions, and measuring transmission loss.

This was followed up during my first month with more familiar work. I produced a spreadsheet model that went from the sound power level from an engine, all the way through to the sound pressure level in the nearest back garden. Also, the Noise at Work Regulations would need to be assessed for people working near the facility.

Next, basic engineering: if we make an enclosure too small, how difficult would it be to physically get the engine in and out? Solution: Make a scale model and see for yourself? Finally, meet with a quantity surveyor and see how much your wonderful ideas will cost!

Also in my first week, I attended a Public Inquiry. A planned dock extension, for which the outcome is still pending, was under scrutiny. My company's expert witness pointed out that the noise from the new site would be lower than at present for nearby residents, but the opposition seemed more concerned with the impact on birds. Being grilled by a London barrister was not something I expected to happen to an acoustic consultant! Luckily, the ace up our sleeve was a Dutch article concerning birds living next to firing ranges. Quite a difference from jet engines.

The greatest attraction of a career in consultancy has to be the sheer diversity of jobs undertaken. It is very difficult to judge what you will be working on next. The best example of this during my first month was in Leeds. A new building refurbishment was exhibiting strange acoustical behaviour, and we had been asked to find out why. On walking into the building, it wasn't too difficult. A curved section of bare plasterboard in the centre of a ceiling was creating a great deal of flutter echo, making speech virtually impossible whilst underneath. This flutter echo was then followed by a slap-back echo from two bare side walls. This created a very entertaining, but highly distracting effect on speech, especially considering that the room was to be filled with telephone operators. The next problem was finding a workable solution as the room had already been filled with desks and computers. A few weeks later, after resolving that particular problem, it has been found that the air conditioning units that were already fitted before the refurbishment have very poor vibration isolation and the building's new open-plan

design suffers from intolerable amounts of structure-borne sound, another interesting project on the way.

Next, following on from the glamorous world of architectural acoustics, I was seconded as a sheet metalworker's fitter, installing silencers onto a mill in a powder factory. I had been wondering about the overalls I had been given! Apart from getting very dusty, I discovered how a consultant's drawings are turned into real-life products and installed on site. As an important part of my training programme, I will shortly be spending a week working in an engineering factory who produce many of our noise control solutions. I hope this will give me a much better feel of timescale and practicability when I submit drawings in the future.

Nothing really prepared me at university for my first PPG 24 twenty-four hour survey. A land developer had proposed the building of two houses very close to a railway line, it was my job to assess the noise on the site. Starting at seven o'clock in the morning, the first dilemma came at 8:30. Around the corner from the site, the developer was already having a garage built and they were building it during my survey! A few frantic phone calls managed to sort that out, thank goodness I had been provided with a car phone. However, there are rather more basic problems associated with making a field your home for twenty four hours, as I am sure it is not too hard to imagine. The least of this is being careful what you're doing when the trains come past.

The neighbours were all quite friendly up to a point. I was offered countless cups of tea, then asked what I was going to do about the trains at night. By the end of the morning, I had perfected my look of sheer ignorance about who I worked for and why I was there. I was also asked, around closing time, if I really got paid for sitting in my car all day. It takes a while to realise that you actually do.

If all this sounds attractive to any potential consultants, there are a few things I think you should look for from a company. Perhaps the most important is a full description of the job you will undertake. There are more mundane aspects to a life in consultancy and it must be tempting for companies to simply give all this work to their newest addition. Also, realise that just because you may have done a degree, you don't know everything about the real-world of acoustics. Look for a full, structured training programme. I have been given a comprehensive training file covering everything from initial induction to all aspects of consultancy. You should be encouraged by your company to make additions to this file and write about what you are doing. This file will become invaluable in gaining Chartered Engineer status.

This challenge of training must be addressed by existing consultancies. It seems that most consultancies rely on the fact that after a long enough period of time, the new recruit will have seen most aspects of the job and be able to start their own work. Not only is this doing the company and the employee an injustice, it is prone to producing vast periods of tedium. By having a tangible document, the new consultant can never claim to have nothing to do. If I have no specific project to work on, I can simply turn to my training file and see what I have left to learn and then be able to approach a broader range of projects.

Communication is also a key to success during the start of a career. It is important that both sides be able to express both praise and criticism, and time should be set aside at regular intervals to do so.

After nearly two months of being a consultant, I feel a valued member of a consultancy team, with my own particular specialities and responsibilities, not just making the tea. I have completed the first part of my training programme, and am now working toward my three-month goals. The list of clients the company has worked for in my first month runs from blue-chip companies to small engineering works. I have experienced every phase of consultancy, from sales visits, bidding, surveys and design solutions to commissioning reports.

I hope I have given food for thought to both employers and students alike. I have been lucky enough to find a job with both a formal training programme and a contractual commitment to offering a career, not just a job. I also hope that the fast rising market in consultancy will not mean that new jobs are simply a stop-gap for busy periods. For both employers and employees the golden rule must be that you get out of the job what you put into it.

Andrew Asbury is with a consultancy company in the North of England

Professor Elfyn Richards OBE HonFIOA

Elfyn Richards died on 13 September 1995. He was made an Honorary Fellow of the Institute in 1978 and by that time he had long since acquired a formidable reputation in the field of noise control engineering.

In 1950 he was appointed to the first Chair of Aeronautics at Southampton University where he introduced research into noise and vibration, hypersonics and ship science. Elfyn established a Faculty of Engineering at that University, a department of Aeronautics and Astronautics (with himself as head) and a Noise Group to research engineering acoustics and vibration. Among his earliest protegés were Alan Powell and Professor J E Ffowcs Williams.

The Noise Group was so successful that he secured funding from industry and in 1963 turned the group into the Institute of Sound and Vibration Research as a department within the Faculty of Engineering. Richards surrendered his other professorial posts to become director of the ISVR, where he encouraged the combination of academic pursuits with service to industry and the community at large.

In 1986 he became the first county noise consultant, at Surrey, and in the same year was appointed Vice-Chancellor of Loughborough University of Technology.

After retiring at the age of 60 he returned to Southampton and the ISVR as research professor, and created a Research Group in Industrial Machinery Noise and Vibration.

A schoolmaster's son, Elfyn John Richards was born into a Welsh speaking family at Barry, near Cardiff, on 28 December 1914. He was educated locally and at Aberystwyth University College and St John's College, Cambridge (MA 1939). He claimed a Welsh Archbishop and a Bishop among his mother's ancestors; her father was a sea captain who plied the Australian grain route for many years.

He entered the aircraft industry and during the Second World War worked at the National Physical Laboratory, directing experimental and theoretical research on fluid dynamics. After the war Elfyn moved to Vickers Armstrong at Weybridge, where the first post-war civil aircraft were being considered. As chief aerodynamicist and assistant chief designer (at the age of 30) he helped to design the Viking, Viscount, Valiant and VC 10 aircraft.

In the late 1960s he foresaw that the world was 'entering an era of noise limitation'. He was instrumental in establishing acoustics and vibration as an engineering discipline and campaigned vigorously for recognition of noise control as a discipline in its own right.

Elfyn helped to develop a sound suppressor for the Boeing 707 in 1957 and went on to deliver warnings about the increase in noise at British airports.

In 1971 he issued a strong statement which described the unchecked rise of noise levels at Heathrow as 'scandalous' and called for the establishment of an Airport Advisory Council to monitor airport development.

He was also an early advocate of the importance of introducing forms of noise control in factories. In 1968 a study by ISVR revealed that hearing was often seriously impaired by industrial noise and in 1972 the Department of Employment issued a voluntary code of practice outlining acceptable noise levels in factories. It was generally agreed that the original code carried little weight and six years later Elfyn energetically called for measures to be introduced to make the measure more effective. 'There are at least 500,000 people in this country who are gradually becoming deaf because of noise levels at work' he said at that time. 'This is a conservative figure. It could be as high as 1,500,000'. The code was eventually enforced in 1990.

He was a founding member of the Noise Advisory Council set up by the government of the day to advise upon approaches to noise control. Elfyn served on a number of other committees including the Inland Transport and Development Council, the University Council for Adult Education, the General Advisory Council of the BBC and the Wilson Committee on Problems of Noise.

He was president of the British Acoustical Association from 1968 to 1970. In addition to the Honorary Fellowship of the Institute of Acoustics, he was awarded an Honorary Fellowship of the Royal Aeronautical Society and was also the first foreign Honorary Fellow of the Acoustical Society of America.

The Universities of Southampton, Wales, Loughborough and Heriot-Watt acknowledged his international standing by awarding him honorary degrees and the Institute of Acoustics presented him with its Rayleigh Gold Medal in 1986. He was also the recipient of the Taylor Gold Medal of the Royal Aeronautical Society, the James Watt Medal of the Institution of Civil Engineers and the Silver Medal of the Royal Society of Arts. Elfyn received an OBE in 1958.

The world of technology and the acoustics world in particular are the poorer for the passing of this warm and delightful personality. His ability to establish easy relationships with all around him and his seemingly unlimited capacity for encouraging young, and the not so young, research colleagues will be sadly missed.

The many members who knew him would particularly wish to join with Council in offering sympathy to his widow and all the members of his family. ❖

COMMUNICATIONS FROM THE ENGINEERING COUNCIL

The New Engineering Council Takes Shape

Earlier this year The Engineering Council and the engineering institutions agreed to create a new unified body to represent and focus the interests of the profession. This will consist of a senate of 54 members from which two operating boards will be drawn.

The Board for the Engineering Profession (BEP) will provide leadership across the many engineering disciplines. The Board for Engineering Regulation (BER) will set and monitor standards of education, training and discipline.

Plans have been developed for this new body, which will retain the name Engineering Council, to begin operation on January 1, 1996. To ensure an orderly transition from the present to the future Engineering Council, 16 transition members of the senate and chairmen of the senate, the BEP and BER have been elected for one year by a policy group representing the interests of the engineering institutions and the present Engineering Council.

The Privy Council will appoint six members and the remainder of the senate will be elected by engineers on the register and institution councils later this year. Senate members will normally serve for three years and these transitional arrangements have the added benefit of smoothing the transition to a normal election process.

Dr Alan Rudge CBE OBE Feng FRS FIEE, Deputy Group Managing Director, BT plc, is to be first chairman of the senate. Dr Rudge is a past president of the Institution of Electrical Engineers.

The transition chairman of the Board for the Engineering Profession will be Mr Brian Kent Bsc HonDSc Feng FIMechE FIEE. Mr Kent is chairman of Wellington Holdings plc and a past president of the Institution of Mechanical Engineers.

The transition chairman of the Board for Engineering Regulation will be Mr Robin Wilson, CBE, BSc, HonDSc FEng FICE FIHT FCIT. Mr Wilson is chairman of the Construction Industry Council and is a past president of the Institution of Civil Engineers.

1995 Environment Award

Four engineering projects which give priority to environmental issues were the finalists in The Engineering Council's prestigious 1995 Environment Award for Engineers. The award encourages engineers to demonstrate their skill and versatility in taking account of environmental issues when planning projects.

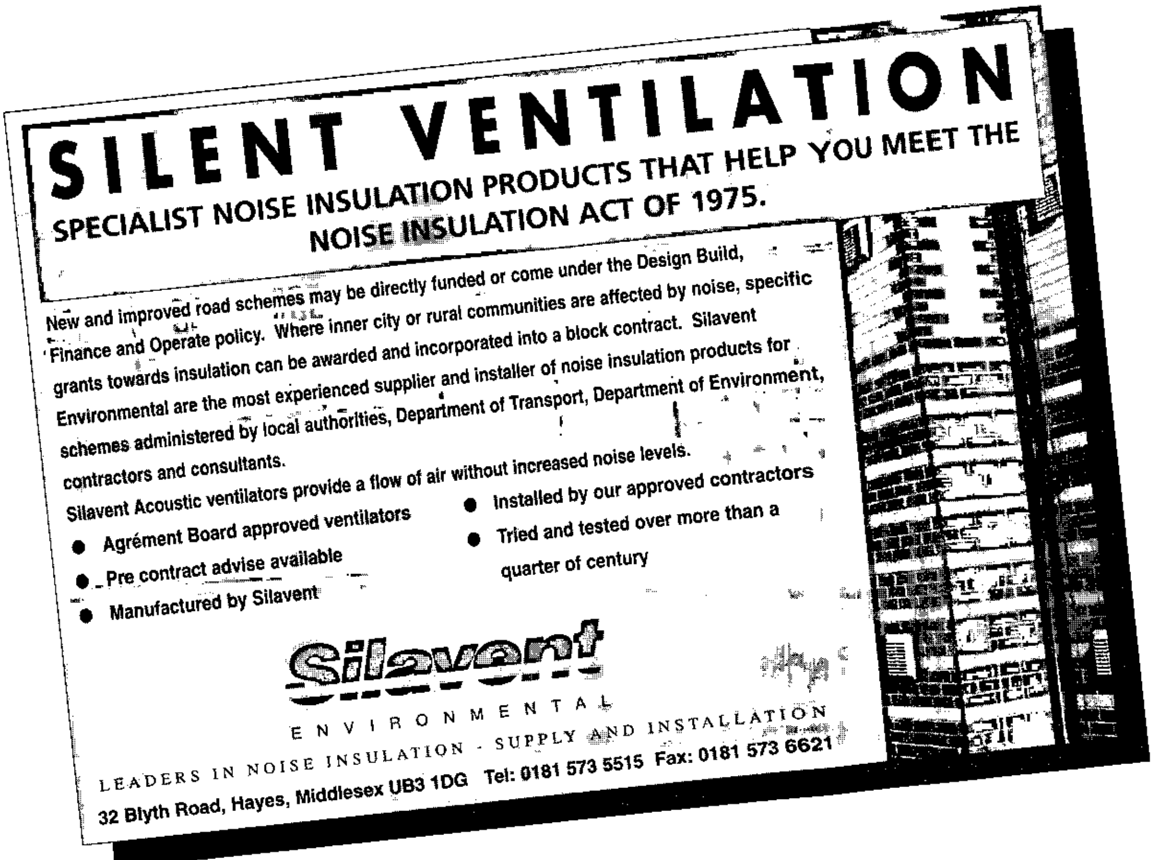
The first prize of £5000 and the Lloyd's Register Trophy went to Stephen Maxwell CEng and Ian Barnard from Cleveland Potash Ltd. Their project was the Cleveland Cascade Chute the purpose of which was to ensure that ship loading chutes discharge bulk in such a manner that no dust escapes. As well as the environmental health benefits of this project, there is no possibility of charged dust particles causing explosions.

The St Fergus gas–gas exchanger project, won the second prize of £1000. This was the work of Keith Sterrow CEng, John Love CEng, and Mike Rothwell CEng, from Total Oil Marine plc, Aberdeen and is a method of chilling gas arriving from offshore without using the CFC Freon 12 as the refrigerant. This will ensure that some 30 tonnes of Freon 12 can be removed from the plant by the end of 1995.

The two remaining projects on the short list and which were highly commended, receiving prizes of £500 each, were as follows.

Automobile exhaust gas ignition which was the project of Nicholas Collings, CEng, from the Department of Engineering, University of Cambridge. The purpose was to reduce exhaust emission from cars and it showed a way of heating the catalyst in a few seconds from start by igniting a rich exhaust just ahead of the catalyst, improving the environmental performance of cars fitted with catalytic convertors.

The 'Elephant' stabilised soil blockmaker developed by Arthur George Laming, CEng. This is a tool which can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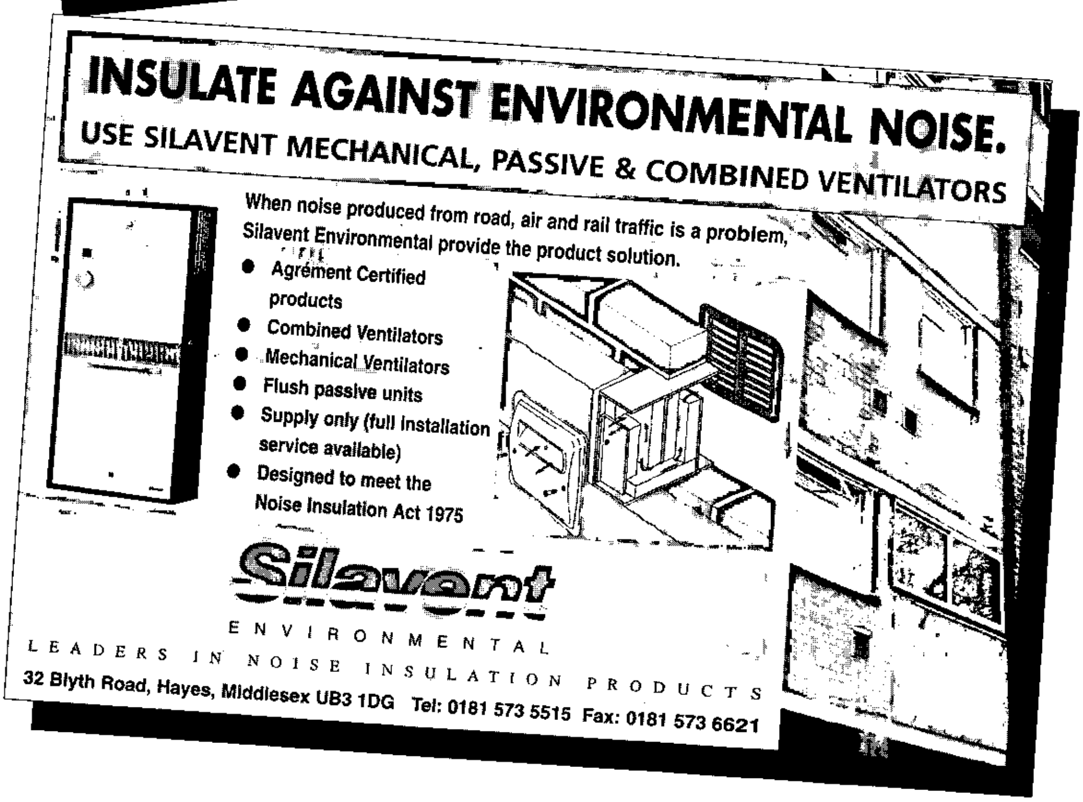
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be used with ease (particularly useful in the developing world) to make durable, thermal efficient housing.

The 1995 Environment Award for Engineers was open to individuals registered with the Council as Chartered Engineers (CEng), Incorporated Engineers (IEng) or Engineering Technicians (EngTech), or to teams of engineers and technicians including at least one member who is registered. Entrants have to be responsible for the design, manufacture or construction of an engineering project or process which provides an engineering solution to an environmental problem.

Message From The Director General

At the annual Engineering Assembly held at Exeter on 18 July, which provides a forum for engineers to voice their views on professional matters, Mike Heath, the new Director General of The Engineering Council, made the following points.

'Instead of receiving a coherent message from the engineering profession, the government had in the past tended to get a 'Tower of Babel' response with a different view from each of the many bodies'.

There had not been an effective mechanism for forming a profession view. This was a weakness in the eyes of the public and was partly responsible for the relatively low esteem in which engineering and engineers were held. 'It is a much more important weakness, however, in the eyes of the Government,' said Mr Heath.

'The sadness was that our national character gave us a national affinity and flair for engineering but we had been unable to capitalise on it. The Government, which today realised that engineering was a great wealth creator for the nation, badly needed coherent advice from the profession'.

He also highlighted other topics which had driven home to him very clearly how badly needed was the coming together of the profession, which unification represented. They included: The number and diversity of technical education initiatives hurled at schools from the Government, industry, from institutions and the Council itself, creating duplication but also leaving gaps; the overlapping of work by the Council and the institutions in the regions.

We must now do better and get our act together in these and many other ways. No one organisation could do it alone. 'We can, however, do it together and that, of course, is what unification is about,' said Mr Heath.

Action for Engineering

The efforts by The Engineering Council and the engineering institutions to unify to create a single voice for the profession is a key component of the Government's 'Action for Engineering' initiative.

Dr David Evans, Head of Technology and Innovation at the Department for Trade and Industry, said that 'Action for Engineering' is aiming to achieve improved competitiveness through better use of engineers and technicians.

The 'Action for Engineering' initiative was launched last October by the President of the Board of Trade in the wake of last year's competitiveness white paper. ❖

inter•noise 96

Progress Report

It seems a long time now since I presented the winning bid for inter•noise 96 at inter•noise 93 in Leuven. Although the Organising Committee have been actively preparing for 1996 since then, the pace of action is increasing steadily as the event approaches.

Recently the main activities have been in the general promotion of the 1996 Congress, arranging sponsorships and setting up the panel of organisers for the Special Technical Sessions. There are two main activities to report in the promotional field. Ralph Weston took a display stand, on loan from the Merseyside Tourism and Convention Bureau together with associated literature, to ICA 95 in Trondheim in June. Also four of the Institute's organising team attended the 1995 Congress at Newport Beach in July, where we were permitted to place the same display stand in a very prominent location, working diligently to ensure that every delegate took away material in the form of tourist information and Beatles carrier bags. Cardboard cut-out figures of a policeman, a Scottish piper and a Beefeater were provided by the Los Angeles office of the BTA. Japanese delegates were often seen having photos taken standing smartly to attention next to the cut-outs!

After the Closing Ceremony, Nicole Porter and I gave the traditional 15 minute slide show, in case the venue for the 1996 Congress had possibly escaped the notice of an occasional delegate, and this seemed to go down well. This was followed by a reception attended by 300 plus delegates, where the English beer went down equally well. CEL Instruments generously sponsored this parting celebration; they also covered the cost of picture post cards of the Liverpool waterfront at night with an invitation to attend Inter•noise 96 on the reverse.

I attended the 1995 meeting of the Executive Board of I/INCE and gave a detailed progress report and realised then that we needed to make use of other major national conferences world-wide to publicise Liverpool and accordingly arranged for promotional literature to be displayed at the annual gatherings of the Japanese, Canadian, Italian, Brazilian societies. This is in addition to the several thousand copies of the Call for Papers kindly distributed on our behalf by our sister societies in I/INCE including DEGA, SFA and ASA. 600 copies of the Call for Papers were also sent for distribution with a mailing of Acoustics Australia and a major world-wide mailing has been completed using the databases of delegates at earlier Congresses. I think I can safely say that a large percentage of the world's acousticians and noise control engineers are now aware of the venue and the dates.

Ian Campbell, now of Gracey & Associates, has been working hard attracting an initial list of sponsors. Among his successes to date is the British Tourist Authority who are helping with a proportion of some of the costs involved in mailing overseas. Another has been a discount arrangement with British Airways.

The initial distributions are soon to be reinforced by a Final Call for Papers and an internet Home Page is being generated. The Final Call carries information about the named topics. At the time of writing we have 44 Special Sessions (which is rather more than this year) and two workshops. It is an encouraging omen that for those Special Sessions, very many potential session organisers responded positively to approaches at Newport Beach from Nicole and me.

As a result of that effort, and from other subsequent contacts, 71 organisers or co-organisers from 15 countries are now listed in the Final Call for Papers – a veritable international Who's Who of the noise control discipline. The expectation is that during the next 3 months each of these subjects will yield a list of 8 to 10 papers to act as the main skeleton of the eventual programme. For the purpose of organising the final timetable, it seems inevitable that some of the topics will be amalgamated to form larger ones or else will fissure to spawn additional ones. Indeed this had already happened in the Active Control sessions. In this way we should reach our framework target of 350 papers to which will be added the offers of contributed papers (of which we have already received an encouraging number) received in response to our literature distributions.

We hope as many as possible of the papers will originate from the UK; to offer your contribution contact Nicole, who is Technical Programme Manager, at NPL on 0181 943 6705 or fax 0181 943 6217; alternatively contact may be made through the Institute office.

Bernard Berry ❖

Bernard Berry and Nicole Porter at the Closing Ceremony, inter•noise 95

New Products

Brüel and Kjær (UK)

New Brochure

A new brochure from B&K describes the time savings which the company claim arise from the use of their Type 2236 Sound Level Meter which, both in the field and back in the office, eases the effort required for environmental and workplace noise monitoring.

Because the 2236 measures all the parameters required for a complete characterisation of a noise nuisance simultaneously, and stores a full day's measurements in memory, it substantially reduces the time needed to collect information. Built-in software transfers results into a Microsoft Excel spreadsheet, making graphical representation of results quick and easy.

Further information: Tim Hoban, Brüel and Kjær, 92 Uxbridge Road, Harrow HA3 6BZ Tel: 0181 954 2366, Fax: 0181 954 9504.

Bruel and Kjaer is a Key Sponsor of the Institute.

Gracey & Associates

Real Time Frequency Analysis Now Available for the NOR-110

Norsonic AS have announced the introduction of the real time frequency analysis option for their popular NOR-110 Sound Level Analyser. The current facilities that provide extensive functions covering environmental and architectural applications have ensured a large and professional user base who will appreciate the addition of the new real time frequency analysis functions.

The instrument will now provided real time frequency analysis over the range from 1 Hz to 20 kHz in either third or full octave bands with the simultaneous measurement of a number of broad band indices. A full range of time averaging and storage functions are provided that allow the power, maximum and minimum spectra to be obtained simultaneously. Being in full compliance with the latest issues of the British and International Standards the instrument is available with NAMAS certification if required.

The growing demand for the documentation of the spectral content of 'offending' noises in nuisance investigations and the move towards product noise certification programmes are only two of the many new applications that the real time option for the NOR-110 will open up.

All new NOR-110 Sound Level Analysers are delivered with the new option whilst instruments already in service may be fitted with the new option by simply returning them to the Authorised UK distributors (Gracey and Associates) for a firmware upgrade, although with some of the very early units hardware modification may be necessary.

For further information contact Ian Campbell of Gracey and Associates, High Street, Chelveston, Northamptonshire NN9 6AS Tel: 01933 624212 Fax: 01933 624608

Gracey & Associates is a Sponsoring Organisation of the Institute.

CEL Instruments

Building Acoustics – A new approach

A new building acoustics measurement system has been announced which will, say CEL Instruments, take reverberation time and transmission loss measurements in buildings into a new era.

The system combines a CEL real-time sound level analyser to carry out the measurement, control and analysis functions together with a choice of noise sources.

The analyser, weighing less than a kilogram, acts as the core of the system and uses its advanced processing power and speed to give the operator a range of features usually associated with much larger and heavier instruments.

The building acoustics application provided by the analyser has four modes of operation; reverberation time measurements with an impulsive or constant noise source and measurement levels on the transmit and receive sides of a partition.

All of these operating modes can be used with any of the bandwidths (Broadband, Octave or Third Octave) that are available for CEL analysers.

The application is an option for all new CEL sound level analysers or can be installed quickly in existing units because no hardware changes or accessories are needed.

The easily portable CEL electronic noise source incorporates a combined loudspeaker/amplifier unit, a graphic equaliser and a pink noise source. This can be remotely triggered from the analyser, via an optional radio transmitter, thus eliminating the problems associated with long cable connections. It can also be set to automatically trigger, up to 20 times, for repeated tests.

The hand-held analyser can also be used on its own to measure the effects of an impulsive noise, like that provided by the CEL dummy pistol, in large spaces like auditoria.

With clear menu prompts, many of the expected measurement criteria are automatically calculated. The 'Fastore' rapid data storage facility, supplied with the building acoustics package, can be used separately for the capture of other transient signals like vehicle drive by, speech and ballistics tests.

For information on the CEL building acoustics application contact 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.

KEMO Ltd

Two-channel filter can switch modes

The new VBF18 from Kemo is a true adjustable bandpass and bandstop filter which can be fitted with one or two signal channels, each of which can be freely switched from bandpass to bandstop mode. The new filter, which offers a cutoff frequency range from 0.01 Hz to 99.9 Hz, is designed to offer sharp bandpass and band elimination responses from each channel.

In bandpass mode, the characteristic of the signal channel meets ANSI Class III specifications for one third octave filters and the ability to set the frequency with a resolution of three digits allows all standard band centres to be set.

When switched to bandstop mode, the VBF18 provides a notch filter response with theoretical ripple of ± 0.1 dB in the upper and lower passbands. Response is typically 1 dB down at points one-sixth of an octave each side of the cut-off frequency and typically greater than 50 dB down in a region ± 2% from the notch centre.

The VBF18 features simple front panel operation with frequency being set by three rotary decade switches and a range switch. The control lines of the two channnels can be linked so that one follows the settings of the other and a rear panel socket allows for external remote-control options. Each channel has a switchable AC coupling and 0/10/20 dB input gain. A 4 mA transducer supply is also fitted. The VBF18 is housed in a 1U high case suitable for bench use or 19 inch rack mounting.

For further information contact: Terry Grinstead, Kemo Ltd, 9 – 12 Goodwood Parade, Elmers End, Beckenham, Kent, BR3 3QZ Tel: 0181 658 3838.

Pioneer High Fidelity Ltd

Digital Audio Tape Deck

Pioneer High Fidelity Ltd have launched the D-9601 DAT recorder for the professional audio market. Dubbed 'HS DAT' (High Sampling), the D-9601 can operate at a 96 kHz sampling rate, twice that of conventional DAT recorders. It can also operates at 88.2 kHz as well as the standard 44.1 kHz and 48 kHz sampling frequencies. The D-9601 will be available exclusively in the UK from HHB Communications Ltd.

To achieve 96 kHz sampling the tape passes the head drum at 16.3 mm per second rather than the normal 8.15 mm per second, and the head drum's rotational speed is doubled from 2000 to 4000 rev/min.

As a result high frequency response increases to 44 kHz and any undesirable side-effects of anti-aliasing and post-DAC filtering are forced an octave higher in frequency.

For further information may be obtained from: Steve Angel, HHB Communications Tel: 0181 962 5000, Fax: 0181 962 5050, or John Bamford, Pioneer High Fidelity, Tel: 01753 789583 Fax: 01753 789528.

News

Arup Acoustics

Milton Keynes Theatre Modelled

The picture below shows the acoustic scale model which Arup Acoustics have been using to optimise the acoustics within the Milton Keynes Theatre. A feature of the design, which has been tested in the 1:50 scale model, is a moveable ceiling (similar to that in the Theatre Royal, Plymouth). This moves up and down at the touch of a button, to change audience capacity, overall appearance and acoustics according to the performance.

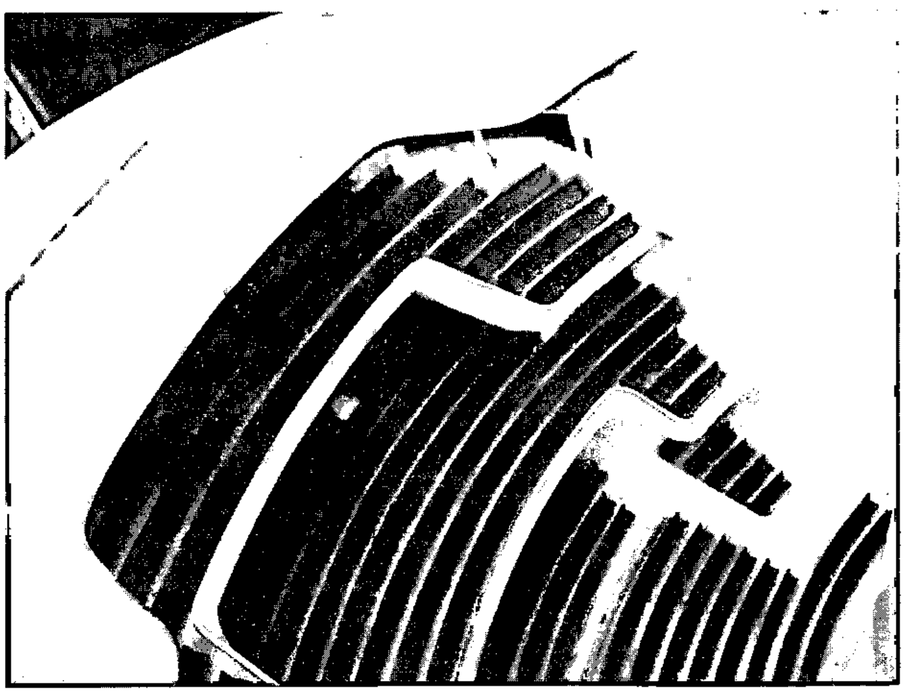
Other variable acoustics elements will complement the effect of the ceiling. Originally intended to be part of a commercial development, alternative funding for the theatre is being progressed.

For further information contact Rob Harris FIOA, Arup Acoustics, Parkin House, 8 St Thomas Street, Winchester SO23 9HE Tel: 01962 869111 Fax: 01962 867270.

Health and Safety Executive

New Practical Guide

The HSE have produced a practical guide, 'Health Risk Management' for managers in small businesses. Designed to help managers control health risks arising from work, the



booklet details case studies to illustrate particular points. Each year 2.2 million people suffer ill health caused, or made worse by work. The number of accidents which occur in the workplace each year is 1.6 million. In total 30 million working days a year are lost due to accidents and ill health. 'Health Risk Management' aims to show managers that identifying and controlling health risks before they become a problem will help to improve the control of risk within the workplace. Hazards dealt with include noise in the workplace. Copies of 'Health Risk Management' HS(G) 137 ISBN number 0717609057 can be purchased from HSE Books, PO Box 1999, Sudbury, Suffolk, CO10 6FS Tel: 01787 881165 Fax: 01787 313995.

Health Campaign

HSE also launched a major health management campaign on 5 May aimed at reducing the number of people who suffer ill health caused or made worse by work. The Campaign, 'Good Health is Good Business' is being backed by Sir John Harvey-Jones MBE and asthma physician, Professor Anthony Newman-Taylor of the Royal Brompton Hospital, London. The campaign will run for three years and is aimed at persuading managers in all firms to take action to make sure that their work does not make employees ill.

During the first year of the campaign inspectors will carry out about 600 in-depth visits to companies and organisations to look at health management systems and performance in dealing with each of this year's health risks – noise, strain injury and respiratory problems.

UKAS

New Accreditation Body

The Department of Trade and Industry announced on 3rd August a new national accreditation body, the United Kingdom Accreditation Service (UKAS). UKAS takes over the work of the National Measurement Accreditation Service (NAMAS), and the National Accreditation Council for Certification Bodies (NACCB), hitherto operated as part of the National Physical Laboratory and the British Standards Organisation respectively. It will provide a unified national accreditation service for laboratories performing tests and calibrations as well as bodies undertaking certification of products, personnel or systems (including environmental management and audit systems).

UKAS is a new private sector company, operating under the terms of a Memorandum of Understanding with DTI which recognises its unique national role in the field of accreditation.

UKAS will accredit in its own right, and be able to use the familiar NAMAS and NACCB accreditation logos incorporating the Royal Crown, subject to strict compliance with national and international regulations and standards.

UKAS is a non-profit distributing company and it has no share capital. Operating surpluses are retained within the business and used for developmental purposes. UKAS members will be organisations representing a balance of those with a significant interest in accreditation, direct customers, industry, the end-user and government. UKAS will be managed by a Board of Directors consisting of four non-executive directors (including the Chairman) and three executive directors (including the Chief Executive).

Dr Douglas Munro has been appointed as Chief Executive of the new company; he joins Chairman Dr Bryan Smith.

NAMAS now stands for National Accreditation of Measurement and Sampling and NACB for National Accreditation of Certification Bodies.

Essex University

Audio Engineering Course

The Department of Electronic Systems Engineering at Essex University announce a new MSc postgraduate course in Audio Systems Engineering. The course is designed to reflect and respond to the rapid pace of development in this technology.

Further details from Professor Malcolm O Hawksford FIOA, Department of Systems Engineering, University of Essex, Colchester CO4 3SQ Tel: 01206 872419/8 Fax: 01206 872900.

Industrial Acoustics Company (IAC)

Engine Test Facilities

IAC has announced the completion of two aircraft test facilities, one in Portugal and the other in Holland.

i) Aircraft/engine hush house for the Portuguese Air Force.

This has just been completed at a location 130 km north of Lisbon at one of the Air Force's main strike bases at Monte Real. It is capable of testing F100 and TF30 engines both installed in their aircraft and uninstalled on a test stand. The hush house – so named for its ability to reduce the very high noise levels generated by engines under test to no more than a loud hum outside-exceeds the project's acoustic specification in cutting noise emissions to just 70 dB(A) at 200 metres.

The facility has two separate control rooms from which engine test routines are set up and observed. These rooms have very high noise reduction properties to allow control room personnel to run engines up to full power in comfort and safety. While an F16 running at maximum re-heat emits a noise level of over 140 dB(A) just a few metres away, inside the control room the noise

level is below 65 dB(A).

ii) Special indoor T56 engine test facility for Royal Netherlands Navy. The facility is used by the Navy to test the T56-A-14 engines which power its Orion P3 aircraft. It also contains a separate area in which Garrett Auxiliary Power Units (APU's) are tested. Previously the Navy had tested its engines on a remote site in the open air. However, problems from noise pollution and difficulties created by erratic weather conditions were major factors in the Navy's decision to bring the entire test process inside.

The new IAC-built test cell, located at Valkenburg naval air station in the western part of the Netherlands, is unusual in several respects. Whereas most turboprop aero-engines are tested with a dynamometer providing the appropriate loading, in this facility an aircraft propeller performs this function thus saving the cost of a dynamometer and services and speeding up the test process. To combat noise, IAC built the test cell and control room from sound-absorptive high performance Noise-Lock modular panels in a portal steel frame, the whole structure being lined externally with weatherproof cladding. The facility met a specification of 68 dB(A) at 25 metres.

Further information from Simon White, IAC Tel: 01784 456251 Fax: 01784 463303.

IAC is a Sponsoring Organisation of the Institute.

LMS International

Acquisition of Skalar Computer

LMS International has acquired Skalar Computer GmbH, a manufacturer of mobile multichannel data acquisition systems, based in Gottingen, Germany. The company has been renamed LMS Skalar GmbH and becomes a product division of the LMS International group. Dr Helling and Dr Langhans, the cofounders of Skalar, continue the management of LMS Skalar. The Skalar system will be marketed under the name 'Roadrunner'.

LMS International is a Sponsoring Organisation of the Institute.

HHB Ltd

Portadat

HHB have recently published the first edition of a news bulletin which aims at demonstrating the different uses of PORTADAT portable DAT recorders. The PORTADAT News Bulletin is available free of charge from HHB in London or any of their distributors worldwide.

HHB Communications, 73 – 75 Scrubs Lane, London NW10 6QU Tel: 0180 962 5000 Fax: 0181 962 5050 email: sales@hhb.co.uk. ❖

Due to a printer's error, the address for KFA Sound Design & Construction in the advertisement on the back cover of the 1995/6 Register was given incorrectly. It should have read Royal Ordnance Unit G403, Beechfield Walk, Sewardstone Road, Waltham Abbey EN9 1AT. Tel: 01992 653324 Fax: 01992 653321

Non-Institute Meetings

1995

20 – 22 October
2nd International Acoustics Meeting, Valdiva, Chile

23 October
Doppler Ultrasound: Its Development and Clinical Application, London

23 – 26 October
Environmental Protection 1995, Scarborough

7 – 10 November
IEE International Ultrasonics Symposium, San Francisco, U S A

7 – 9 November
Noise and Vibration 95, Pretoria, South Africa

15 – 17 November
Acoustics Applied, Annual Conference of the Austrialian Acoustical Society, Fremantle, Western Australia

16 – 17 November
Gearbox Noise, Vibration and Diagnostics, London

21 – 22 November
Annual Meeting of the Brazilian Acoustical Society, Sao Paulo, Brazil

26 – 27 November
Spectral & Phase Space Techniques in Acoustics, St Louis, USA

27 November – 1 December
Asia-Pacific Vibration Conference, Kuala Lumpur, Malaysia

27 November – 1 December
130th Meeting of the Acoustical Society of America, St Louis, U S A

4 – 7 December
International Conference on Structural Dynamics, Vibration, & Noise Control, Hong Kong

5 – 7 December
British Medical Ultrasound Society, Annual Scientific Meeting & Exhibition, Torquay

1996

10 – 11 January
Second Annual Meeting, Society of Acoustics, Singapore

19 – 21 February
1st Australasian Applied Mechanics Congress, Melbourne, Australia

22 – 24 February
National Hearing Conservation Association, San Francisco, USA

26 – 29 February
DAGA – German Acoustical Society Meeting, Germany

1 – 4 April
Forum Acusticum, 1st Convention of the EAA, Antwerp, Belgium

26 – 28 April
Catgut Acoustical Society, Michigan, USA

11 – 14 May
100th Audio Engineering Society Convention, Copenhagen, Denmark

13 – 17 May
131st Meeting of the Acoustical Society of America, Indianapolis, USA

21 – 24 May
4th Speech Production Seminar, France

27 – 31 May
International Symposium on Acoustic Remote Sensing of the Atmosphere & Oceans, Moscow, Russia

28 – 31 May
Noise and Planning '96, Pisa, Italy

12 – 14 June
Nordic Acoustical Meeting, Finland

16 – 20 June
13th International Congress of Audiology, Italy

17 – 21 June
14th International Symposium on Nonlinear Acoustics, Nanjing, China

24 – 26 June
International Symposium on Nonlinear Acoustics, Netherlands

24 – 28 June
3rd European Conference on Underwater Acoustics, Heraklion, Crete

26 – 31 August
19th International Congress on Theoretical & Applied Mechanics, Kyoto, Japan

9 – 13 September
2nd European Nonlinear Oscillations Conference, Prague, Czech Republic

15 – 20 September
25th International Congress on Occupational Health, Stockholm, Sweden

18 – 20 September
Noise & Vibration Engineering Conference, Leuven, Belgium

23 – 25 September
FASE Symposium on Transport Noise, St Petersburg, Russia

29 September – 2 October
Noise-Con 96, Bellevue, USA

3 – 6 November
1996 IEEE International Ultrasonics Symposium, Texas, USA

7 – 10 November
101st Audio Engineering Society Convention, Los Angeles, USA

27 – 29 November
3rd International Conference on Vibration Problems, North Bengal, India

2 – 6 December
132nd Meeting of the Acoustical Society of America, Honolulu, Hawaii, USA

8 – 13 December
14th World Conference on Non – Destructive Testing, India

1997

21 – 24 April
International Conference on Acoustics, Speech and Signal Processing, Munich, Germany