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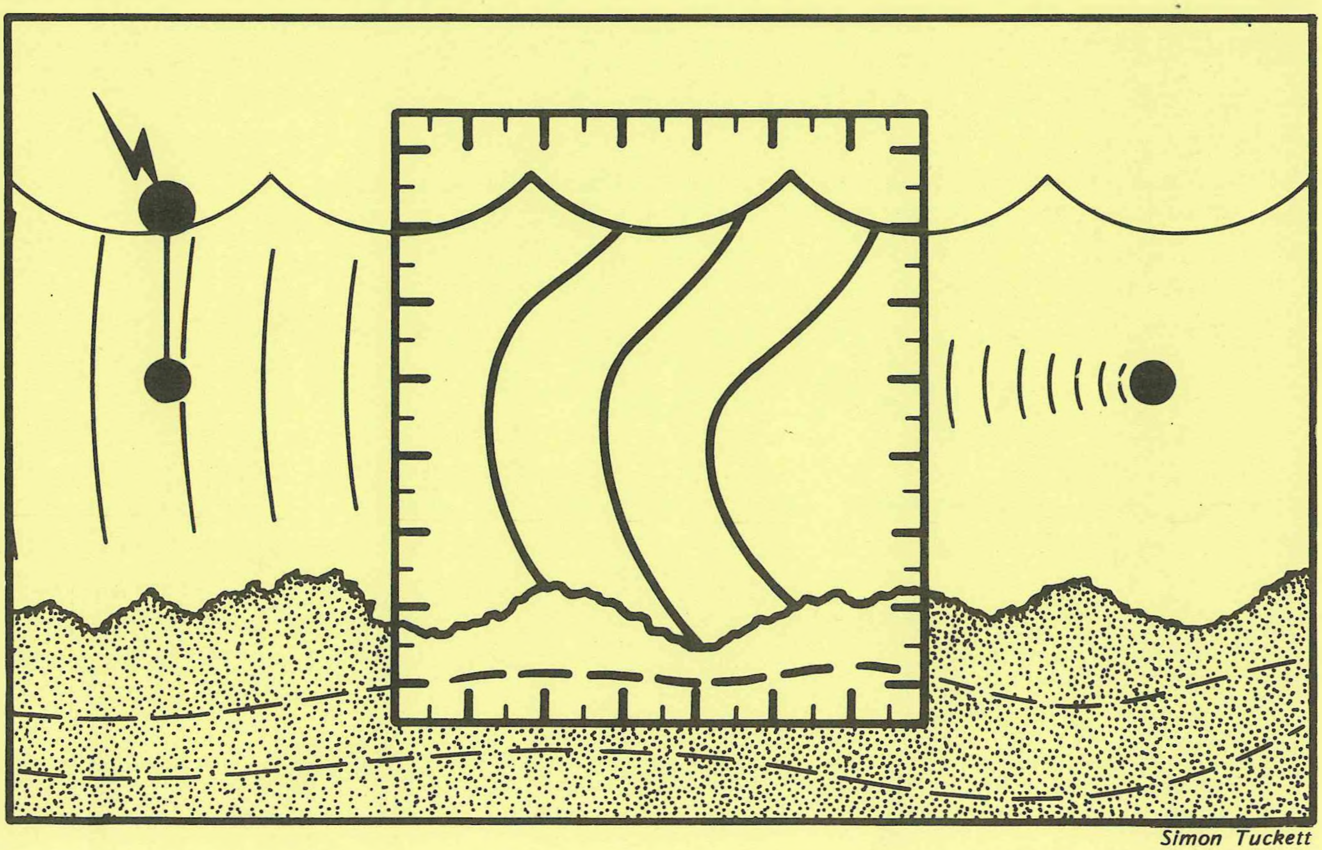

Simon Tuckett

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Articles on all aspects of Acoustics and Vibration in English and French are welcome, and should be addressed to any editor. All papers are reviewed.

Vous êtes invités à soumettre des articles sur tous les domaines de l'Acoustique et des Vibrations, en français ou en anglais. Prière de les envoyer à un des rédacteurs. Tout article est révisé.

ITORIAL

This issue contains a number of ems of information important to CAA mbers. There is a letter from our new esident, Cameron Sherry, on page 2. is is followed by information on the A fee structure, and the Call for pers for the CAA Annual Symposium, ncouver, 1983. On the international ene, there is some news from INCE. We courage you to submit abstracts for the A Annual Symposium now to help the cal Organizing Committee - and to able us to publish the meeting ogramme in the October issue of NADIAN ACOUSTICS.

ITORIAL

Dans ce numéro, il y a quelques nformations importantes pour nos membres. ut d'abord une lettre de notre nouveau ésident, M. Cameron Sherry, à la page 2. isuite, vous trouverez des renseignements propos des frais d'inscription de l'ACA : l'appel aux communications pour le lloque Annuel de l'ACA qui aura lieu à ncouver, C.B. Finalement, sur la scène nternational, il y a des nouvelles de INCE. Nous vous encourageons de sou- ettre vos résumés maintenant, afin de aciliter la tâche du Comité d'Organisation cal et de nous permettre de publier le ogramme de la réunion dans le prochain méro de l'Acoustique Canadienne.

NEWS

CAA TORONTO CHAPTER MEETING

The first CAA Toronto Chapter Meeting of 1983 was held January 10th at George Brown College. Len Blizzard and Andy McKee were the convenors of the meeting which took the form of a conducted tour of the acoustics laboratory facilities at George Brown College. Len Blizzard organized several students to give demonstrations of audiometric and hearing conservation equipment, standing wave tube measurements, recording studio equipment and level and frequency analysis of noise. Loudspeaker responses inside a small anechoic chamber were demonstrated and several examples of student projects in the area of noise control were on display.

Approximately 30 people attended the meeting. Coffee was provided by courtesy of Bruel & Kjaer Canada Ltd.

The next scheduled meeting of the CAA Toronto Chapter is Monday, April 11, 1983, at the Ontario Hydro Auditorium, 700 University Avenue, where Chris Krajewski and John Swallow will convene a session on Environmental Acoustics.

Andy McKee

CAA TORONTO CHAPTER QUESTIONNAIRE RESPONSE

By the end of 1979, a survey was carried out by G. Michel and A. Behar to test the wishes of Torontonians (and neighbours) about the creation of a CAA Regional Chapter. The result was overwhelming: all answers were "yes" (obviously, we didn't count nonrespondents as "no"). As a result, the Chapter was born and grew steady and healthy.

Three years after, and by using the same method, we intended to see how the membership feels about the way meetings are organized. The answers from the questionnaire can be summarized as follows:

1. We should have four meetings per year including a Technical visit (instead of the three we have now).

2. Meetings to be held on Tuesdays at 7:30 (instead of Mondays at 7:00).

3. Meetings to be on specific topics (as they are now).

4. We should hold a social evening once a year.

Our thanks to the members that took 10 minutes of their time to answer the questionnaire.

A. Behar

IEEE 1983 ULTRASONICS SYMPOSIUM

IEEE announces the Call for Papers of an International Symposium, Atlanta, GA., U.S.A., October 31 - November 2, 1983. Deadline for receipt of Abstracts is July 1, 1983. For further information contact: M. Levy, University of Wisconsin-Milwankee, Dept. of Physics, Milwankee, WI, 53201, U.S.A. Telephone (414) 963-4168.

INTERNATIONAL STANDARDS MEETINGS

ISO/TC43 "Acoustics", ISO/TC43/SC1 "Noise" and IEC/TC29 "Electro-Acoustics", are holding Plenary Sessions and associated Working Group meetings in Paris, France, approximately July 28 - August 10, 1983, at AFNOR Headquarters. For further information contact Mr. C. Ender (ISO) or Mr. S. Buchowski (IEC), Standards Council of Canada, Suite 2-401, 2000 Argentia Road, Mississauga, Ontario, L5N 1V8.

NEW RESEARCH CONTRACTS

To Institut national de la recherche scientifique, Verdun, Qué., $33,900, for "Adaptive transform coding of speech". Awarded by the Dept. of Communications.

To Jatel Communications Systems Limited, Kanata, Ont., $29,788, to "Investigate the feasibility of using constructive phoneme voice synthesis technology with the AN/APR-39 Radar warning receiver". Awarded by the Dept. of National Defence.

To Canadian Instrumentation and Research Limited, Mississauga, Ont., $108,575, for "Design and development of a direction of arrival/frequency acousto optic signal processor". Awarded by the Dept. of National Defence.

To Asecor Limited, Manotick, Ont., $54,845, for "Study to elaborate a computational method for evaluating the blast-noise environment of recoilless rifles". Awarded by the Dept. of National Defence.

To P. de Heering, Toronto, Ont., $10,100, for "Study of the applicability of echo sounding to planktonic insitu measurements". Awarded by the Dept. of Fisheries and Oceans.

To Valcoustics Canada Limited, Willowdale, Ont., $44,386, for "Study of sound transmission through common wall insulation". Awarded by the National Research Council.

To Bolt Beranek and Newman Incorp., Cambridge, Mass., $5,000, for "Engineering support to flexible shaft coupling vibration transmission loss test program". Awarded by the Dept. of National Defence.

To University of British Columbia, Vancouver, B.C., $114,530, for "Longtitudinal study of vibration white finger disease among British Columbia coastal tree fallers (Dr. C.J.G. MacKenzie, Dept. of Health Care and Epidemiology)". Awarded by the Dept. of the Environment.

To University of British Columbia, Vancouver, B.C., $40,170, for "Modelling of structural response to air blast (D.L. Anderson, M.D. Olson, Dept. of Civil Engineering)". Awarded by the Dept. of National Defence.

To Martec Limited, Halifax, N.S., $140,014, for "Propeller strength and vibration analysis". Awarded by the Dept. of National Defence.

I/INCE REQUESTS RESEARCH ITEMS

The International Institute of Noise Control Engineering (I/INCE) was founded in 1974 as an organization dedicated to the application of noise control technology for the benefit of the public. It provides leadership through the organization of international conferences and seminars on noise control engineering, especially the INTER-NOISE series of conferences. I/INCE also seeks to develop interdisciplinary contacts between Noise Control Engineering and other related fields of work, and promotes international cooperation in research on noise control. I/INCE has twenty member societies in seventeen countries spread over five continents.

As part of its responsibility to promote cooperation in research, I/INCE publishes a newsletter which contains news items of international interest. One of the objectives of the newsletter is to publish a survey of research in noise control in progress in laboratories throughout the world. These items will appear in a "Research" column of the newsletter. Individuals working in noise control research are encouraged to send such news items to the newsletter. It is not necessary to provide details of the results of the research; the scope and subject matter are sufficient. Information should be sent to Dr. A. Cops, Editor, I/INCE Newsletter, Celestijnenlaan 200D, B-3030 Heverlee, Belgium. Information on other I/INCE activities may be obtained from the I/INCE General Secretariat at the same address, or from John Hemingway, address on inside back cover.

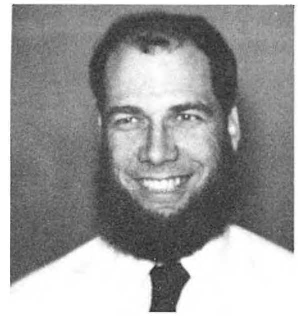
THE INTER-NOISE 82 PROCEEDINGS ARE AVAILABLE

San Francisco was the host city for INTER-NOISE 82, the 1982 International Conference on Noise Control Engineering. INTER-NOISE 82 was the eleventh in a series of International conferences on noise control engineering which are held in even-numbered years in the United States and in other countries in odd-numbered years. Held ten years after the enactment of the Noise Control Act of 1972, the theme of the meeting was "Noise Control: Ten Years Later". INTER-NOISE 82 was held in San Francisco in May, 1982. The meeting was sponsored by the International Institute of Noise Control Engineering and was organized by the Institute of Noise Control Engineering of the USA.

A two volume set of Proceedings of the conference has been published. The set, which contains 190 technical papers and 944 pages, contains papers which detail the progress of noise control engineering in the past ten years and point the direction of future progress.

(cont'd. on p.50)

LETTER FROM THE NEW CAA PRESIDENT



Fellow Acousticians:

Your editor has allowed me to use a few lines of your publication to bring you a little closer to the decision making processes of CAA.

We are now in the active count down to the 1986 12th ICA congress. Your chairman of the congress, Edgar Shaw, already has many of his subgroups very active on our behalf. If we all start together the workload will be ever as much lighter so if you are approached to lend a helping hand please find the courage to say "yes" and the time to carryout the job to the best of your ability.

Your directors will be considering on your behalf how we can approach more of the Canadian populace who have an interest in acoustics. Our starting point will be Anabelle Cohen's list she gave me in October. So watch the next issue for further news.

Your directors are puzzling over how to best set up the scholarship for some worthy university student with an interest in acoustics. The major problem being how do we evaluate a student in St. Johns against one in Victoria or Dawson City.

All of you now should have your savings account swelling with the funds required to visit Vancouver next fall. The organizers Stu Eaton and Doug Whicker assure me that they will have a very interesting and entertaining package.

Standardization of acoustical measurements one of the prime reasons that Dr. Northwood started this organization is still alive. There is a need, however, to have more people reviewing the international acoustic standards. To obtain a true Canadian viewpoint we need reviewers from coast to coast. If you are interested please drop me a note or phone.

Have a Happy & Properous 1983.

Cameron W. Sherry
President

LETTRE DU NOUVEAV PRESIDENT DE L'ACA

Chers acousticiens

Votre équipe de rédaction m'a permis de me servir de votre publication pour vous renseigner sur les prises de décisions de l'ACA.

Nous nous trouvons maintenant dans la période du compte à rebours pour le 12ème congrès du CIA, soit en 1986. Votre président du congrès, M. Edgar Shaw, et ses sous-groupes ont déjà commencé le travail en notre nom. Si nous faisons le travail ensemble, la tâche sera plus facile; alors si vous êtes invités à participer, je vous prie d'avoir le courage et la bonne volonté de répondre par l'affirmative et de faire votre mieux.

Vos directeurs vont étudier les moyens les plus efficaces d'approcher la population canadienne s'intéressant à l'acoustique. Notre point de départ sera la liste que m'a donnée Anabelle Cohen en octobre dernier. Je vous en ferai part dans le prochain numéro.

Vos directeurs s'interrogent sur la question de la bourse d'études universitaires destinée à un étudiant ou une étudiante doué et intéressé à l'acoustique. Le problème principal concerne l'évaluation d'un(e) étudiant(e) de St. Johns comparé(e) à un(e) autre de Victoria ou de Montréal.

A l'heure actuelle, j'espère que vous avez déjà économisé les fonds nécessaires pour vous rendre à Vancouver l'automne prochain. Les organisateurs, MM. Stu Eaton et Doug Whicker m'ont assuré que le programme sera intéressant et varié.

Une des raisons primordiales pour laquelle Dr. T. Northwood a fondé cette association, est la normalisation de mesures acoustiques. Cette activité est toujours en plein essor. Mais nous avons besoin de personnes pour faire la critique des normes acoustiques internationales. Afin d'obtenir un point de vue canadien valable pour tout le pays, il est nécessaire d'avoir des réviseurs venant de toutes les parties du Canada. Si vous êtes intéressé(e), écrivez ou appelez-moi.

Heureuse et prospère année 1983.

Cameron W. Sherry
Président

CAA ADOPTS NEW INVOICING SYSTEM.

The CAA Board of Directors at its meeting in October, 1982 agreed to adopt a new invoicing system for the collection of members and students fees, subscriptions and sustaining memberships. Invoices were mailed at year end and the response of the majority of CAA members and subscribers was excellent. We thank you most sincerely for your sterling support. The new invoice form, for the first time, encourages members and subscribers to make voluntarily donations to the funding of the 12th International Congress on Acoustics which will be held in Canada in 1986. An additional feature of the invoice form is the solicitation for support for a proposed "CAA Scholarship Prize in Acoustics" open to students in Canadian Universities. Details of the Prize nominating procedures will be announced in due course.

Preliminary 1983 List of Contributors to 12th ICA 1986 Fund and CAA Scholarship Prize Fund

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D. J. WHICKER
M. G. WIEBE
S. S. WILSON

Training Courses in Acoustics in Toronto, 1983/84

The Canadian Acoustical Association has agreed to cooperate with the Ontario Ministry of the Environment in presenting the 1983/84 series of training courses in environmental and occupational noise. These training courses will be of interest to municipal employees, planners, and industry. All the courses will be held in the Macdonald Block, Queen's Park, Toronto. The course fee is $150.00 and each course will run for four days with the final examination optional. The acoustics technology course material has been thoroughly revised by Dr. T. D. Northwood. The new standard procedures contained in the revised NPC publications and the new impulse vibration standards will also be included in the training courses for the first time. Enquiries concerning the schedule and registration should be directed to John Manuel (416) 965-5885.

CALL FOR PAPERS

The annual meeting of the Association will be held Thursday and Friday, 20 and 21 October, 1983 at the Georgia Hotel, Vancouver, B.C.

Contributions on all aspects of acoustics are welcome. The following special sessions have been planned:

Transportation Noise
Architectural Acoustics
Underwater Acoustics
Industrial Noise and Vibration
Psychoacoustics and Physiological Acoustics
Speech and Voice - Synthesis and Analysis

Send all abstracts to:

Dr. David Y. Chung
Hearing Branch, WCB
10551 Shellbridge Way
Richmond, B.C. V6X 2X1

Deadline for receipt of abstracts if July 15, 1983.

APPEL AUX COMMUNICATIONS

La réunion annuelle de l'Association Canadienne de l'Acoustique aura lieu le jeudi et le vendredi, le 20 et le 21 octobre, 1983, à l'Hôtel Georgia, à Vancouver, C.B.

Des communications sur tous les aspects de l'acoustique peuvent être présentées. Des séances spéciales sur les thèmes suivants seront organisées:

Bruit des transports
Acoustique architecturale
Acoustique et vibrations industrielles
Acoustique sous-marine
Acoustique physiologique et psychoacoustique
Parole et voix - Synthèse et Analyse

Envoyer votre résumé à:

Dr. David Y. Chung
Hearing Branch, WCB
10551 Shellbridge Way
Richmond, B.C. V6X 2X1

Date limite de réception de résumé est le 15 juillet, 1983.

A Progress Report on Ultrasonics International

Halifax, 12 - 14 July '83

A meeting of the scientific panel was held in London to review papers, arrangements and related matters for the coming conference. Over 130 abstracts were received from 24 different countries and 23 sessions are planned, including: 4 on non-destructive testing; 2 on medical ultrasonics; 2 on transducer technology; 1 on underwater acoustics; 2 on high power generation and applications; 2 on opto acoustics; 3 on physics of ultrasound; 1 on material characterisation; 1 on acoustic microscopy and 2 on acoustic emission.

Mr. R. Thornhill, the Nova Scotia Minister of Development, will open the conference and associated equipment exhibition.

The interest in the conference from all quarters seems to guarantee that it will be better attended than any previous meeting in the series.

Those who would like further details should write to:

Dr. H. W. Jones
Department of Physics
Dalhousie University
Halifax, N.S.
B3H 3J5.

or

Dr. Z. Novak
Butterworth Scientific Ltd.
P.O. Box 63
Westbury House, Bury Street
Guildford, Surrey GU2 5BH
U.K.

GEO-ACOUSTIC MODELS FOR PROPAGATION MODELLING IN SHALLOW WATER*

D. M. F. Chapman and Dale D. Ellis
Defence Research Establishment Atlantic,
P.O. Box 1012, Dartmouth, Nova Scotia, Canada, B2Y 3Z7

ABSTRACT

Acoustic propagation in shallow water is viewed as a guided-wave phenomenon, with the sea surface and seabed forming the boundaries. At sub-kilohertz frequencies, the acoustic properties of the seabed to a depth of several wavelengths can have a strong effect on propagation. The computer modelling of propagation requires estimates of such parameters as sound speed, density, attenuation, and layer thicknesses, which are collectively called the geo-acoustic model of the seabed. Direct measurement of these quantities is difficult, and methods must be devised to infer these values from other experiments, often employing acoustic techniques. At DREA, we have adopted the approach of independently determining as many geo-acoustic parameters as possible, and adjusting the less precisely known parameters within reasonable limits to effect an agreement between theory and experiment. To this end, we have used sub-bottom vertical reflection profiles to determine sediment types and thicknesses, large and small scale seismic refraction experiments to estimate sound speeds, and processing of sub-bottom reflection data to estimate volume attenuation. Examples of geo-acoustic models and comparisons with experiment are presented for shallow water sites on the Scotian Shelf and the southwestern approaches to the English Channel.

RESUME

La propagation des sons en eau peu profonde est considérée comme un phénomène d'onde guidée, la surface de la mer et le fond marin constituant les limites. Aux fréquences inférieures au kilohertz, les propriétés acoustiques du fond marin jusqu'à une profondeur de plusieurs longueurs d'ondes peuvent avoir une grande influence sur la propagation. La modélisation par ordinateur de la propagation nécessite l'estimation de paramètres comme la vitesse du son, la densité, l'atténuation et l'épaisseur des couches, qui portent collectivement le nom de modèle géo-acoustique du fond marin. La mesure directe de ces paramètres est difficile et on doit mettre au point des méthodes permettant de déduire ces valeurs d'autres expériences souvent basées sur l'application de techniques acoustiques. Au CRDA nous avons adopté une méthode visant à déterminer séparément le plus grand nombre possible de ces valeurs avant d'ajuster les valeurs des paramètres moins bien connus à l'intérieur de limites raisonnables pour faire correspondre les résultats expérimentaux à la théorie. A cette fin nous avons utilisé des profils de réflection sous le fond pour déterminer les types de sédiments et leur épaisseur, des expériences de sismique réfraction à petite et à grande échelle afin d'estimer les vitesses du son et le traitement des données de réflection sous le fond afin d'estimer l'atténuation de l'intensité. Des exemples de modèles géo-acoustiques et des comparaisons avec les résultats expérimentaux sont présentés pour des emplacements en eau peu profonde de la plateforme néo-écossaise et des approches sud-ouest de la Manche.

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* Presented at the 103rd meeting of the Acoustical Society of America, Chicago, Illinois, 27 April, 1982.

1 Introduction

One component of DREA's research program in shallow water acoustics during the last several years has been the attempt to model acoustic propagation in a variety of shallow water environments. This effort, coupled with our bank of experimental data, allows us to study the influence of different environmental factors on propagation. This paper will describe the formation of geo-acoustic models of the seabed, concentrating on conditions in which the propagation is bottom-dominated.

The seabed properties of primary interest for the computer modelling of acoustic propagation are the sound speed, density, attenuation, and layer thickness. This paper will discuss various methods used to measure these properties; for example, sub-bottom profiling, seismic refraction, and dispersion analysis. Examples of geo-acoustic models and comparison of predictions with experimental propagation loss data will be presented for shallow water sites on the Scotian Shelf and the southwestern approaches to the English Channel.

The acoustic propagation of a given environment, source/receiver geometry, and frequency is often characterized by a quantity known as propagation loss (or transmission loss). This is defined to be ten times the logarithm (base ten) of the ratio of the acoustic pressure at the receiver to the pressure at a reference distance (1 meter) from an ideal point source. The units are then dB re 1 m. A spherical wave radiating from a point source exhibits a 20 log R range dependence, where R is the source/receiver distance. Acoustic energy propagating in a waveguide formed by two perfectly reflecting, plane-parallel boundaries exhibits a 10 log R dependence.

In a typical ocean environment, propagation loss has several contributing factors apart from geometric spreading, such as refraction by a depth-dependent sound speed, sea-water absorption, loss due to imperfect reflection at the seabed, and scattering of energy at rough interfaces and inhomogeneities. Imperfect reflection at the seabed may be due to absorption in the surficial sediment layers and/or conversion of compressional waves to shear waves at the interface. The role of the propagation model is to estimate the combination of all these factors, based on physical mechanisms and our best knowledge of the acoustic environment.

In Figure 1, the shallow water areas of primary interest to DREA are represented by the region inside the 500 m contour tracing the edge of the continental shelf. As well as containing a significant part of the trans-Atlantic shipping lanes, these areas undergo intense exploration activity for the possible exploitation of mineral resources, and host the fishing fleets of several nations. The seabed formations of these areas range from exposed bedrock and glacial till to sediment deposits of gravel, sand, silt and mud. The water depth on the shelf can be as shallow as 70 m on the bank areas, or as deep as 250 m in the basins.

Acoustic data from the Scotian Shelf and Grand Banks serve to demonstrate the range of propagation conditions that the acoustic modeler must be prepared to encounter in shallow water environments. In Figure 2, the curves of propagation loss vs range for a 1/3 octave band of energy centered at 40 Hz show a tremendous difference: the Scotian Shelf data show the same loss as would be predicted by a cylindrical spreading law, implying little bottom loss. In contrast, the Grand Banks data show considerably more loss than would be predicted even by a spherical spreading law, leading us to the conclusion that loss due to seabed interaction plays a significant role in this case.

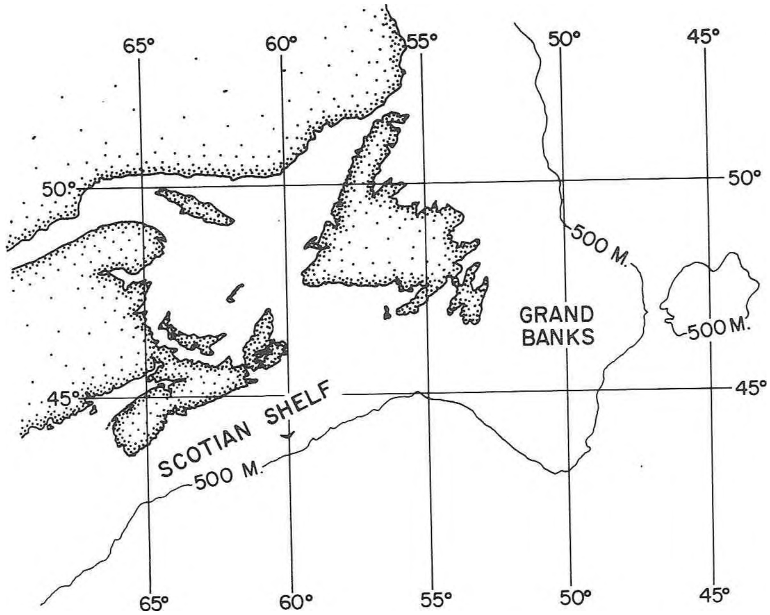

Figure 1. **The shallow water areas of primary interest to DREA, inside the 500 m contour.**

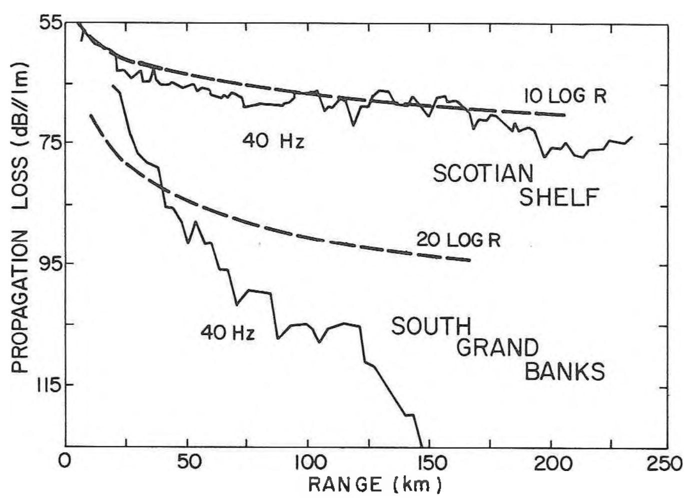

Figure 2. **Extremes of propagation variability.**

2 Modelling acoustic propagation in the ocean

As shown in Figure 3, the shallow water acoustics problem consists of solving the wave equation in the ocean waveguide bounded on top by the ocean surface, and on the bottom by the imperfectly reflecting seabed. These boundaries may be rough, and the medium is generally inhomogeneous, due to a depth-dependent sound speed profile. The variation of the waveguide properties in depth is typically much stronger than the variation in range, making this problem well-suited for analysis by a normal mode computer code using an adiabatic assumption [1],[2]. This assumption requires that no energy be transferred between modes propagating through a range-dependent environment. Mode coupling techniques [3], which transfer energy between modes, can be introduced to manage extreme range-dependence. Other models which can be used in shallow water are the parabolic equation (PE) [4], the fast field program (FFP) [5], and ray trace models [6], although each has its limitations.

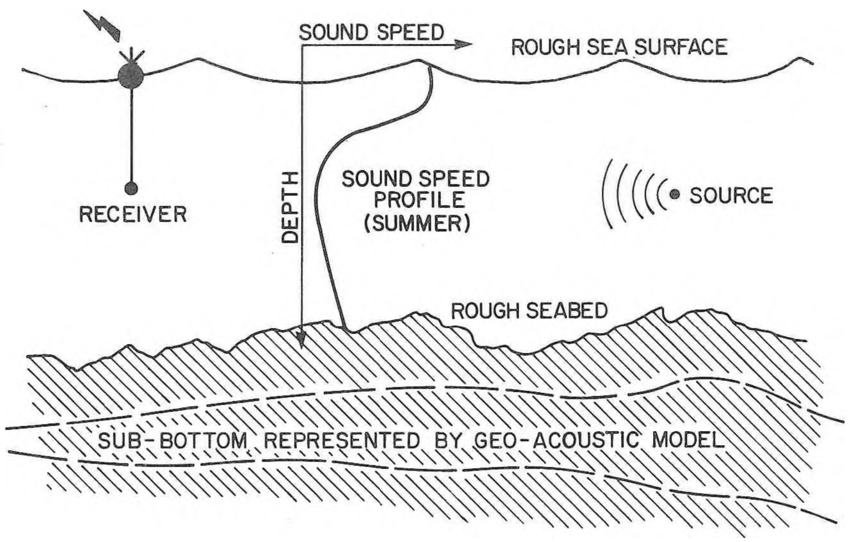

Figure 3. **The shallow water acoustics problem.**

It is the interaction with the seabed which provides the greatest challenge in the modelling of shallow water propagation, since the parameters needed for the geo-acoustic model are not generally accessible for direct measurement. Special experiments must be designed to extract the characteristics of interest. The construction of a geo-acoustic model of the seabed is a complex task, often iterative, and requires the compilation of facts from diverse sources.

The geo-acoustic model is generated in the form of a sequence of layers of sediment or rock having constant values of compressional wave sound speed, specific gravity, bulk attenuation, and shear wave speed. Vertical gradients of these values within a layer may be accommodated by sub-dividing the layer into finer piece-wise constant layers, although some normal mode codes can handle piece-wise linear variation of these parameters. Of those normal mode models which incorporate shear wave effects, most allow only the bottom-most layer to support shear, but there are specialised programs which treat the general problem. The present normal mode program at DREA uses a piece-wise constant geo-acoustic model, with no shear waves.

3 Sources for the model inputs

Oceanographic inputs for the propagation model are readily available: sound speed profiles in the water can be measured using expendable bathythermographs or conductivity-temperature-depth probes. The water depth can be measured using the source ship's echo sounder, or from a sub-bottom seismic profile survey. Surface roughness can be estimated visually, deduced from wind speed, or measured using devices deployed from the ship. In the absence of direct measurement of these factors, environmental data banks can provide an estimate of their expected characteristics.

Seabed characteristics are inferred from several sources: the main instrument used by DREA is a high-resolution vertical incidence reflection profiler [7] supplied by Huntec ('70) Ltd. This device generates a graphic record of the sub-bottom echoes from a broad-band source towed along the survey track, resolving features as small as 1 meter, and penetrating the surficial sediments to a depth of several tens of meters, depending on the bottom hardness. Seismic refraction and wide-angle reflection experiments provide estimates of the layer velocities and thicknesses. Dispersion analysis of transient arrivals provides group velocity values which can be compared with modelled values. For some areas [8], the seabed types have been compiled into reference charts which can be consulted in the absence of direct measurements to provide a crude geo-acoustic model. The published literature on the geophysical characteristics is always consulted to take advantage of previous surveys, and to guide the interpretation of the newly acquired data.

3.1 Seismic profiling

Figure 4 is a reproduction of the graphic output of the Huntec seismic sub-bottom profiler, taken from a region on the Scotian Shelf exhibiting different seabed formations. A geo-physicist has interpreted this record with the aid of "ground truth" obtained from more traditional survey techniques such as core sampling and grab sampling. In addition to the echo time series, the analysis software provided with the system estimates the percentage of energy reflected [9] at the water/sediment interface, r_1, and the percentage of energy scattered non-specularly, r_2. As the outcropping sediment laterally grades from glaciomarine sediment to holocene clay, notice that both of these values decrease and that the fluctuation in r_2 is greatly reduced. These reflectivity values aid in the identification of the surficial sediment, especially when there are no distinctive features such as the bedding in the sediment. Note here, and in many of the figures which follow, that the horizontal scale is several orders of magnitude greater than the vertical scale.

Another method of processing applied to these data generates a time-frequency plot [10], or sonogram, of the received energy. The frequency dependence of the energy from the seafloor return is compared with that from a buried coherent reflector. Assuming that the attenuation coefficient (the loss in dB/m suffered by a plane wave) varies linearly with frequency, an average value for the layer can be estimated. Typically, this value varies from place to place and with layer thickness, but the values obtained are useful in placing bounds on the parameters of the geo-acoustic model.

Figure 5 shows an interpreted profile for use in the geo-acoustic model for an area in the southwestern approaches to the English Channel (SWAP). The sediments have been classified by geological period, after consulting the geo-physical literature [11]. The Pliocene to Recent sediments are unconsolidated, and vary considerably in thickness due to the occurrence of sand bars. The Paleogene layer is a more compacted material, and the Upper Cretaceous layer is a semi-consolidated bedrock, probably chalk. The sound speeds have been assigned according to the literature, and the attenuation values were measured at points where the various sediment types outcrop at the sea floor. The large variation in the sand values may be due in part to a depth dependence of attenuation, since it has been proposed that there is a negative gradient of attenuation in unconsolidated sediments [12].

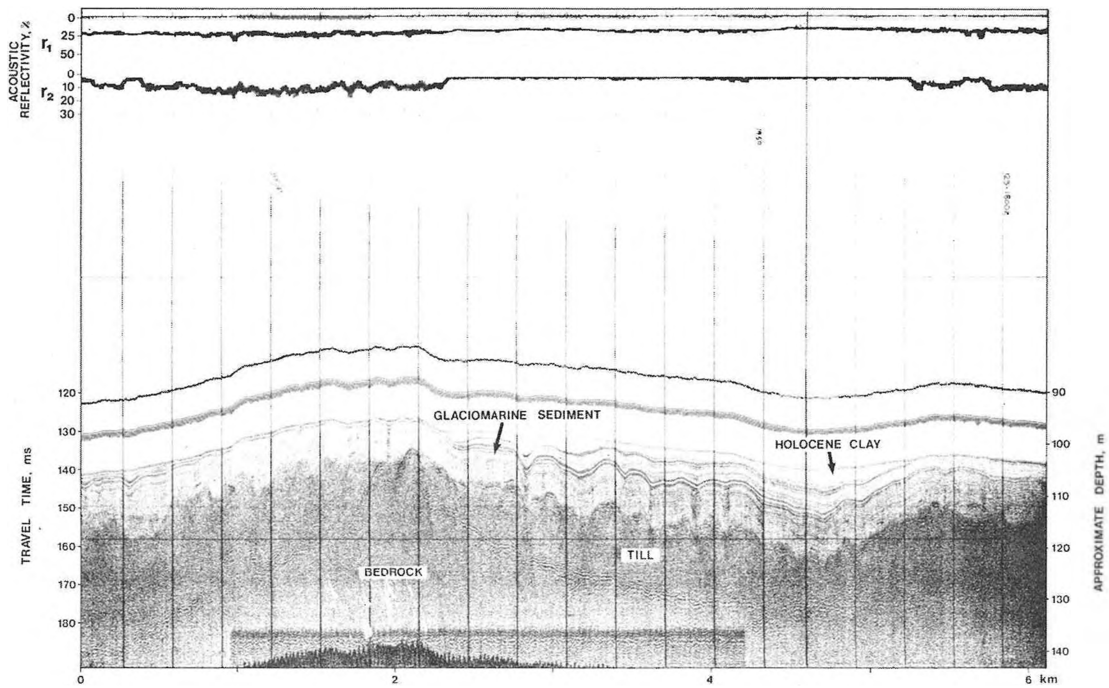

Figure 4. **Graphic output of the Huntec ('70) Ltd. seismic profiler.**

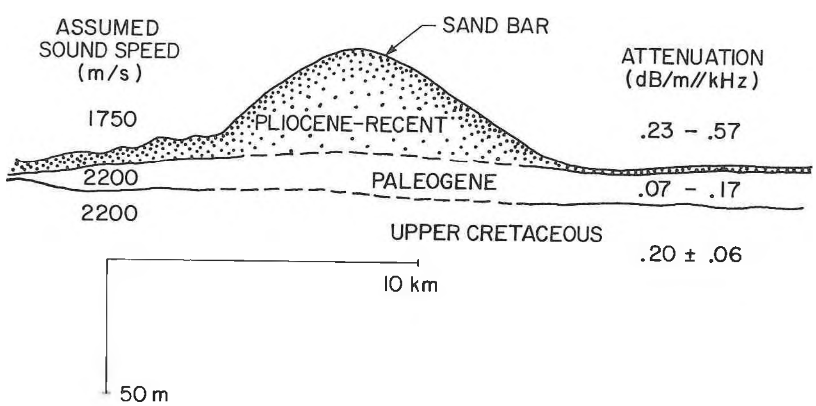

Figure 5. **Geological interpretation of the seismic profile for an area in the southwest approaches to the English Channel.**

3.2 Seismic refraction

Seismic refraction, illustrated in Figure 6, makes use of energy critically refracted along a layer boundary, giving a linear relationship between range and travel time. Arrivals at a horizontal array of sensors can be processed to give the velocities of several consecutive layers, and their thicknesses. Geophysicists use this technique on a scale of tens or hundreds of kilometers to investigate the layering of the earth's crust to a depth of several kilometers. The Geological Survey of Canada have an array of considerably smaller size which is used to investigate the permafrost layer at the bottom of Arctic waters [13]. Data from this same array deployed on the Scotian Shelf have enabled us to measure velocities within the surficial sediment layers, and to measure layer thicknesses. A similar device is being developed for the measurement of shear wave velocities.

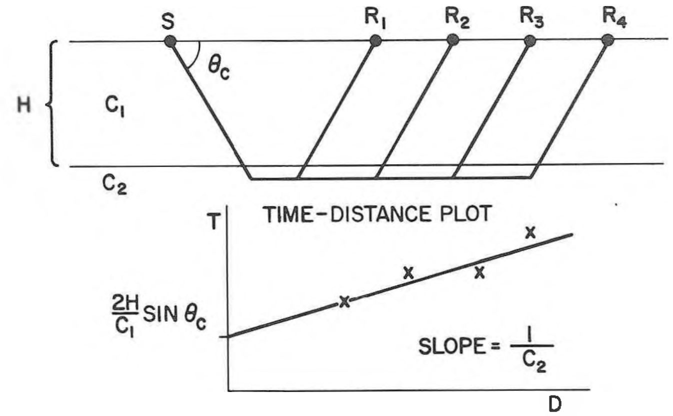

Figure 6. **Schematic representation of the seismic refraction measurement process.**

3.3 Dispersion analysis

The dispersive nature of the shallow water waveguide [14] causes time spreading of the various frequency components of a transient signal as it propagates down-range. Figure 7 shows a time series from an explosive deployed in a region near St. George's channel between Cornwall and Ireland, where the surficial sediment layer is quite thin, and Cretaceous bedrock forms the seafloor. The first arrival is a low-frequency signal due to refraction of the compressional wave at a high-speed bottom layer. The earliest high-frequency energy travels at the minimum phase velocity in the water column. The Airy phase is the arrival corresponding to the group velocity minimum of a given mode, in this case probably mode one. The Scholte wave is an interface wave travelling at just less than the shear speed in the bottom [15]. For non-crystalline bedrock, this is usually slower than the minimum phase velocity, so the interface wave is the last arrival. A quantitative analysis of transient arrivals can give curves of group velocity vs frequency which can be compared with theoretical curves calculated using the geo-acoustic model. In this way, the layer velocities and thicknesses of the geo-acoustic model can be tuned. We have not yet pursued this line of investigation at DREA, although other workers have employed this technique with success [16].

4 Comparison of model and experiment

With a combination of the above methods, it should be possible to generate a reasonable geo-acoustic model for an experimental site. We have done this for several areas on the Scotian Shelf and the southwest approaches to the English Channel.

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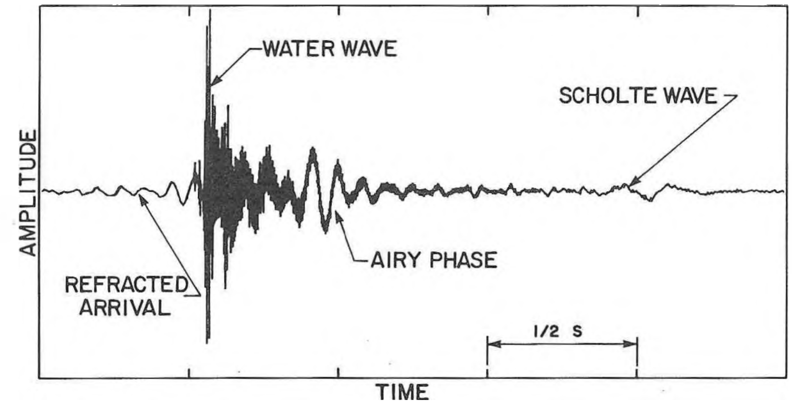

Figure 7. Time series of an arrival from an explosive source, showing the principal features of dispersion.

4.1 Scotian Shelf

Figure 8 shows the bathymetry and sound speed profiles for a propagation run over a track on the Scotian Shelf, in winter. The sound speed profile is slightly upward refracting, but the shallow depth ensures a large contribution to the propagation loss from seabed interaction.

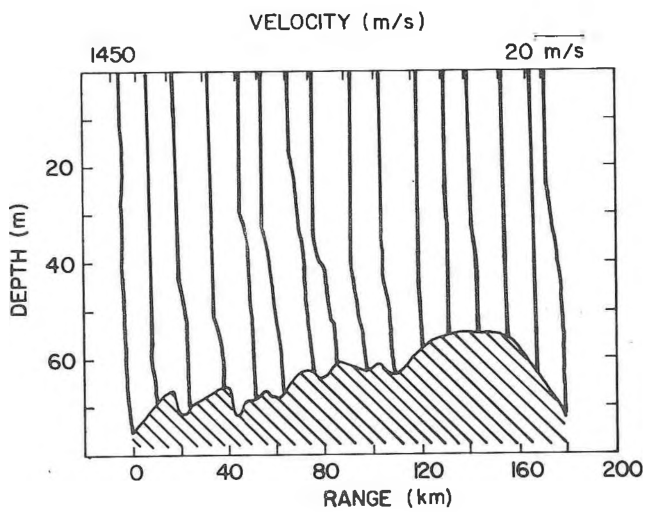

Figure 8. Bathymetry and sound speed profiles for a propagation track on the Scotian Shelf, in winter.

Figure 9 shows the range-dependent, segmented geo-acoustic model for this run. We have previously published the parameters of the geo-acoustic model, as well as the results shown here [17],[18]. The geo-acoustic parameters are contained in Table 1. The piece-wise constant layering is based on Huntec profiler records, and the sound speeds have been assigned by seismic refraction experiments. The attenuation in the sand was based on sonogram analysis [10], which in general gives estimates that are lower than those of Hamilton [19].

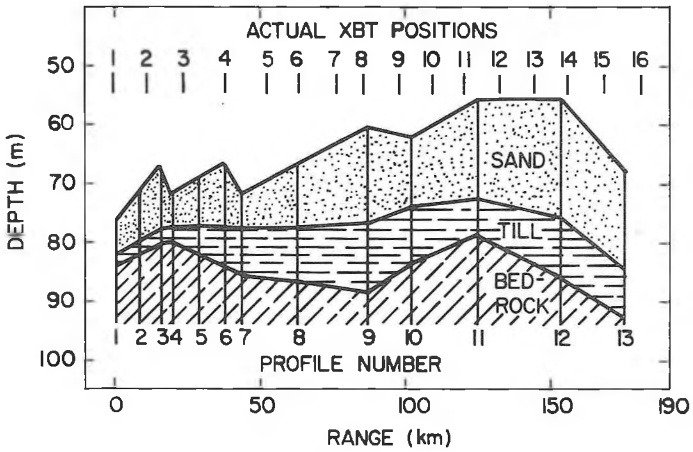

Figure 9. The geo-acoustic model for the Scotian Shelf track.

Table 1

Acoustic Properties of Sediments - Scotian Shelf

Type	**Sound Speed** (m/s)	**Density** (g/cm^3)	**Attenuation** (dB/m//kHz)
Sand	1750	2.1	0.26
Till	1900	2.1	0.08
Bedrock	2050	2.2	0.05

The experimental data (heavy lines) and model predictions (light lines) for a ›urce and receiver approximately at mid-depth are shown in Figure 10 for the three ›west frequencies. The experimental data are 1/3-octave averages, but still show ›nsiderable fluctuation. The model results are narrow-band, but interference 'fects have been removed by summing over the modes incoherently. We feel that the ;reement is reasonable, except at 25 Hz. Rather than increase the loss by creasing attenuation in the sand or decreasing the sound speed, we have left room ›r shear wave effects to supply the extra loss required, when they are included in e propagation model.

At the intermediate frequencies of 200 Hz and 400 Hz, shown in Figure 11, the t of model and experiment is not as good. Since the fit was good for the lower equencies shown on the previous figure, we feel that the gross features of the o-acoustic model are correct, and that agreement at the intermediate frequencies y be obtained by honing the finer details of the model. We have tried including und speed and attenuation gradients in the sand layer. We also tried a non-linear equency dependence of attenuation in the sand. Neither of these refinements has proved the fit. The good fit at 800 Hz can be attributed to scattering at the a-surface, a common high-frequency loss mechanism in winter. Akal [20] has shown at losses above the optimum frequency of propagation are less dependent on bottom

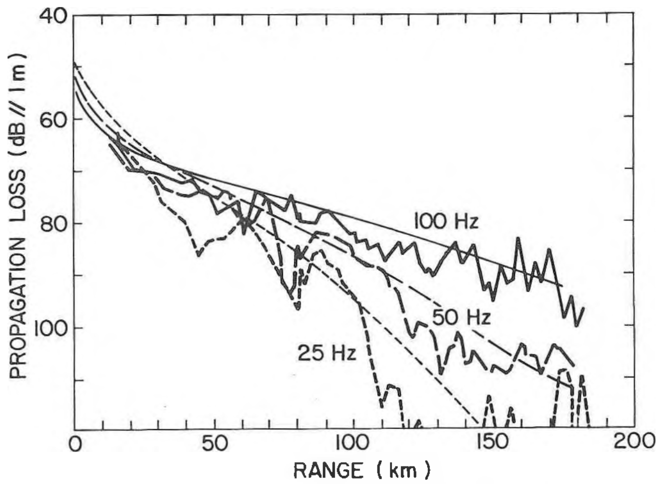

Figure 10. **Experimental propagation loss data and model results for the Scotian Shelf site, 25 Hz–100 Hz.**

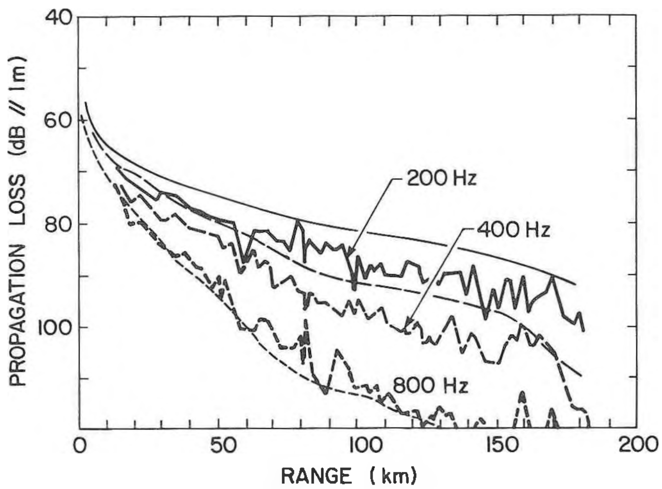

Figure 11. **Experimental propagation loss data and model results for the Scotian Shelf site, 200 Hz–800 Hz.**

effects than on high-frequency loss mechanisms such as scattering or seawater absorption. Since the optimum frequency in our case is about 150 Hz, the required improvement may result not from adjusting the geo-acoustic model, but from some loss mechanism not yet included in the propagation model.

4.2 Southwestern approaches to the English Channel

Figure 12 shows the bathymetry, sound speed profiles, and interpreted geological profile for a propagation track in the southwest approaches to the English Channel, in summer. The velocities and attenuations were assigned as discussed earlier. A range-dependent, segmented geo-acoustic model similar to the previous case was constructed for this environment.

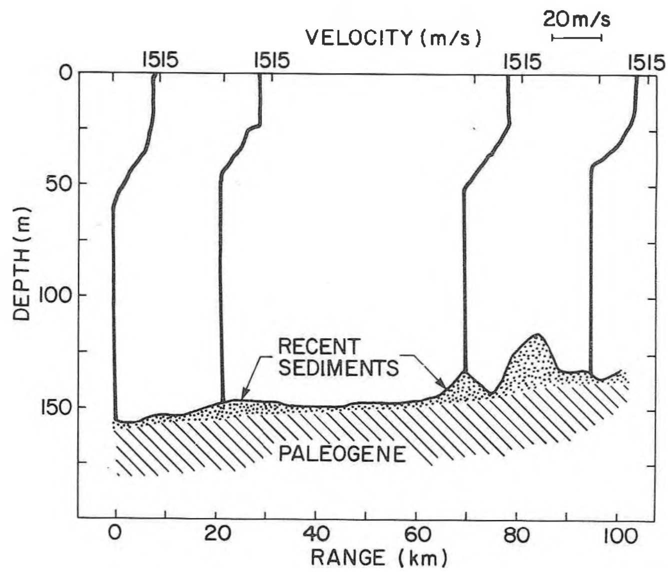

Figure 12. **Bathymetry, sound speed profiles, and interpreted geological profile for the southwest approaches to the English Channel.**

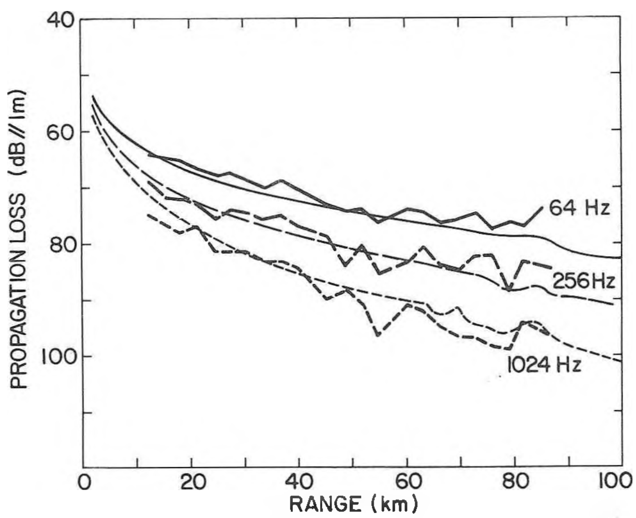

Figure 13. **Experimental propagation loss data and model results for the site in the preceding figure.**

Figure 13 shows the experimental data (heavy lines) and model results (light lines) for this case. The data in the range 25 Hz - 64 Hz are not shown since they were essentially the same as the 64 Hz data. The model reproduced this result. There is perhaps some disagreement at 1024 Hz, but this is probably not due to a fault in the geo-acoustic model. Surface scattering does not supply the required loss in this case, since the summer profile isolates the dominant modes from the surface. Note that agreement at low frequencies has been obtained without introducing shear wave effects. Although we have no measurements of the shear speed in the bottom, the modelling results suggest that it is low and of little consequence to propagation at the frequencies considered here.

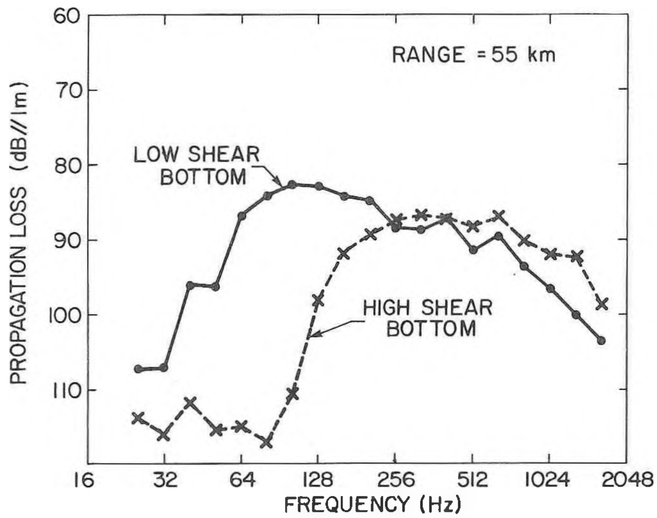

Figure 14. Data demonstrating the effect of a seabed supporting shear waves.

Although we have no shear wave capability in our propagation model, we do have some data which encourages us to include this effect in the future. The data shown in Figure 14, also from the southwest approaches to the English Channel, are from two tracks radiating from the same receiver position, at similar ranges, but over completely different seabed types. The curve showing the better propagation at low frequency corresponds to a seabed similar to that in Figure 12, having a low shear speed. The curve showing the higher losses at low frequency corresponds to a seabed composed of Cretaceous bedrock, which is likely to have a higher shear speed. We attribute the higher losses of this track to conversion of compressional waves to shear waves at the water/seabed interface. In this case there is no "insulating" layer of unconsolidated sediment over the bedrock, as we have seen in previous examples.

5 Conclusion

In conclusion, we have shown the sources of information we use to construct geo-acoustic models of the seabed, and the results of our attempts to model shallow water propagation. The results have shown moderate success, in that some environments are acceptably modelled using a simple geo-acoustic model. Other environments provide data for which agreement over a wide frequency range is difficult to obtain. A schematic view of the modelling process is shown in Figure 15. In some cases a more refined geo-acoustic model may provide the required improvement. For example, more investigation into the effect of sound speed and attenuation gradients is required, and the non-linear frequency dependence of attenuation should be considered further. In other cases, the propagation model itself may have to be improved by including an effect previously ignored. In our own modelling efforts, we have identified a need for improved high-frequency loss mechanisms in the model, and for the inclusion of shear wave effects. We have avoided the temptation to "fit" the curve by adjusting the several parameters at our disposal, unless we have justification from independent seabed studies. This philosophy does not always produce a satisfactory agreement between theory and experiment, but we have found that we often learn more about the problem when theory does not fit experiment, than when it does.

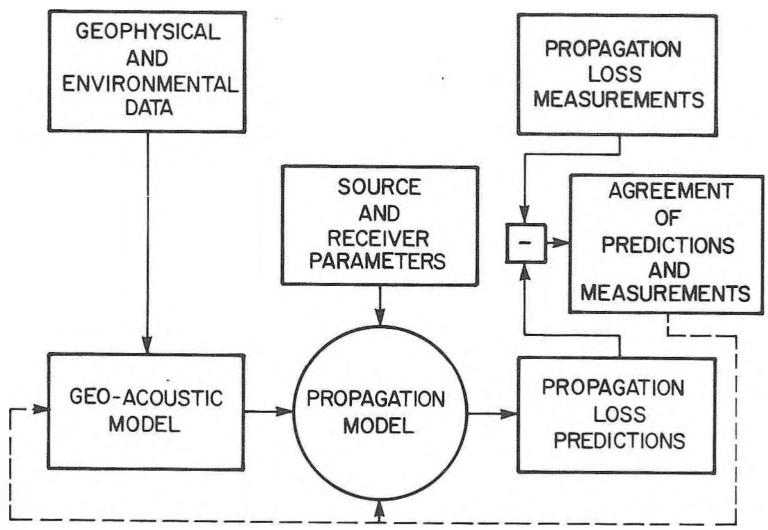

Figure 15. Schematic illustration of the modelling process.

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NOISE SOURCE IDENTIFICATION - ACOUSTIC INTENSITY TECHNIQUE

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ABSTRACT

The determination of the sound power of audible noises and their location are usually complicated by room effects, high ambient conditions and frequently the presence of other sources. The two-microphone acoustic intensity approach was found to be a promising technique for analyzing sources of noise where conventional methods are not particularly practical. A procedure is described for measuring directly acoustic intensity levels using a simple "calibrator" and commercial available dual channel analyzer.

RESUME

En général, la détermination de la puissance de bruits audibles ainsi que leur localisation se complique par des effets du local, par des bruits de fond hauts et souvent par la présence d'autres sources. La technique de mesure de l'intensité sonore à l'aide de deux microphones est trouvée prometteuse pour l'analyse des sources des bruits, là où les méthodes conventionnelles ne sont pas particulièrement pratiques. Une procédure est décrite pour mesurer directement l'intensité sonore en utilisant un "calibreur" simple et un analyseur à deux canaux.

1.0 INTRODUCTION

A principal objective in noise control engineering should be identification of the sources of noise and reduction at the source, rather than obstructing the transmission of the noise using enclosures, ear plugs, etc. This approach usually provides cost effective solutions to noise problems while maintaining the efficiency and reliability of the equipment involved.

In many industrial plants, the noise radiated by a particular piece of equipment is often difficult to isolate because of operational constraints. Similarly in many machines, the noise radiated by a given component is frequently difficult to identify. Conventional methods of noise analysis are sometimes impractical due to reflections from nearby surfaces, closely spaced sources, or high levels of background noise/1/.

Recent advancements in instrumentations, such as in the two-channel Fast Fourier Transform (FFT) analyzer, together with the development of a new mathematical analysis for acoustic intensity has made it possible to determine sound power directly and relatively simply using two closely spaced microphones/2,3,4/. Preliminary reports from investigators using this technique have been positive and it is anticipated that acoustic intensity measurements will become widely used in the future.

This paper describes a practical method for measuring acoustic intensity and presents some experimental results.

2.0 THEORETICAL BACKGROUND

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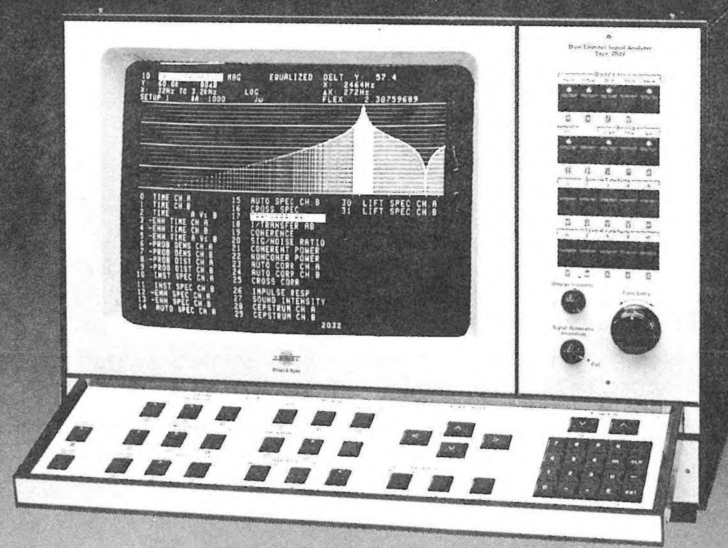

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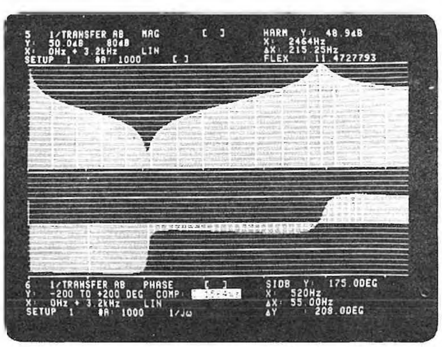

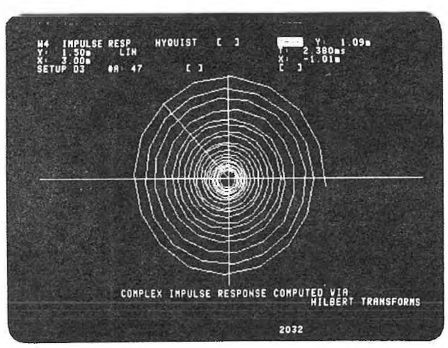

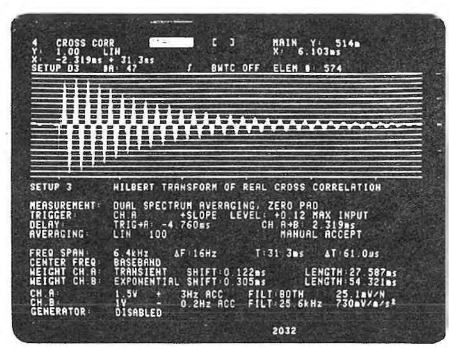

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CALIBRATION ANNOTATION: in V/V, V/unit, V/Pa, $V/m.s^{-2}$, $V/m\cdot s^{-1}$, V/m, V/N, V/g, $V/in\cdot s^{-1}$, V/mil

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Enhanced time function: ch. A vs. ch. B
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Probability distribution: ch. A or ch. B
Instantaneous spectrum: ch. A or ch. B
Enhanced spectrum: ch. A or ch. B
Auto spectrum: ch. A or ch. B
Cross spectrum
Transfer function: AB or 1/TRANSFER AB
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Signal-to-noise ratio
Coherent output power
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$$\vec{I} = p.\vec{u} \qquad (1)$$

where p is the sound pressure in N/m^2 and $\vec{u}$ is the particle velocity in the direction of propagation in m/s.

In the past, Equation (1) was difficult to use because the instrumentation for making reliable measurements of u was not available/6/. However, it can be shown that for a free-progressive wave the intensity becomes/5/

$$I = \frac{p_{rms}^2}{\rho c} \qquad (2)$$

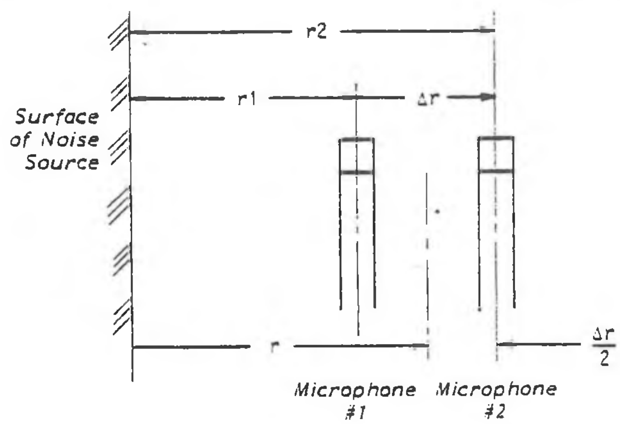
where p_{rms} is the root-mean-square of the sound pressure and ρc is the acoustic impedance (ie for air $\rho c \simeq 400$ N-s/m^3).

Equation (2) applies in the far-field of a source where $\vec{u}$ and p are in phase. In this case, reference quantities have been chosen so that the level in decibels corresponding to the intensity and to the pressure are the same. That is,

$$L_I \text{ (re } 10^{-12} \text{ watt/m}^2) = L_p \text{ (re 20 } \mu\text{Pa)} \qquad (3)$$

Therefore, in most atmospheric conditions found in practice $L_I \simeq L_p$ and can be readily obtained using pressure sensitive instruments, ie microphone.

The alternative method of measuring intensity, hence sound power is based on Euqation (1) and the signals from two closely spaced microphones arranged as shown below: (r, r_1, etc are distances in meters).



The acoustic velocity and pressure can be represented, in complex form, by the following finite difference approximations:

$$u = -\frac{1}{\rho \Delta r}\int (p_2 - p_1)dt \text{ and } p = (p_1 + p_2)/2$$

where p_1 and p_2 are the pressures measured at r_1 and r_2 respectively, ρ is the density of the medium, and Δr is the spacing between microphones. Substituting these approximations into Equation (1) and converting the result into the frequency domain, using Fourier Transform, the acoustic intensity can be expressed as/3,4/

$$I(f) = \frac{\text{im }(G_{12}(f))}{\rho \Delta r \omega} \qquad (4)$$

where im $(G_{12}(f))$ is the imaginary part of the cross-spectrum between the two microphone signals (rms pressure), $\omega = 2\pi f$ the circular frequency, Δr and ρ as before. This equation can be readily computed using commercially available two channel FFT analyzers with calculators.

One inherent limitation in this technique is associated with the spacing of the microphone relative to the wavelength of sound being analyzed. The following limits have been proposed, tentatively, for achieving an accuracy within ±1.5 dB:

$$0.1 \leq k\Delta r \leq 1.3 \text{ and } 0 \leq \Delta r/r \leq 0.5$$

where $k = \omega/c$ is the wave number, c is the speed of sound, and Δr, r as before/7/.

Another limitation is due to the fact that Equation (4) is sensitive to phase and gain differences between the two microphone-channel systems. Although some instrument manufacturers provide special, phase matched components, in practice it is desirable to verify on-site that the complete two channel systems are acceptably matched.

One method of compensating forphase and gain differences is by switching channels while measurements are made/4/. This provides very accurate results but is relatively slow because two sets of data must be collected for every measurement. A preferred method is to use the transfer function of the two channel system for compensating for phase and gain differences/8/. There are also other methods presently being investigated/9/.

3.0 DESCRIPTION AND PROCEDURE OF A PRACTICAL SYSTEM

3.1 Introduction

Several microphones and microphone configurations, and data processing techniques are available for acoustic intensity measurements/10/. A typical arrangement is illustrated in Figure 1.

Briefly, the signals from the two microphones are fed into the analyzer which computes the cross-spectrum. The analyzer, in conjunction with a programmable calculator, is used to make the necessary calibration corrections, compensation for phase and gain, and the calculation of the acoustic intensity level in dB. A calculator can be used to make additional computations such as sound power level, octave band analysis, source order ranking, etc. Finally, the results may be recorded using a digital plotter.

In this study a simple calibration procedure was used with an FFT analyzer having complex mathematical capability. This enables the intensity level, in dB, to be obtained directly from the analyzer without an auxiliary calculator and facilitates making exploratory scanning of sound fields around mechanical equipment in-situ with the minimum of instrumentation and programming.

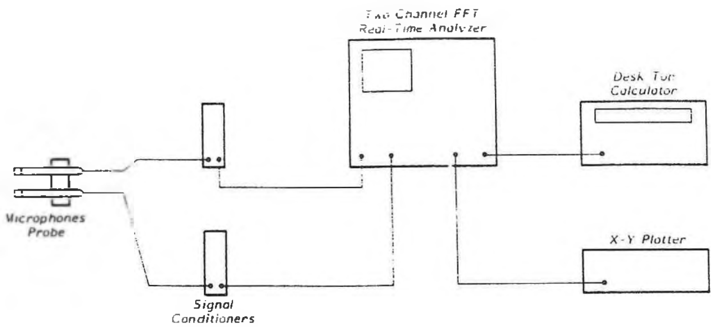


FIGURE 1
TYPICAL INSTRUMENTATION ARRANGEMENT FOR ACOUSTIC INTENSITY MEASUREMENTS

3.2 Selection of Microphone Size and Spacing

The choice of microphone size and spacing appropriate for the particular application depends on the required dynamic and frequency ranges. The dynamic ranges of typical microphones are shown in Table I.

TABLE I

Microphone Size, mm	Dynamic Range
25 mm (1 in)	15-145 dB
13 mm (1/2 in)	30-145 dB
6 mm (1/4 in)	50-150 dB
3 mm (1/8 in)	65-170 dB

In most applications involving large power equipment, either the 6 mm or the 13 mm microphones will give satisfactory results. Based on the frequency range of interest, the spacing between the two microphones and the distance from the source can be chosen. A tentative selection chart is given in Figure 2.

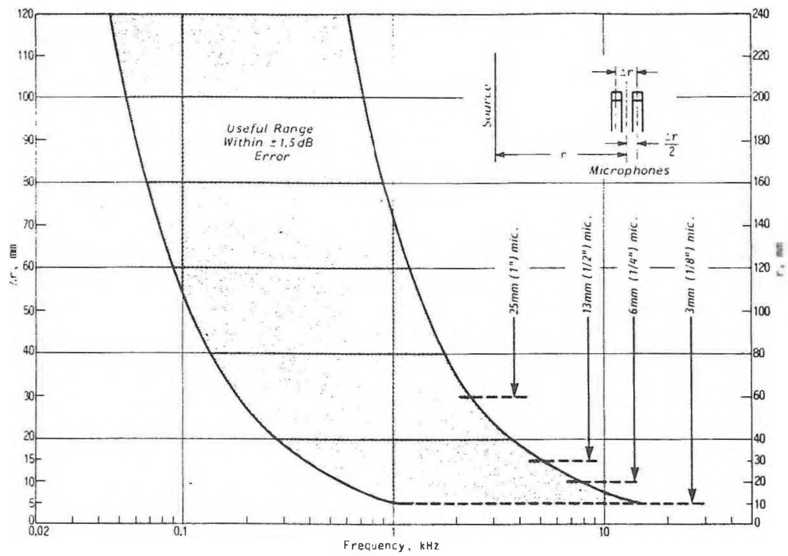


FIGURE 2
TENTATIVE CHART FOR SELECTING PARAMETERS FOR ACOUSTIC INTENSITY MEASUREMENTS

3.3 Gain Calibration

It was found convenient in this procedure to use two sound level meters as signal conditioners. These facilitated calibration in terms of acoustic intensity level and monitoring the input signals during analysis.

Using a standard calibration signal fed into one of the microphones, the sound pressure levels shown by the correponding sound level meter and the analyzer were adjusted to read correctly. This channel, therefore, was designated for reference purposes. The second channel was then adjusted to agree with the reference channel above.

3.4 Phase Mismatch Compensation

Corrections for phase differences between the two channel systems were made using the transfer function method described in Ref 8 Accordingly, the transfer function was obtained by exposing the microphones simultaneously to random noise in a duct as illustrated in Figure 3.

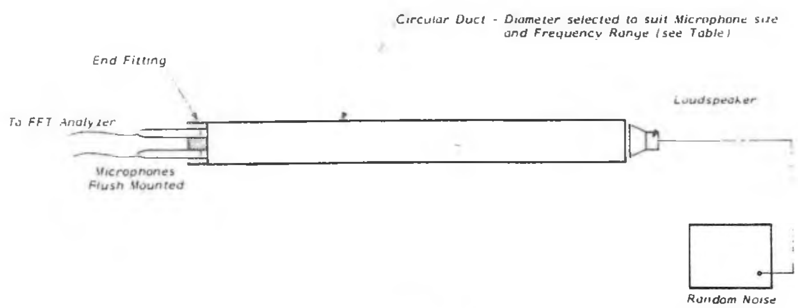


FIGURE 3

The size of microphones, of course, determines the minimum diameter of duct that can be used. This in turn determines the upper cutoff frequency of the duct where the first cross-mode occurs/11/.

It was found that for a duct having the smallest practical diameter that would fit a given pair of microphones, the cutoff frequency is greater than the maximum frequency range of this technique (shown in Figure 2). A summary of the maximum frequency ranges corresponding to four microphone sizes and the recommended duct diameter and its upper cutoff frequencies are in Table II.

TABLE II

RECOMMENDED DUCT SIZES FOR OBTAINING THE TRANSFER FUNCTION BETWEEN MICROPHONES

MIC DIAM mm in	Upper Freq for Intensity* Hz	Recommended Duct Diam for Transfer Function mm in	Upper Cutoff Freq of Duct Hz
25 (1")	2345	63.5 (2.5")	3138
13 (1/2")	4690	40.1 (1.5")	4878
6 (1/4")	7035	19.1 (0.75")	10460
3 (1/8")	14069	12.7 (0.5")	15690

*Based on $0.1 \leq k\Delta r \leq 1.3$

Phase mismatch compensation was made, therefore, by dividing the cross-spectrum measurement by the transfer function in their complex notations. The imaginary part of this result was then used in Equation 4 for computing acoustic intensity.

3.5 Intensity Level Computation

In order to compute the intensity level, a special duct arrangement was used as an "acoustic intensity calibrator" (Figure 4).

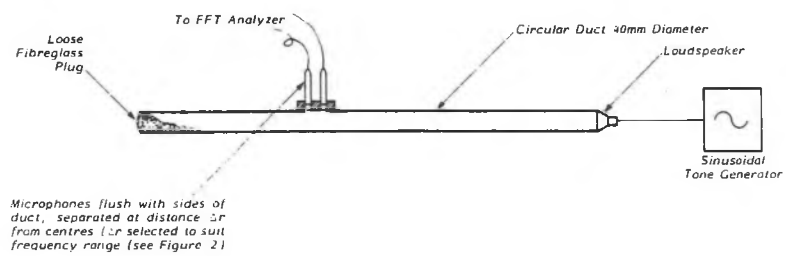


FIGURE 4

ARRANGEMENT FOR ACOUSTIC INTENSITY CALIBRATION

The microphones were mounted, at their preselected spacing, in the side of the duct. A sinusoidal tone (1 kHz) generated by a loudspeaker at one end of the duct propagated free progressive waves past the microphones. The other end was filled with loose fibre-glass wool to reduce reflection of sound. With the analyzer programmed, the intensity of the tone signal was obtained. Since the level of sound pressure and intensity at the microphones in the duct are essentially the same (Equation 3) the intensity level (re the standard 10^{-12} watts/m^2) was read directly from the sound level meter that was designated for reference in section 3.3. The analyzer was then "calibrated" to read the same intensity level as the meter with the necessary corrections for barometric pressure and temperature.

The level of the calibrating tone was set 40 dB higher than the ambient level in order to minimize error due to sound waves incoming at the open end of the tube.

Successive acoustic intensity level measurements were made by simply collecting the time-averaged cross-spectrum and executing the programmed phase and amplitude mismatch compensation and intensity level calculations. The direction of sound flow was shown by displaying the imaginary part of the cross-spectrum.

4.0 EXPERIMENTAL RESULTS

A few experiments were performed in the laboratory in order to verify the procedure described above. The duct used for obtaining the transfer function was a plastic pipe, 40.1 mm in diamter, and 2400 mm long. The same duct was used for intensity calibration by replacing the end fitting with a section of pipe as illustrated in Figure 4.

The intensity level of a random noise source was measured using the conventional method (Equation (2)) and compared to the acoustic intensity method (Equation (4)). The test was made inside the duct described above, and in an anechoic chamber. The microphones were 13 mm in diameter, the spacing was 30 mm and the expected useful frequency range, from Figure 2, was 270 to 3600 Hz. The results within this range were in very good agreement, see Figure 5(a), (b).

Figure 6 shows the sound power level of a small loudspeaker generating random noise measured by the acoustic intensity method and by the standard anechoic room method which requires 20 measurement points (ANSI S1.35/12/). The agreement was again good over the expected useful frequency range of the probe. The time taken to obtain these results was estimated to be about 1/2 h compared to 2 h for the standard method.

The sound power level of a small loudspeaker generating random noise was obtained with and without the presence of an interfering, uncorrelated noise from jig-saw. The interfering noise level was 10 dB higher, overall, than the loudspeaker, see Figure 7. The agreement between the sound power levels of the source only (standard method) and of the source with the interfering noise (acoustic intensity method) was satisfactory - ie within 3 dB, except at frequencies where the level of the interfering noise exceeded that of the source by more than 10 dB. See Figure 8.

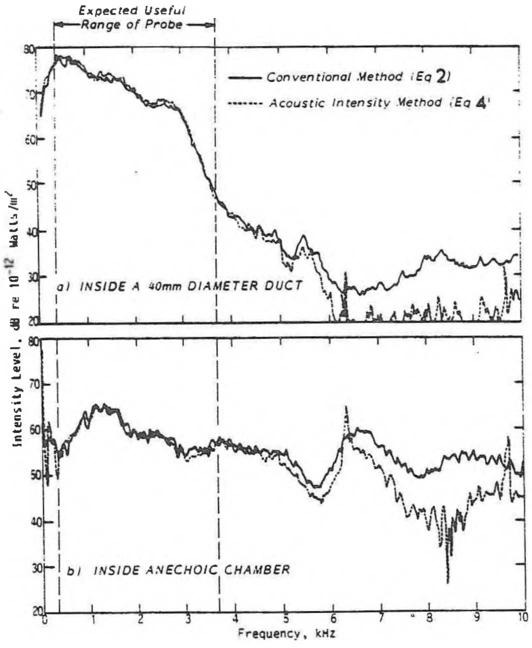


FIGURE 5
COMPARISON OF ACOUSTIC INTENSITY SPECTRUM LEVELS USING THE CONVENTIONAL AND THE CROSS-SPECTRUM METHODS UNDER CONTROLLED CONDITIONS

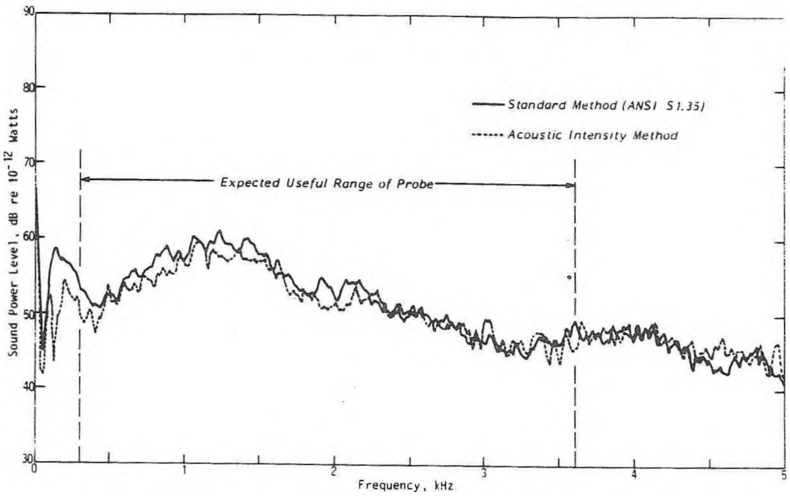


FIGURE 6
COMPARISON OF SOUND POWER LEVEL OF A NOISE SOURCE USING STANDARD METHOD AND ACOUSTIC INTENSITY METHOD

Figure 9 illustrates the degree of correlation expected with this technique at low frequencies. Although a wider microphone spacing would expand this range further, the result here indicates very acceptable accuracy with the configuration used down to about 100 Hz.

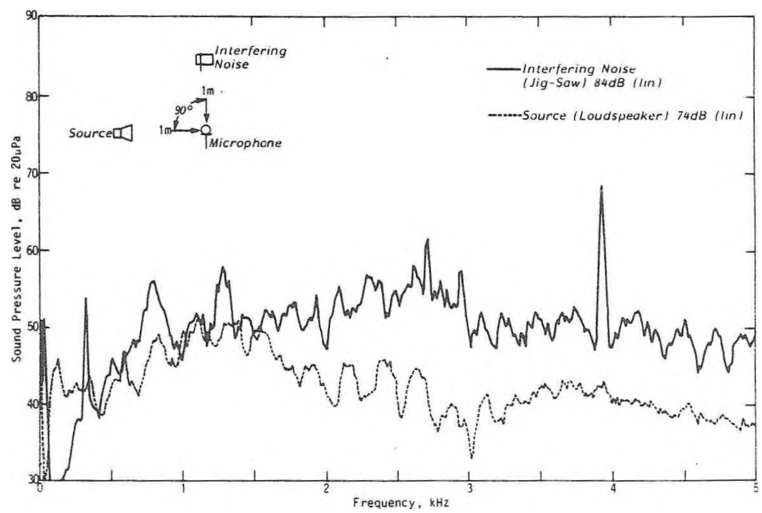


FIGURE 7
SOUND PRESSURE LEVEL OF SOURCE AND OF INTERFERING NOISE AT 1M

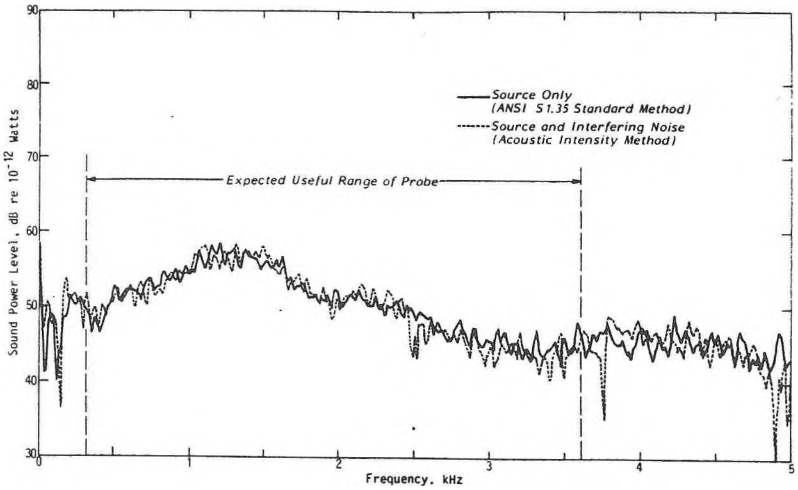


FIGURE 8

COMPARISON OF SOUND POWER LEVEL OF A NOISE SOURCE AND OF THE SOURCE IN THE PRESENCE OF AN INTERFERING NOISE USING ACOUSTIC INTENSITY METHOD

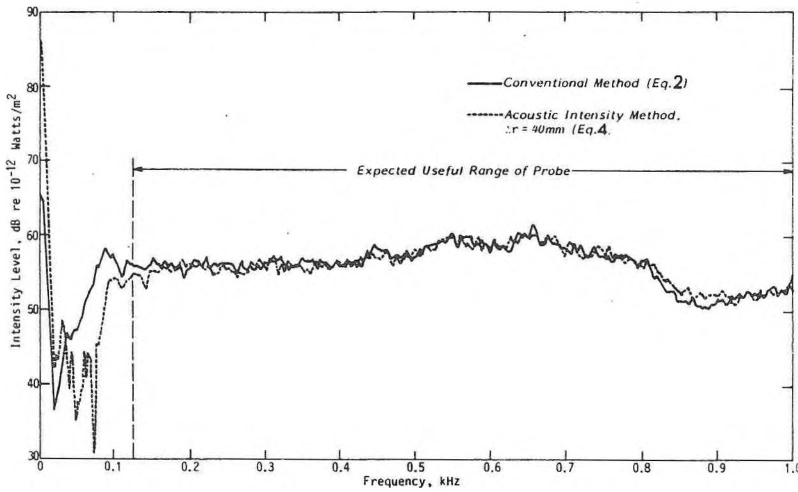


FIGURE 9

EXAMPLE OF CORRELATION OF ACOUSTIC INTENSITY METHOD AT LOW FREQUENCIES

5.0 CONCLUSIONS

A relatively simple method was developed for making acoustic intensity level measurements directly in dB re 10^{-12} watts/m^2, using a special calibrator and an FFT analyzer with complex mathematics capability.

The parameters to be selected for a particular application, ie microphone size, spacing and distance from source, and their corresponding frequency and dynamic ranges, have been identified (see Table II and Figure 2).

Comparison of the acoustic intensity technique with the conventional (pressure squared) method have shown the technique under a variety of conditions to be well within practical accuracy.

The determination of the sound power of a source required about one quarter of the time compared with the conventional anechoic room method.

ACKNOWLEDGEMENTS

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STATISTICAL MODELS IN VIBRATION ANALYSIS

by

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Introduction

Statistical models are often used in the analysis of vibration levels of complicated dynamic structures, particularly at high frequencies when the high numbers of modes involved in the vibration make both the usual modal analysis and also numerical analysis unfeasible. Results from such models often compare favourably with experimental results. There has been little effort, however, to compare the results from statistical models with exact analytic results, or to estimate analytically how well the statistical model of the structure represents the actual structure.

A particular simple coupled-beams structure is considered here (Figure 1). The vibration analysis is carried out within the framework of statistical energy analysis. In particular, results for the power flow from one beam to another are obtained. An ensemble of similar structures is constructed by varying the lengths of the beams. Exact values of the mean and standard deviation of the power flow are calculated for this ensemble. Approximate results from statistical models of the structure, including the statistical energy analysis result, are shown to compare very well with the exact results. Also, the standard deviation is found to be surprisingly small. One concludes that it is indeed justifiable when analyzing complicated dynamic structures to model not the structure itself but the simplest-to-analyze sample (in this case the symmetric case of beams of equal length) from an ensemble of structures similar to the actual one.

Statistical modelling of dynamic structures

SEA [1] is one way of estimating the dynamical response of complicated structures to high frequency excitation. In this approach the structure is treated as a number of interacting component subsystems. The energy of vibration of each sybsystem is the variable chosen to define the state of the system. Other dynamical variables such as acceleration or stress are found once the energy is known. The word statistical implies not necessarily that the excitation is random but that the parameters describing each subsystem are chosen from a known statistical distribution of similar parameters. The actual structure of interest is treated as one sample of an ensemble of similar structures.

The basic power flow and energy balance relations for a two subsystem case where only one of the sybsystems is externally excited is shown in Figure 2. P represents power, E represents the energy of the linear oscillators or modes of vibration that are used to characterise each of the subsystems and N represents the number of modes of each subsystem taking part in the energy exchange.

The power dissipated by each subsystem is related simply to the modal bandwidth Δ (which may be measured). For example $P_{1,diss} = \Delta_1 N_1 E_1$. One of the basic results of SEA is that a similar expression can be written for the power flow between the subsystems:

$$P_{12} = A_{12}(E_1 - E_2) \qquad (1)$$

where A_{12} is a constant of proportionality which depends only on the dynamical parameters of the structure. With reasonable assumptions E may represent either the actual modal energies of the coupled subsystems, or the modal energies they would have if they were uncoupled but the same forces acted, although the constant A_{12}, of course, is different in each case. Results for the power flow P_{12} between the beams shown in Figure 1 are discussed below.

Considerable effort has been put into estimating the value of A_{12} for coupling between various structural components such as beams, plates and shells, and into comparing the basic SEA results such as (1) with experimental measurements. Lyon [1] lists several references on these topics. Almost all of this work is concerned with mean value estimates of the energies and power flows. Some general results for the variance of these estimates based on assumed distributions of parameters have been obtained [1,2]. Two aspects are of interest: the amount of spatial response concentration on a particular structure, and the accuracy with which the statistical model describes the actual structure. It has been shown recently [3,4] that very marked concentrations indeed are found in some cases. On the other hand, little work has been done to compare SEA results with those obtained from exact calculations for a particular structure. Remmington and Manning [5] compared mean values of power flow with an exact calculation for a few parameter values on a simple system. Smith [6] in his reworking of SEA from a wave propagation point of view has compared an SEA result with a precise statistical result. A more complete statistical treatment of the power flow in a simple structure is described below.

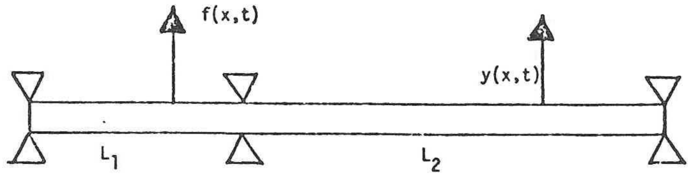

FIGURE 1

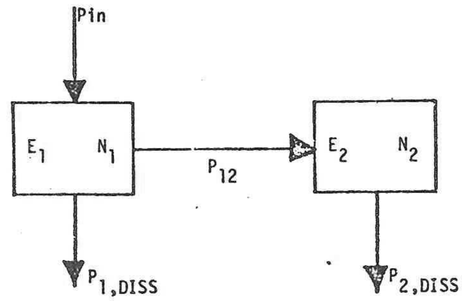

FIGURE 2

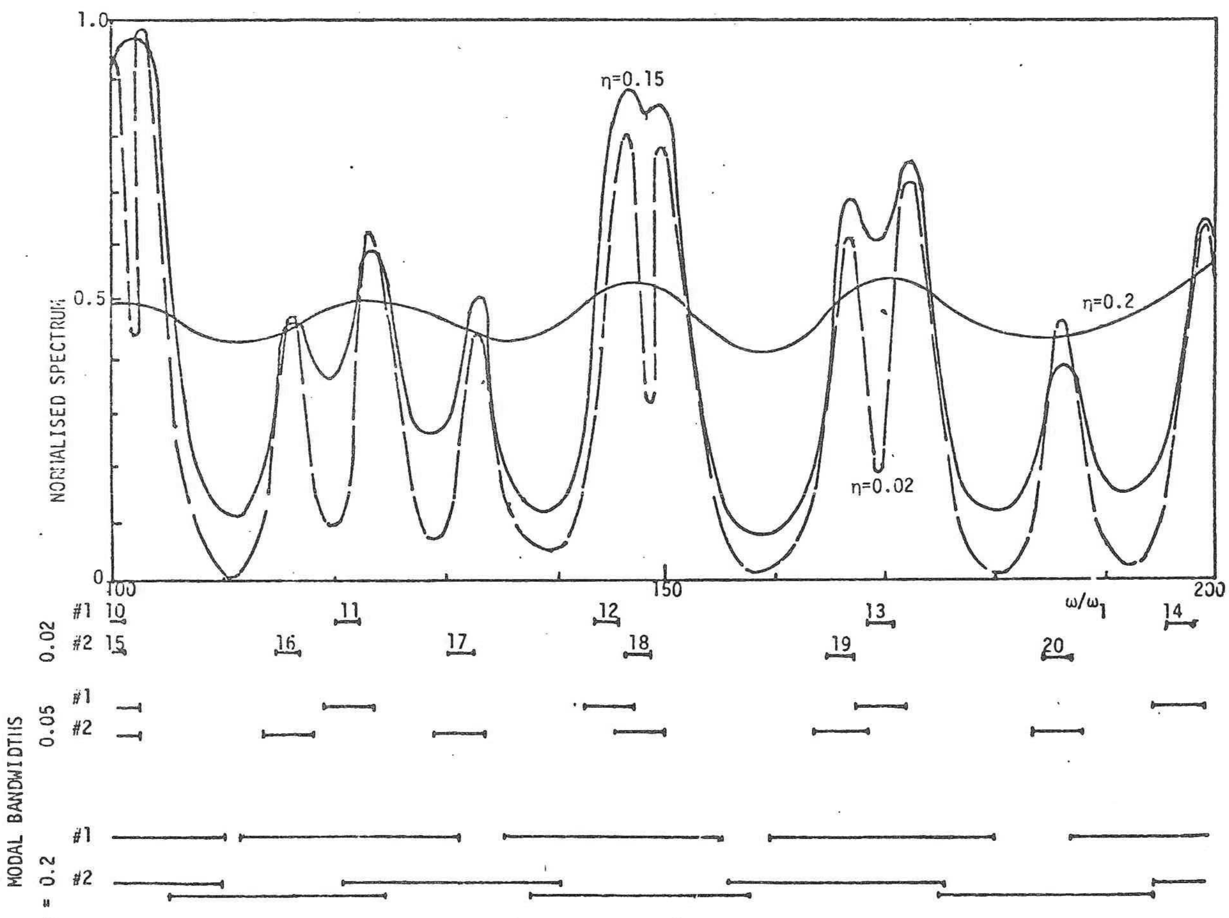

FIGURE 3

Calculations of the mean and variance of the power flow P_{12} shown in Figure 1 are discussed for a wide range of parameters. Three types of averaging are considered, ensemble, spatial and frequency, for two limiting types of random force, rain-on-the-roof and point excitation [7,8].

Power flow in a beam-beam structure

A simply supported coupled beam-beam structure is shown in Figure 1. y represents the transverse vibrational displacement response to the distributed transverse loading f(x,t). The coupling is at the central simple support. The power flow between the beams is described by the product of the bending moment and rate of change of slope at the coupling point. This structure was chosen because it is sufficiently complicated to exhibit many of the multi-modal interactions inherent in the SEA assumptions yet sufficiently simple that an exact solution can easily be obtained, at least within the limits of the Bernoulli-Euler bending theory.

Two limiting types of random forces are considered here: rain-on-the-roof where f(x,t) is white in both space and time, and a point force at the point x = z so that $f(x,t) = f_o(t)\,\delta(x-z)$ where $f_o(t)$ represents a white noise force. In both cases only beam 1 is externally excited.

The problem can be solved either in terms of the simple support-simple support eigenfunctions of the beams or by using a closed form Green's function. For rain-on-the-roof excitation the modal forces are uncorrelated. This fact was used in [7] to obtain an eigenfunction expansion for the power flow which was subsequently summed. For point excitation a closed-form Green's function is obviously more appropriate. A Green's function for the beam-beam structure was obtained in [8] by superposing results for the point force at x=z and an unknown force at the coupling point, and evaluating the unknown force from the requirement that the displacement be zero at the coupling poing.

Expressions for the spectrum of the power flow, or more strictly for the frequency decomposition of that part of the power flow at the coupling point that can be dissipated in beam 2 can be written in non-dimensional variables in the form

$$\frac{\Pi_{12}(\omega)}{E_1 - E_2} = \text{fn}\left(\frac{\omega}{\omega_1}, \frac{L_2}{L_1}, \frac{z}{L_1}, \frac{\Delta}{\omega_1}\right) \qquad (2)$$

Here ω_1 represents the fundamental resonance frequency of beam 1 and η the loss factor which is assumed the same for both beams. The z/L_1 dependence occurs of course only for the point excitation case. Δ/ω_1 is a damping loss factor.

The functional form in (2) is sufficiently complicated that general results concerning changes in structural parameters that may be required in a design process are not easy to determine. Various statistical averages of the spectrum can be considered instead for given values of the loss factor. Frequency averages over ω/ω_1 are typically over one-third octave or octave bandwidths. Since in many if not most cases of practical interest energy exchange between subsystems is by resonant modes the important parameter in frequency averages is not the averaging bandwidth itself but the number of modes that have resonance frequencies within the band. Averages over L_2/L_1 can be thought of as ensemble averages. The ensemble of similar systems considered here has a uniform distribution of L_2/L_1 between the values one and two. Spatial averages are taken over the variable z/L_1. It is assumed here that z/L_1 is uniformly distributed between the values zero and one.

Numerical Results

Figures 3 and 4 are for the case of rain-on-the-roof excitation. Figure 5 includes results for both types of excitation considered here. Typical values of the normalised spectrum of power flow are shown in Figure 3 for $L_2=1.4L_1$ for three values of the loss factor η. The corresponding value of the modal overlap ratio M, the ratio of modal bandwidth to average spacing between resonance frequencies is also shown. The bars underneath the graph show the modal bandwidths for each mode of the uncoupled beams.

The modal nature of the response is seen clearly, and it is evident that at low values of the damping the power flow is predominantly by resonant mode interaction. Proximate modes whose bandwidths overlap give high values of the power flow spectrum. As the modal bandwidth increases the power flow in the octave band shown in Figure 3 increases, at least in the range $M < 1$. Figure 4 shows that the relation is in fact linear. Considerable smoothing of the spectrum occurs as M increases. For the case $M = 1.2$ shown the spectrum varies only slightly about a mean value of almost 0.5. The SEA result due to Lotz [9] using Lyon's [1] wave propagation approximation gives a value of 0.5 for this problem.

The graphs in Figure 3 emphasise the complicated nature of the function in equation (2). Meaningful results concerning structural parameter dependence can only be obtained in general terms if suitable average values of the power flow are considered.

It is shown in references [7] and [8] that some smoothing of the spectrum is obtained by ensemble averaging over an "octave" of structures $1 \leq L_2/L_1 \leq 2$. Marked peaks in the ensemble spectrum still occur near the resonance frequencies of beam 1, and it is still not easy to determine the effect of various structural parameters on the results. On the other hand, if frequency averages are taken, the rain-on-the-roof octave band spectrum is rather insensitive to changes in L_2/L_1.

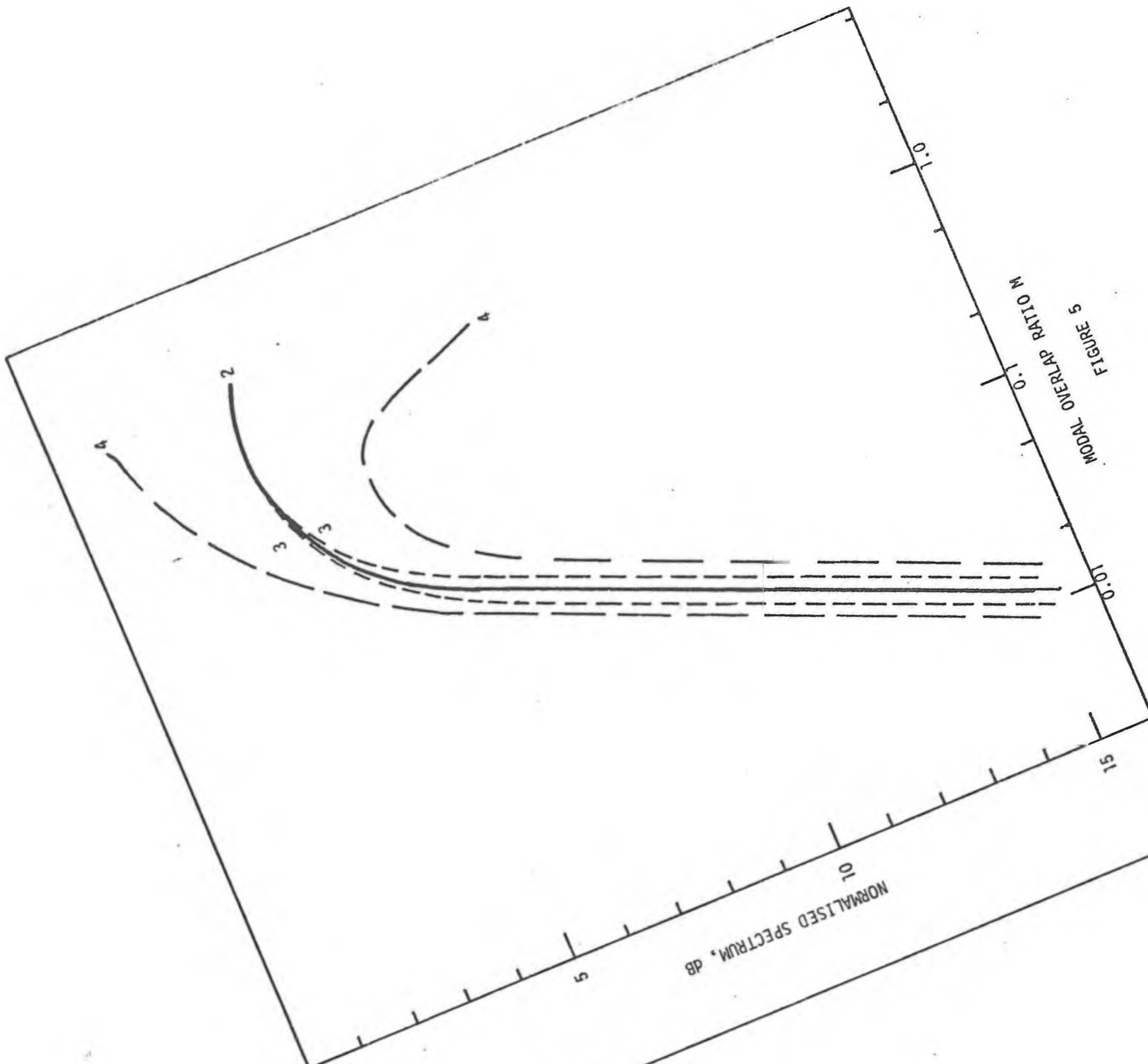

FIGURE 5

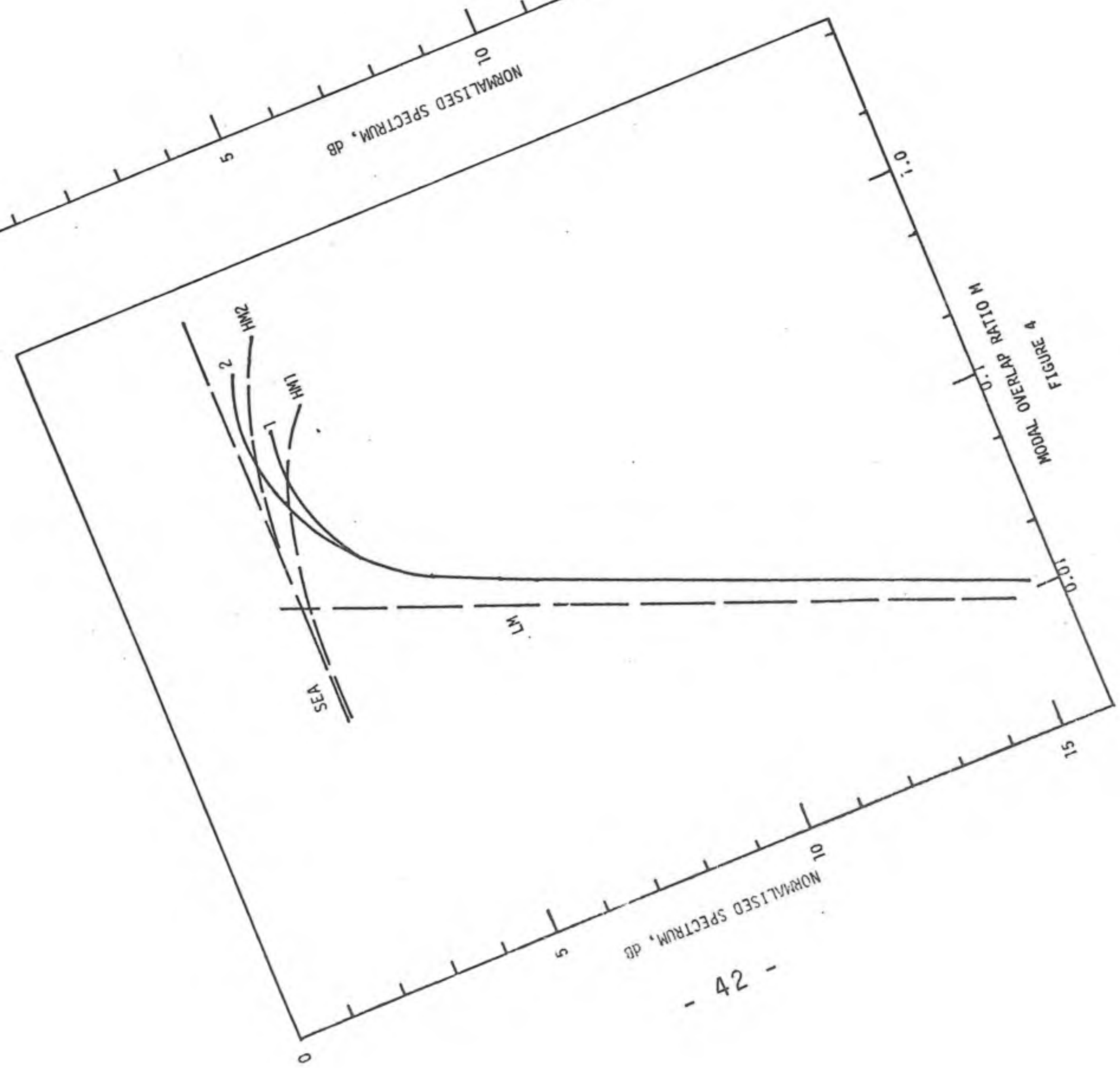

FIGURE 4

Octave band results for rain-on-the-roof excitation are shown in Figures 4 and 5. Frequency averaged values of the spectrum of power flow are plotted against the modal overlap ratio for two octave bands. Curves labelled 1 and 2 in Figure 4 are for $10 < \omega/\omega_1 < 20$ and $100 < \omega/\omega_1 < 200$, respectively. These are the exact octave band mean values for the ensemble $1 \leq L_2/L_1 \leq 2$. For $M \ll 1$ the curves are the same. In the region $M = 1$ and for $M > 1$ there are small differences. Figure 5 shows the mean ± standard deviation (curve 3) for curve 2, the deviation being over the ensemble $1 \leq L_2/L_1 \leq 2$. The deviation is surprisingly small. For curve 2 there are 4.8 resonant modes in the octave band. For curve 1 there are only 1.3 resonant modes. The deviation (not shown) even in this case is still surprisingly small.

Several approximate results are also shown in Figure 4. The SEA result is due to Lotz [9] and as expected shows good agreement with the exact results when the modal overlap ratio is high. The curves LM and HM are approximate results for the case $L_2 = L_1$. The symmetry in this case makes the calculation simpler. The curve LM is obtained by considering only the resonant mode contribution from the perfectly overlapping modes of the two systems [7]. Curves HM1 and HM2 are obtained by assuming that because of the smoothing caused by high modal overlap, summations over modes can be replaced by integrals [7].

Figure 5 shows standard deviations of the octave band power flow for the case $100 < \omega/\omega_1 < 200$. Curve 2 is the same as in Figure 4 for the rain-on-the-roof excitation. Curves 3 are the mean ± standard deviation for this case. Curves 4 are the mean ± standard deviation for the octave band power flow in the point force case when $L_2 = L_1\sqrt{2}$, the deviation being taken over the spatial average $0 \leq z \leq L_1$. The mean value for this case is so close to curve 2 that it has not been shown. For rain-on-the-roof excitation the smoothing caused by high modal overlap makes the standard deviation very small. High modal overlap here implies high damping. For $M \geq 1$, the damping is so high that there is appreciable decay of waves along beam 1 emanating from the point of excitation. For small z there is very little energy incident on the coupling point so the power-flow through the coupling point is small. On the other hand, for $z \simeq L_1$ there is considerable energy incident on the coupling point. The deviation over the spatial average thus increases as M increases. This decay effect for the point excitation case is examined in more detail in reference [8].

Conclusion

Figures 4 and 5 add considerable credence to the use of statistical models in vibration analysis. Excellent agreement is obtained if octave band values are considered adequate. As expected the SEA wave transmission result [9] which assumes in essence that the beams are infinitely long shows good agreement with exact values when the modal overlap ratio is high. Because the standard deviation is so small, a statistical model using equal beams and uniformly spaced perfectly overlapping modes shows good agreement for all values of M, although different approximations must be used for M<1 and M>1. Again provided octave band values are used results for the spatially averaged point force case agree well with those for the rain-on-the-roof case.

Further work is in progress at UNB extending the results to more complicated structures and examining spatial concentration of vibration levels along the beams. It is expected that this work will confirm the conclusions outlined above. One may conclude it indeed seems justifiable that when analyzing the vibration of a complicated structure one may use results obtained from the simplest to analyze (for example, a symmetric case) sample from an ensemble of similar structures.

Acknowledgement

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LETTER TO THE EDITOR

THE EFFECT OF HAIR, GLASSES, OR CAP ON THE PERFORMANCE OF ONE PAIR OF BILSOM VIKING CIRCUMAURAL HEARING PROTECTORS.

by

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ABSTRACT

A pair of modified dosimeters were used to measure the equivalent noise exposure level inside and outside an earmuff simultaneously. The difference of the two measurements was the index of attenuation. In the present study the effect of hair, glasses, or cap on the performance earmuffs was examined with this method of comparative measurement. It was found that although the effect of hair, glasses, or a thin cap was significant in the reduction of attenuation, the amount was usually no more than 5 dB. However, a thick cap caused more than a 10 dB reduction in most cases. The results of this study support the notion of a fitting procedure for this type of earmuff.

SOMMAIRE

Pour mesurer simultanement l'intensite du niveau sonore ambiant et de celui qui est transmis a travers un casque antibruit, on a utilise deux dosimetres modifies. La difference entre les deux mesures representait l'indice d'attenuation. On a applique cette methode dans la presente etude sur l'effet des cheveux, des lunettes ou d'un chapeau sur l'efficacite des casques antibruit. On a constate que meme si les cheveux, les lunettes ou un chapeau mince reduisaient effectivement l'attenuation du niveau sonore, cette baisse ne depassait generalement pas 5 dB. Cependant, le port d'un chapeau epais entrainait, dans la plupart des cas, une reduction de plus de 10 dB. Les conclusions de l'etude favorisent l'idee de proceder a l'ajustement des casques antibruit.

INTRODUCTION

Personal hearing protection plays an important role in any hearing conservation program. There are, however, concerns whether hearing protectors are actually yielding adequate protection in real-world situations. In previous studies[1,2] we measured the field performance of earmuffs with a pair of modified Quest M-8 dosimeters. Results from these two studies indicated that not only the mean attenuation obtained in real-world situations was lower than in the laboratory, but the range and the standard deviation were higher in the former situations.

In the previous field study[2] while we were able to identify some of the obvious causes for low attenuation in the industrial working situations, the effect of hair, glasses, or thin caps on the performance of earmuffs was not clear. The present study was designed to examine these effects in the laboratory.

MEASUREMENT METHOD

Measurements of the noise exposure inside and outside the earmuff were made with a pair of modified Quest M-8 dosimeters, each of which was connected to a ¼-inch ceramic microphone. The 15-cm long portion of the regular cable, that was connected to the microphone, was replaced with a 0.5 mm thick cable. This thin portion of cable, when passed underneath the earmuff cushion, would cause negligible sound leakage[3]. The dosimeter that was to be used to measure the noise level inside the earmuff was modified to have a response range of 60 to 100 dBA instead of the normal range of 80 to 120 dBA.

The two dosimeters had an exchange rate of 3 dB, i.e. 3 dB increase for each doubling of the exposure time. Calibration was done in a B & K (Type 4212) hearing aid test box. The response curves of the two dosimeters were almost identical to each other and flat up to 6 kHz.

Five male subjects were used for all the testing conditions: (1) short hair I, (2) long hair, (3) short hair and glasses, (4) long hair and glasses, (5) long hair and a thin cap, (6) long hair and a thick cap, and (7) short hair II. Five female subjects were tested only for the effect of long hair. Both the short-hair I and II conditions for a male subject were when he had just had a hair cut and with his hair pushed backwards and upwards as much as possible so that the earmuffs were sitting on as little hair as possible. The short hair II condition was just a repeat of the short hair I condition at the end of all testing to confirm the reliability of the test and the condition of the earmuffs after they had been used during the period of the test. In no cases was the hair of the male subjects long enough to cover the whole ear. All female subjects, however, had shoulder-length hair. The short-hair condition for a female subject was when her hair was pushed backwards and upwards as much as possible and the long-hair condition was when the earmuffs were sitting on the subjects' hair both above and below the ear. In both cap conditions, the earmuffs were tested with the seals over the edge of the caps.

The noise source used in these experiments was a pink noise. The octave noise spectrum measured at the ear level of the subject position is shown in Figure 1. The overall noise level was 103 dBA. Only one pair of earmuffs was used in this study, a new pair of Bilsom Viking earmuffs with standard foam seals. They weighed 235 gms.

Each subject was seated inside a double-walled IAC sound insulated room three feet from the two speakers, each of which was located at 45° to either side of the front of the subject.

The inside microphone was taped onto the foam at the center of the cup, facing upwards. The outside microphone was taped onto the center of the cup facing forwards. The earmuff-dosimeter assembly was fitted onto the subject by one of the experimenters. The noise was then turned on for a period of five minutes, after which the readings of both dosimeters were taken. This procedure was repeated ten times. Every time the microphones were taken out and re-attached on the muffs again.

The difference in noise exposure level between the inside and outside dosimeters was the index of attenuation used in this study.

RESULTS AND DISCUSSION

Table I shows the results of the five male subjects. These are comparative data on 1 set of earmuffs under carefully controlled conditions. The numbers shown under the condition short hair I are the mean attenuation data of the ten repetitions. The numbers in parentheses represent the standard deviations. These numbers constitute the baseline data for the subjects. The numbers shown under the remaining conditions represent the difference between the baseline data and the mean attenuation data in each condition for each subject. A paired t-test was performed to test if there was any significant difference between the short hair I condition and each of the other conditions for each subject. The level of significance for each test is shown in parentheses.

It can be seen in Table I that the effect of hair varied with the individual subject. The average effect was small. It did not seem to be related to the thickness of the hair. The subject (DH) with the most hair was the one with the smallest difference.

The effect of glasses also varied with the subject. It was quite apparent that the effect was dependent on how well the glasses fitted against the skin around the ear and how thick the temples of the glasses were.

A combination of long hair and glasses seemed to affect the performance of the earmuffs more than either one of them alone. This was most obvious for subject (DH).

A thin cap and long hair together, seemed to decrease the attenuation of the earmuffs more than with long hair alone. The amount, however, was minimal.

The effect of thick cap on the attenuation achieved by the earmuffs was marked. The mean reduction in attenuation was 13.1 dB. This effect was highly significant in all subjects.

Only four subjects were re-tested again in the short hair condition (short hair II). The difference in results between the first test and the re-test was very small, confirming the reliability of the test.

Table II shows the effect of the shoulder-length hair on female subjects. Despite the fact that the muffs were sitting on the subjects' hair both above and below the ear, the average reduction of attenuation was less than 4 dB. Again, the thickness of the hair did not seem to be related to the amount of reduction.

A word of caution is appropriate here. The amount of sound leakage usually varies with the noise source. For example, if a significant amount of low-frequency noise is present, the effect of long hair, glasses, and thin cap may become serious.

Also, since only a single pair of earmuffs was used in this study and since the effect of hair, glasses, and caps could vary with earmuffs due to, for example, the difference in hardness of seals, the results of this study can only be used as a comparative guide. The absolute amount of reduction in attenuation should not be generalized for different types of noise or earmuffs.

The results of this study support the notion of a fitting procedure for earmuffs. While headgear such as a thick cap or turban is definitely detrimental to the effectiveness of earmuffs, the effect of glasses, long hair, or a thin cap varies with the subject and the noise spectral distribution. The only way to be sure of maximum attenuation, is to test the fit of the earmuffs as suggested in a previous study[2]. It is a relatively simple procedure. All workers exposed to noise levels above a certain intensity, e.g. 100 dBA, should have their hearing protectors fitted by this procedure. Only those hearing protectors that reduce the exposure level to below 85 dBA should be given to the worker. This procedure of fitting earmuffs only takes about 10 minutes, during which time the worker would be able to work. One dosimeter with similar modifications made for this study would be adequate, since in that case all one needs to know is the noise exposure inside the earmuff. Perhaps a small device, which can be placed conveniently inside the earmuff to detect a noise exposure level over 85 dBA, could be developed in the near future at reasonable cost. Such a device would certainly increase the effectiveness of a hearing conservation program.

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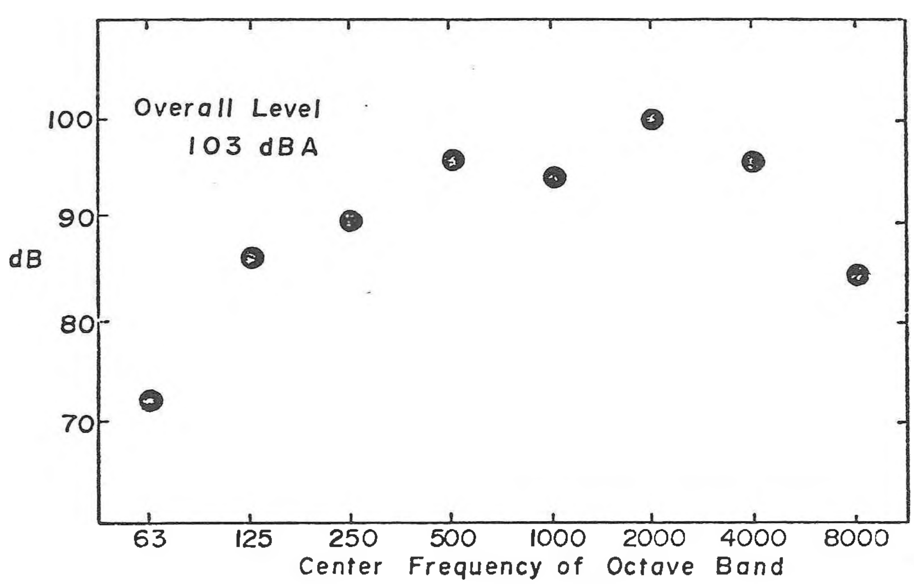

FIG. I Octave spectrum of the experimental noise as measured at the ear level of the subject.

TABLE I The effects of hair, glasses, and cap on the performance of a pair of Bilsom Viking earmuffs in male subjects. Numbers shown under 'Short Hair I' are mean attenuation data in dB and Standard deviations (in parentheses). They constitute the baseline data. The numbers shown under the remaining conditions represent the difference between the baseline data and the mean attenuation data in each condition for each subject. The t-test significance levels are shown in parentheses. NS = Not Significant.

Subject	Short Hair I (attenuation)	Glasses	Long Hair	Long Hair & Glasses	Long Hair & Thin Cap	Long Hair & Thick Cap	Short Hair II
SM	36.45 (2.01)	1.50 (NS)	2.90 (0.05)	4.75 (0.001)	1.85 (0.05)	14.90 (0.001)	-0.45 (NS)
DC	35.60 (1.60)	5.10 (0.001)	2.00 (0.05)	5.95 (0.001)	4.45 (0.001)	9.40 (0.001)	-0.30 (NS)
DH	38.4 (2.18)	-0.40 (NS)	-0.45 (NS)	6.55 (0.001)	3.9 (0.001)	15.75 (0.001)	0.05 (NS)
AM	39.4 (0.88)	1.35 (NS)	0.55 (NS)	3.90 (0.001)	1.20 (0.01)	13.45 (0.001)	1.35 (NS)
HW	38.2 (0.92)	5.40 (0.001)	3.20 (0.05)	6.30 (0.001)	2.1 (0.001)	12.1 (0.001)	--
Mean	37.61	2.59	1.64	5.49	2.70	13.12	0.16

TABLE II The effect of shoulder-length hair in female subjects. See Caption of Table I for details.

Subject	Short Hair I	Shoulder-Length Hair
SA	40.25 (1.01)	8.15 (0.001)
KE	35.05 (1.23)	5.02 (0.001)
MP	41.00 (1.13)	3.55 (0.001)
AC	36.35 (1.99)	0.85 (NS)
LB	37.70 (1.97)	1.50 (NS)
Mean	38.07	3.81

Copies of the Proceedings can be obtained from Noise Control Foundation, P.O. Box 3469, Arlington Branch, Poughkeepsie, N.Y. 12603, U.S.A. The two-volume set is $55.00 which includes surface mail postage and handling. Overseas orders should add an extra $25.00 if shipment of the set of books is to be by air.

INTER-NOISE 84

The location for INTER-NOISE 84, to be held December 3-5, will be the Hotel Ilikai, at one end of Waikiki Beach. The conference will be jointly organized by INCE/USA and INCE/Japan.

FASE 84

The 4th Federation of Acoustical Societies of Europe (FASE) Congress will be held in Sandefjord, Norway, 21-24 August 1984. Topics are: (1) Planning with respect to community noise, and (2) Acoustical methods in condition monitoring and analysis. For further information contact FASE 84, ELAB, N-7034 Trondheim-NTH, Norway, Telephone: +47 75 92 645.

Le 4ème Congrès de la FASE (Fédération Européenne des Sociétés d'Acoustique) aura lieu à Sandefjord, Norge, 21-24 août, 1984. Les sujets sont: (1) Les méthodes d'estimation du bruit urbain, et (2) Survellance et diagnostics par méthodes acoustiques. Pour autres informations écrire à FASE 84, ELAD, N-7034 Trodheim NTH, Norge.

CONGRESS ON BIOLOGICAL EFFECTS OF NOISE - Italy - June 1983

The International Commission on Biological Effects of Noise has announced details of the Fourth International Congress on Noise as a Public Health Problem: Biological and Behavioral Effects. The congress is to be held 20-25 June 1983 in the BIT-ILO Center of Turin, Italy. The official language of the congress is English; simultaneous Italian translations will be available. In addition to the invited and contributed papers on research and applications, major discussions are planned on governmental and industrial needs and problems. Other discussions will be held on ways to develop procedures that will permit practical solutions both for governments and for industry. Inquiries should be addressed to Professor Giovanni Rossi, Department of Audiology, Via Genova 3, 10126 Torino, Italy.

SYMPOSIUM ON MECHANICS OF HEARING - Delft - July 1983

A "Symposium on Mechanics of Hearing", jointly sponsored by the International Union of Theoretical and Applied Mechanics (IUTAM) and the International Commission on Acoustics (ICA), will be held in Delft, 13-15 July 1983. Approximately 30 invited papers will be presented on recent theoretical and experimental work concerning (i) the mechanical movement of cochlear structures, (ii) related physiological questions, and (iii) the mechanics of the middle ear and external ear. While all aspects (models, measurements, and mechanisms) of these subjects will be covered, the emphasis will be on mathematical modeling. The members of the scientific committee are Prof. E. de Boer (Chairman), Sir James Lighthill, Dr. E.A.G. Shaw, Prof. C.R. Steele, and Dr. M.A. Viergever (Secretary). The Symposium is associated with the 11th International Congress on Acoustics which opens in Paris on 19 July 1983. Further information can be obtained from Dr. M.A. Viergever, Department of Mathematics and Informatics, Delft University of Technology, P.O. Box 356, 2600 AJ Delft, The Netherlands.

QUELQUES ADRESSES UTILES A PARIS?

Si vous avez l'intention de vous rendre à Paris à l'occasion du 11^{e} Congrès International d'Acoustique, le 19 au 27 juillet 1983; et vous voudriez prendre contact avec des organisms français qui s'occupent de la lutte antibruit, les adresses suivantes vous seront utiles:

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If you intend to go to Paris to attend the 11th International Contress on Acoustics, 19-27 July 1983, and you wish to contact some of the French organizations working on noise control, here are some useful addresses:

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