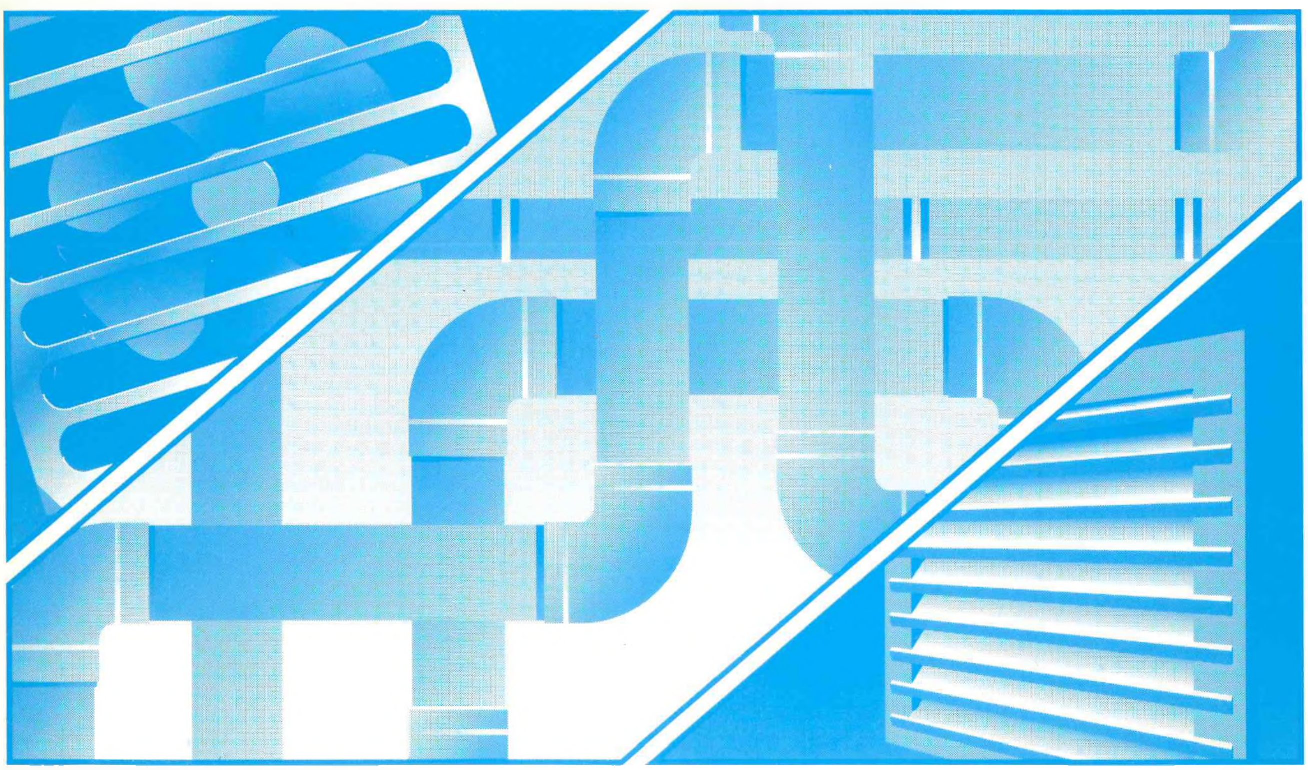
ISSN 0711-6659

canadian acoustics
acoustique canadienne

JULY 1991 JUILLET 1991
Volume 19 — Number 3 Volume 19 — Numéro 3



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CANADIAN ACOUSTICS is published four times a year - in January, April, July and October. Publications Mail Registration No. 4692. Return postage is guaranteed for undeliverable copies.

ACOUSTIQUE CANADIENNE est publiée quatre fois par année - en janvier, avril, juillet et octobre. Poste publications - Enregistrement n°. 4692. Affranchissement de retour garanti pour les exemplaires non distribués.

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EDITORIAL

In this issue we present three research articles in physical- and psycho-acoustics.

There is apparently some confusion as to whether Canadian Acoustics publishes Technical Notes or Application Articles. Yes, it does! We welcome submissions, for example from consultants, describing interesting and novel practical applications or case studies. These will be reviewed, as are research articles, but keeping the objectives of this type of article in mind.

As a new service to readers, we introduce on page 54 a Job Page which will appear in every issue. We will publish, at no charge, advertisements from employers looking for staff, and from individuals seeking employment. To take advantage of this service, simply send your advertisement to the Editor-in-Chief.

The Board of Directors met recently; the minutes are published in this issue. One issue which was discussed with some concern was the recent sharp drop in student members. This is difficult to understand in the light of the improved quality of the journal, the increase in student prizes and the subsidies available to students who attend the annual conference. We would be happy to hear from anyone who has an explanation for this change.

This year's Canadian Acoustics Week in Edmonton is fast approaching. Excellent courses and technical sessions, not to mention the Rocky Mountain Bus Tour, await those who attend. You will find the titles of the papers to be presented in this issue. To those of you who have had abstracts accepted, we look forward to receiving (before 31 July) your two-page summary papers, to be published in the September Proceedings Issue. We hope to see all of you in Edmonton.

Dans cette édition nous publions trois articles de recherches en acoustique physique et psychologique.

Il semble règner une certaine confusion quant à la possibilité de soumettre des notes techniques ou des articles appliqués à l'Acoustique Canadienne. Oui, c'est possible! Nous accueillons par exemple la soumission d'articles, de la part des consultants, qui décrivent de nouvelles applications pratiques ou des études de cas. Celles-ci seront révisées, comme le sont les articles de recherche, tout en considérant les objectifs poursuivis par ce type de publication.

A titre de nouveau service aux lecteurs, nous introduisons à la page 54 une section "Emplois" qui paraîtra dans chaque édition. Nous publierons, sans frais, les annonces d'employeurs qui cherchent du personnel et d'individus qui sont à la recherche d'un emploi. Pour bénéficier de ce service, envoyez simplement votre annonce au rédacteur en chef.

Le Conseil d'Administration s'est réuni récemment; le procès-verbal est publié dans ce numéro. Un sujet qui a particulièrement retenu l'attention est celui de la diminution dramatique du nombre de membres étudiants. Ceci est difficile à comprendre compte tenu de la qualité accrue du journal, de l'augmentation du nombre de prix étudiants et des allocations de voyages disponibles aux étudiants qui participent aux congrès. Nous apprécierions recevoir vos commentaires sur cette question.

La Semaine de l'Acoustique de cette année approche à grands pas. Des cours et des sessions techniques de haut calibre attendent les participants. Mentionnons également l'excursion en autobus dans les Rocheuses. Vous trouverez dans ce numéro les titres des communications à être présentées. A ceux dont le sommaire a été accepté, nous attendons votre résumé de deux pages (avant le 31 juillet) qui sera publié dans le numéro des Actes du Congrès de septembre. Nous souhaitons vous rencontrer en grand nombre à Edmonton.

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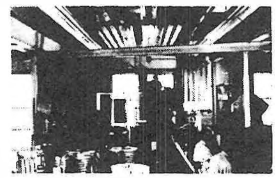

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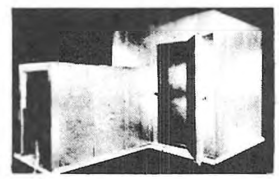

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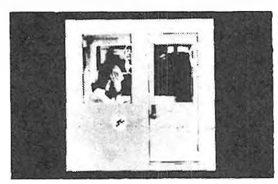

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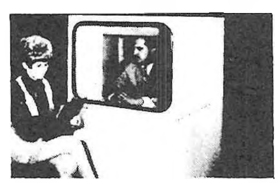

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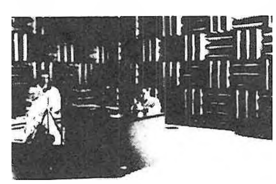

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Canadian Acoustics / Acoustique Canadienne 19(3) 3-15 (1991) **Research article / Article de recherche**

ISOPARAMETRIC FINITE ELEMENT USING CUBIC HERMITE POLYNOMIALS FOR ACOUSTICS IN DUCT COMPONENTS WITH FLOW

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ABSTRACT

This paper describes the development of a new finite element model to analyse the propagation of sound through duct system components. The element model was first tested by predicting the acoustic resonant frequencies of hard walled cavities. It was then used to predict the acoustic propagation characteristics of duct bends and junctions, including higher order mode propagation in attached straight ducts, and the convective effect of low Mach number air flow.

SOMMAIRE

Cette communication porte sur la mise au point d'un nouveau modèle à éléments finis d'analyse de la propagation du son dans des éléments d'un réseau de conduites. Les premiers essais du modèle ont consisté à prévoir les fréquences de résonance acoustique de cavités à parois dures. Le modèle a ensuite servi à prévoir les caractéristiques de propagation du son dans des coudes et des raccords de conduites, y compris les caractéristiques de la propagation de mode plus élevé dans des conduites droites raccordées, et l'effet convectif d'un écoulement d'air à faible nombre de Mach.

1 INTRODUCTION

There is a need for improved methods for the prediction of noise transmission and generation in heating, ventilation and air conditioning (HVAC) duct systems. While the propagation of sound waves along a long duct or pipe is quite well understood, the behavior of the sound wave when it is incident on a bend or a junction is not easily calculated without using numerical procedures. At low frequencies (where the wavelength is large compared to the duct width), the sound propagates along a straight duct in a plane wave mode. This plane wave approximation has been used to advantage by Munjal [1] in developing transfer matrix methods for duct and muffler analysis and by Eversman [2] and Craggs and Stredulinsky [3, 4] for the study of branched duct systems.

In Reference [4], exact plane wave solutions are used in straight ducts, and finite element models are employed in components such as bends, duct junctions and plenums where two and three-dimensional propagation effects are important. The finite element models are constrained to plane waves at connecting straight duct interfaces. The procedure was developed on a desktop computer with the aim that it could be used by design engineers on desktop systems. The resulting method was still limited in the size of duct system which could be handled on a "PC" type computer.

As an extension of Reference [4], this paper is concerned with the development of a more efficient acoustical finite element to allow solution of larger problems on a desktop computer. The work is concentrated on propagation through individual duct bends and junctions with a specified incident sound wave entering the bend or junction.

The convective effect of the flow on the sound propagation is considered, but flow generated noise within the duct components is not included. The predictions are extended to higher frequencies by considering higher order mode propagation in connecting straight ducts. The methods developed were implemented on a desktop computer with 1.5 megabytes of RAM, which limited the size of problems that could be solved.

2 THE NEW FINITE ELEMENT

In the earliest work on acoustic finite elements, rectangular brick elements, tetrahedral elements and triangular elements were used. Refer for example to Gladwell [5], Craggs [6, 7], Shuku and Ishihara [8] and Young and Crocker [9]. The edges or surfaces of these elements could only model straight lines or flat planes. A cuboid brick element with Hermite polynomial interpolation functions has been used by several researchers [6, 9, 10] and found to give accurate results and high rates of convergence [11]; however, this element has the disadvantage that it cannot be distorted to model curved boundaries or even oblique flat boundaries. More recently, isoparametric elements which can be distorted to model curved boundaries have been extensively used by Craggs [12], Astley and Eversman [13, 14] and Cabelli [15], for example.

In the present work a new isoparametric element is developed using Hermite polynomials. This new hexahedral element, shown in Figure 1, has thirty-two degrees of freedom and is referred to subsequently as the ISOHERM32 element. Cubic Hermite polynomials are used to approximate the dependent variable functions within the element. These interpolation functions are based on the corner node values of the dependent variable and first partial derivatives. For example, in one dimension, the Hermite polynomial is a cubic function based on the dependent variable and slope at each end of the interval in which it is defined. Additional nodes along the edges of the element (shown in Figure 1b) are used to define the element geometry. For details of the interpolation functions and transformation between the global coordinate system and the local element coordinate system refer to Stredulinsky [16].

In many acoustic problems, typically the acoustic pressure or the acoustic velocity potential is used as the dependent variable. In the initial development of the new element the acoustic pressure was used; however, in later work involving flow, it was found more convenient to use a velocity potential for both the acoustic and flow fields. In the initial development, the four degrees of freedom at each corner of the element were the acoustic pressure P and pressure gradient components $\partial P/\partial x$, $\partial P/\partial y$, and $\partial P/\partial z$. In the later development the velocity potential and velocity potential gradient components were used. The main motivation for using Hermite polynomials in

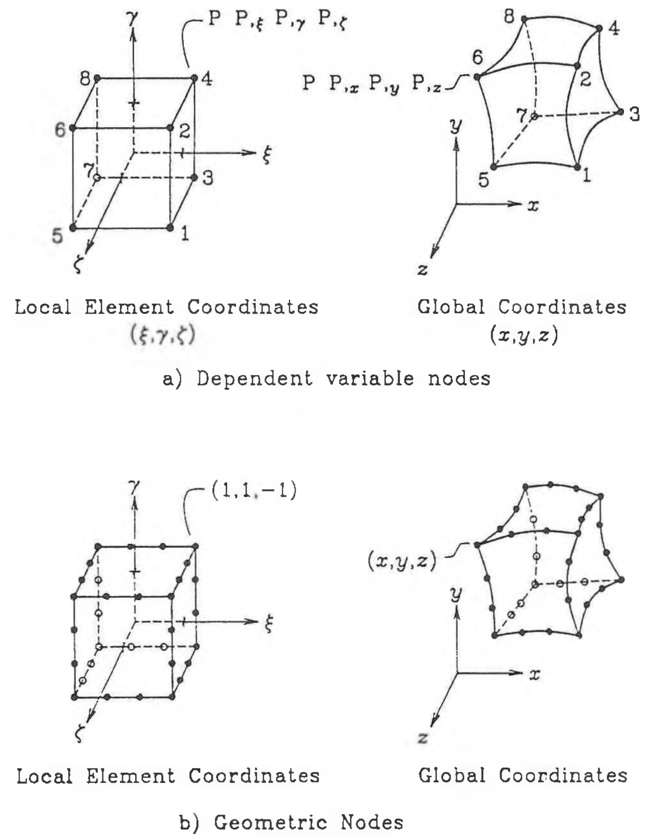


Figure 1: The ISOHERM32 finite element

problems with hard walled ducts is that the gradient degrees of freedom, normal to the duct wall, can be constrained to zero. This leads to smaller global finite element models as discussed in the following paragraph.

The closest "competitive" conventional finite element to the new element is the cubic hexahedral isoparametric element (HEX32), which uses cubic Serendipity interpolation functions. This element also has thirty-two degrees of freedom, given by dependent variables at the eight corner nodes and the two nodes along each edge of the element. The main difference between this element and the new element is that the nodal degrees of freedom of the new ISOHERM32 element are concentrated at the corners of the element. This leads to fewer global degrees of freedom (and thus a smaller system of linear equations to be solved) for models using the new ISOHERM32 element compared to models with the same number of conventional HEX32 elements. For the case of hard walled ducts, with the new element further reductions in the overall global degrees of freedom can be achieved by constraining normal derivative degrees of freedom at the wall to zero (based on the boundary condition of zero normal flow velocity and a zero normal acoustic particle velocity at the hard surface).

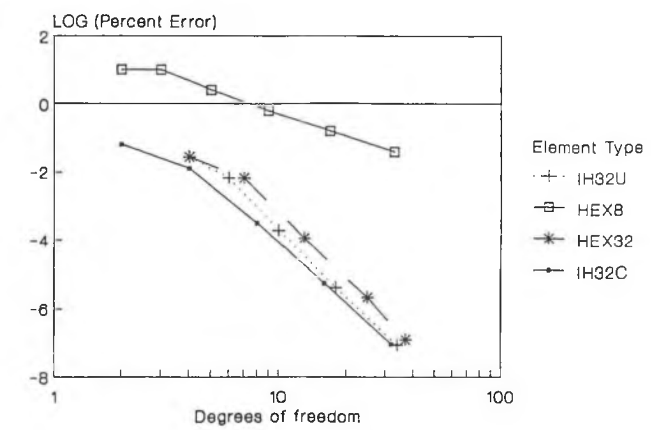


Figure 2: The convergence of different FEM models for the prediction of the natural frequencies for the first axial mode in a 1D tube

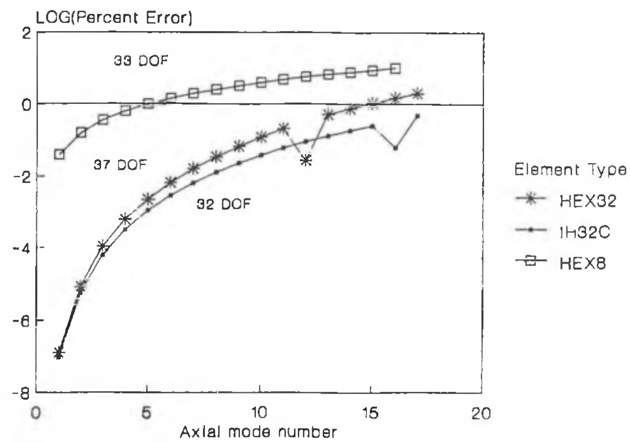


Figure 3: The comparison of different FEM models for the prediction of the natural frequencies of higher order modes in a 1D tube

3 INITIAL TESTING

The new element was initially used to find the acoustic resonant modes and natural frequencies of a stationary compressible fluid within rigid walled cavities for which analytical solutions are known. This problem is governed by the Helmholtz equation which is reduced to a discrete matrix eigenvalue problem using a Galerkin finite element method as described in many textbooks on finite element methods, including Burnett [17].

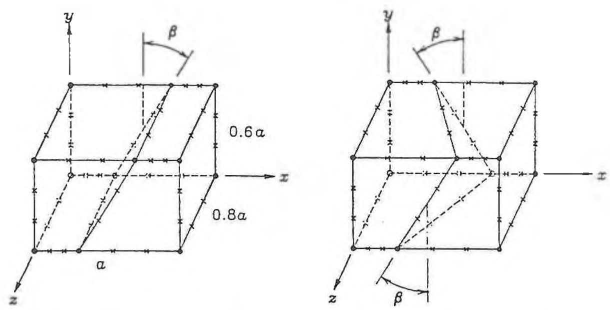
3.1 A Rectangular Cavity

The solution of the acoustic eigenvalue problem for a rigid walled rectangular cavity is well known, and is given, for example, in Morse [18]. The convergence of the finite element models is demonstrated by considering a linear string composed of one to sixteen cuboid elements with nodal quantities constrained to solve a one-dimensional problem.

The resulting prediction error for the natural frequency of the first axial mode is shown in Figure 2. The $\log_{10}$ of the percent error is plotted as function of the global degrees of freedom for the models. The upper curve, labelled HEX8, for the conventional linear isoparametric element, shows significantly higher errors and a lower rate of convergence than the other three curves which are for the cubic elements. The curve labelled HEX32 is for the conventional 32 degree of freedom hexahedral element. The curves labelled IH32U and IH32C are for the new ISOHERM32 element with the axial acoustic pressure gradient nodal quantities, respectively, left unconstrained (the hard wall boundary condition implicitly satisfied by the finite element method), and explicitly constrained to zero at the rigid ends of the tube. On a number of element bases, the HEX32 model gave slightly better results than the new element, but on a global degree of freedom basis the new element gave more accurate results (typically 1/3 the errors of the HEX32 models).

In Figure 3, the prediction errors for the natural frequencies of higher order axial modes are compared for models with similar numbers of degrees of freedom. The large differences noted between the HEX8 linear element model and the cubic elements for the first axial mode become progressively smaller as the mode number is increased. The ISOHERM32 element curve, labelled IH32C, shows progressively better results than the conventional cubic element HEX32 curve as the mode number is increased. The notches in the graphs for the HEX32 and IH32C curves occurred when each finite element modelled exactly one half wavelength.

The elements used in the above one-dimensional tube problem are undistorted, maintaining the cuboid parent element shape. Figure 4 shows a rigid walled rectangular cavity modelled using two ISOHERM32 elements. The elements are distorted first by rotating the common plane between the elements and then by twisting this plane. The errors in the fifteen resonant frequencies predicted with this model are given in Table 1 for rotation of the common plane and in Table 2 for twisting of this plane. The parameter ka used in these tables and subsequent tables and figures is a non-dimensional frequency parameter based on the wave number k and a typical dimension a taken in this case to be the length of the cavity in the x direction The distortion has the greatest effect on the axial modes along the x axis and very little effect on the axial modes in the y and z directions. The prediction for the first axial mode $[n_x, n_y, n_z] = [1, 0, 0]$ was found to be extremely sensitive to the twisting distortion. Additional results were obtained with the conventional HEX32 isoparametric element. The ISOHERM32 and HEX32



Rotation of the common plane   Twisting of the common plane

Figure 4: Element distortion within a two-element model of a rectangular cavity

Table 1: Prediction errors for the natural frequencies of a two-element rectangular cavity with the common plane rotated

Mode				Percent Error in ka				
				Rotation angle in degrees				
No.	n_x	n_y	n_z	0	15	30	45	59
1	1	0	0	0.0130	0.0313	0.1439	0.7071	3.668
2	0	0	1	0.0646	0.0646	0.0646	0.0646	0.0646
3	1	0	1	0.0445	0.0516	0.0955	0.3158	1.486
4	0	1	0	0.0646	0.0639	0.0620	0.0593	0.0573
5	1	1	0	0.0509	0.2975	1.269	4.177	13.49
6	2	0	0	0.0646	0.3444	2.358	10.89	50.15
7	0	1	1	0.0646	0.0641	0.0629	0.0612	0.0599
8	1	1	1	0.0549	0.2294	0.9184	2.991	9.732
9	2	0	1	0.0646	6.2659	1.717	7.958	37.93
11	2	1	0	0.0646	1.333	5.919	17.25	43.86
13	2	1	1	0.0649	1.096	4.847	14.23	36.72
14	3	0	0	3.008	5.305	13.75	37.12	156.4
18	3	0	1	2.578	4.546	11.83	32.29	139.8
20	3	1	0	2.322	5.654	16.16	38.29	124.6
24	3	1	1	2.060	5.014	14.39	34.37	113.8

Table 2: Prediction errors for the natural frequencies of a two-element rectangular cavity with the common plane twisted

Mode				Percent Error in ka				
				Rotation angle in degrees				
No.	n_x	n_y	n_z	0	15	30	45	59
1	1	0	0	0.0130	1.405	4.859	9.572	16.35
2	0	0	1	0.0646	0.0640	0.0627	0.0615	0.0611
3	1	0	1	0.0445	0.6566	2.233	4.942	11.16
4	0	1	0	0.0646	0.0634	0.0608	0.0562	0.0577
5	1	1	0	0.0509	0.7616	2.495	4.987	9.848
6	2	0	0	0.0646	0.3193	1.851	6.685	17.36
7	0	1	1	0.0646	0.0637	0.0631	0.0569	0.0598
8	1	1	1	0.0549	0.7048	2.374	5.898	20.08
9	2	0	1	0.0646	0.1232	1.183	4.754	14.68
11	2	1	0	0.0646	0.1229	1.121	4.293	14.52
13	2	1	1	0.0649	0.8284	3.693	11.55	38.59
14	3	0	0	3.008	3.366	8.658	20.04	38.70
18	3	0	1	2.578	5.560	13.60	28.68	67.79
20	3	1	0	2.322	6.577	18.73	33.97	94.71
24	3	1	1	2.060	4.519	13.78	41.10	122.8

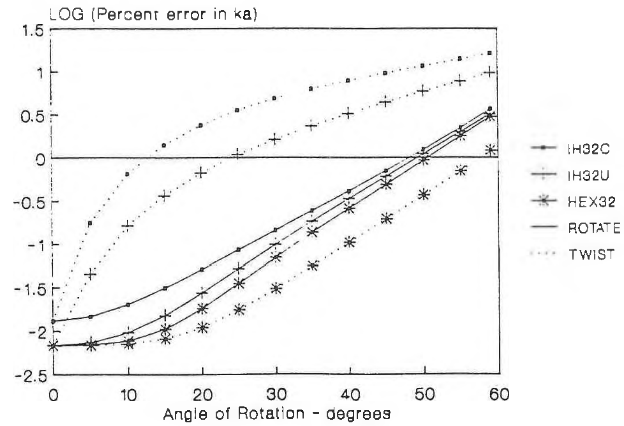


Figure 5: The effect of element distortion on the error in natural frequencies for a two-element model of a rectangular cavity

models are compared in Figure 5 where the $\log_{10}$ of the percent error is plotted as a function of the angle of rotation β. Both models show similar behavior for rotation of the common plane; however, the conventional HEX32 model does not exhibit the high sensitivity to twist observed with the new ISOHERM32 element model for the first axial mode. Most of the subsequent work is limited to two-dimensional problems, to reduce the sizes of the computer models, and thus does not involve twisting of element planes. Certainly, further investigation is needed to resolve this problem if general three-dimensional models are to be used.

3.2 A Circular Duct Cross-section

A more realistic problem, involving distortion of the element boundaries, but which still has an analytical solution, is the prediction of natural frequencies of a cylindrical cavity.

This is considered with a two-dimensional version of the new ISOHERM32 element, referred to as ISOHERM12, and the conventional two-dimensional cubic isoparametric element HEX12, using the single-element and four-element models shown in Figure 6. The solid circles at each node represent the acoustic pressure degrees of freedom and the short arrows represent the pressure gradient degrees of freedom. In the constrained models, the arrows represent the effective gradient degrees of freedom after explicitly constraining the normal acoustic pressure gradient to zero at the hard surface. In the lower three models, one edge of each element was collapsed to a point at the centre of the circle.

Table 3 shows the prediction errors in natural frequencies for these finite element models of a circular cross-section of radius a. The first number m in the mode

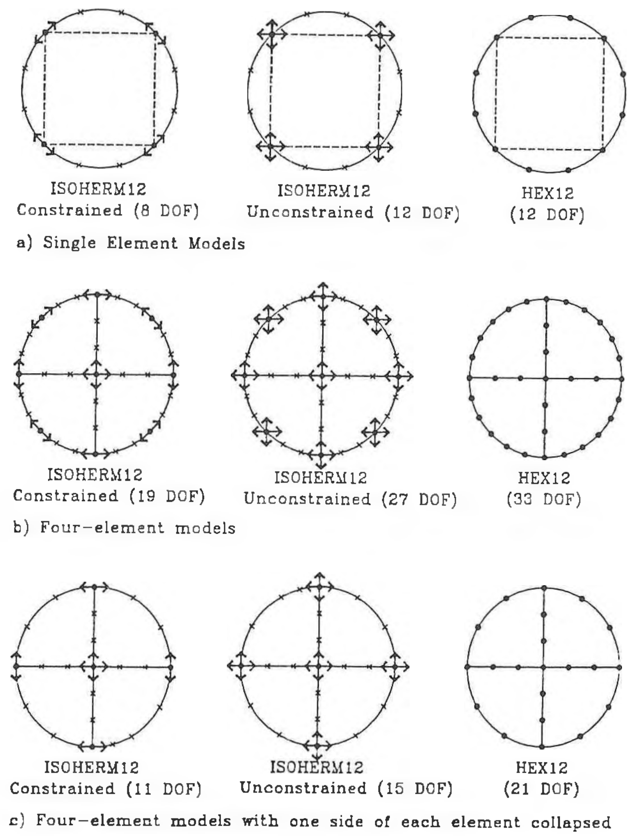


Figure 6: Finite element models of a circular duct cross-section

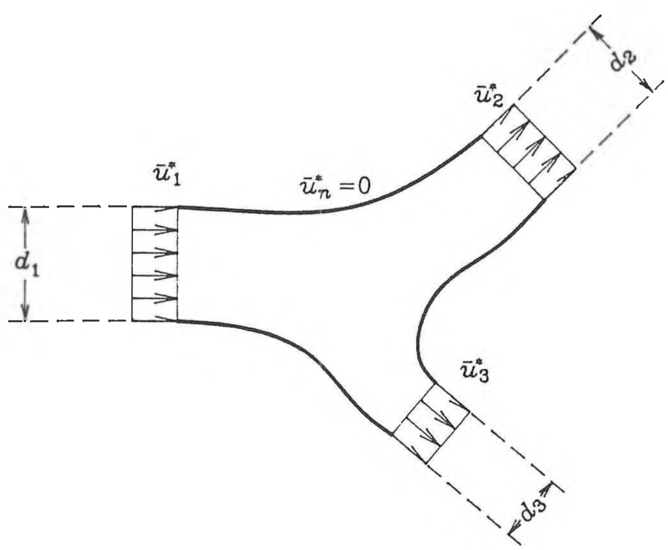


Figure 7: Model of a duct junction showing inlet and outlet flows

description refers to the angular coordinate direction and the second number n to the radial direction. The errors are much higher than obtained when modelling rectangular enclosures with undistorted elements. Of particular interest, the four-element model using the new element, with one collapsed edge and constrained degrees of freedom at the wall, has only 11 degrees of freedom and gives significantly smaller errors than the conventional isoparametric HEX12 single-element model which has 12 degrees of freedom and similar errors to the four-element HEX12 model having 21 degrees of freedom.

4 DUCT COMPONENTS WITH FLOW

Figure 7 shows a general two-dimensional model of a duct junction. The junction region is attached to three infinitely long (or anechoically terminated) straight ducts containing uniform flow at velocities $\bar{u}_1^*$, $\bar{u}_2^*$ and $\bar{u}_3^*$. The incident wave (which could be a combination of several modes) is specified in one of the ducts. The problem is then to determine the flow field and acoustic field in the junction region, and to determine the reflected acoustic modes in the incident wave duct and the transmitted modes in the other connected ducts.

4.1 Model Development with Flow

Acoustic propagation in non-uniform ducts in the presence of mid to high subsonic flows has been considered by Sigman et al [19], Eversman and Astley [14, 20], and Ling et al [21]. Cabelli [15] considered the influence of flow on the acoustic characteristics of a duct bend with inlet Mach numbers in the range of 0.25 to 0.4. Computing the mean flow field alone is a significant problem. In the work referenced above either approximate flow models applicable to specific geometries were used, or numerical solutions to the inviscid compressible potential flow problem were implemented.

Since flow velocities in HVAC systems are generally low (less than Mach 0.1), a flow model similar to that described by Peat [22] has been incorporated in this work. Acoustic wave propagation is a compressible phenomenon, therefore compressible potential flow equations are used as in [19], with the velocity potential, ϕ^*, as the dependent variable. It is acknowledged that an ideal inviscid flow model may not realistically represent the real flow in many cases but should at least give some indication of effect of flow on the acoustic propagation at low Mach number.

Dimensionless quantities, the velocity potential $\phi = \phi^*/(Mc_0a)$, time $t = t^*c_0/a$ and angular frequency $\omega = \omega^*a/c_0$ are defined based on the ambient speed of sound c_0, the typical flow Mach number M, typical dimension a, time t^* and angular frequency ω^*. Note that the dimensionless angular frequency $\omega = ka$ where k is the

Table 3: Natural frequencies for a circular cross-section of a hard walled duct

Model	Element	DOF	Percent Error in ka					
			Mode $[m,n]$					
			[1,0]	[2,0]	[0,1]	[3,0]	[4,0]	[1,1]
1 EL	IH12C	8	8.855	33.57		54.97	52.99	
	IH12U	12	3.548	24.29	154.9	51.48	52.99	196.3
	HEX12	12	2.688	14.11	92.80	33.14	27.76	141.3
4 EL	IH12C	19	0.287	2.926	.168	5.215	2.762	3.447
	IH12U	27	0.200	2.815	.087	3.684	2.642	3.447
	HEX12	33	0.122	2.549	.136	4.174	4.330	5.770
4 EL Collapsed	IH12C	11	0.475	0.500	.769	4.533	6.391	8.259
	IH12U	15	0.437	0.490	.400	4.488	6.387	8.259
	HEX12	21	0.196	2.095	.006	8.071	4.971	12.21
Exact ka			1.841	3.054	3.832	4.201	5.318	5.331

wave number. The total flow velocity potential is split into a steady mean flow potential $\bar{\phi}$ and a small acoustic harmonically fluctuating potential $\phi' e^{\mathrm{i}\omega t}$. With this, and the assumption that the Mach numbers are small, the compressible potential flow equations are reduced to the Laplace equation for an incompressible steady flow

$$\nabla^2 \bar{\phi} = 0, \tag{1}$$

and a second equation involving this mean flow velocity potential and the acoustic velocity potential ϕ' given by

$$\nabla^2 \phi' + \omega^2 \phi' - 2\mathrm{i} M \omega \nabla \bar{\phi} \bullet \nabla \phi' = 0. \tag{2}$$

The steady flow potential can be obtained from Equation 1 and then substituted into Equation 2 to find the acoustic velocity potential. Note that if there is no flow, $\nabla \bar{\phi} = 0$, and Equation 2 reduces to the Helmholtz equation.

A Galerkin finite element procedure is applied with the new element to reduce these differential equations governing the continuous acoustic and flow fields to a system of linear equations in terms of the unknown discrete nodal acoustic and flow velocity potential quantities.

The acoustic boundary conditions at the interfaces of the finite element model of the junction and the connecting straight ducts can be determined based on the analytical solution of governing equations for the case of uniform flow in a straight duct. Alternatively, the better known solutions of the convected wave equation, valid for uniform flow at higher Mach numbers can be adopted; refer for example to Munjal [1, Chapter 1] and Morfey [23]. The differences between the solutions is small for low Mach numbers and both take the form

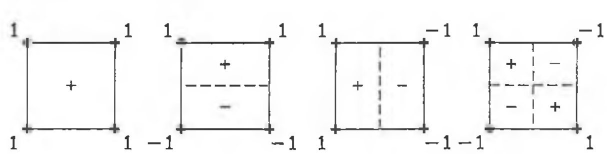
$$\phi' = \sum_{m=0}^{\infty} \Phi_m(y,z) \left(A_m e^{\mathrm{i}\omega_m^+ x} + B_m e^{\mathrm{i}\omega_m^- x} \right) \tag{3}$$

for a straight duct of arbitrary cross-section, where x is the dimensionless coordinate along the axis of the duct and y and z are in the plane of the duct cross-section. The term $\Phi_m(y,z)$ defines the m^{th} mode shape for the cross-section. The terms ω_m^+ and ω_m^- are a function of the dimensionless angular frequency ω, the flow Mach number and the natural frequency of the m^{th} mode. The modes can be evanescent or propagating depending on whether ω_m^+ and ω_m^- are real or complex quantities.

In linking the straight ducts to the finite element models of a junction or bend, the connecting straight duct acoustic mode shapes and natural frequencies are determined from finite element models of the duct cross-section. This is illustrated for the simplest case of a rectangular duct cross-section modelled with one finite element. The derivative nodal quantities at the hard wall boundaries in the plane of the cross-section can be set to zero leaving four corner nodal velocity potential values to define the modes. In this case the plane wave mode [0,0], and the cross modes [1,0] [0,1] and [1,1] can be approximated as shown in Figure 8. The vector of incident wave nodal velocity potential values can then be written as a modal matrix multiplied by a vector $\{a\}$ defining the incident modal mixture (the mixture of incident plane wave and higher order modes) in one of the connecting ducts. For this simple example the interface nodal acoustic velocity potentials are given by

$$\begin{Bmatrix} \phi'_1 \\ \phi'_2 \\ \phi'_3 \\ \phi'_4 \end{Bmatrix} = \begin{bmatrix} 1 & -1 & 1 & -1 \\ 1 & 1 & 1 & 1 \\ 1 & -1 & -1 & 1 \\ 1 & 1 & -1 & -1 \end{bmatrix} \begin{Bmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{Bmatrix}. \tag{4}$$

Similarly vectors $\{b\}$, $\{c\}$ and $\{d\}$ etc. are defined for



MODE 0 0 1 0 0 1 1 1

Figure 8: Modes for a rectangular duct cross-section modelled with one element

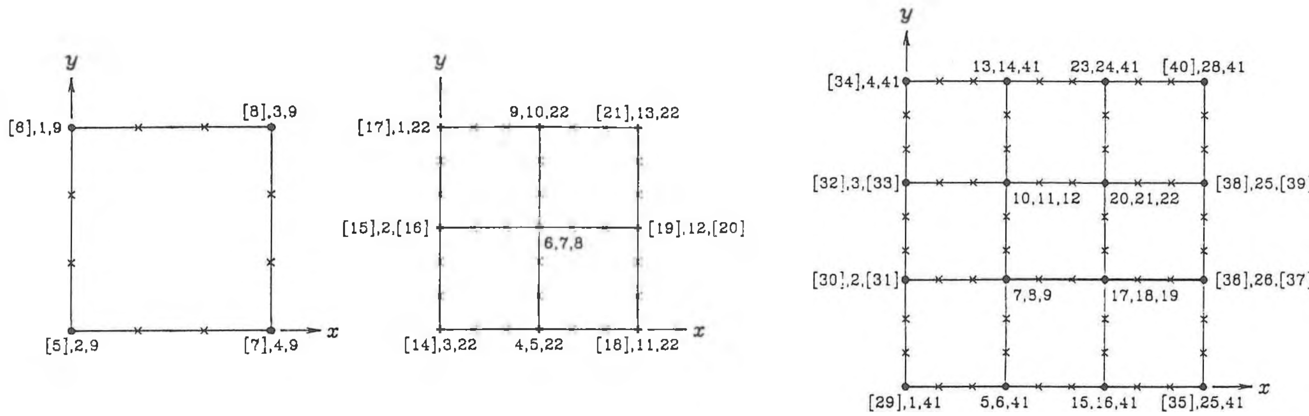


Figure 9: Two-dimensional finite element meshes for models of a straight duct segment

the the reflected modal mixture and transmitted modal mixtures in the remaining ducts.

The derivation and details of the finite element equations are given in reference [16]. Since the finite element model contains no internal source terms, the unknown acoustic velocity potentials and gradient quantities at internal nodes in the model can be eliminated from the resulting linear system of equations, leaving a final matrix equation which is solved for the real and imaginary parts of the unknown transmitted and reflected modal mixtures, given a specified mixture of incident modes.

4.2 Testing the Finite Element Model: A Straight Duct

The finite element model for prediction of acoustic propagation with flow was initially tested for a straight duct of rectangular cross-section. Figure 9 shows two-dimensional finite element meshes for a duct segment of width a in the y direction and of length a in the x direction, with one, two and three elements across the width of the duct. Infinitely long connecting straight ducts are extended to the left and right of the model. The left side of the model has been assigned the incident wave modal mixture and the flow taken as positive from left to right. The global node numbering scheme is shown with a group of three numbers at each node. The first number in each group represents the velocity potential degree of freedom ϕ, and the remaining two respectively, the $\partial\phi/\partial x$ and $\partial\phi/\partial y$ degrees of freedom. In this case the inlet and outlet duct modes are defined in terms of nodal quantities shown in square brackets at each end of the model. The highest node number in each model is assigned to all nodal degrees of freedom explicitly constrained to zero at the hard walls of the duct.

Typical results are shown in Figure 10 for the case of a specified unit incident first cross mode velocity potential. The graphs show the real (RE) and imaginary (IM) parts of the outlet first cross mode acoustic velocity potential, at the lower wall of the duct, for models with one, two and three elements spanning the duct cross-section. The analytical solution is shown by the solid line. The left graph is for a flow at Mach number $M = 0.1$ in the same direction as the acoustic propagation. The right graph is for the case of the flow in the opposite direction. The cut-on frequency for this mode occurs in this case at $ka = 0.995\pi$ (when the duct width is close to half a wavelength). Below the cut-on frequency the mode is evanescent and decays between the inlet and outlet, but above this frequency the mode propagates unattenuated. The prediction errors increase as the non-dimensional frequency parameter ka increases. The results converge closer to the exact solution as the mesh is refined. Also the predictions with flow in the opposite direction to the acoustic propagation show greater errors than that for propagation in the same direction as the flow.

4.3 Modelling a 90° Bend

Figure 11 shows example finite element meshes used to model a duct bend with an inner corner radius equal to half the duct width. The predictions obtained with these models are given in Figure 12 and compared to results obtained by Cabelli [15] using a conventional isoparametric finite element model. The graph shows the velocity potential transmission coefficient $T_{\phi'}$ for the transmitted plane wave and first cross mode components and the reflection coefficient $R_{\phi'}$ for the reflected plane wave and first cross mode. Three elements were needed across the duct width for the predictions to converge to Cabelli's result over the frequency range considered. Below the cut-on frequency of the first cross mode in the connecting ducts, only the plane wave mode is reflected and transmitted. At low frequencies most of the acoustic energy is transmitted; however, as the cut-on frequency of the first cross mode is approached most of the sound energy

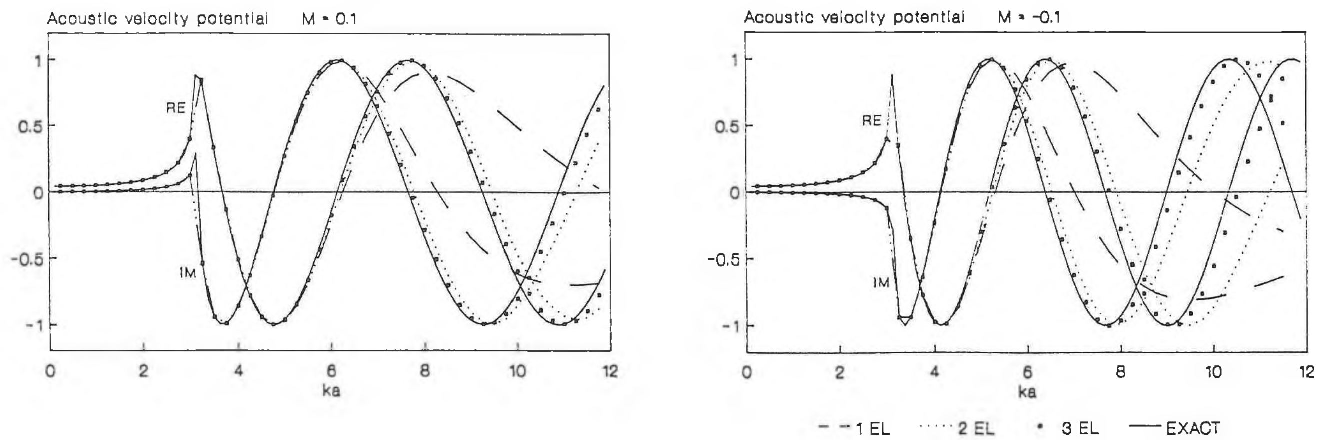


Figure 10: Outlet acoustic velocity potential for the first cross mode in a straight duct segment of width a and length a

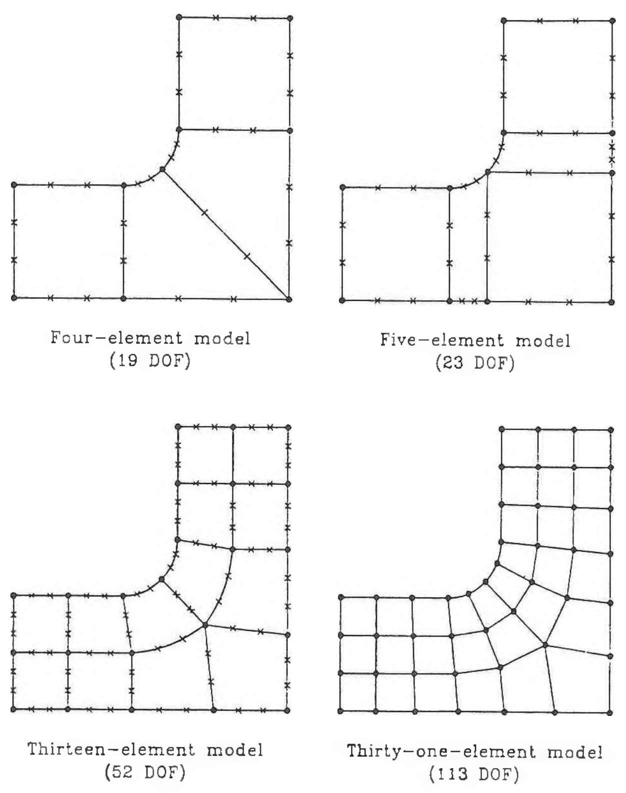


Figure 11: Finite element meshes for a duct bend with an inner corner radius of half the inlet duct width

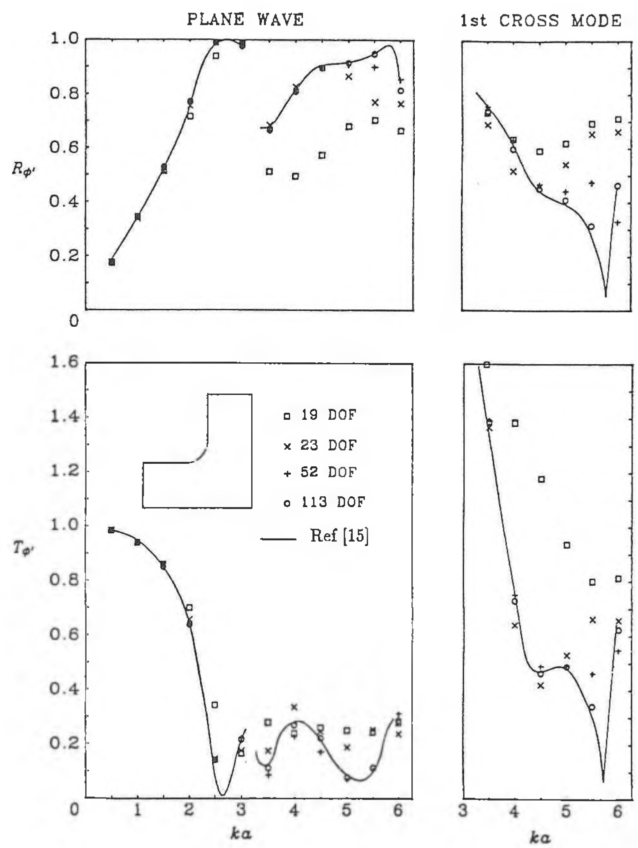


Figure 12: Acoustic velocity potential reflection and transmission coefficients for a bend with inlet and outlet widths a

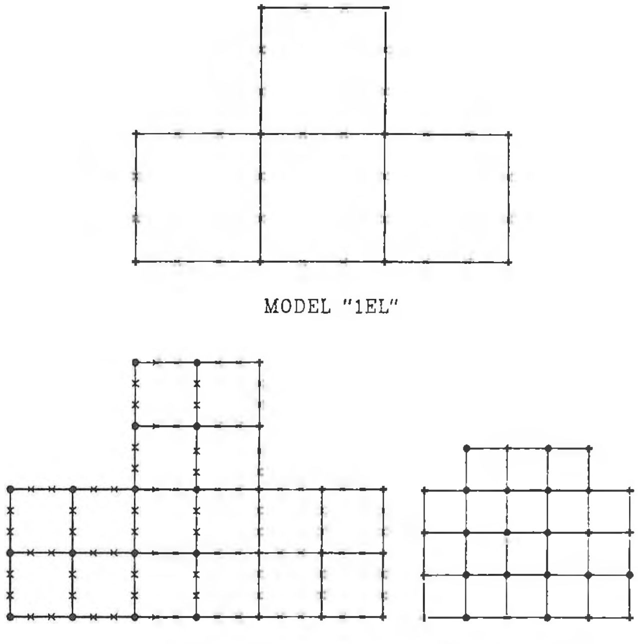


Figure 13: Finite element meshes for a 90° side branch with all connecting ducts of width a

is reflected as a plane wave. Above this cut-on frequency, some acoustic energy is transmitted and reflected both in the first cross mode and the plane wave modes. Cabelli also obtained some results with flow but at Mach numbers too large to be valid with the model developed in the present work.

4.4 Modelling a 90° Side Branch Junction

Compared to the volume of research done on duct bends, there appears to be relatively little research literature concerned with duct junctions. Some solutions with no flow have been obtained for a two-dimensional "T" junction (Miles [24] and von Said [25]) where the incident wave entered the stem of the "T". A 90° side branch was considered by Redmore and Mulholland [26] using a mode coupling theory. This side branch was essentially a "T" junction in which the incident wave entered one arm of the "T". Figure 13 shows element meshes used to model a 90° degree side branch junction which is attached to infinite ducts extending left, right and up from the models shown. Note that with three elements across the duct width, a reduced model with shortened inlet and outlet regions is used due to memory limitations of the computer. This is acceptable for the acoustic problem, since the evanescent and propagating modes are included in the connecting duct boundary conditions, but not acceptable for modelling the flow since longer transition regions are needed for a uniform flow to develop. The duct on the left is taken to contain the incident sound wave and the flow taken as positive when entering this duct and exiting the side branch and the continuing duct to the right.

Before presenting the results for these models, the subject of acoustic intensity and transmitted sound power will be discussed. Flow considerably complicates the definition of acoustic intensity. The definition of acoustic intensity with flow, given by Morfey [23] and also used by Cabelli [15] has been adopted in this work, although as discussed by Eversman [27], this definition does not give correct results with absorptive walls in the presence of flow. The axial acoustic intensity for each propagating mode is integrated over the connecting duct cross-section to give a transmitted sound power for each mode. A reflection coefficient for the reflected m^{th} mode in the duct containing the incident wave can be defined by $R_m = W_m^{\mathrm{refl}}/W^{\mathrm{inc}}$ where W_m^{refl} is the reflected sound power for the m^{th} mode and W^{inc} is the total sound power for the incident modal mixture. Similarly the modal transmission coefficient T_m^i for the m^{th} mode in the i^{th} transmitting duct can be defined by $T_m^i = W_m^i/W^{\mathrm{inc}}$ where W_m^i is the transmitted sound power for the m^{th} mode in the i^{th} transmitting duct. The concept of transmission loss normally used for a single acoustic transmission line is extended to a junction to give the transmission loss TL_m^i for the m^{th} mode in the i^{th} transmitting duct as

$$TL_m^i = -10\log_{10} T_m^i. \tag{5}$$

A similar equation is used with reflected modes, treating the reflected wave as another transmission path. For lack of a better word this can be called the reflection loss RL_m for the m^{th} mode given by

$$RL_m = -10\log_{10} R_m. \tag{6}$$

Figure 14 shows the convergence of the finite element models for the 90° side branch with no flow and a plane incident wave. The results are given in terms of transmission loss in decibels. The upper graph shows the reflection loss, RL, for the reflected plane wave and the first cross mode. The lower two graphs show the transmission losses, TL, for the plane wave and the first cross mode in the 90° side branch and in the continuing main duct. Above the cut-on frequency of the first cross mode at $ka = \pi$, most of the sound energy propagates along the continuing straight duct as a plane wave. The results for the model with two elements across the duct width are close to those obtained for the "shortened" model with three elements across the duct width. This would indicate that the models, with only two elements across the duct width, can be used for the problem with flow and give a reasonable approximation of the transmission characteristics over the frequency range considered.

At low frequencies, where the wavelength is large compared to dimensions of the duct junction region, the classical approach to plane wave propagation in pipes can

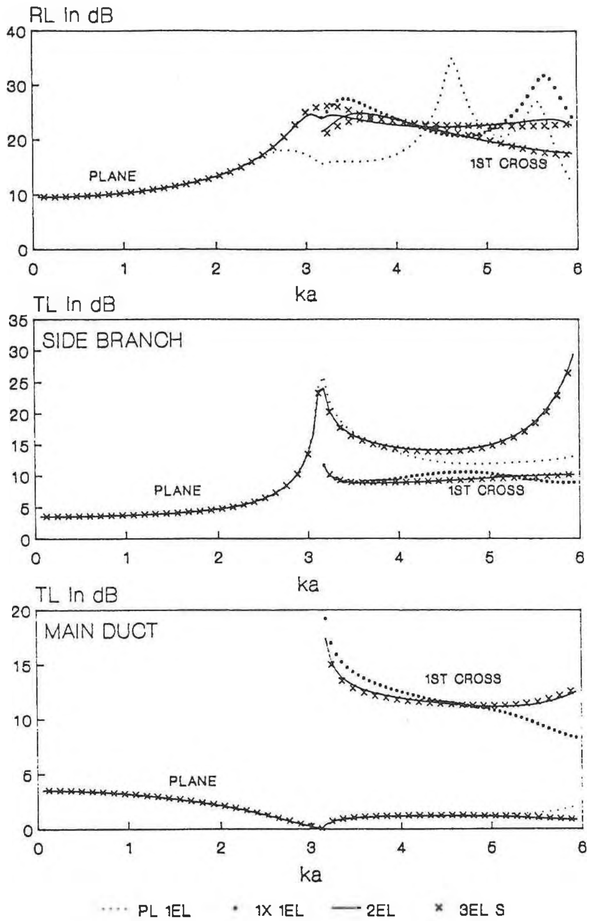


Figure 14: Convergence of FEM models for a 90° side-branch with all ducts of width a and a plane incident wave with no flow

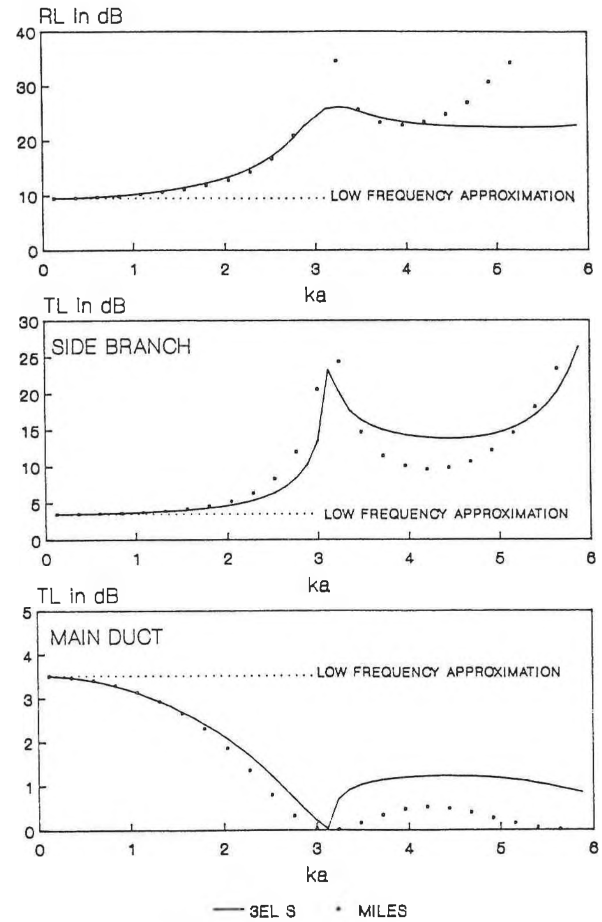


Figure 15: Comparison with other approximate solutions for a 90° side branch with all ducts of width a and a plane incident wave with no flow

be used to derive the transmission characteristics of the junction. This prediction assumes that the acoustic pressure is the same in each duct near the junction and results in transmission and reflection coefficients which are only dependent on the connecting duct cross-sectional areas. An approximate solution was developed by Miles [24] using an electrical circuit analogy which limited his approach to plane waves in connecting ducts and assumed that any higher order modes generated at the junctions decayed over short distances. The finite element prediction of the plane wave reflection and transmission losses with a plane incident wave are compared to the classical low frequency approximation and Miles approximation in Figure 15. For small values of ka the three methods converge to the same value. As the cut-on frequency of the first cross mode is approached one would expect Miles solution to deviate from the true solution. Even above this cut-on frequency Miles results show similar trends to the finite element model results.

Figure 16 shows the change in reflection and transmission loss with flow compared to the no-flow case, for the case of equal flow out the continuing straight duct and side branch, and a plane incident wave. The greatest changes tended to occur near the cross mode cut-on frequencies. At Mach 0.1, the flow generally produced changes in transmission loss of only 1 dB or less. Results were also obtained for the first cross mode incident wave, and for a side branch with one half of the width of the main duct. The ratio of flow out of the continuing duct and side branch was also varied and in all cases the effect of flow on the transmission losses was small. A negative Mach number indicates cases where the flow was taken to be in the opposite direction to the incident wave and transmitted wave propagation.

4.5 Modelling a 45° Side Branch Junction

Figure 17 shows a finite element mesh for a more complex 45 degree side branch junction modelled with only one element across the duct width. The current method is limited to modelling surfaces with more than one element across the connecting duct width only when the interface

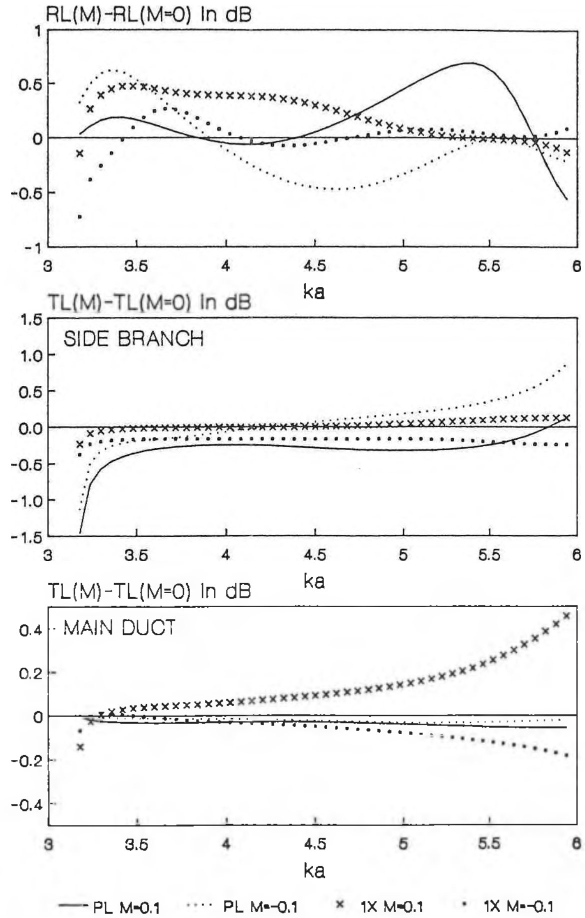


Figure 16: Change in RL and TL with respect to the no-flow case for an equal flow split between the 90° side branch and continuing duct

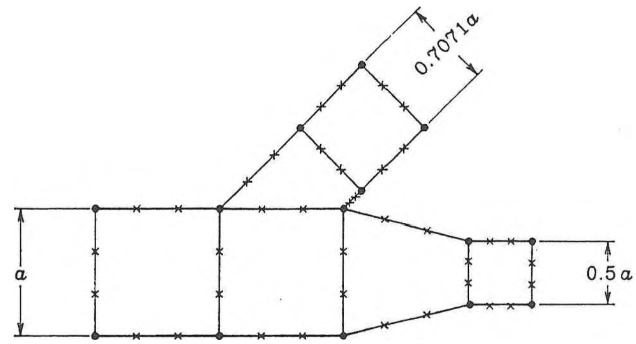


Figure 17: The finite element model of a junction with a 45° side branch

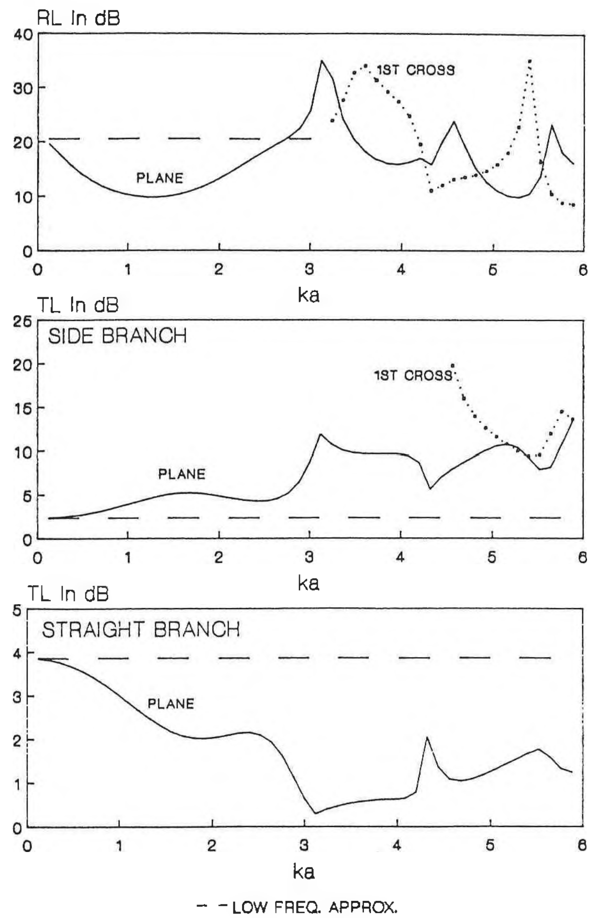


Figure 18: Propagation characteristics of a duct junction with a 45° side branch for a plane wave incident and no flow

surfaces are parallel to one of the global axes. When more than one element is used across the duct width, the cross-section acoustic modes are defined in terms of the nodal acoustic velocity potential and tangential derivative nodal quantities at the interface; however, the global model is defined in terms of the derivatives with respect to the global coordinate axes. The conventional isoparametric element does not have this limitation.

The predicted transmission characteristics of this 45 degree side branch model are shown in Figure 18. Note that the cut-on frequency for the first cross mode is different for each duct since each has a diffeṙent width. The higher frequency results may be inaccurate due to the coarseness of the finite element mesh. The dashed curves show the classical plane wave low frequency approximation. This approximation is commonly used in HVAC acoustic models to predict the sound power split between branches at a junction. The finite element model predictions indicate that even at relatively low frequencies the classical plane wave approximation may not be very realistic.

5 SUMMARY AND FURTHER WORK

A cubic isoparametric finite element has been developed using Hermite polynomials. The element has been used to model the acoustic propagation characteristics of duct junctions including higher order mode propagation and mean flow effects. The use of this new element has allowed certain problems to be solved on a desktop computer which would have been difficult to solve using the conventional cubic isoparametric element without using a more powerful computer. It was found that flows typical of HVAC systems (Mach 0.1 or less) had only a small effect on the bend and junction transmission losses, changing the component transmission losses by generally less than one decibel with the exception, that near the cross mode cut-on frequencies, changes of a few decibels occurred. Some areas for further research include:

- Investigation of the difference in the behavior observed with the new element compared to the conventional isoparametric element under certain element boundary distortions.
- Confirmation of some of the model results by running larger models on a mainframe computer and also testing three-dimensional junction models with connecting ducts of rectangular and perhaps circular and oval cross-sections. The advantages of the new element over the conventional isoparametric element may not be as great in these cases.
- Modify the existing method to handle duct interfaces at oblique angles.
- Extension of the method of Reference [4] for predictions in duct networks and branched systems to higher frequencies. This could be achieved by including higher order modes in connecting straight duct models in a manner similar to that used in the current work on individual components.
- Include acoustically absorptive linings and flexible duct walls in the prediction method. In these cases the advantage of the new element to reduce the model size by explicitly constraining derivative nodal quantities could not be applied.

ACKNOWLEDGEMENTS

The work presented here has been supported through a grant from the Natural Sciences and Engineering Council of Canada, Grant No.A7431, and through a Killam Scholarship (to D.C.S.).

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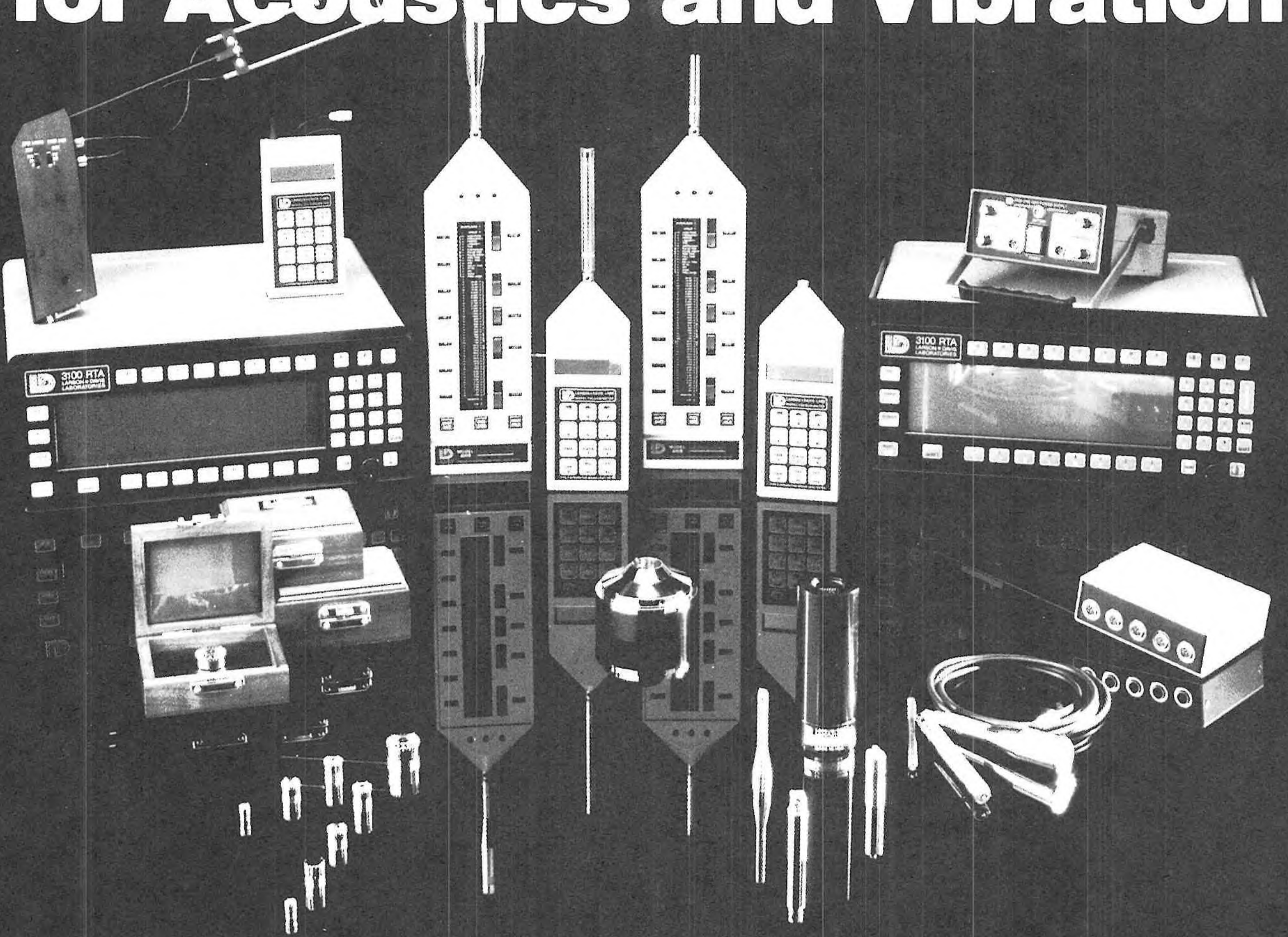

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Canadian Acoustics / Acoustique Canadienne 19(3) 17-27 (1991) **Research article / Article de recherche**

DIRECTIONAL RESPONSE OF A VECTOR INTENSITY HYDROPHONE ARRAY

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ABSTRACT

This paper describes the test results of a procedure to measure the directional response of a vector intensity hydrophone array. The NORDCO 3-D hydrophone array was designed to simultaneously capture the three components of a sound intensity vector. The phase matched array requires accurate positioning of the receiver elements to achieve a real time response. To calculate the directional response of the array, the x, y and z components of a sound intensity field point produced by a stationary source were measured while rotating the array about its z axis. The resulting sound intensity curves showed the expected cosine patterns with the minima of the x and y components spaced precisely 90° apart.

SOMMAIRE

Cet article décrit les résultats de test d'une méthode afin de mesurer la réponse directionnelle d'une sonde d'intensité vectorielle d'hydrophones. La sonde hydrophonique d'intensité en 3 dimensions de la compagnie NORDCO a été conçue afin de capturer simultanément les trois composantes du vecteur intensité d'un champ acoustique. La sonde d'intensité aux hydrophones en phase nécessite de positionner avec précision les éléments receveurs afin d'obtenir une réponse en temps réel. Pour calculer la réponse directionnelle de la sonde d'intensité, les composantes vectorelles x, y et z d'un champ acoustique généré par une source stationnaire ont été mesurées en faisant tourner la sonde d'intensité autour de l'axe z. Les courbes d'intensité acoustique ainsi obtenues ont montré que l'on obtenait les variations en cosines espérées avec un écart très précis de 90° entre les minima des composantes en x et en y.

1. INTRODUCTION

The realization of an acoustic wattmeter has been the goal of numerous research scientists. Early work was plagued by instrument and array design errors that were difficult to identify and quantify. T.J. Schultz[1] refers to their work for the U.S. Navy in the early 60's as "a case history in the pathology of over-simplification". Their early results demonstrated and highlighted the importance of understanding the underlying theory and assumptions involved in applying sound intensity measurement techniques.

Researchers persisted despite the early problems encountered. Fahy[2], Hodgson[3], Pavic[4] set the stage for renewed interest in the direct measurement of the sound intensity field. Their papers discuss the theory of using two closely spaced receivers to measure the component of the intensity vector along the direction of the receiver pair (see Appendix). This work was enhanced by Chung[5], Elliott[6], Dyrlund[7] and Shirahatti et al.[8]. They concentrated on the analysis of the errors associated with the measurement of sound intensity. For instance, Chung refers to the phase mismatch error and demonstrates a signal processing technique to eliminate the effect of the phase difference between the two channels. Elliott and Shirahatti et al. discuss the finite difference approximation errors; i.e., the error caused by approximating the pressure gradient by the pressure difference between the two closely spaced receivers. Dyrlund and Seybert[9] address the statistical errors in acoustic intensity measurements. Rasmussen[10,11] illustrates the importance of phase matching and discusses random errors. His work on the effects of a microphone's orientation on the accuracy of the measurement highlights the importance of considering the directionality responses of the individual receivers when designing a sound intensity array.

2. THE 3-D SOUND INTENSITY HYDROPHONE ARRAY

In 1987, NORDCO Limited in association with C-CORE undertook research into sound intensity measurements for underwater geophysical applications in seabed mapping.

By 1988, NORDCO Limited had developed a 3-D sound intensity hydrophone array. Underwater testing and calibration of the array has since taken place.

The hydrophone array consists of three pairs of Bruel & Kjaer omnidirectional hydrophones, phase matched and aligned so that the pairs lie along the mutually orthogonal X, Y and Z axes with the midpoints of the pairs coincident at the geometric center of the array (see Figure 4 for plan view). The spacing between any two paired hydrophones is 5.00 ± 0.01 cm with the measurement made between the geometric centers of the hydrophones. (The geometric center of each hydrophone was assumed to be coincident with its acoustic center). The alignment of the three pairs along the X, Y and Z axes was performed to a similar degree of accuracy. The phased matching procedure was performed with prototype Bruel & Kjaer calibration equipment and standard type 2035 sound intensity analyzers and calibration software. A phase match of better than 50×10^{-3} degrees at 250 Hz exists between any pair of hydrophones.

The objective of this paper is to exhibit the directional response of the array as measured in the reverberant field of a water tank. This is achieved by measuring the X, Y and Z components of intensity emitted from a stationary source while rotating the array about its Z axis.

3. METHODOLOGY

The experiments were performed in the acoustics tank at the Marine Institute of Technology (in Newfoundland). The tank dimensions and physical setup are illustrated in Figure 1. It was recognized that a significant amount of reflected energy would exist in the tank even through the source was pulsed to minimize the accumulation of this energy. This provided a true test for the ability of the sound intensity method to distinguish the active and reactive components of the sound field.

The instrumentation for the experiments is shown in Figure 2. During any one test, two Bruel & Kjaer real-time dual channel, digital filtering analyzers were used. Each analyzer was dedicated to one direction only. With a common clock connection, the analyzers simultaneously measured two components of the intensity vector. (The X and Y directions and the Z and Y directions were normally selected and these plots are shown.) Thus, an intensity vector in the X-Y or Z-Y plane was measured in real time.

The projector was an 8105 hydrophone and this source remained stationary throughout the experiments. The projector transmitted pulses at frequencies of 1, 4, 8 and 10 kHz with various pulse lengths and levels chosen, as indicated, for each experiment. It was necessary to use pulses to minimize the accumulation of reflecting sound waves within the tank from one set-up to the next rotation set-up. A time gating technique was also used to insure that the analysis interval was identical for each rotation measurement location of the array. To ensure proper timing for the measurements, the pulse from the gating unit was also used to trigger the two sound intensity analyzers.

The analyzers were set for 12 mm spacing between transducers. The analyzers were designed for use with microphones in air. The 12 mm space yields an approximate maximum transit time between receivers of 35.8 micro seconds (0.012 metre divided by 335 metres per second). This was the closest setting available for the hydrophone spacing of 50 mm which yields an approximate maximum transit time in water of 33.3 micro seconds (0.050 metres divided by 1500 metres per second). This produces a small error with respect to absolute intensity values but it is constant for each experiment and does not affect the results which only compare relative curve shapes, smoothness and the location of the minima.

Measurements involved 1/2 second linear averaging on the analyzers to ensure that the entire pulse was captured. The collected data were dumped to a computer to free the analyzers for the next measurement at the new rotation point. A printout was generated at the end of each test.

The transmitted signals are illustrated in Figure 3. The function generator produced a sinusoid at the selected frequency for each test. The gating unit truncated the sinusoid with the time window selected creating a pulse which was sent to the power amplifier and the projector. This window was also sent from the gating unit to a trigger box which controlled both sound intensity analyzers (see Figure 2).

The pulse length was normally set at 250 milliseconds. The pulse levels, controlled by the power amplifier, were varied depending on the desired frequency of the source. This was necessary since the 8105 hydrophone which was used as a projector is not an efficient transmitter at these low frequencies. Thus, its output level at 1 kHz is very much lower than at 8 kHz if the input level is held constant. Even with the changes in output levels, noted below, the difference between the measured intensity levels at different frequencies is clearly evident from the plots.

A further note on the pulse length must be made. For a 250 millisecond pulse in a small water tank, it is clear that numerous reflections occur and are incident upon the hydrophone array during the analysis window. It is a characteristic of the sound intensity technique that the array discriminated between the active component of the sound

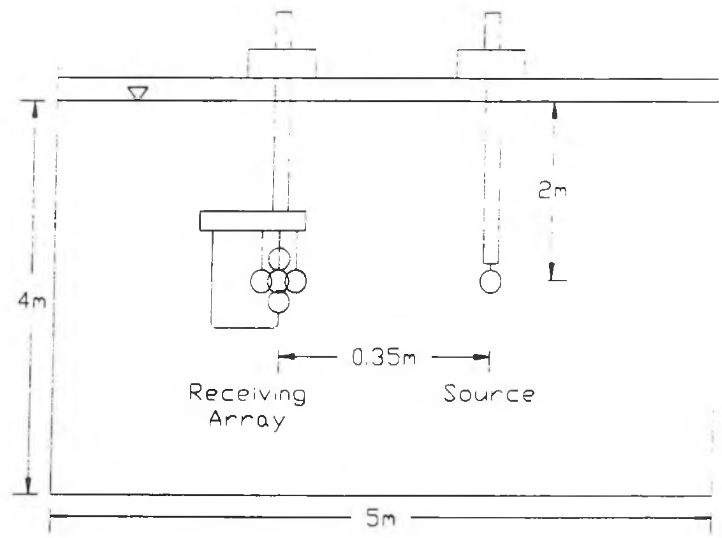


FIGURE 1 Physical setup. Note tank width is 4m.

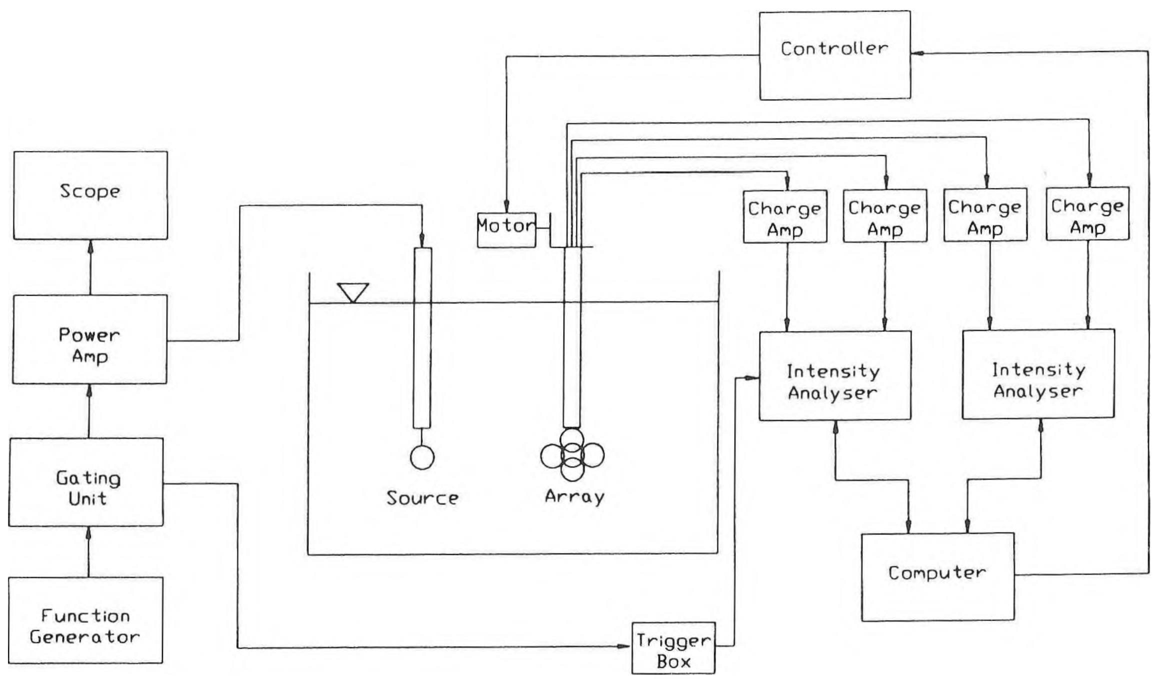


FIGURE 2 Instrumentation

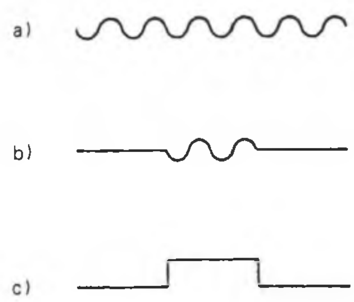


FIGURE 3 Signal waveforms, a) from function generator
b) from gating unit to source,
c) from gating unit to analysers.

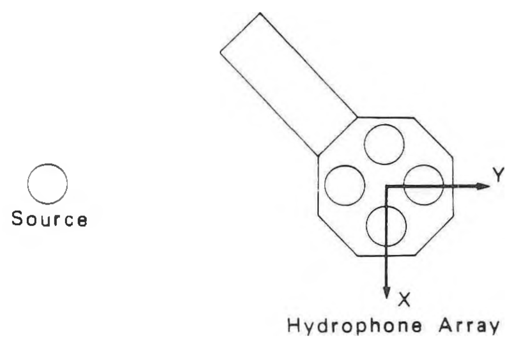


FIGURE 4 Initial (0 degree) position of array showing X and Y directions.

field produced by the source and the background reverberations.

To determine the directional response of the hydrophone array, the array was rotated counter-clockwise about its Z axis while measurements were made at incremental steps. The initial (0°) position of the array is shown in Figure 4. The X and Y directions are also delineated in this figure. After each test, the array was rotated clockwise back to its 0° position. Rotation of the array was controlled by the computer and confirmed by visually checking a scale inscribed on the turntable.

The data are plotted as directional characteristics curves using polar coordinates, as shown in Figure 5 to 14.

4. RESULTS AND INTERPRETATION

The array was set to the zero position by visual inspection and rotated 360° with an X-Y measurement recorded at each 1° increment. The source was set to produce a 250 ms pulse at 8 kHz with a signal generator output of 10 mV. The measurement was performed three times generating three nearly identical curves of the array response at 8 kHz. Figure 5 displays one of these response curves.

The curve shows the expected cosine patterns with minima spaced precisely 90° apart. The 10° offset from the zero position is due to a slight misalignment between the array and turntable axes arising from the dependence on visual inspection for the initial positioning of the array. This 10° offset was eliminated by resetting the zero position for all subsequent experiments.

The analyzers were also set to record sound pressure rather than intensity in the X-Y plane. Two 360° rotations were required. During the first, the channel A pressure on both analyzers (hydrophones A and B in Figure 6a) was measured, and during the second, both channel B pressures (hydrophones C and D in Figure 6b) were measured. Ambient reverberation now becomes an obvious problem when measuring only pressure since both the reactive and active components of the field are captured and summed. This is evident from the jagged appearance of the pressure data curves. For this dataset the pressure measured by an individual hydrophone in the array for each new rotated location is different due to the spatial variation of the sound field created by the interaction of the reflected energy which varies from point to point. The sound intensity dataset produces smooth curves since the intensity measurement is taken at a single point at the center of the array for all array orientations. Thus, the background reverberations at this point are constant for every measurement position.

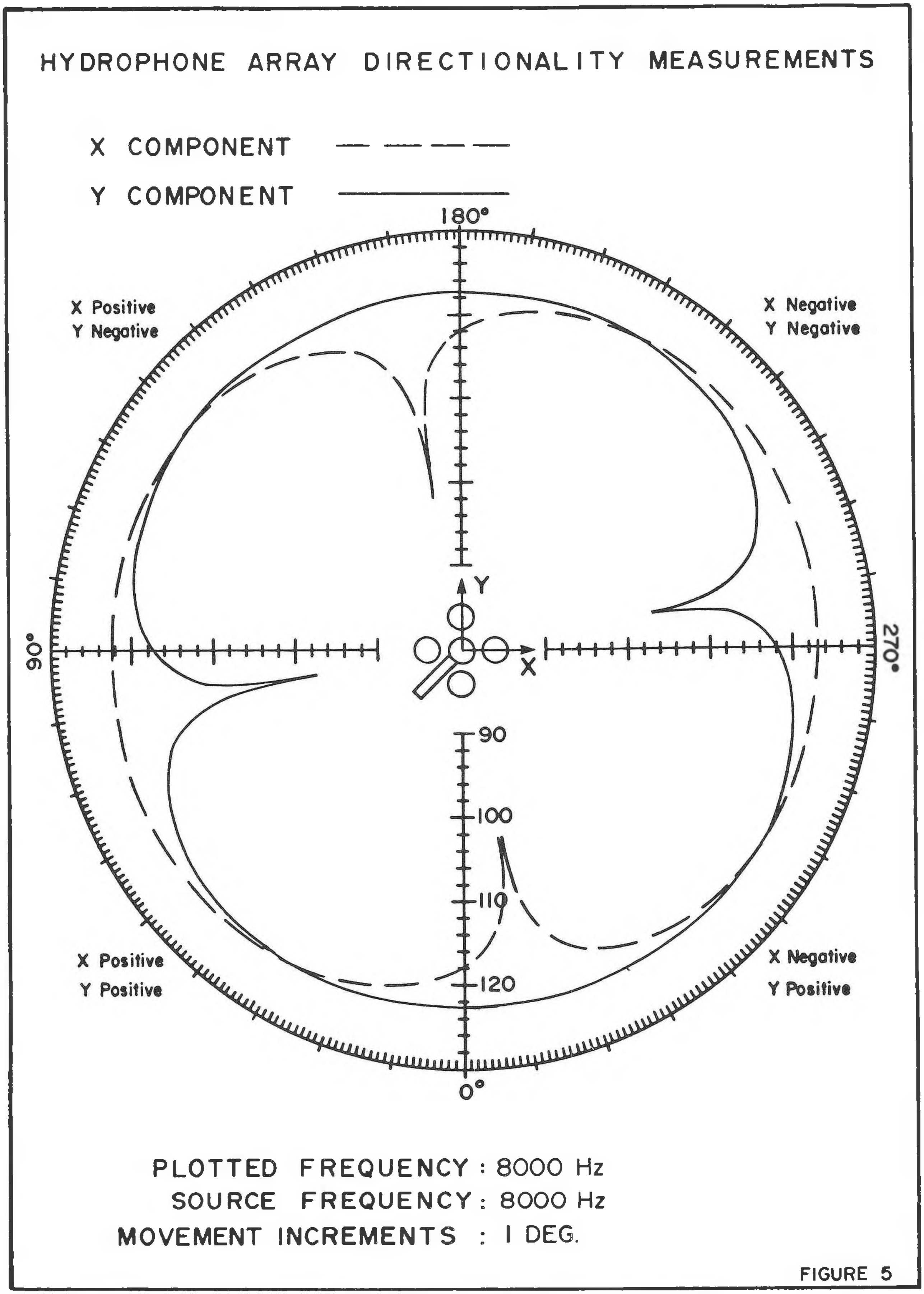
The array was again set to the zero position and rotated 360° with the source producing a 250 ms pulse at 4 kHz with a signal generator output of 15 mV. The plot of Figure 7 exhibits the intensity array response at 4 kHz for 1° incremental steps. As in the 8 kHz plot (Figure 5), the expected curves were generated with minima separated by 90°.

The source was then set to produce a 250 ms pulse at 1 kHz with a level of 120 mV. Figure 8 resembles the cosine bell curves although the plots are slightly skewed as minima are not precisely 90° apart. Some roughness (not evident in the drafted figure) in the cosine curves exists. The roughness of the curves can be explained by sporadic incoherence in the transmission signal due to the low frequency of propagation which is outside of the normal operational frequencies of the projector. This interference, which did not exist at higher frequencies, was evident in the analysis during the testing.

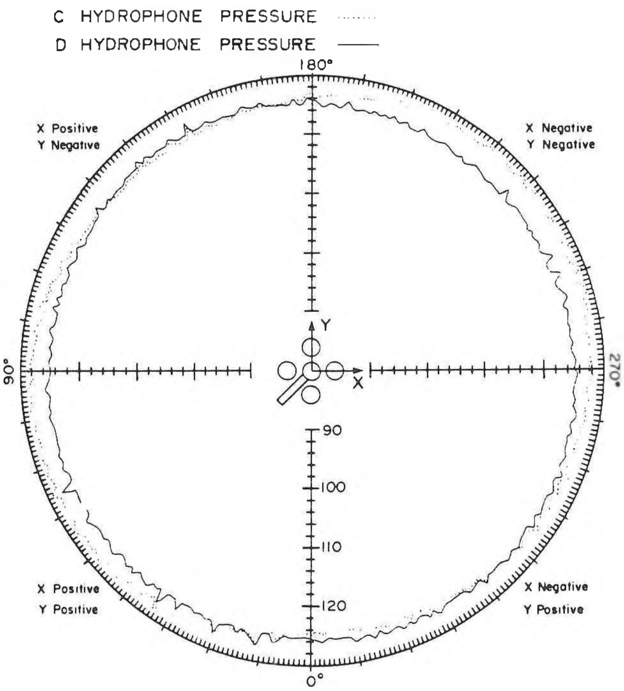
After locating a minima at 80° (Figure 5), the array was rotated counterclockwise 60° from the initial position. The test began here as the array was rotated a further 36° with measurements taken at every 0.1° increments. This test was performed to observe the detail of the array response about the null point. Figure 9 was generated with the source set to produce a 250 ms pulse at 8 kHz with a level of 12 mV. The noise in the curves is interesting and could be related to the physical interference of the hydrophone elements with the passing sound wave. This interference phenomenon is consistent on both X and Y components. It is important to note the symmetry about the null point of the Y component. It is only evident when rotations of 0.1 degree are implemented indicating that we are observing "resonant like" internal reflection effects within the array. The coarser 1° sampling smooths over this fine structure of the array response. Further investigation of this phenomenon is warranted.

The Z pair of hydrophones was then connected to the second analyzer to allow the measurement of the Y and Z components of intensity. The source was set to produce a 250 ms, 8 kHz pulse at 15 mV. A plot was generated for the 6.3 kHz pulse at 15 mV (Figure 10).

In this figure the Z direction plot is low and an almost perfect circle is expected since the Z components should be constant and at a minimum. The fact that the curve is not exactly at a minimum is a result of the source and acoustic center of the array being at slightly different depths. Slight imperfections in the circle are due to the array not hanging exactly vertically in the tank. The skewed circle is therefore produced. The supporting bracket was visually set and plumbed and slight errors in the alignment were noted. The plot is, however, close to the expected behavioural shape.


HYDROPHONE ARRAY DIRECTIONALITY MEASUREMENTS
X COMPONENT
Y COMPONENT
180°
X Positive
Y Negative
X Negative
Y Negative
90°
270°
Y
X
90
100
110
120
X Positive
Y Positive
X Negative
Y Positive
0°
PLOTTED FREQUENCY : 8000 Hz
SOURCE FREQUENCY : 8000 Hz
MOVEMENT INCREMENTS : 1 DEG.
FIGURE 5

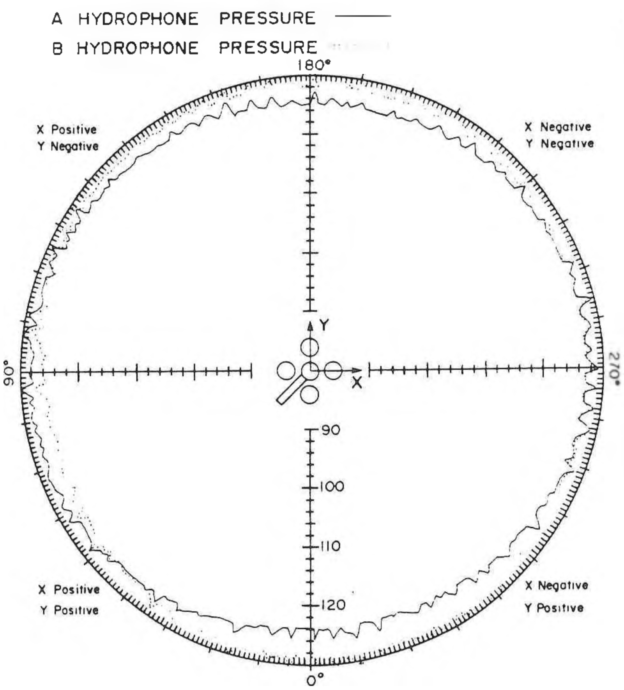
HYDROPHONE ARRAY DIRECTIONALITY MEASUREMENTS



PLOTTED FREQUENCY : 8000 Hz
SOURCE FREQUENCY : 8000 Hz
MOVEMENT INCREMENTS : 1.0 DEG.

FIGURE 6a

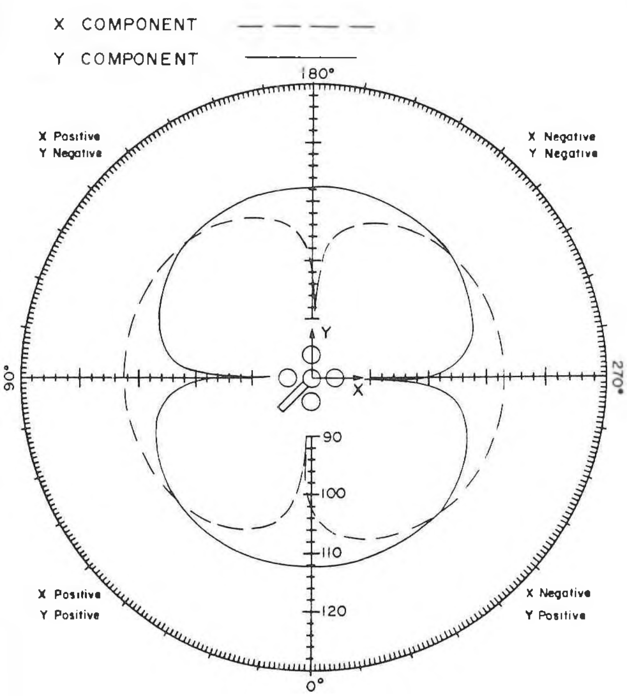
HYDROPHONE ARRAY DIRECTIONALITY MEASUREMENTS



PLOTTED FREQUENCY : 8000 Hz
SOURCE FREQUENCY : 8000 Hz
MOVEMENT INCREMENTS : 1.0 DEG.

FIGURE 6b

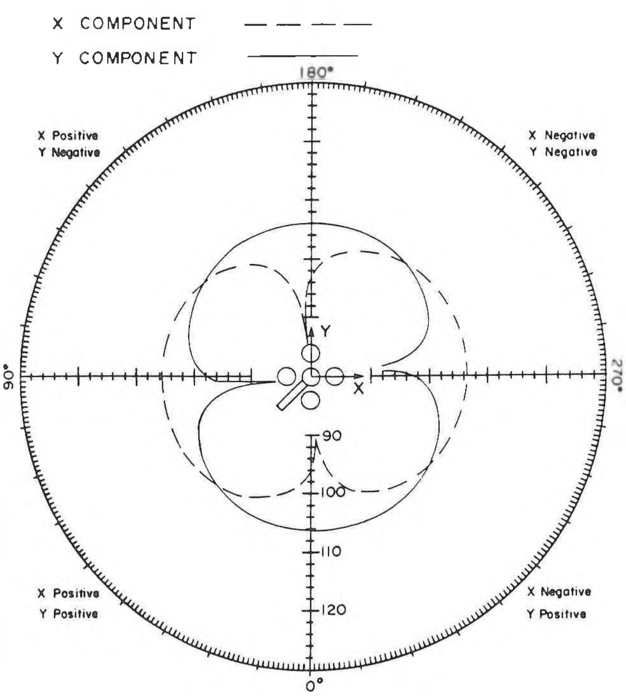
HYDROPHONE ARRAY DIRECTIONALITY MEASUREMENTS



PLOTTED FREQUENCY : 4000 Hz
SOURCE FREQUENCY : 4000 Hz
MOVEMENT INCREMENTS : 1 DEG.

FIGURE 7

HYDROPHONE ARRAY DIRECTIONALITY MEASUREMENTS



PLOTTED FREQUENCY : 1000 Hz
SOURCE FREQUENCY : 1000 Hz
MOVEMENT INCREMENTS : 1 DEG.

FIGURE 8

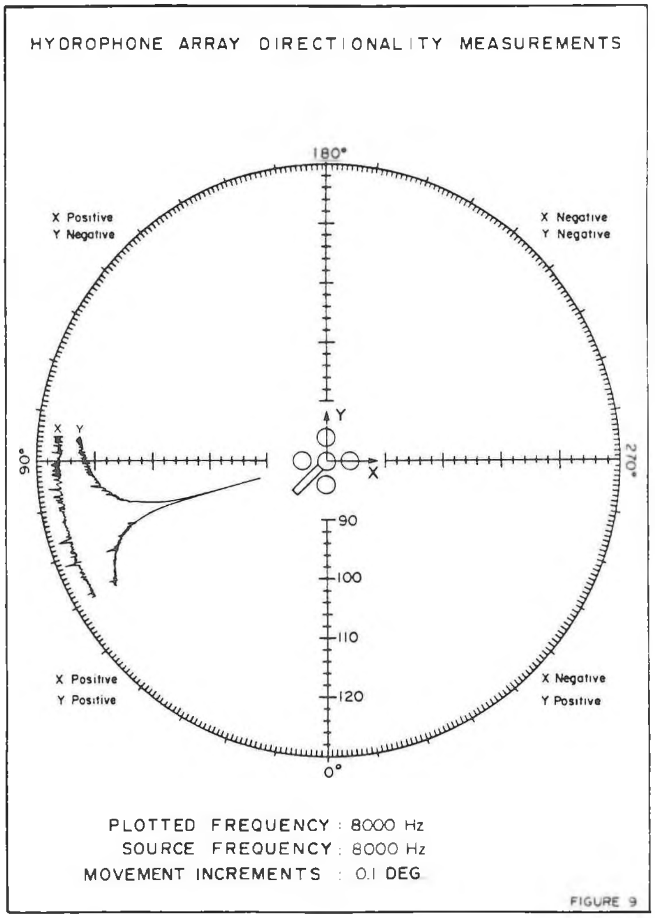


FIGURE 9

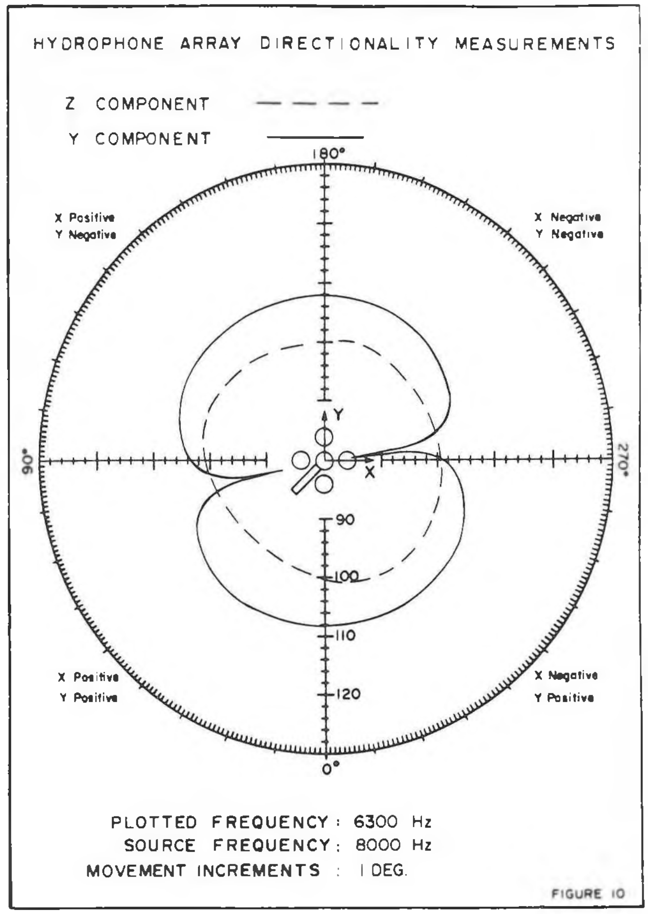


FIGURE 10

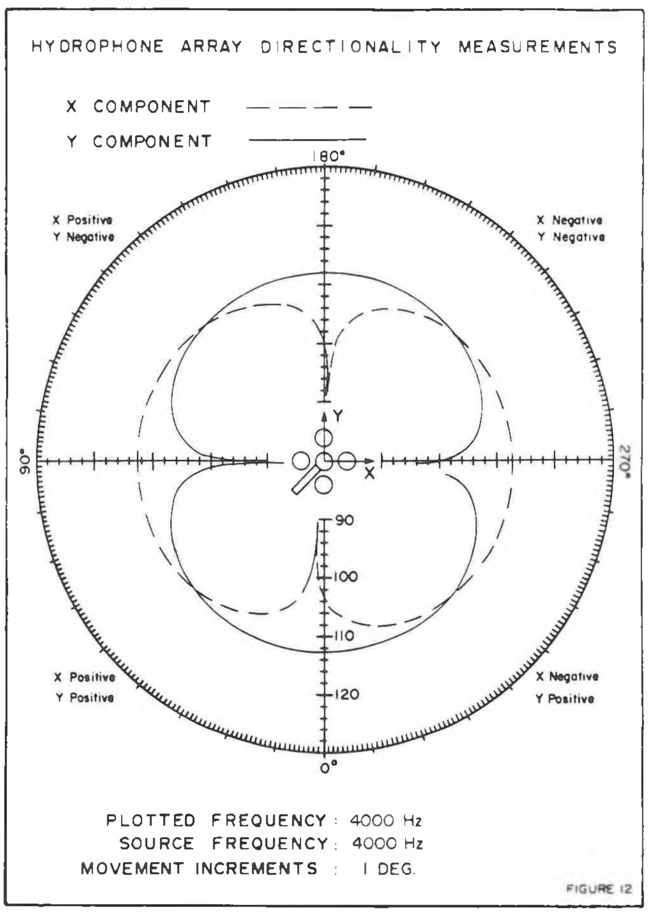


FIGURE 12

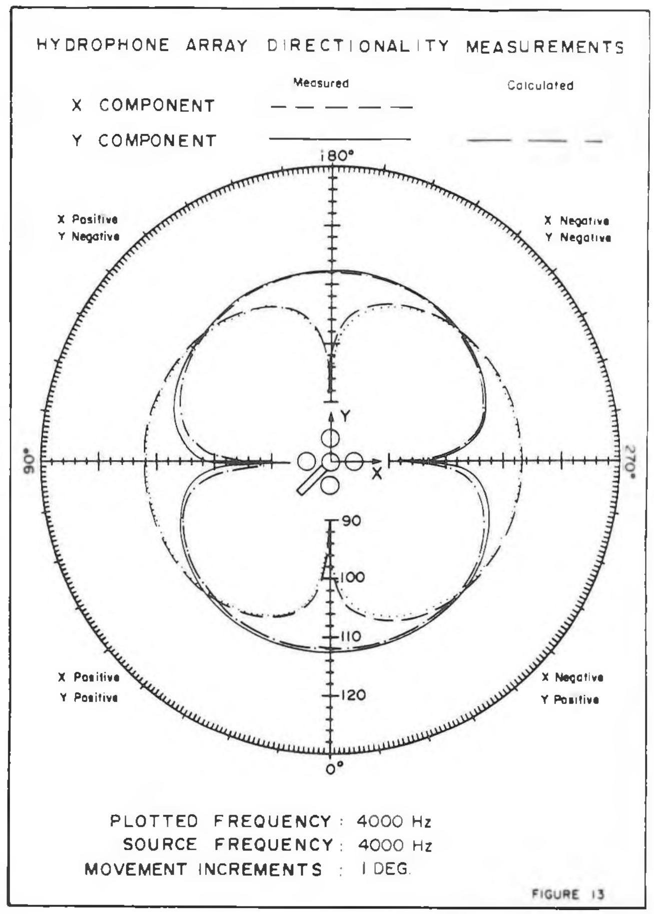


FIGURE 13

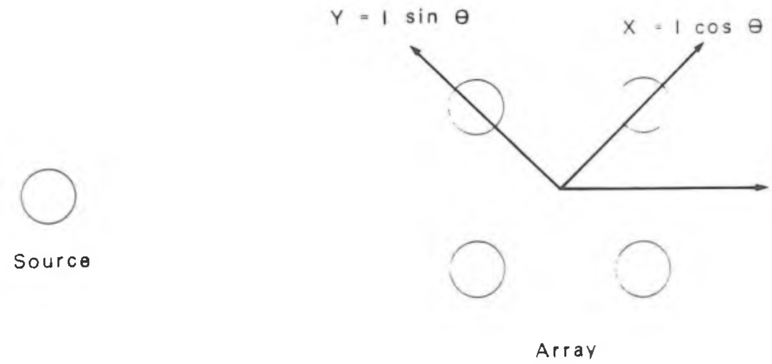


FIGURE 11 Intensity vector components

NORDCO Robotic ASI
3-D Sound Intensity Hydrophone Array
(Preliminary Design Nov. 1987)

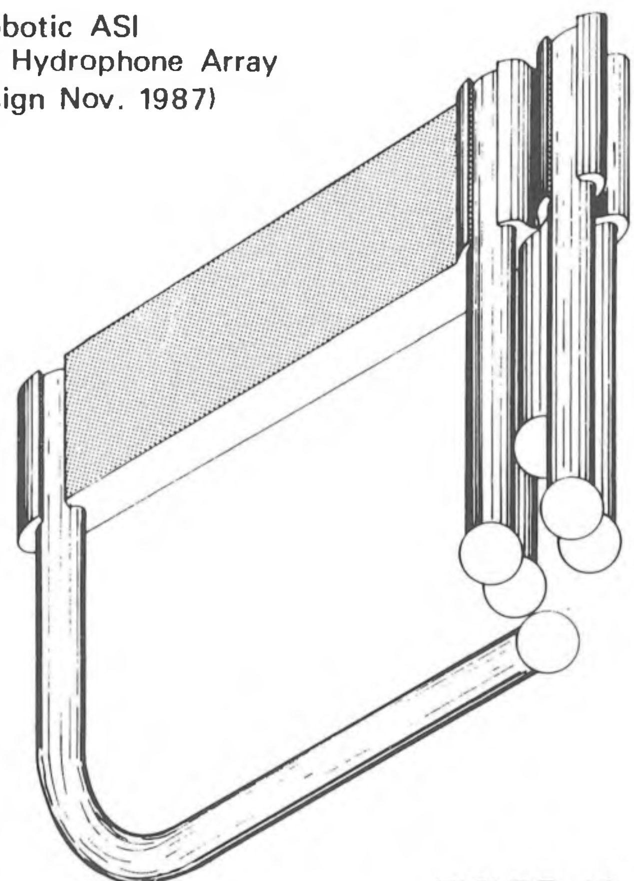


FIGURE 14

Theoretical curves were computed for the X-Y tests at 4 kHz for comparison to the corresponding experimental curves. An example of the measured 4 kHz plot is shown in Figure 12 whilst Figure 13 illustrates the same data against theoretical curves. The calculations used the following relationships:

$$X = I \cos \theta$$
$$Y = I \sin \theta$$

where θ is the rotation of the array from the initial position (see Figure 11) and I is the maximum intensity value measured which represents the magnitude of the source intensity vector.

5. CONCLUSION

The NORDCO underwater 3-D vector intensity array has a directionality response that closely matches the ideal, theoretical response. This provides confidence that the array is performing correctly allowing true sound intensity data to be acquired underwater. It should be noted that the data was acquired in a reverberant sound field. Clearly, the ability of the sound intensity method to accurately measure the source amplitude and direction in this type of field demonstrates its superiority over conventional pressure receivers.

The advantages of the vector intensity approach are in its signal-to-noise ratio, 1° directivity at low frequencies (e.g. 1 kHz), incoherent noise suppression, and sound intensity mapping of dominant energy paths. Future work will be on beamforming with this intensity array. Simple algorithms can be applied using the approach to identify sound patterns in the water such as for automatic event detection and for spatial, temporal and spectral signal decomposition.

APPENDIX

The technique of directly measuring the vector component of sound intensity along the axis of two closely spaced receivers requires careful phase matching of the receiver pair. The spacing between the receivers is optimized for the desired measurement frequency range. The directionality plots of the individual receiver elements is also an important consideration. Each element should ideally be omnidirectional.

The measurement technique relies on the pressure difference between the two receivers to provide an estimate of the pressure gradient at center of the array.

$$\nabla p \approx \frac{p_1 - p_2}{\Delta r}$$

where Δr is the spacing between receiver 1 and 2.

Integrating the pressure gradient over time gives an estimate of the particle velocity provided that there is zero mean flow of the fluid through which the sound wave is propagating. The derivation of this is from Euler's equation for fluid momentum.

$$\rho \frac{\partial v_r}{\partial t} + \frac{\partial p}{\partial r} = 0$$

where ρ is the fluid mass density. Therefore

$$v_r \approx \frac{1}{\rho \Delta r} \int_0^t (p_1 - p_2)\, dt$$

Since the component of the vector intensity along the receiver pair axis, I_r, can be given by the time average of the product of the acoustic pressure and the particle velocity at a point,

$$I_r = \langle p(t).v_r(t) \rangle$$
$$= \langle \frac{p_1 + p_2}{2} \cdot \frac{1}{\rho \Delta r} \int_0^t (p_1 - p_2)\, dt \rangle$$

The importance of phase matching the array is thus obvious.

To measure the three components of the sound intensity vector at a point it is necessary to orient three pairs of receivers along the three orthogonal axes, X, Y and Z so that the center point of each pair is coincident.

Since the original tests were performed in 1988 with the Bruel & Kjaer sound intensity analyzers, electronic receiver boards and controllers have been developed at NORDCO Limited to permit the measurement of sound intensity in the underwater environment using the FFT method.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the support of Mr. Gareth Williams in the data collection and Mr. Gunnar Rasmussen of Bruel & Kjaer Ltd. for his advice.

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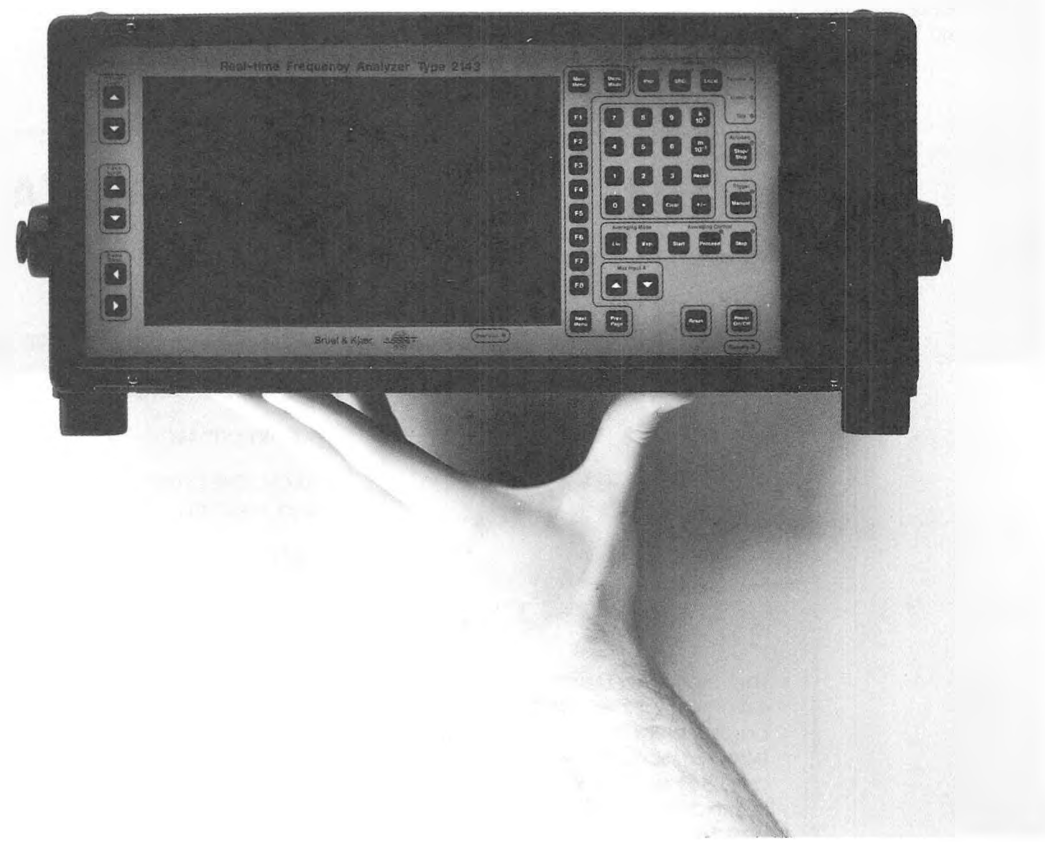

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THE EFFECT OF MARKER PARAMETERS ON GAP DISCRIMINATION

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Hearing Research Laboratory
Samuel Lunenfeld Research Institute
Mount Sinai Hospital
Toronto, Ontario, Canada

ABSTRACT

A preliminary investigation was conducted of the effects on gap discrimination of variation in marker rise/decay, in combination with other marker parameters. Three well-practiced normal-hearing listeners participated. In each, the just noticeable increment (Δt) was measured for silent gaps of 10, 20 and 100 ms, within the context of sixteen different marker conditions. These reflected variations in bandwidth (octave and 1/3 octave), centre frequency (500 and 4000 Hz), intensity (75 and 85 dB SPL) and rise/decay time (5, 25 and 50 ms). The results showed that Δt increased significantly with an increase in rise/decay time. Marker intensity and bandwidth had no effect. Discrimination improved with an increase in marker frequency only for the longest gap, given the shortest rise/decay.

SOMMAIRE

Nous présentons les résultats d'une étude préliminaire qui a pour but d'étudier l'effet du temps de montée/descente et d'autres paramètres sur l'habileté du système auditif à détecter une variation de la durée d'un silence compris à l'intérieur d'un signal-marqueur. Trois sujets bien entraînés et possédant une audition normale ont participé à l'étude. Nous avons mesuré pour chacun des sujets la plus petite variation de durée détectée (Δt) pour des silences de 10, 20 et 100 ms en fonction de seize paramètres caractérisant le signal-marqueur. Ces paramètres étaient: la largeur de la bande passante (octave et tiers d'octave), la fréquence centrale (500 et 4000 Hz), l'intensité (75 et 85 dB SPL) et le temps de montée/descente (5, 25 et 50 ms). Nos résultats démontrent que Δt augmente de façon significative avec le temps de montée/descente. Par contre, l'intensité et la largeur de bande n'affectent pas les résultats. Δt décrôit si la fréquence centrale du signal-marqueur augmente, mais seulement dans le cas du silence le plus long et du temps de montée/descente le plus court.

1. INTRODUCTION

Auditory temporal acuity is generally assessed in one of two ways, by measuring either the just noticeable difference in the duration of a tone or noise burst or the just noticeable difference in a silent gap bounded by a pair of markers (Abel, 1972a, 1972b). Investigators who used these methods in the 1960s and early 1970s thought the latter method might provide a way of studying the perception of time unconfounded by perceived changes in loudness and pitch that might provide a cue to a change in duration (e.g., Garner, 1947). Experiments demonstrated, however, that the characteristics of the markers in the latter paradigm do affect the perception of the gap (e.g., Plomp, 1964; Penner, 1977).

In an experiment designed to investigate the effect of marker duration and intensity, Abel (1972b) measured just noticeable differences (Δt) for standard gaps ranging from 0.63 to 640 ms. Three different Gaussian noise burst markers were compared, two with the same energy (10 ms/85 dB SPL and 300 ms/70 dB SPL) and a third with the same duration as the first and the same intensity as the second (10 ms/70 dB SPL). The results indicated that Δt was shortest for the marker with the highest intensity. Neither marker energy nor marker duration were significant determinants of performance. Subsequent studies have shown that intensity will only be an important parameter, when markers are not clearly audible (Florentine and Buus, 1982; Fitzgibbons, 1984). The effect of marker duration is somewhat controversial. Penner (1977) found that temporal acuity decreased as the marker preceding the gap increased from 2 to 200 ms. Forrest and Green (1987) found no change for markers ranging between 5 and 400 ms. The discrepancy in outcome may have been due to procedural differences.

Temporal acuity has also been shown to improve with increases in marker frequency in the range below 5000 Hz (Fitzgibbons and Wightman, 1982; Fitzgibbons 1984). The effect of marker bandwidth interacts with frequency. Shailer and Moore (1983; 1985) found that the minimum detectable gap decreased with an increase in marker bandwidth. This was particularly evident for a low-frequency marker of 400 Hz. For higher frequencies the effect was negligible for bandwidths greater than 0.25 times the centre frequency.

The present experiment was undertaken to investigate the interaction of four marker parameters on the just noticeable increment in a silent gap: frequency, bandwidth, intensity and rise decay time. The effect of systematic variation in the rise decay time (RD) of the marker has not been studied previously. Generally, in such studies, the marker RD is relatively short. This has necessitated the use of background masking noise to overcome possible spectral cues due to the onset and termination of the marker (e.g., Shailer and Moore, 1985).

2. EXPERIMENTAL DESIGN

Each subject served as his/her own control. Gap discrimination, the ability to differentiate between two silent gaps of different duration, was measured for sixteen marker conditions. These were generated by choosing from two levels of noise bandwidth (octave or one-third octave) and two levels of centre frequency (500 Hz and 4000 Hz). Noise bands were used in preference to pure tones in order to minimize possible spectral cues from variation in RD. Within each of the four bandwidth by centre frequency conditions, the effect of four intensity by RD combinations shown in Table 1 were explored. For combinations 1 and 2, the energy of the marker was the same. It was predicted that if marker energy was the critical determinant of performance, then a longer RD (50 ms) and duration of peak amplitude (200 ms) would compensate for a decrease in stimulus intensity (75 dB SPL). Combination 4 allowed us to study the effect of reducing intensity alone for the short marker. A comparison of combinations 2, 3 and 4 allowed an evaluation of variation in RD with marker intensity held constant. Based on previous research, it was assumed that the duration of peak amplitude would not affect gap discrimination. For each marker bandwidth by frequency by intensity/RD combination, the just noticeable increment in temporal gap was measured for three standard gaps of 10, 20 and 100 ms.

Table 1: Marker Intensity and Rise Decay Combinations

Combination	Intensity (dB SPL)	RD (ms)	Peak (ms)	Total Duration (ms)
1	85	5	20	30
2	75	50	200	300
3	75	25	200	250
4	75	5	20	30

3. METHOD

3.1 Subjects

The subjects were three university undergraduates, who had some previous experience as listeners in psychoacoustic experiments. All were under the age of 25 years and had normal hearing.

3.2 Apparatus

The experiment was conducted in a sound proof booth. The stimulus marker was generated using a noise generator (Bruel & Kjaer Type 1405) and band pass filter (Bruel & Kjaer Type 1617). A Coulbourn Instruments modular system allowed for fine adjustment of stimulus level, duration and envelope shaping. The output of the modular system was fed to a manual range attenuator (Hewlett Packard 350D) and integrated stereo amplifier (Rotel RA-1412) for binaural presentation over a matched headset (Telephonics TDH 49P). All devices were controlled by means of a personal computer (AST Premium 286) via IEEE-488 Labline and digital I/O lines. Subjects responded using a handheld response box.

3.3 Procedure

The just noticeable increment (Δt) in temporal gap was measured using a two-interval forced-choice procedure. On each trial, a sequence of two listening intervals was presented. These were cued by successive flashes of light-emitting diodes on the response box. The standard gap (t ms), bounded by a pair of identical markers, was presented in one of the two intervals, randomly determined from trial to trial. The comparison gap ($t + \Delta t$ ms), bounded by the same markers, was presented in the other interval. The duration of the light flashes was the same as the longer of the two periods of auditory stimulation. The time between the flashes was 300 ms. A typical sequence is shown in Figure 1. The subject's task was to choose the listening interval in which the longer of the two gaps had been presented by pressing the corresponding push-button on the response box. No feedback was given about the correctness of judgements.

Within a block of 24 trials, the marker condition, standard gap, and comparison gap remained the same. Across blocks, only the comparison gap was varied, so as to generate a psychometric function with P(C) ranging from 0.60 to 0.90 for the particular marker condition and standard gap chosen. A straight line fit to the data points by eye allowed an interpolation of the just noticeable increment, that value of Δt which generated $P(C)=0.75$. A mimimum of two values of P(C) were required, at least one between 0.55 and 0.75 and at least one between 0.75 and 0.90. In practice, four to five blocks were usually presented.

The order of presentation of the sixteen marker conditions was randomized independently for each subject according to the following scheme. The order of the two bandwidths was randomized within each frequency. The intensity by rise decay time combination was randomized within bandwidth. The order of the three standard gaps was then randomized within the marker intensity by rise decay combination. This scheme was adopted to maximize the subject's familiarity with the various marker combinations, so that cues, if present, could be fully utilized.

A concern in conducting the study was that practice might affect temporal acuity. Based on evidence for learning, the experiment was repeated three times in two of the subjects and four times in the third subject. For each subject the final two replications gave fairly similar just noticeable differences in each marker condition and were averaged for the final statistical analyses.

4. RESULTS

The mean values of Δt based on the data for three subjects are shown for each marker by standard gap condition in Table 2 and Figure 2. The relatively large standard deviations were due to one subject, whose values were two to three times greater than those for the other subjects. In spite of this difference in absolute value, the trends were quite similar for all three individuals.

The data were analyzed using two within-subject ANOVAs. In the first analysis, only those data obtained for a marker level of 75 dB SPL were included. The effect of three marker parameters (bandwidth, frequency and rise decay) and standard gap were assessed. The results indicated that the standard gap was significant at the 0.05 level ($F=10.41$, $df=2,4$) and marker RD was significant at the 0.01 level ($F=24.88$, $df=2,4$). The left panel of Figure 3 shows these outcomes. The mean Δt for three subjects is plotted as a function of the standard gap for combinations of RD and frequency. The results have been averaged across levels of marker bandwidth. The functions indicate that the value of Δt increases with an increase in the standard gap. For each standard gap, Δt increases as the RD increases.

The significance of the rise decay time of the marker precluded an ANOVA to compare the equal energy marker combinations 1 and 2. A significant difference in Δt might be due to either the intensity or RD of the marker. However, a second ANOVA was carried out to investigate the significance of marker intensity. The analysis included the data obtained for intensity by rise decay time combinations 1 and 4 for all levels of marker frequency, marker bandwidth and standard gap. The results indicated that the standard gap and the interaction of standard gap by marker frequency were significant at 0.01 level ($F=19.74$, $df=2,4$ and $F=24.80$, $df=2,4$ respectively). Marker intensity and bandwidth were not significant factors. Figure 3 (right panel) shows the mean Δt for three subjects, as function of the standard gap for each level of marker frequency, collapsed across marker bandwidth and marker intensity by rise decay combination. The effect of marker frequency is evident only for the longest of three standard gaps, i.e., 100 ms. The higher the frequency, the lower the value of Δt.

In spite of previous findings to the contrary, a concern in carrying out the first ANOVA was that the variation in rise decay time was confounded with the change in the duration of the marker. Judgments could be based on the duration of the standard gap alone, the standard gap plus the rise decay time of the marker or the standard gap plus the duration of the marker. In order to discern which of these was the critical standard duration, Weber ratios ($\Delta t/t$) were computed for the three possible options. In the first case (G), the standard gap was measured from the end of the decay of the first marker to the beginning of onset of the second marker (see Figure 1). In the second case (RG), the standard was computed as the sum of the standard gap plus half the fall of the first marker plus half the rise of the second marker. In the third case (BG), the standard was taken as the sum of the standard gap plus the peak duration and fall of the first marker.

Table 3 shows the Weber ratios ($\Delta t/t$), computed using G, RG, and BG respectively for t. The numbers tabulated are means, based on the results for the three subjects. Comparing these data with the results obtained by Abel (1972b) for standards gaps ranging from 0.63 to 640, it appears that Weber ratios calculated using G are two large and those obtained using BG are too small. The RG (rise decay time plus the standard gap) method seems to provide the best match.

5. DISCUSSION

This experiment was carried out to determine the effect of variation in a number of marker parameters on the acuity for a change in the duration of a silent gap. The parameters included centre frequency, bandwidth, intensity and rise decay time. A weakness of this design was that changes in the duration of the marker were confounded with the variation in rise decay time. One possible method of avoiding this problem is the randomization of duration of the markers (Formsby and Forrest, 1991). Allowing covariation permitted the opportunity to study the effect of marker duration in combination with RD.

The results indicated that the centre frequency of the noise band marker had a significant effect on the perception of the gap but only when the rise decay time was relatively short (5 ms) and the standard gap, relatively long (100 ms). The effect of increasing the centre frequency from 500 Hz to 4000 Hz was a decrease in the just noticeable increment (Δt). This outcome was only statistically significant in the second ANOVA, likely because the number of conditions were restricted, and thus the overall variance limited. The same trend was however evident in the data for the first ANOVA (see the left panel of Figure 3).

Shailer and Moore (1985) argue that the peripheral auditory system can be modelled as an array of band pass filters. The bandwidth of the filter increases with the centre frequency of the stimulus. Since "ringing" of the hypothetical filter with cessation of the stimulus varies inversely with bandwidth, these authors predict that temporal resolution will improve as the frequency of the marker increases. In the present study, this effect was apparent only at the longest of the three standard gaps, possibly because for the shorter gaps, the range in Δt was relatively small.

A change in the bandwidth of the marker from one-third octave to one octave did not affect temporal acuity, confirming the conclusion of Fitzgibbons (1983). It may also be the bandwidths chosen for this study were outside the effective range (Shailer and Moore, 1985). The level of the marker also did not provide a critical cue. As suggested previously, marker intensity is unlikely to have an effect, so long as the marker is clearly audible.

The effect of systematic variation in the rise decay of the marker on the perception of the gap had not been previously explored. This experiment represented a preliminary investigation of the effect. The results of the first ANOVA indicated that the value of Δt increased as rise decay time increased from 5 ms to 50 ms. A comparison of Weber ratios computed using either the standard gap alone or the standard gap corrected for either the rise decay time or the duration of the first marker, suggested that the rise decay time has its effect by increasing the effective duration of the standard gap. It appeared highly unlikely that the total duration of the marker had an important role in the judgment of silent gaps, confirming previous studies by Abel (1972b) and Forrest and Green (1987).

ACKNOWLEDGEMENTS

This research was supported in part by a National Health Research Scholar Award from Health and Welfare Canada (SMA), and in part by a Summer Studentship awarded through the Institute of Medical Science by the Health Science Committee, University of Toronto (MBC).

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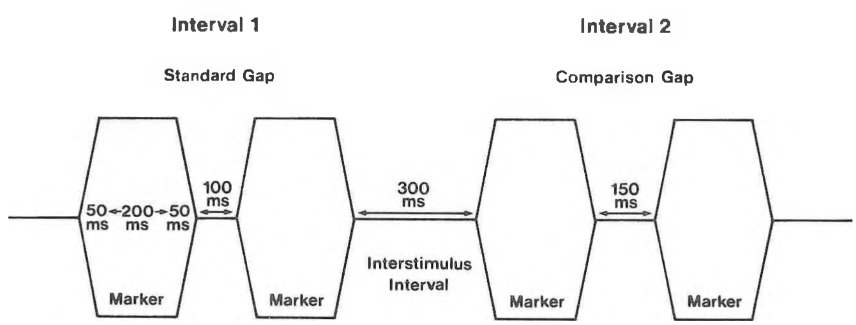

Fig. 1 A typical sequence presented during a two-interval forced-choice trial.

Table 2. Gap discrimination as a function of marker parameters.

Freq. (Hz)	Band-width	Ampl. dB SPL	RD/Pk (ms)	Standard Gap (ms) 10	20	100
500	1/3	85	5/20	6.3± 3.1⁺	11.2± 6.9	31.5±14.5
		75	50/200	32.3±12.5	34.7±16.6	51.6±10.3
		75	25/200	22.6± 8.1	32.6± 9.0	51.9±27.2
		75	5/20	11.0± 8.3	11.7± 8.7	45.4±28.0
	1/1	85	5/20	10.0± 7.3	13.7± 6.8	27.8± 8.3
		75	50/200	29.0± 5.5	36.1±17.7	48.2±20.9
		75	25/200	24.7±11.2	32.8±19.4	47.4±23.3
		75	5/20	10.7± 7.5	18.2±15.5	34.3±10.5
4000	1/3	85	5/20	13.5±10.7	14.4±10.1	31.9±15.2
		75	50/200	27.8± 9.3	22.9± 2.2	49.0±24.2
		75	25/200	26.1±14.2	25.2± 8.1	41.4±28.3
		75	5/20	12.8± 7.2	11.2± 8.4	26.0±15.8
	1/1	85	5/20	13.5± 8.7	13.0±10.9	24.0±14.2
		75	50/200	28.3± 3.8	28.0± 9.7	37.3±19.1
		75	25/200	31.8±16.6	21.1± 9.4	41.1±23.5
		75	5/20	13.8± 9.5	14.7±12.3	23.4±13.1

⁺mean Δt for 3 Ss

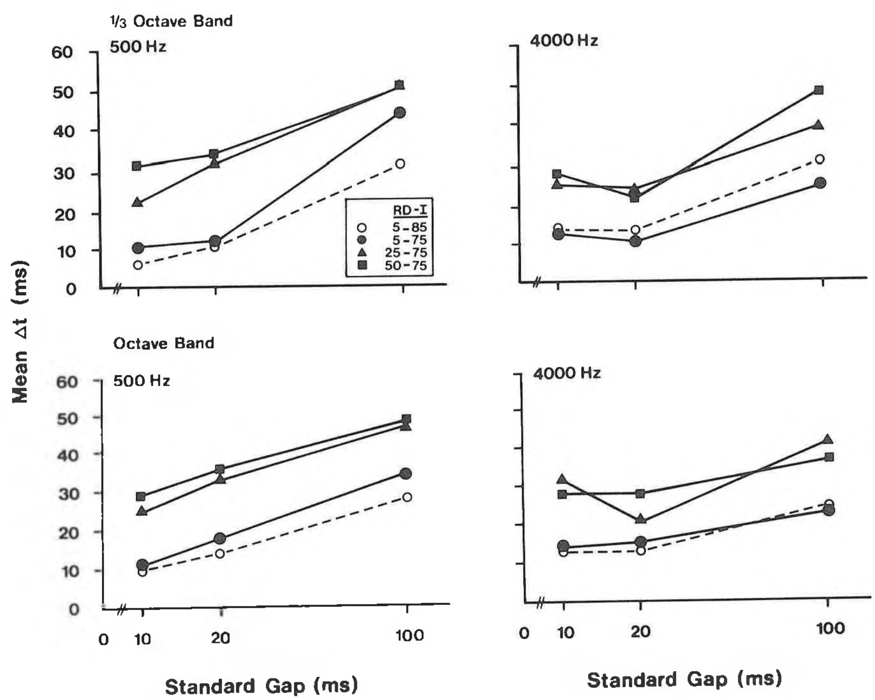

Fig. 2 The just noticeable increment in gap as a function of the duration of the standard gap. The parameters are marker bandwidth, centre frequency, intensity and rise decay time.

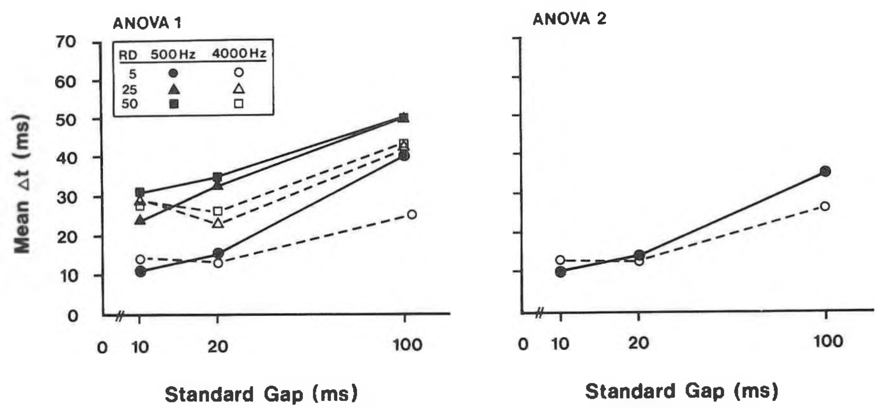

Fig. 3. The significant outcomes for two analyses of variance.

Table 3. Weber ratios calculated using the standard gap (G), rise decay plus gap (RG) and burst plus gap (BG).

			Calculation Method					
Gap (ms)	Freq. (Hz)	RD (ms)	G (ms)	Δt/G	RG (ms)	Δt/RG	BG (ms)	Δt/BG
10	500	5	10	1.09	15	0.73	35	0.31
		25	10	2.37	35	0.67	235	0.10
		50	10	3.07	60	0.51	260	0.12
	4000	5	10	1.33	15	0.89	35	0.38
		25	10	2.90	35	0.83	235	0.12
		50	10	2.81	60	0.47	260	0.11
20	500	5	20	0.75	25	0.60	45	0.33
		25	20	1.64	45	0.72	245	0.13
		50	20	1.77	70	0.51	270	0.13
	4000	5	20	0.65	25	0.52	45	0.29
		25	20	1.16	45	0.51	245	0.10
		50	20	1.28	70	0.36	270	0.09
100	500	5	100	0.40	105	0.38	125	0.32
		25	100	0.50	125	0.40	325	0.15
		50	100	0.50	150	0.33	350	0.14
	4000	5	100	0.25	105	0.23	125	0.20
		25	100	0.41	125	0.33	325	0.13
		50	100	0.43	150	0.29	350	0.12

SOUND ANALYSIS AND NOISE CONTROL

by John E.K. Foreman

Every time I teach a course on acoustics, vibration and noise control to undergraduate engineers I am faced with the considerable problem of choosing a suitable reference text. There are many potential candidates available. However, none seem to cover the right topics in the right order, to have the right balance between theory and application and to give a Canadian perspective regarding regulations etc. Thus, when I saw that a Canadian acoustician had written a book entitled "Sound Analysis and Noise Control", I naturally wondered if I had finally found the 'perfect' text.

This book deals with both acoustics and vibration. Its stated objectives are "to provide engineers with the basic science background they need to understand the behaviour of sound...[and to]...bring them up to date on the latest advances in technology for measuring noise and controlling it". A further objective is to put particular emphasis on measurement instrumentation, especially for sound intensity. The book claims to be the "only book on the subject that bridges the gap between theory and practice". Given the many books that have the same objective, this is a very bold claim, and one that is completely unjustified.

Regarding my search for the perfect text, an initial look through the book's table of contents made me very hopeful, with reservations. It covers all of the topics that an engineer must study, including several that are often ignored - sound waves and fields, the auditory system and hearing loss, instrumentation, vibration, criteria and regulations, noise control. It describes many case studies. The chapters are well organized, though some subsections have been located in strange places. There are many figures and illustrations. Each chapter is followed by a list of the references cited. The balance between theory and application is good. The book is very comprehensive in that it contains worked problems, case studies, details of legislation and appendices providing a wealth of information. However, many of the figures and tables look very familiar. In fact, a tremendous amount of material, including one 100-page section, has been taken from other sources. Disappointingly, the book invites confusion by mixing metric and English units. Further, some figures are of very poor quality, having simply been drawn by an unskilled hand.

Chapter 1 introduces the reader to fundamental acoustic quantities, the properties of plane waves, and to such basic concepts as the decibel and frequency spectra. A brief discussion of Fourier's theorem would have been useful here. The second chapter deals with the human hearing system, loudness perception and hearing loss. Fully demonstrating that this is a book for engineers, there is a subsection entitled "*Construction* of the Ear".

Chapter 3 is a comprehensive and welcome review, complete with photographs, of analogue and digital acoustical and vibration instrumentation. Discussed are microphones, sound level meters, vibration transducers, frequency analysers, level recorders, filters, tape recorders and FFT analysers. Sound-intensity measurement - theory, instrumentation and sound power determination and source localization with examples - is also discussed. Strangely - and possibly indicating that this book is not quite as up to date as it claims to be - Fahy's book on the subject is not mentioned.

The fourth chapter, entitled "Sound Fields", contains a general discussion of sound sources. Next, anechoic and reverberation rooms are discussed; would this not fit better in the previous chapter? Sound propagation in a free-field and in enclosures follows. The latter consists of a discussion of steady-state levels using diffuse-field theory. Once again, this is done as if diffuse-field theory works in every situation. There is no discussion of its assumptions or practical limitations, nor of more accurate and generally-applicable prediction methods. Outdoor sound propagation is described in a very qualitative manner. This includes a discussion of the performance of infinite-length barriers; finite-length barriers are ignored. Some details are given of practical outdoor sound propagation prediction models. Surprizingly, this chapter does not discuss sound propagation in pipes and ducts.

Chapter 5 deals with sound absorption and absorbers. Comprehensive absorption coefficient data is provided. Dissipative, reactive and, very briefly, active silencers are considered. Resonator and perforated-panel absorbers are discussed in the subsection on reactive silencers and not that on absorbers. Next follows a section on the behaviour of sound in rooms, discussing sound decay and reverberation; again only diffuse-field theory is used. And why is this material not with that discussing the steady state in Chapter 4? Finally, sound transmission between rooms is covered. For some reason Γ is used to express the sound transmission coefficient instead of the conventional τ. Sound transmission measurement is illustrated with a drawing of a strange scale-model facility; that of a standard full-size facility would be more educational.

Chapter 6 is dedicated to vibration. Discussed are single-degree-of-freedom theory, available anti-vibration mounts and their selection, vibration criteria and common vibration damping materials.

The seventh chapter treats noise criteria and regulations. Noise-rating variables and criteria related to environmental and indoor acoustical environments are discussed. Surprizingly, open-plan offices are discussed here. Also covered in some detail are the OSHA occupational-noise regulations. There is some discussion of similar Canadian regulations, but it is not up to date; in fact the chapter reveals that the time of writing is about 1986. Next, noise-control approaches and, far too briefly, hearing protectors are discussed. I would have discussed hearing protection in Chapter 2 or 8.

Chapter 8 deals with the principles of noise control and measurements to evaluate an acoustic environment (should this be here?). Remarkably, it also contains, in 100 pages, an exact reproduction of the English translation of the Swedish handbook, *Noise Control - Principles and Practice*, also published by Bruel and Kjaer.

Chapter 9 discusses how to determine which of the sources in a given region are dominant (this is referred to 'noise-source diagnosis'). Then a broad selection of noise- and vibration-control case studies is presented. The last section of the chapter reviews published acoustical and vibration textbooks, handbooks and manuals. Why this useful information was put here and not in an appendix is beyond me.

This is particularly surprizing since what follows is a number of appendices containing similar and equally-useful information. These include an acoustical-vibration glossary, a list of standards and standards organizations, and details of noise- and vibration-control suppliers and their products. One appendix gives the names and publishers of acoustical and vibration periodicals. Canadian readers will be disappointed to see that this includes the old address of the Canadian Acoustical Association which was changed in 1986, and the incorrect name of its periodical.

This is a very comprehensive book with much useful information, the correct 'engineering' balance and a few short-comings. It goes a long way to meeting its objectives. It is only up to date with respect to about 1986. Is it the 'perfect' text for my purposes? No, it isn't! I may use it in the short term, but I won't stop looking for a better one.

[This book (ISBN 0-442-31949-5) is available from Nelson Canada, 1120 Birchmount Rd., Scarborough, Ontario M1K 5G4 at a price of $69.95]

Reviewed by Murray Hodgson, National Research Council.

HANDBOOK OF ENVIRONMENTAL COMPLIANCE IN ONTARIO

by John-David Phyper and Brett Ibbotson

This book covers the whole range of environmental concerns in its 346 pages, and devotes only 12 pages to acoustics. Most of those 12 pages just list or describe the publications of the MOE (Ontario Ministry of Environment); the real message is given in one paragraph on the seventh page:

> "To be qualified to assess noise as it relates to land use planning, a certificate of competency in environmental acoustic technology should be obtained from the MOE. The MOE conducts certification courses and provides manuals based on the guidelines available from the Model Noise By-Laws and other documents."

Apparently no certificate of competency is required to write a textbook chapter on acoustics. The text includes bloopers suggesting minimal grasp of acoustics, such as, "the frequencies of sound in the environment can range over one million hertz" or, "If information on the wavelength is unavailable ...". The few bits of technical content are marred by silly mistakes, such as mangling the reference sound power (10^{-12} watts/m^2 is described as "10 to 12 watts/m^2"), and an incorrect example of the source directivity parameter Q accompanying the equation relating sound pressure to sound power. Unfortunately, this inadequate and offhand approach to environmental acoustics is probably indicative of our society's priorities.

If you want to learn about environmental noise control in Ontario, you would do much better with the MOE publications.

[This book (ISBN 0-07-551143-6) is available from McGraw-Hill Ryerson Ltd., 330 Progress Ave., Scarborough, Ontario M1P 2Z5 at a price of $49.95]

Reviewed by J.D. Quirt, National Research Council.

CANADIAN ACOUSTICAL ASSOCIATION

1991 Acoustics Week in Canada
Ramada Renaissance, Edmonton, Alberta

SEMINARS (October 7 - 8)

NOISE AND VIBRATION CONTROL IN BUILDINGS

This course will present basic and advanced criteria for noise and vibration control in buildings, particularly at the design stage. All noise sources will be discussed, including low frequency duct rumble, building vibration, and ground vibration. The lecturers include: **Charles Ebbing**, Carrier Corporation, **Doug Reynolds**, UNLV, representing the TRANE Company, **Don Allen**, Vibron Ltd., **Steve Wise**, Digisonix Corporation. Course Fee is $275.00.

RECENT ADVANCES IN ELECTROACOUSTIC MEASUREMENTS AND HARDWARE

This course is directed towards sound system designers, sound contractors, acoustical consultants, and architects with electroacoustic experience. Topics will include advances in the assessment of acoustic conditions within spaces, acoustic and electroacoustic measurement techniques and related hardware. The lecturers include: **W. J. Cavanaugh**, Cavanaugh Tocci Associates, **John Bradley**, National Research Council, **Larry Shank**, Techron Div., Crown International, **John Hemingway**, Bolstad Engineering Associates. Course Fee is $275.00.

ACTIVE SOUND CONTROL

A technical course on active sound control theory combined with recent advances and practical applications using active sound attenuation. Discussion will be on various free and enclosed sound fields, as well as active control within headsets, ducts, aircraft, and cars. The lecturers include: **Steven J. Elliott**, I.S.V.R., University of Southampton, and **Steve Wise**, Digisonix Corporation. Course Fee is $300.00.

DEADLINE FOR REGISTRATION FOR SEMINARS IS AUGUST 31, 1991

CONVENTION (October 9 - 10)

SYMPOSIUM

The program commences with special plenary sessions on each day. The guest speakers will be concert hall designer **Russell Johnson** of Artec Consultants, and **John O'Hala**, University of California, Berkley, who specializes in experimental phonetics and phonology. The plenary sessions will be followed by parallel sessions of technical papers on all aspects of acoustics. A listing of abstracts is contained elsewhere in this issue of Canadian Acoustics.

CAA ANNUAL GENERAL MEETING

The Annual General Meeting of the Canadian Acoustical Association will be held on Thursday afternoon, October 10, at the Hotel. All members are urged to attend. Guests are welcome.

BANQUET AND AWARDS PRESENTATION

A Thursday evening banquet for participants and their guests will conclude the weeks formal events and will include the presentation of awards for best student papers given during the symposium. Cost of the banquet is $35.00 per person.

CANADIAN ACOUSTICAL ASSOCIATION
1991 Acoustics Week in Canada
Ramada Renaissance, Edmonton, Alberta

COMPANION PROGRAMS

On Wednesday, Oct. 9, a conducted bus tour of some of Edmonton's featured visitor spots will take place during the morning, depositing the group for lunch and an afternoon of exploring the world famous shopping and entertainment complex known as the West Edmonton Mall. They will be returned to the Ramada in late afternoon in time to either enjoy dinner and a free evening or take advantage of the hosted reception at the University of Alberta Mechanical Engineering Acoustics and Noise Unit (MEANU).

On Thursday, Oct. 10, a short walking tour of the City Centre shopping area (all enclosed), including Manulife Place, Eaton Centre, and Edmonton Centre will bring you to Edmonton's professional theatre center, the Citadel Theatre. After a conducted visit to the theatre you will have lunch in the beautiful Wedgewood Room of the newly restored historic Macdonald Hotel. The afternoon will be free, giving time for shopping or resting until the evening banquet.

UNIVERSITY OF ALBERTA RECEPTION

The University of Alberta Mechanical Engineering Acoustics and Noise Unit will host a reception on Wednesday evening after the last technical sessions are over. Transportation will be provided, and you will be returned in time for a late evening dinner (not included). The laboratory is the only fully accredited test facility in Western Canada.

PRODUCT EXHIBITION

Distributors of goods and services, including instrumentation, will have a continuous display of their materials during the Convention just across the hall from the Symposium meeting rooms. Attendees will have ample opportunity to examine these displays during the day and evenings.

HOTEL INFORMATION / AIR TRANSPORTATION

All meeting activities will be held in the Ramada Renaisssance, 10155 - 105 St., Edmonton, Alta. T5J 1E2. A block of rooms has been reserved at reduced rates as follows: Regular, single or double occupancy - $73.00 per night; Renaissance Club Floor, single or double occupancy - $88.00 per night; Executive Suite, single or double occupancy - $125.00 per night. Federal and Provincial taxes extra. Reduced rate release date is September 6, 1991. Later reservations will be made on a space available basis. To reserve a room, complete and mail the registration card contained in the information package or call the Hotel at (403) 423-4811 or FAX (403) 423-3204.

Reduced air fares are available from Canadian Airlines International, who have been designated as the Official Conference Airline. To obtain air fare discounts, call toll-free 1-800-665-5554, Canada and USA, and quote Conference Registration Number 0621. Discounts are also available on Canadian Air Cargo for demonstration materials.

Ground transportation from the Edmonton International Airport to the Ramada Renaissance costs approximately $32.00 by taxi. Shuttle bus service is available at $9.00 per person, one way, $16.00 round trip, plus tax.

For a complete information package on the entire Acoustics Week in Canada program, write, phone or FAX to:

CAA 1991 CONVENTION COMMITTEE
c/o BOLSTAD ENGINEERING ASSOCIATES LTD.
9249 - 48 St. Edmonton, Alta. T6B 2R9
Tel. (403) 465-5317 FAX (403) 465-5318

CANADIAN ACOUSTICAL ASSOCIATION
1991 CONVENTION COMMITTEE
c/o Bolstad Engineering Associates Ltd.
9249 - 48 St. Edmonton, Alta. T6B 2R9
Tel. (403)465-5317 Fax (403)465-5318

ROCKY MOUNTAIN BUS TOUR

October 11 - 13, 1991

A three day, conducted bus tour is being planned for all those interested in sightseeing after the Convention. The places featured on this trip are Jasper, Yoho and Banff National Parks, the Icefield Parkway and the Athabasca Glacier, and the world famous Royal Tyrrell Museum of Palaeontology in Drumheller. Participants will have the option to end the tour in Calgary at noon on Sunday, October 13, or complete the journey back to Edmonton in the evening.

DAY 1 - JASPER NATIONAL PARK -

Your Canadian Rockies tour begins as you board your luxury **Red Arrow** motorcoach at the **Ramada Renaissance Hotel** and meet your fellow travellers. Your trip will take you through the rolling farmlands and majestic foothills of central Alberta along the Yellowhead Highway, with a lunch break in Hinton prior to arriving in Jasper Park. A short tour of Jasper, including Patricia and Pyramid Lakes, Maligne Canyon and Jasper Park Lodge will culminate with a breathtaking ride on the **Jasper Sky Tram** (weather permitting) to the top of Whistler Mountain. After an enjoyable view of the valley and townsite, you will be taken to the **Jasper Inn** for dinner and your overnight accommodation.

DAY 2 - THE ICEFIELD PARKWAY AND BANFF NATIONAL PARK -

Today you travel on the Icefield Parkway, with picture stops at Sunwapta and Athabasca Falls prior to arriving at the **Athabasca Glacier** of the Columbia Icefield. The **Snocoach** ride up the glacier may or may not be available, depending on weather. The tour continues to the Saskatchewan River Crossing for a lunch break and then on to further picture stops at **Peyto Lake, Bow** and **Crowfoot** glaciers, before arriving at the remarkable **Spiral Tunnel** in **Yoho National Park.** After a brief visit at the Spiral Tunnel you will continue to the "Jewel of the Rockies", **Lake Louise**, and then on to **Banff** and the **Travellers Inn** for the night. This evening, enjoy a walk along Banff Avenue to shop and browse the many quaint shops and tourist attractions.

DAY 3 - DRUMHELLER AND THE ROYAL TYRRELL MUSEUM -

This morning see the sights of Banff townsite, including Bow Falls, the Buffalo Paddock, and Lake Minnewanka, prior to departing for **Calgary** and the **Canada Olympic Park** which was the premier site of the 1988 Olympic Winter Games. For those wishing to leave the tour in Calgary, the bus will drop travellers off at the airport before 12:00 noon.
After lunch at the Park, depart for **Drumheller** and a guided tour of the world famous **Royal Tyrrell Museum of Palaeontology.** After leaving Drumheller, travel through the rich farmlands of central Alberta, making a stop for dinner along the way back to Edmonton.

TOUR COSTS -

Single Accommodation - $335.00 per person. Double (shared) Accommodation - $290.00 per person.
Cost includes: Bus fare, 2 nights hotel, dinner in Jasper, Jasper Sky Tram, Olympic Park fee, Tyrrell Museum fee, trip cancellation insurance, gratuities, Provincial Hotel Tax and GST.

A minimum number of prepaid registrations will be needed prior to the deadline of **August 31, 1991.** A deposit of **$150.00** per person is required, with full payment prior to boarding on October 11. Make checks or money orders, payable in Canadian funds, to **CAA 1991 CONVENTION**, and mail to the address shown above. A full refund will be made if the tour is cancelled by the organizing committee. Individuals forced to cancel for sickness or other causes beyond their control after August 31, will recover their costs through the cancellation insurance policy included in the tour package.

REGISTRATION FORM
(FORMULAIRE D'INSCRIPTION)
1991 Acoustics Week In Canada
Ramada Renaissance, Edmonton, Alberta

Surname (Nom): ______________________ FirstName (Prénom): ______________________

Representing (Représentant): ______________________

Address (Adresse): ______________________

____

____

Postal Code (Code Postal): ______________ Telephone: (______) ______________

Companion Name (Nom de Personnes qui accompagnent) ______________________

SEMINARS (SÉMINAIRES en anglais)
October 7 - 8 (octobre) 1991

		Amount (Montant)
NOISE AND VIBRATION CONTROL IN BUILDINGS	$275.00	$__________
RECENT ADVANCES IN ELECTROACOUSTIC MEASUREMENTS	$275.00	$__________
ACTIVE SOUND CONTROL	$300.00	$__________

SYMPOSIUM
October 9 - 10, 1991

REGISTRATION (INSCRIPTION)			
- before August 31 (avant le 31 aôut)		$ 75.00	$__________
- after August 31 (après le 31 aôut)		$ 85.00	$__________
STUDENT REGISTRATION (INSCRIPTION D'ETUDIANT)		$ 20.00	$__________
BANQUET TICKETS (Billets) __________	X	$ 35.00	$__________
COMPANION PROGRAM (Programme pour les Personnes qui accompagnent)		$ 15.00	$__________
		TOTAL	**$__________**

_____ YES, I would like to obtain more information on the Rocky Mountain Bus Tour October 11 - 13, 1991

_____ OUI, J'aimerais obtenir plus d'information au sujet de la tournée des Montagnes Rocheuses 11 - 13 octobre, 1991

PLEASE make cheques payable in Canadian funds to CAA 1991 CONVENTION and mail to
S.V.P. Faites vos chèques à l'ordre de CAA 1991 CONVENTION en fonds Canadiens et postez à

CANADIAN ACOUSTICAL ASSOCIATION
c/o BOLSTAD ENGINEERING ASSOCIATES LTD.
9249 - 48 STREET
EDMONTON, ALBERTA, CANADA, T6B 2R9

CANADIAN ACOUSTICAL ASSOCIATION

1991 Acoustics Week in Canada
Ramada Renaissance, Edmonton, Alberta

Following is a listing of the abstracts of papers received to date for presentation at the 1991 Convention:

SMALL ENCLOSURES - COMPUTATIONS

Comparison of Computational Methods for Rectangular Silencer Insertion Loss Prediction - *R. Ramakrishnan, B. Howe and M.Q. Wu*

Bagpipes - A Program for Analyzing Acoustic Transmission in Ductwork - *P. Fuchshuber and A. Craggs*

PC.Circle, Circular Duct Silencer Performance Prediction Software - *R. Ramakrishnan and N. Ball*

SMALL ENCLOSURES - MEASUREMENTS

Effect of Bulkhead Fixing on the Noise Inside the Airplane Cabin - *L. Cheng and J. Nicolas*

Optimum Positioning of Duct Silencers in Sound-Rated Construction - *M.Q. Wu, T. Paige and D.L. Allen*

Acoustic Pulsations in Reciprocating Machinery - *B.C. Howes, S.D. Greenfield, and C.K. Schuh*

Simulation of the Orifice Gauge Line Effect in Pulsating Flow - *W.M. Jungowski, G. Petela*

ARCHITECTURAL ACOUSTICS I

Reverberation Chamber Measurement of Theatre Chair Absorption - *J.S. Bradley*

Modern Acoustic Measurements on Canadian Stages - *J.P.M. O'Keefe and M. Bracken*

Practical Design Aspects for Canada's Newest Anechoic Chamber - *Dr. A. Lightstone*

Acoustic Strategy: Public Works Canada - *G.E. Clunis*

Predicting Airborne Sound Transmission Loss Performance of Floating Floors - *T. Paige*

ARCHITECTURAL ACOUSTICS II

A Comparison of Subjective Speech Intelligibility Tests in Reverberant Environments - *K. Kruger, K. Gough and P. Hill*

Sound System Gain and Intelligibility - *K. Bell*

Background Noise, Noise Isolation and Speech Privacy - *P. Moquin*

The Benefits of Field Testing the Acoustic Performance of Sound Isolation Rooms - *E. Rebke*

On the Slope(s) of the Sound Propagation Curves in Typical Factories - *M. Hodgson*

ACOUSTIC RADIATION

Numerical Methods for Solving Acoustic Radiation Problems - *L.J. Cremers and K.R. Fyfe*

Vibro-Acoustic Behaviour of a Plane Radiator in the Case of Impact Excitation - *D. Trentin and F. Laville*

Simulation of the Acoustic Radiation Emitted by Vibrating Structures - *J. Nicolas, A. Berry and L. Cheng*

ACOUSTIC SOURCES

Acoustic Augmentation of the Entrainment Coefficient of Axisymmetric Free Air Jets - *P.J. Vermeulen, P. Rainville and V. Ramesh*

Experiments on Active Power Minimisation - *M.E. Johnson and S.J. Elliott*

Electromagnetic Acoustic Noise and Vibrations of Electrical Machines; Their Production and Means of Reduction - *S.P. Verma and A. Balan*

Symphonic Bells of "Fantastic" Proportion - *D. Caswell*

VIBRATION AND NOISE CONTROL

Quality Control Using Energy Flow - *G. Rasmussen*

A Moving Load as a Dynamic Vibration Absorber - *A.W. Lipsett*

Subsynchronous Vibration of an Auxiliary Turbine - *B. Alavi and C. Hugh*

Development of Diesel Generator Isolation Systems for Low Noise and Vibration - *G.E. Clunis and S.J. Bradley*

Design Optimisation of High Speed Axially Loaded Ball Bearings of a Turbo-Pump - *B. Alavi*

Intensity Measurements on Structures - *G. Rasmussen*

Computed Order Tracking Applied to Vibration Analysis of Rotating Machinery - *E. Munck and K. Fyfe*

Rock-drill Handle Vibration: Measurement and Hazard Assessment - *S.E. Keith, A.J. Brammer*

ELECTROACOUSTICS

Progress on the Development of Standards for Sound Intensity Measurements - *G. Krishnappa*

Electroacoustical Research and Acoustical Calibrations at INMS - *G.S. Wong*

Calculations of RMS and Other Functions for Acoustic Signals Stored in Digital Format - *M. Roland-Mieszkowski and W. Young*

Digital Generation of the High Quality Periodic Audio Signals with the Aid of a D/A Converter and Computer - *M. Roland-Mieszkowski*

ENVIRONMENTAL NOISE CONCERNS

Aircraft Noise Assessment, Is NEF Adequate? - *W.G. Richarz*

An Update on ID 88-1, the Noise Regulation for the Energy Industry in Alberta - *C.D. DeGagne, R.G. Wright and H.O. Lillo*

A Method for the Comparison of Noise Exposure Levels of Workers in Different Workplaces - *A. Behar*

HEARING AND NOISE EXPOSURE

Assistive Listening Devices: How "Assistive" Are They? - *P. Dobbins and S. Douglas*

Signal Detection and Speech Perception with Level-Dependent Hearing Protectors - *S.M. Abel, N.M. Armstrong and C. Giguère*

Indicators of Hearing Impairment Among Noise-Exposed Workers - *R. Hétu and C. Brassard*

Digital Hearing Aids - The Way of the Future - *M. Roland-Mieszkowski and S.D. Clemens*

UNDERWATER ACOUSTICS

The Effect of Sediment Layering on Ocean Bottom Reflection Loss - *F. Desharnais*

Predicting Acoustic Radiation from Coupled Fluid/Structure Systems: A Comparison of Two Computer Codes - *L.E. Gilroy and D.P. Brennan*

Vibration and Sound Radiation of a Double-Plate System - *A. Berry, F. Laville, J. Nicolas and D. Stredulinsky*

Acoustic Backscattering from Cylinders: Near-Field Corrections - *D.M.F. Chapman and F.D. Cotaras*

SPEECH PRODUCTION

Influence of Vocal Intensity on Temporal Quotients Obtained from the Photoglottographic (PGG) Waveform - *S. Fraser and P.C. Doyle*

An Acoustical and Perceptual Study of Changes in Dysphonia with Voice Therapy - *K. Ward and A. Rochet*

Acoustical Analysis of Nasal Resonance Patterns in Speech - *A. Putnam Rochet and B.L. Rochet*

Developmental Aspects of Second Formant Trajectories - *M.M. Hodge*

The Role of Phonetic Context in the Articulation of Semivowels by Preschool Children - *E.B. Slawinski*

SPEECH PERCEPTION AND SPEECH SYNTHESIS

Computer Simulation of Lexical Tone Perception - *F. Chen and A.J. Rozsypal*

Effect of Consonant and Vowel Context on Mandarin Chinese VOT: Production and Perception - *B.L. Rochet and Y. Fei*

A Demisyllable-Based Text-to-Speech Synthesis System for English - *S.J. Eady, P. Ollek and J.R. Woolsey*

SPEECH PERCEPTION AND AUDITORY PROCESSING

Representation of Speech Signals in the Disordered Peripheral Auditory System - *D.G. Jamieson, M.F. Cheesman, S. Krol*

Distribution of Auditory Filter Bandwidths at 250, 500, 1000, 2000, 3000 and 4000 Hz Among Young Normal Listeners - *R. Hétu and H. Tran Quoc*

Discrimination of Static and Dynamic Frequency Changes in Children and Adults - *J.F. MacNeil and E.B. Slawinksi*

Acoustical Cues in /R-W/ Discrimination - *L.K. Fitzgerald and E.B. Slawinski*

SPEECH RECOGNITION

Automatic Speech Recognition Using Accurate and Robust Stochastic Models - *L. Deng*

Exploiting Pauses in Continuous Speech Recognition - *D. O'Shaughnessy*

A Non-Linear Analysis for Clean and Noisy Speech - *J. Rouat and Y.C. Liu*

SPEECH PROCESSING AND APPLIED SPEECH TECHNOLOGY

Canadian-Designed Software for Speech Analysis and Synthesis - *B.C. Dickson, A.G. Wynrib, R.C. Snell, S.J. Eady and J.A.W. Clayards*

An Imelda Based Voice Recognition System: A Step Towards Effective Voice Recognition for Persons with Severe Disabilities - *G.E. Birch, D.A. Zwierzynski, C. Lefebvre*

Factors Affecting Performance Evaluation of Automatic Speech Recognition Systems - An Overview - *S.M. Ulagaraj*

The Canadian Acoustical Association
l'Association Canadienne d'Acoustique

MOT DU PRESIDENT

Une autre édition, un autre mot. Comme d'habitude, je désire encourager les membres à prendre leur crayon et leur traitement de texte dans le but de s'exprimer. Un comité de l'ACA, présidé par Sharon Abel, essaie ardemment de rassembler de l'information sur les programmes dans toutes les sphères de l'acoustique. Il peut s'agir de programmes officiels ou simplement de labo s'adressant aux étudiants supervisés par un étudiant gradué, dans l'un ou l'autre domaine de l'acoustique. La demande pour de telles informations provient de plusieurs sources externes à l'ACA. Dans le même ordre d'idées, on nous a demandé de l'information sur les emplois en acoustique. Ma réponse à cela est de vous demander de les publier dans l'*Acoustique Canadienne*.

J'ai reçu un certain nombre de lettres de gens qui aimeraient voir certains points discutés aux rencontres de l'ACA. Nous tenterons de laisser du temps à cette fin en octobre. Certaines des suggestions ont déjà été discutées à la dernière assemblée de l'exécutif. Certaines inquiétudes ont été exprimées concernant la tendance de l'*Acoustique Canadienne* à publier seulement des articles révisés. Je vous prie de lire la rubrique à l'intérieur de la page couverture qui solicite clairement des articles de revue et des notes de recherche, en anglais et en français. Lisez aussi l'éditorial de l'édition d'avril 1991.

J'ai récemment agi comme juge et présenté à la Foire Canadienne des Sciences. Les organisateurs de cet événement apprécient beaucoup que les commanditaires tel que l'ACA agissent comme juges. Il y a eu 12 présentations dans le domaine de l'acoustique. Parmi celles-ci, la gagnante en acoustique fut Maria-Graciele Holin de Beaconsfield, Québec et la gagnante d'une médaille d'or en "physique junior" fut Marie-Claude Blanchet de Thornhill, Ontario. Les articles reliés à ces deux projets seront publiés dans le présent numéro ou l'édition de décembre de l'*Acoustique Canadienne*. Je vous demande de les lire afin de constater la qualité de la recherche menée par des jeunes Canadiens. A cet effet, je vous encourage à demeurer disponibles afin d'aider et d'encourager les étudiants qui envisagent de réaliser des projets en acoustique.

Je vous demande de bien lire le procès-verbal de la dernière assemblée des Membres de l'Exécutif. Il y a plusieurs congrès à venir, particulièrement dans le domaine du language et de l'audiologie, auxquels notre nom est associé. Nous ne tiendrons pas nos congrès

NOTE FROM THE PRESIDENT

Another issue, another note. As usual, I want to exhort the membership into going into action with their pencils and word processors to produce information. The CAA has a committee, chaired by Sharon Abel, which is trying very hard to put together a list of programs in all areas of acoustics. These may be formal programs or may simply be a lab in which students can be supervised through to a post-graduate degree in some area of acoustics. The request for such information has come from a number of sources outside the CAA. In a similar vein, we have been asked for information on jobs in acoustics. My response to this is to ask that you advertise them in *Canadian Acoustics*.

I have received a couple of letters from people who would like to see changes discussed in CAA meetings. We are going to try to make more time available in October. Some of the suggestions have already been discussed at the Board meeting. There has been some concern with the proclivity of *Canadian Acoustics* to publish only refereed articles. However, I request that you read the section inside the cover in which it clearly requests tutorial papers and research notes in both English and French. Please also read the editorial in the April 1991 issue.

I recently judged and presented at the Canada-Wide Science Fair. The organizers of the Fair are very eager for sponsors, such as CAA, to judge. There were 12 presentations in acoustics. Of these there was the judged winner in acoustics, Maria-Graciela Holln from Beaconsfield, Quebec and the winner of a physics junior gold medal, Marie-Claude Blanchet from Thornhill, Ontario. Articles from both projects will appear in *Canadian Acoustics* either in this issue or in December. Please read them so that you can see how good the research is by young Canadians. In this regard, I would like to urge you to be available to help and encourage students who envisage acoustics projects.

Please read the minutes of the Board meeting carefully. There are a number of conferences coming up, particularly in the areas of speech and audiology which we are attaching our name to. We will not be holding our conferences along with them, but the material in the conference may be of great interest to some of you. In addition, don't forget that Inter-Noise '92 is coming up in Toronto.

On a less pleasant note, I would like to request that those who have associations with the CAA or its avec eux mais le matériel diffusé lors de ces congrès pourra être d'un grand intérêt pour vous. Par ailleurs,n'oubliez pas que Inter-Noise '92 aura lieu à Toronto.

Sur une note moins agréable, j'aimerais demander à ceux qui associent leur nom à l'ACA ou à ses "ancêtres" d'être scrupuleusement prudents dans la façon d'aficher publiquement cette association. Il est vraiment dommage de voir des chercheurs utiliser cette appartenance à leur profit. Je pense qu'il s'agit d'une importante question morale.

Enfin, Je vous encourage tous à participer à la Semaine de l'Acoustique. La présentation de Gene Bolstad à la dernière réunion nous a enthousiasmés. Ce sera merveilleux et encore davantage si plusieurs personnes participent. Laissez-moi inviter tous ceux qui prévoient s'incrire aux séminaires se réserver tôt. Si un nombre insuffisant de gens s'inscrit, les cours seront annulés. Par ailleurs, laissez-moi rappeler à ceux qui encouragent les étudiants à s'inscrire pour les prix d'être certains que l'étudiant soit le premier auteur. De plus, assurez-vous que nous soyons mis au courant que vous désirez que votre résumé soit considéré éligible aux prix étudiants. A notre prochaine rencontre en octobre!

ancestors be scrupulously careful as to how they publicly represent that relationship. It is very depressing to see respected scientists misrepresent this relationship to their own profit. I think this is an important moral issue.

Finally, I urge all of you to attend Acoustics Week in Canada. The presentation by Gene Bolstad at the Board meeting enthused us all. It will be great and even greater if lots of people come. Let me urge all of those who are planning to attend a workshop to book early. If not enough people sign up, the under-subscribed workshops will be cancelled. In addition, let me also urge those of you who are sponsoring students for prizes to be sure the student is the first author. In addition, please be sure that we know your submission is from a student eligible for the prize. So, see you all in October.

Bruce E. Dunn

MINUTES OF THE BOARD OF DIRECTORS MEETING

May 26, 1991, 10:00 a.m.
National Research Council, Ottawa, Ontario

Present:	Bruce F. Dunn, President	Eugene Bolstad, Treasurer	David Chapman, Director
	Sharon Abel, Past President	Murray Hodgson, Editor-in-Chief	Annabel Cohen, Director
	Winson Sydenborgh, Secretary	Alberto Behar, Director	Chantai Laroche, Director

Regrets: Tony Embleton, Stan Forshaw, John Hemingway

1. Report of the President

Bruce Dunn welcomed the members of the board present. In his opening address, the President stressed openness in communication between members and the board. At the previous General Meeting in Montreal, members were asked to come up with suggestions. Only one letter was received, from M. Jean Nicolas, University of Sherbrooke. The following points are noted, dealing with the lack of francophones on the C.A.A. Executive, the scientific calibre of the Journal and a more open discussion at the Annual General Meeting. It is suggested that this letter should be published in its entirety in the Journal. Consent will be requested from the writer before publication. Announcements from the forthcoming World Building Congress and the scholarship services organization are noted.

2. The Minutes of the Board of Directors meeting held in Montreal on October 3, 1990 are tabled and accepted. Motion made by S. Abel and seconded by G. Bolstad. The Secretary's report noted that the paid membership for the year 1991, as of May 24, 1991, is as follows:

Memberships:	254	Student Members:	28
Subscriptions:	67	Sustaining Subscriptions:	24

Observed in the above is a noticeable drop in student membership and the necessity to promote our organization to students. The suggestion is made that provision should be made to change the wording to Fax and/or electronic mail address on the 1992 membership forms. This will be done.

3. Treasurer's Report

Interim statement of receipts and disbursements to May 20, 1991 for

A. The General Operating Fund
B. The Capital Fund

The General Operating Fund is essentially a chequing account. The funds in this account are held to the amount sufficient to handle all budgeted cash flow.

The Capital Fund has sufficient assets to generate interest income to more than balance our present commitments to prizes and awards. However, interest percentages are changing and inflation does continue. Prudent administration of the Fund will require that some of the interest be reinvested and/or the fund be increased by further contributions. Any excess funds resulting from operations should be funnelled into the Capital Fund.

4. Report of the Editor-in-Chief

Murray Hodgson noted that more papers are required for the Journal. The September issue will from now on be dedicated to Proceedings. The budgeted amount for the Journal of 1991 will have to be reviewed, since costs have increased. A revised budget for the 1992 year has been set at $12,000. Moved by M. Hodgson and seconded by S. Abel. Carried.

5. Montreal 1990 Symposium

Chantai Laroche reports that the books for this meeting can be closed as soon as all accounts have cleared. A surplus is expected for the Treasury.

6. Progress Report Acoustics Week 1991 - Edmonton

Gene Bolstad, the Convenor, reports that the Convention will be in the Ramada Inn, downtown Edmonton, with exhibits on the same floor. Sixty-three abstracts for papers were received. A sum of $2000.00 has been set aside to subsidize travel for students who are presenting papers at the Symposium, up to a maximum of $200.00 per student, or 25% of the total, whichever is the lower of the two. This proposal is passed unanimously. Edmonton is ready for us!

7. Nomination Committee Chairperson - S. Abel

Sharon reports that two directors are to be elected in October to replace directors who have fulfilled their four-year term.

8. Prizes and Awards

Directors Award (Chantai Laroche, Chairperson)
Post-Doctoral Prize (S. Abel)
Bell Speech Prize (L. Brewster)
Underwater Prize D. Chapman)
Student Presentations (A. Behar)
Eckel Award (M. Hodgson)

9. Report from Prize Review Committee

Alberto Behar has developed a procedure for judging student papers. David Chapman suggests adding the requirement of publication of the written paper in the Journal before the prize is issued.

Awards will be publicized by the chairpersons involved.

Alberto Behar to publish a cumulative list of award and prize recipients in the Journal.

10. Report of Education Committee - S. Abel

To the questionnaire on Programmes of Education in Acoustics and Vibration, only Carleton University, Université de Sherbrooke and the Ontario Ministry of the Environment responded.

11. A short report re: International INCE and Internoise '92 was given by S. Abel on behalf of T. Embleton. About 800 registrants are expected at Toronto's Inn-On-The-Park in July 1992.

12. Report on Science Fair

B. Dunn attended, judged and presented a $250.00 award to the winner of a science presentation in Acoustics. Paper will be published in the Journal.

13. Discussed letter on the Institute's co-sponsorship of Canadian awards. This will be discussed at the Annual General Meeting in Edmonton.

14. Halifax Chapter - D. Chapman

The Halifax Chapter has elected a Board of Directors. By-laws have been formulated. Activities include participation in a regional Science Fair and a summer barbecue. The Chapter has 42 members.

15. A letter received from the Nova Scotia Hearing and Speech Clinic is dealt with for either a joint meeting or support. Members in the Halifax Chapter will report to the next meeting since it pertains to a 1994 Congress in Audiology in that city.

16. S. Abel asks that a committee be formed for Convention Policy. Referred to the fall meetings.

17. Other Business

a) Comment was made that the $75.00 per provincial border which is available to alleviate costs for directors travelling to the June meetings is not fair since provincial borders do not reflect distance, nor costs of travel. This item will be brought up again in the fall meeting for further discussion.

b) A proposal for availability of a lapel pin or tie clip with the C.A.A. logo is circulated. This can be made available in gold, silver or gold-plated. Referred to the Edmonton meetings. The Secretary will investigate further.

18. New Business

a) A letter is received from John O'Keefe that Toronto hosts the 1994 Acoustics Week in conjunction with the 100th Anniversary of Massey Hall. He is willing, as interim Chairperson, to set up a committee made up of members of the Toronto Chapter to organize this Symposium.

b) B. Dunn asks that ads for job availability or those seeking positions in Acoustics be advertised in the Journal free of charge. Adopted.

19. Adjournment of the Meeting proposed by B. Dunn. Seconded by G. Bolstad and A. Behar.

20. Meeting closed at 4:30 p.m.

Reported by W.V. Sydenborgh

NEWS

CONFERENCES

14th International Congress on Acoustics: Beijing, China, September 3-10, 1991. Contact: ICA Secretariat, Institute of Acoustics, P.O. Box 2712, Beijing 100080, China or Fax at 256-1457.

6th International Meeting on Low Frequency Noise and Vibration: Leiden, The Netherlands, September 4-6, 1991. Contact: Dr. W. Tempest, Multi-Science Publishing Co. Ltd., 107 High Street, Brentwood, Essex CM14 4RX, United Kingdom.

ISSA '91, 3rd International Symposium on Shipboard Acoustics: The Hague, The Netherlands, October 8-10, 1991. Contact: H.F. Steenhoek, Head, Ship Acoustics, TNO Institute of Applied Physics, P.O. Box 155, 2600 AD Delft, The Netherlands. Phone +31 15 69 20 00 or Fax +31 15 69 21 11.

Inter-Noise 91 (Costs of Noise): Sydney, Australia, December 2-4, 1991. Contact: Christine Bourke, Conference Secretariat, University of New South Wales, P.O. Box 1, Kensington, NSW 2033, Australia.

International Conference on Sonar Signal Processing, Institute of Acoustics: Leicestershire, U.K., December 16-18, 1991. Contact: Professor J.W.R. Griffiths, Dept. of Electronic Engineering, University of Technology, Loughborough LE11 3TU, U.K. Phone: (0509) 222830, Telex: 34319, Fax: (0509) 22830.

2nd International Congress on Recent Developments in Air- & Structure-Borne Sound and Vibration: Acoustical Society of America Institute of Noise Control Engineering, March 4-6, 1992. Contact: For further information, call (205) 844-4820.

2nd French Congress on Acoustics: Arcachon, France, April 14-17, 1992. Contact: Congres Francais d'Acoustique, Mecanique Physique, Université de Bordeaux I, 33405 Talence Cedex, France. Telephone: (33) 56 84 62 26, Telefax: (33) 56 84 69 64.

COURSES

Aero- and Hydro-Acoustics: Ecole Centrale de Lyon, France, July 15-19, 1991. Contact: The Course Administrator, Cambridge Programme for Industry, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge, CB2 1PZ, England. Telephone: 0223-332712, Fax: 0223-0332662.

Technical Audiology: Institute of Sound & Vibration Research, England, September 9-13, 1991. Contact: The University, Southampton, SO9 5NH. Telephone: (0703) 592310, Fax: (0703) 593033.

Introduction to Mechanical Vibration Measurement Techniques: (run in association with Bruel & Kjaer) Institute of Sound & Vibration Research, England, September 10-12, 1991. Contact: The University, Southampton, SO9 5NH. Telephone: (0703) 592310, Fax: (0703) 593033.

10th Annual Engine Noise & Vibration Control Course: Institute of Sound & Vibration Research, England, September 10-12, 1991. Contact: The University, Southampton, SO9 5NH. Telephone: (0703) 592310, Fax: (0703) 593033.

INFORMATIONS

CONFERENCES

14e congrès international sur l'acoustique: Beijing, Chine, du 3 au 10 septembre 1991. Contacter: ICA Secretariat, Institute of Acoustics, P.O. Box 2712, Beijing 100080, Chine. Télécopieur: 256-1457.

6e rencontre internationale sur le bruit et les vibrations basse fréquence: Leiden, Pays-Bas, du 4 au 6 septembre 1991. Contacter: Dr. W. Tempest, Multi-Science Publishing Co. Ltd., 107 High Street, Brentwood, Essex CM14 4RX, Grande-Bretagne.

ISSA '91, 3e symposium international sur l'acoustique de bord: La Haye, Pays-Bas, du 8 au 10 octobre 1991. Contacter: H.F. Steenhoek, Head, Ship Acoustics, TNO Institute of Applied Physics, P.O. Box 155, 2600 AD Delft, Pays-Bas. Téléphone +31 15 69 20 00, télécopieur: +31 15 69 21 11.

Conférence Inter-Noise 91 (sur les coûts du bruit): Sydney, Australie, du 2 au 4 décembre 1991. Contacter: Christine Bourke, Conference Secretariat, University of New South Wales, P.O. Box 1, Kensington, NSW 2033, Australie.

Conférence internationale sur le traitement des signaux de sonar, Institute of Acoustics: Leicestershire, Grande-Bretagne, du 16 au 18 décembre 1991. Contacter: Professor J.W.R. Griffiths, Department of Electronic Engineering, University of Technology, Loughborough LE11 3TU, Grande-Bretagne. Téléphone (0509) 222830, télex 34319, télécopieur (0509) 22830.

2e congrès international sur les derniers progrès dans le domaine des vibrations et des sons aériens et des corps: Acoustical Society of America Institute of Noise Control Engineering, du 4 au 6 mars 1992. Renseignements: (205) 844-4820.

2e Congrès français d'acoustique: Arcachon, France, du 14 au 17 abril 1992. Contacter: Congrès français d'acoustique, Mécanique physique, université de Bordeaux I, 33405 Talence Cedex, France. Téléphone: (33) 56 84 62 26, télécopieur: (33) 56 84 69 64.

COURS

Aero- and Hydro-Acoustics: Ecole centrale de Lyon, Lyon, France, du 15 au 19 juillet 1991. Contacter: Course Administrator, Cambridge Programme for Industry, Department of Engineering, University of Cambridge, Trumpington Street, Cambridge, CB2 1PZ, Grande-Bretagne. Téléphone (0223) 332712, télécopieur: (0223) 32662.

Technical Audiology: Institute of Sound & Vibration Research, Grande-Bretagne, du 9 au 13 septembre 1991. Contacter: The University, Southampton, SO9 5NH. Téléphone: (0703) 592310, télécopieur: (0703) 593033.

Introduction to Mechanical Vibration Measurement Techniques: (donné en collaboration avec Bruel & Kjaer), Institute of Sound & Vibration Research, Grande-Bretagne, du 10 au 12 septembre 1991. Contacter: The University, Southampton, SO9 5NH. Téléphone (0703) 592310, télécopieur (0703) 593033.

10th Annual Engine Noise & Vibration Control Course: Institute of Sound & Vibration Research, Grande-Bretagne, du 10 au 12 septembre 1991. Contacter: The University, Southampton, SO9 5NH. Téléphone (0703) 592310, télécopieur (0703) 593033.

20th Advanced Course in Noise and Vibration: Institute of Sound & Vibration Research, England, September 16-20, 1991. Contact: The University, Southampton, SO9 5NH. Telephone: (0703) 592310, Fax: (0703) 593033.

Industrial Audiology & Hearing Conservation: Institute of Sound & Vibration Research, England, September 16-20, 1991. Contact: The University, Southampton, SO9 5NH. Telephone: (0703) 592310, Fax: (0703) 593033.

Applied Digital Signal Processing: (run in association with Bruel & Kjaer), Institute of Sound & Vibration Research, England, September 16-20, 1991. Contact: The University, Southampton, SO9 5NH. Telephone: (0703) 592310, Fax: (0703) 593033.

Acoustics & Noise Control: Seven Springs, Pennsylvania, October 21-15, 1991. Contact: AVNC, Continuing Education Division, 250 Shagbark Drive, R.D. #1, Cheswick, PA 15024.

Signal Processing: Seven Springs, Pennsylvania, October 21-25, 1991. Contact: AVNC, Continuing Education Division, 250 Shagbark Drive, R.D. #1, Cheswick, PA 15024.

PEOPLE IN THE NEWS

AIUM welcomes new Officers and Board of Governors Members - The American Institute of Ultrasound in Medicine (AIUM) announces the officers and Board of Governors to be inducted at the 35th Annual Convention in Atlanta, Georgia. The newly elected officers are John C. Hobbins, MD, President; Michael S. Tenner, MD, President-Elect; Lewis H. Nelson, III, MD, Secretary. Elected to the Board of Governors are Edward I. Bluth, MD, FACR; Lennard D. Greenbaum, MD; Mazie M. Havens, BSS, RMDS; Samuel B. Ritter, MD, FAAP, FACC; and John W. Seeds, MD. For more information on the new officers and Board of Governors members, contact the AIUM Publications Department, 11200 Rockville Pike, Suite 205, Rockville, MD 20852-3139. Phone: (301) 881-2486. Fax: (301) 881-7030.

NEW PRODUCTS

The American Institute of Ultrasound in Medicine (AIUM) announces the publication of a new document entitled *Safety Considerations for Diagnostic Ultrasound*. This publication includes such topics as official AIUM statements on safety, exposure-parameter definitions, in-vivo bioeffects, mechanisms of action, instrument output levels, epidemiology, and appropriate clinical attitudes regarding risk and safety.

The new safety document is available for $28.00 each for AIUM members and $50.00 each for non-members. Postage and handling are included. To order, simply call, fax or write to AIUM, Publications Department, 11200 Rockville Pike, Suite 205, Rockville, MD 20852-3139. Phone: (301) 881-2486. Fax: (301) 881-7303. American Express, MasterCard and VISA are welcome.

Scantek has outgrown its Rockville offices and moved! Its new address: 916 Gist Avenue, Silver Spring, MD 20910. Phone: (301) 395-7738, Fax: (301) 495-7739. For further information, call or write Richard J. Peppin, P.E., President, Scantek, Inc., 916 Gist Avenue, Silver Spring, MD 20910. Phone (301) 395-7738, Fax: (301) 495-7739.

20th Advanced Course in Noise and Vibration: Institute of Sound & Vibration Research, Grande-Bretagne, du 16 au 20 septembre 1991. Contacter: The University, Southampton, SO9 5NH. Téléphone (0703) 592310, télécopieur (0703) 593033.

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Acoustics & Noise Control: Seven Springs, Pennsylvania, du 21 au 25 octobre 1991. Contacter: AVNC, Continuing Education Division, 250 Shagbark Drive, R.D. #1, Cheswick, PA 15024, Etats-Unis.

Signal Processing: Seven Springs, Pennsylvania, du 21 au 25 octobre 1991. Contacter: AVNC, Continuing Education Division, 250 Shagbark Drive, R.D. #1, Cheswick, PA 15024, Etats-Unis.

LES GENS QUI FONT PARLER D'EUX

L'American Institute of Ultrasound in Medicine (AIUM) annonce la nomination des personnes suivantes à son comité directeur et à son conseil d'établissement. Ces personnes seront officiellement installées dans leurs fonctions lors du 35e congrès annuel de l'institut qui se tiendra à Atlanta en Georgie. Comité directeur: John C. Hobbins, MD, président; Michael S. Tenner, MD, président désigné; Lewis H. Nelson, III, MD, secrétaire. Conseil d'établissement: Edward I. Bluth, MD, FACR; Lennard D. Greenbaum, MD; Mazie M. Havans, BSS, RDMS; Samuel B. Ritter, MD, FAAP, FACC; John W. Seeds, MD. Renseignements: AIUM, Publications Department, 11200 Rockville Pike, Suite 205, Rockville, MD 20852-3139. Téléphone (301) 881-2486, télécopieur (301) 881-7303.

NOUVEAUX PRODUITS

L'American Institute of Ultrasound in Medicine (AIUM) annonce la publication d'un document intitulé Safety Considerations for Diagnostic Ultrasound. Cet ouvrage contient les déclarations officielles de l'AIUM sur la sécurité, les définitions des paramètres d'exposition, les effets biologiques in-vivo et in-vitro, les mécanismes d'action, les niveaux de rendement des instruments, les attitudes cliniques recommandées du point de vue de la sécurité, en plus de traiter d'épidémiologie.

Cet ouvrage est disponible au prix de 28 $ pour les membres de l'AIUM et de 50 $ pour les non-membres. Ce prix inclut les frais de poste et de manutention. Pour le commander, contacter: AIUM, Publications Department, 11200 Rockville Pike, Suite 205, Rockville, MD 20852-3139. Téléphone: (301) 881-2486, télécopieur: (301) 881-7303. Cartes American Express, MasterCard et VISA acceptées.

Scantek, Inc. a une nouvelle adresse: 916 Gist Avenue, Silver Spring, MD 20910. Téléphone: (301) 495-7738, télécopieur: (301) 495-7719. Pour tous renseignements, contacter: Richard J. Peppin, P.E., président de Scantek, Inc.

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Montreal, Quebec H3G 1M8
(514) 848-7919 (office)
(514) 342-2263 (residence)

Poste: Assistant de recherche en acoustique

Fonctions: Effectuer des recherches fondamentales dans le domaine du rayonnement acoustique des structures immergées. **Exigences**: Le candidat devra avoir suivi plusieurs cours reliés à l'acoustique et aux vibrations au niveau 2è cycle et avoir travaillé en recherche sur un sujet relié au couplage fluide/structure. Faire parvenir curriculum vitae détaillé avec bulletin scholaire et publications dans le plus bref délai à:

Jean Nicolas, directeur
Groupe d'Acoustique et Vibrations
Département de génie mécanique
Faculté des sciences appliquées
Université de Sherbrooke
Sherbrooke, Quebec J1K 2R1

Engineers - Acoustics

Architectural acoustics, environmental acoustics, noise and vibration control. Experience an asset, but not mandatory. Interest, enthousiasm and willingness to learn, as well as good verbal and written communication skills mandatory. Entry level candidates will be considered. Submit resumés to:

Elaine Lightstone, Office Manager
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The Professional Centre
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L'abonnement pour la présente année est dû le 31 janvier. Les abonnements reçus avant le 1 juillet s'appliquent à l'année courante et incluent les ancient numéros (non-épuisés) de l'Acoustique Canadienne de cette année. Les abonnements reçus à partir du 1 juillet s'appliquent à l'année suivante.

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Submissions: The original manuscript and two copies should be sent to the Editor-in-Chief.

General Presentation: Papers should be submitted in camera-ready format. Paper size 8.5" x 11". If you have access to a word processor, copy as closely as possible the format of the articles in Canadian Acoustics 18(4) 1990. All text in Times-Roman 10 pt font, with single (12 pt) spacing. Main body of text in two columns separated by 0.25". One line space between paragraphs.

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Photographs: Submit original glossy, black and white photograph.

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