①

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

AD-A231 499

1a REPORT SECURITY CLASSIFICATION
Unclassified

1b RESTRICT

2a SECURITY CLASSIFICATION AUTHORITY

2b DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release; distribution unlimited.

4 PERFORMING ORGANIZATION REPORT NUMBER(S)
NCPA LC. 3 1989

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a NAME OF PERFORMING ORGANIZATION
ITD - National Center for Physical Acoustics

6b. OFFICE SYMBOL *(If applicable)*
LC

7a. NAME OF MONITORING ORGANIZATION
Office of Naval Research

6c. ADDRESS *(City, State, and ZIP Code)*
National Center for Physical Acoustics
Coliseum Drive
University, MS 38677

7b. ADDRESS *(City, State, and ZIP Code)*
Department of the Navy
800 N. Quincy Street
Arlington, VA 22217

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
Office of Naval Research

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
N00014-89-J1739

8c. ADDRESS *(City, State, and ZIP Code)*

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11 TITLE *(Include Security Classification)*
Final Report FY 89 Acoustics Research

12. PERSONAL AUTHOR(S)
Dr. Lawrence A. Crum, Interim Director

13a. TYPE OF REPORT
Technical

13b. TIME COVERED
FROM 10/1/88 TO 9/30/90

14. DATE OF REPORT *(Year, Month, Day)*
September 11, 1990

15. PAGE COUNT

16 SUPPLEMENTARY NOTATION

17 COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Bubble releated ambient noise in the ocean and bubble clouds and surface reverberation, acoustically active surfaces, scattering by structures, machinery noise, (over

19 ABSTRACT *(Continue on reverse if necessary and identify by block number)*

This is a final technical report for the Institute for Technology Development from the National Center for Physical Acoustics. Details of the individual projects are included in the attached technical narrative. A list of published papers and oral presentations is included.

DTIC
ELECTE
FEB 04 1991
S E D

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a NAME OF RESPONSIBLE INDIVIDUAL
Dr. Lawrence A. Crum

22b. TELEPHONE *(Include Area Code)*
(601) 232-5621

22c. OFFICE SYMBOL
LC

DD Form 1473, JUN 86 *Previous editions are obsolete.* SECURITY CLASSIFICATION OF THIS PAGE

18. propagation physics, solid state acoustics, short-range ultrasonic sensing, electro-rheological fluids, transducer development.

The National Center
for
Physical Acoustics

The
University of Mississippi

REPORT OF INVENTIONS AND SUBCONTRACTS

(Pursuant to "Patent Rights" Contract Clause) (See Instructions on Reverse Side)

OMB No. 0704-0297
Expires Jun 30, 1992

Public reporting burden for this collection of information is estimated to average 5 minutes per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0297), Washington, DC 20503.

1a. NAME OF CONTRACTOR/SUBCONTRACTOR
ITD-Nat'l Center for Physical Acoustics

b. ADDRESS (Include ZIP Code)
NCPA
Coliseum Drive
University, MS 38677

c. CONTRACT NUMBER
N00014-89-J-1739

d. AWARD DATE (YYMMDD)
88-10-01

2a. NAME OF GOVERNMENT PRIME CONTRACTOR
Office of Naval Research

b. ADDRESS (Include ZIP Code)
Dept. of the Navy
800N. Quincy Street
Arlington, VA 22217

c. CONTRACT NUMBER

d. AWARD DATE (YYMMDD)

3. TYPE OF REPORT (X one)
a. INTERIM ☒ b. FINAL ☐

4. REPORTING PERIOD (YYMMDD)
a. FROM 88-10-01
b. TO 90-09-30

SECTION I - SUBJECT INVENTIONS

5. "SUBJECT INVENTIONS" REQUIRED TO BE REPORTED BY CONTRACTOR/SUBCONTRACTOR (If "None," so state)

a. NAME(S) OF INVENTOR(S) (Last, First, MI)	b. TITLE OF INVENTION(S)	c. DISCLOSURE NO., PATENT APPLICATION SERIAL NO. OR PATENT NO.	d. ELECTION TO FILE PATENT APPLICATIONS (1) United States (a) Yes	(1) United States (b) No	(2) Foreign (a) Yes	(2) Foreign (b) No	e. CONFIRMATORY INSTRUMENT OR ASSIGNMENT FORWARDED TO CONTRACTING OFFICER (1) Yes	(2) No
NONE								

f. EMPLOYER OF INVENTOR(S) NOT EMPLOYED BY CONTRACTOR/SUBCONTRACTOR

(1)(a) Name of Inventor (Last, First, MI)
NONE

(b) Name of Employer

(c) Address of Employer (Include ZIP Code)

(2)(a) Name of Inventor (Last, First, MI)

(b) Name of Employer

(c) Address of Employer (Include ZIP Code)

g. ELECTED FOREIGN COUNTRIES IN WHICH A PATENT APPLICATION WILL BE FILED

(1) Title of Invention

(2) Foreign Countries of Patent Application

SECTION II - SUBCONTRACTS (Containing a "Patent Rights" clause)

6. SUBCONTRACTS AWARDED BY CONTRACTOR/SUBCONTRACTOR (If "None," so state)

a. NAME OF SUBCONTRACTOR(S)	b. ADDRESS (Include ZIP Code)	c. SUBCONTRACT NO.(S)	d. DFAR "PATENT RIGHTS" (1) Clause Number	(2) Date (YYMM)	e. DESCRIPTION OF WORK TO BE PERFORMED UNDER SUBCONTRACT(S)	f. SUBCONTRACT DATES (YYMMDD) (1) Award	(2) Estimated Completion

SECTION III - CERTIFICATION

7. CERTIFICATION OF REPORT BY CONTRACTOR/SUBCONTRACTOR (Not required if ☐ Small Business or ☒ Non-Profit organization.) (X appropriate box)

a. NAME OF AUTHORIZED CONTRACTOR/SUBCONTRACTOR OFFICIAL (Last, First, MI)

b. TITLE

c. I certify that the reporting party has procedures for prompt identification and timely disclosure of "Subject Inventions," that such procedures have been followed and that all "Subject Inventions" have been reported.

d. SIGNATURE

e. DATE SIGNED
9/17/90

DD Form 882, OCT 89

Previous editions are obsol

I. TECHNICAL NARRATIVE

SUMMARY

During FY 89, work was performed in nine project areas summarized briefly as follows. A more detailed account, with figures is provided in subsequent sections.

(a) **Bubble Related Ambient Noise in the Ocean and Bubble Clouds and Surface Reverberation.** This project relates to the noise generated by naturally occurring bubbles in the ocean. Work was concentrated on the sound generated by bubbles created by the entrainment of air associated with rain drops impacting on the sea surface. It was shown that the noise of rain drops underwater is due almost entirely to bubble oscillations. It seems likely therefore that bubbles are also the cause of the underwater noise associated with ocean spray.

(b) **Acoustically Active Surfaces.** This project relates to the use of piezoelectric surface layers to actively cancel reflected and transmitted sound. Experimental work has shown that it is possible to cancel reflected sound with a bilayer structure. The outer layer senses the incident sound and the inner layer generates the signal that cancels the reflection. The theory for the operation of these surfaces has been developed and tested against measured values of amplitude and phase of voltages, currents and sound pressures. A unique method of compensating for feedback between the sensing and driving layers has been developed.

(c) **Scattering by Structures.** This project is concerned with understanding the internal vibrations of a sonar target so that methods can be developed to control the vibrations either by passive or active means. The principal outcome of the work performed in FY 89 was the discovery of a new form of wave structure that appears to dominate the vibrational response of closed underwater bodies. These waves are called interlocking rotational waves and behave similarly to a set of meshed gears. So far the waves have been shown to occur in solid spheres and cylinders.

(d) **Machinery Noise.** This project relates to the excitation of structures by internal sources and the consequent radiation of sound. In FY89, effort was concentrated on machinery sources in air. A variety of noise sources were investigated including power generators, small tractors, and motorcycles. Diagnostic techniques were developed, based largely on sound intensity measurement, for identifying and quantifying component noise sources in the machines.

(e) **Propagation Physics.** This project relates to the propagation of sound both in the atmosphere and in the ocean. In the atmosphere, attention was concentrated on the effect of turbulence in an upward-refracting medium. Excellent agreement was found between the predictions of a parabolic equation model and experimental measurements reported in the literature. For sound in the ocean, work was continued on sound in a shallow pond as a scale model of ocean acoustics. Normal mode theory for the ocean was found to apply appropriately to a shallow pond.

(f) Solid State Acoustics. This project relates to the use of acoustics to investigate the fundamental elastic properties of crystalline structures in particular through use of the harmonic generation measurement technique. Progress was made in FY 89 in studying the properties of gallium arsenide and a superconductor material. In the theoretical work, the effect of piezoelectricity has been added to the harmonic generation model and has been shown to have a noticeable effect on the third order elastic constants.

(g) Short-Range Ultrasonic Sensing. This project relates to the use of short-range ultrasonic sensing for the control of automated systems and for the inspection of surface and sub-surface features of structures. In FY 89, the work was concentrated on measurements in air. It was shown that an accuracy of 15 microns for measurements of a step between two precisely machined blocks could be obtained using ultrasound. Other tests showed the use of ultrasonic sensing for studying the flexural motion of sheet material.

(h) Electro-Rheological Fluids. This project relates to the use of acoustical methods in studying the fundamental properties of electro-rheological fluids i.e. fluids whose viscosity is significantly affected by a strong electric field. In FY 89, preliminary work was done on the dependance of ultrasonic compressional waves on the applied field strength. A relatively small effect was observed. No effect on acoustic attenuation was observed.

(i) Transducer Development. This project relates to the development of Gaussian beam transducers. Gaussian beam transducers were shown to work effectively at 4 MHz. Attempts are being made to develop transducers that operate at lower frequencies. A theory of Gaussian beam transducers has been developed based on a superposition of Gaussian functions.

A. BUBBLE RELATED AMBIENT NOISE IN THE OCEAN
AND
BUBBLE CLOUDS AND SURFACE REVERBERATION

I. Introduction

This proposed research is a broad study of the role of gas bubbles in the acoustics of the ocean. It involves both passive and active studies. The various natural processes that readily occur in the ocean produce myriads of gas bubbles of various sizes and distributions. In the production of these bubbles, they can be given energy in excess of the equilibrium state and quite easily radiate this energy acoustically. Similarly these bubbles can be activated by passing pressure waves and can thus scatter and/or radiate sound. We propose to study these phenomena under two general categories: "Bubble Related Ambient Noise" and "Bubble Clouds and Surface Reverberation".

There is extensive experimental evidence [1] to indicate that bubbles play an important role in the underwater ambient noise generated in the ocean, with a frequency range from the hundreds of kilohertz down to a few hundred hertz. Prosperetti [2] has provided theoretical arguments that oscillating gas bubbles can contribute significantly to the ambient noise level over a variety of frequency ranges. Specifically, at high frequencies, the bubbles can oscillate at their natural resonances; here, they are principally stimulated into oscillation by the energy available during production. At medium frequencies, collections of bubbles can undergo collective oscillations. This modality is primarily associated with breaking waves in which a large number of bubbles are produced in a localized region. Again, these bubbles would be stimulated into oscillation by some entrainment process which would produce not only the bubbles but make available energy for bubble oscillation. At low frequencies, the many turbulent fluctuations that exist in the ocean are known to radiate either not at all or very inefficiently due to their multipole nature. If bubbles are present, however, these pressure fluctuations can be radiated much more efficiently to the far field by the monopole response of an oscillating (spherical) gas bubble. The general aspects of this problem have already been studied in some detail and more specific issues are addressed in this proposed research. A brief review of some early progress is now given.

II. Research Progress in FY 89

Our principal region of effort in FY 89 involved studies associated with the natural resonance frequencies of gas bubbles. In order to examine the sound produced by the multiple impacts of rainfall, we have first examined individual drop impacts and advanced from these studies to an acoustic examination of both artificial and natural rainfall.

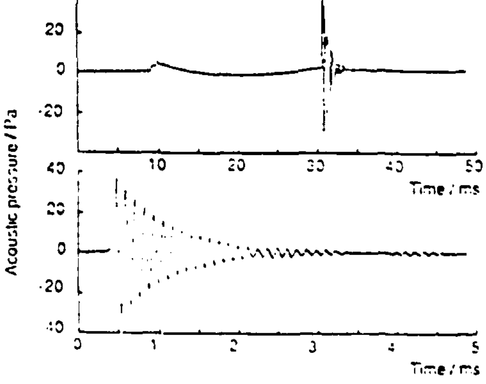


FIG. 1 Sounds produced by drops of 3.0-mm-diam impacting at a velocity of 2.0 m/s. The upper trace shows the whole process with the initial impact occurring at a time of about 8 ms and the bubble sound at 32 ms. The lower trace is an expansion along the time axis of a part of the upper one and shows the bubble sound in greater detail.

Figure 1 shows oscilloscope traces of a single drop impact. It is seen that a much higher sound intensity is radiated from the oscillating air bubble than from the drop impact itself; of course, this fact was known also to others --- the important distinction is that sound is generated by every impacting drop but only a few of these drops entrain gas bubbles. Accordingly, we have examined the physical mechanisms leading to bubble entrainment to discern when (and why) a bubble is occasionally entrained in order to determine its relative importance.

The results of our study of gas bubble entrainment from individual impacting rain drops is shown in Fig. 2a. We determined that under certain conditions, a gas bubble would be entrained on every impact; we called this behavior regular entrainment. We also discovered that there were conditions under which a bubble seemed to be entrained on a random basis; we called this behavior irregular entrainment. Finally, when the initial conditions are different from the above ranges, gas bubbles are never entrained.

Figure 2a shows the areas of regular and irregular entrainment as a function of impact velocity and drop diameter. For example, if a rain drop of 4 mm diameter is dropped from a height that would lead to an impact velocity of 1 m/s, it will never entrain a gas bubble; if it impacts at a velocity of about 1.4 m/s, it will always entrain a bubble; finally, it it impacts at a velocity of about 5 m/s, it will occasionally entrain a bubble.

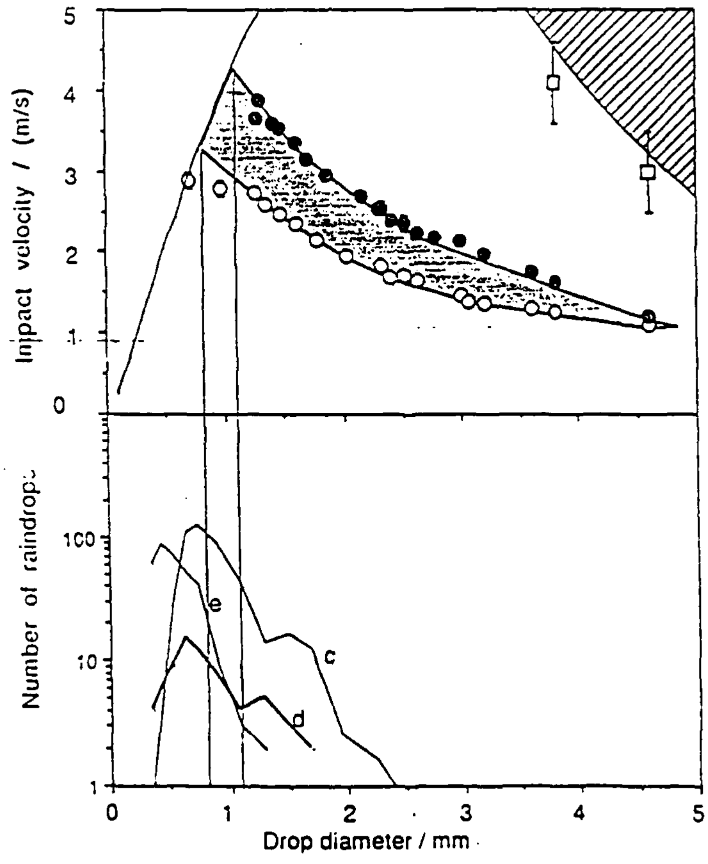


FIG. 2 (a) Conditions necessary for bubble entrainment. Regular entrainment occurs in the shaded region in the center of the figure; irregular entrainment occurs (very approximately) in the striped region at the top of the graph. The line at the left is the terminal velocity curve for raindrops, and the two vertical lines are at the drop diameters at which the terminal velocity curve passes through the regular entrainment region, i.e., 0.8 and 1.1 mm. (b) Drop-size distributions for three different rain showers. Note that many raindrops fulfill the conditions for regular entrainment. The units on the ordinate are: number of drops in a 0.1-mm size range striking an area of 50 cm^2 in a time of 90 s.

In order to consider the underwater sound produced by real rainfall, however, the drops must impact at their terminal velocity. Shown on Fig. 2a on the left-hand-side is a curve that defines the terminal velocity of raindrops as a function of drop diameter. This curve defines the conditions for real rainfall. It is seen that a narrow range of drop sizes travelling at terminal velocity gives rise to regular entrainment. This range of sizes is from about 0.8 - 1.1 mm.

The next important question is whether this range of drop sizes is present in real rain. Shown in Fig. 2b are distrometer plots of three separate measured rainfalls. It is seen by an extension of the regular entrainment limits shown in Fig. 2a that these drop sizes do indeed occur in real rain and are near the peak in the size distribution.

Our view that bubble entrainment was the most important aspect of the underwater sounds of rainfall was strengthened by the following observation and the subsequent set of measurements: when we introduced a surface tension reducing agent into the liquid, regular entrainment essentially ceased. Apparently, the conditions leading to closure of the air cavity are so surface-tension dependent that it is nearly impossible to entrain gas bubbles when the surface tension is reduced from 70 dyn/cm to 30 dyn/cm. This observation was followed by a set of measurements at the Technical University of Denmark by one of our collaborators, Leif Bjorno, that dramatically demonstrated our hypothesis. Shown in Fig. 3 are rainfall spectra taken under similar conditions on the same day. The top trace (filled circles) shows the spectrum obtained for real rainfall; the bottom trace (open circles) shows that the peak at 15 kHz is completely extinguished by the addition of a surfactant to the surface of the tank in which the underwater sound measurements were being made. Since the sound produced by the drop impact should not be affected in any major way by the presence of a monomolecular film, these data provide strong evidence for the preeminence of air bubble entrainment over drop impact as the source of underwater sound production.

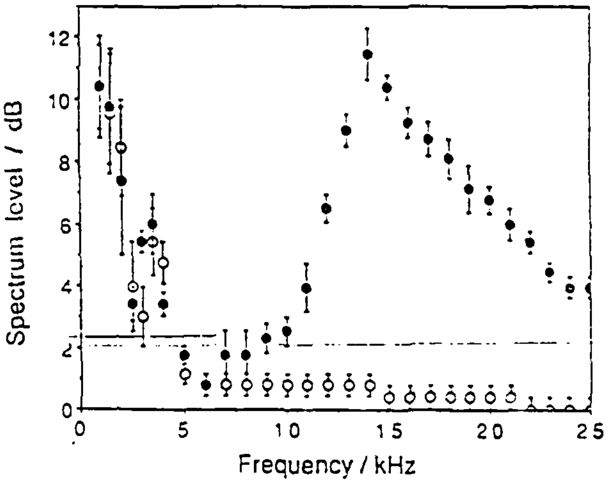


FIG.3 Acoustic power spectra of real rain falling into clean water (closed circles) and water with sulfo detergent added (open circles). Here, dB reference level is arbitrary.

We have attempted to account analytically for the magnitude and shape of the power spectrum of rainfall from our knowledge of fundamental acoustics. Consider the impact process and the entrainment of a gas bubble. Since the bubble is produced near the air-liquid surface, the bubble radiates not as a monopole but as a dipole. Let us now consider how a rainfall spectrum can be obtained. We assume that a certain number of bubbles are produced per unit area per unit time and that they radiate as dipoles. We integrate the intensity from a single bubble over the water half-space and multiply by the total number of bubbles to get the total radiated intensity. In order to evaluate these equations we need to know (1) ß, the decay constant of the bubbles, (2) C, the source strength of the dipole and (3) n_T, the number of bubbles whose resonance frequencies lie in a 1 Hz bandwidth which are entrained per unit area per unit time. We obtain ß by theoretical computation, appropriately modified for the presence of the pressure-release interface; C, the source strength is obtained by measuring the radiation pattern of bubbles produced by regular entrainment; finally, we can obtain n_T by a combination of Scrimger's observations of rainfall rates [3] and our measurement of the frequencies produced by bubbles of a particular size.

Figure 4 shows the measured spectra of Scrimger [3] together with our theoretical estimate based upon a bubble model. It can be seen that the fit is a few dB too low; otherwise, it is quite good. Because Scrimger obtained these data in a fresh water lake of about 90 m depth, it is reasonable to expect some reverberation.

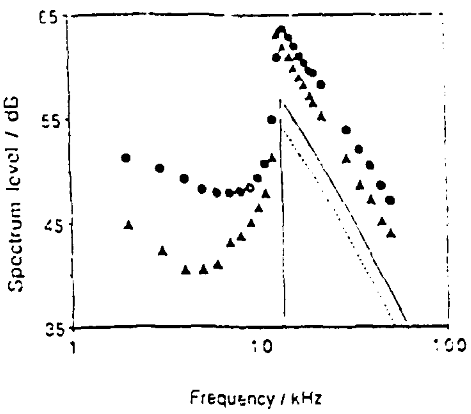


FIG. 4. Comparison of calculated (solid and dashed lines) and measured (solid points) acoustic power spectra for natural rainfall under calm conditions. Measured data are from Scrimger *et al.*[3]

Thus, we have shown that the underwater noise due to rainfall, and thus also probably due to ocean spray, is associated with bubbles. This aspect of our work that deals with precipitation is being brought to a conclusion and we turn our attention to other noise generation mechanisms.

III. References Cited

1. G. Wenz, Acoustic ambient noise in the ocean: spectra and sources, *J. Acoust. Soc. Am.* 34, 1936-1956, 1962.

2. A. Prosperetti, Bubble related ambient noise in the ocean, *J. Acoust. Soc. Am.* 84, 1042-1054, 1988.

3. J.A. Scrimger, D.J. Evans, G.A. McBean, D.M. Farmer and B.R. Kerman, Underwater noise due to rain, hail and snow, *J. Acoust. Soc. Am.* **81**, 79-86, 1987.

4. S.A. Thorpe, On the clouds of bubbles formed by breaking wind-waves in deep water, and their role in air-sea gas transfer, *Philos. Trans. R. Soc. London* , A304, 155, 1982.

5. S.A. Thorpe, A model for the turbulent diffusion of bubbles below the sea surface, *J Phys. Oceanogr.*, 14, 841, 1984.

6. S.A. Thorpe, The effect of Langmuir circulation on the distribution of submerged bubbles caused by breaking wind waves, *J. Fluid Mech.*, 142, 151, 1984.

7. S.T. McDaniel, Acoustical estimates of subsurface bubble densities in the open ocean and coastal waters, in *Sea Surface Sound*, B.R. Kerman Ed., Kluwer, Dordrecht., P. 225, 1988.

8. D.M. Farmer and D.D. Lemon, The influence of bubbles on ambient noise in the ocean at high wind speeds, *J. Phys. Oceanogr.*, **14**, 1762, 1984.

B. ACOUSTICALLY ACTIVE SURFACES

I. Introduction

In the past decade a number of materials have been developed that can be used to detect or generate acoustic waves. These materials are unique in that they can be formed into large flexible sheets. Therefore, it is possible to make large curved surfaces that are acoustically active. Two such materials are polyvinylidene fluoride[1] (often referred to as "PVDF") and piezorubber.[2,3] The first of these is a piezoelectric polymer and the second is a composite made by dispersing piezoelectric ceramic powder in rubber. It is the purpose of this project to develop and exploit acoustically active surfaces for use both in the atmosphere and under water.

Of first priority is the development of "a smart acoustically active surface" that can sense the sound falling upon it and respond in such a way as to eliminate either reflected waves, transmitted waves, or both. For the nonreflecting or nontransmitting surface, two layers of active material are needed. For a smart surface that is both nonreflecting and nontransmitting, it is anticipated that three active layers will be needed. One of the layers in each case is used as a sensing layer. The incident sound striking it creates a signal that is passed through an amplifier and filter and applied with the appropriate gain and phase change to a driving layer. At the present time we are using "state of the art" digital signal processing to produce this gain and phase control. With the DSP capabilities it is possible to apply separate gain and phase change to signals to two driving layers and simultaneously eliminatE both the transmitted and the reflected waves.

II. Research Progress in FY 89

During the past year, the experimental system diagraMmed in Fig. 1 has been constructed and used to drive an acoustically active surface so that it cancels reflected waves (Fig. 3), transmitted waves (Fig.4), or (with a bilayered surface) both reflected and transmitted waves (Fig.5). In the latter case the sound is completely absorbed in the surface and its driving electronic circuit. This bilayered surface has then been configured as a smart surface. One of the layers is used to sense the incident sound wave, the signal from it passed through a digital signal processor and applied to the second layer with the proper gain and delay to produce the cancellation of either the reflected (Fig. 6) or transmitted (Fig. 7) wave. The theory for the operation of these surfaces has been developed and tested against measured values of amplitude and phase of voltages, currents, and sound pressures. A unique method of compensating for feedback between the driving and sensing layers of the smart surface has been developed using the DSP.

The tube in which these experiments were performed is shown in Fig. 1. It is a steel tube 16 feet long and 2.5 inches inside diameter filled with castor oil. The walls are 0.5 inches thick. A removable section allows a disc of material under study to be suspended in the sound path in the center of the tube. The ends of the tube are terminated with nominally identical bi-layered transducers. On the left, one of the layers is used to generate a tone burst and the other to detect the echos. The transducer on the right end is used to detect the transmitted tone burst. The output of the echo transducer at the left end of the tube is shown as trace A and that of the transmission transducer at the right end of the tube as trace B in Figs. 2-5. The tone burst signal is also passed through the DSP where it is given a controlled gain and delay and applied to the layer under study in the center of the tube. Figure 2 shows the echo and transmitted tonebursts when the center layer is passive. Figure 3 shows the responses when it is being driven so as to cancel the reflected wave, and Fig. 4 so as to cancel the transmitted wave. In Fig. 5 a second layer of material has been added to the disc in the center and separate outputs from the DSP applied to the two. The gain and phase to each layer has been adjusted independently so as to cancel simultaneously both the transmitted and reflected waves. As seen in the figure, in this case no sound gets to the right end of the tube. In Figs 6 and 7 the DSP has been reconfigured to produce a smart surface. In this case, the output signal produced by the sound wave striking the first layer is used as the input to the DSP and the gain and delay adjusted to eliminate either the reflection (Fig. 6) or transmission (Fig. 7).

Though the data are not displayed because of lack of space, measured values of the complex voltages, currents and sound pressures have been found to agree with values calculated using the compressibility, density and peizoelectric constants of the piezorubber and the theory for the operation of the surfaces that we have developed.

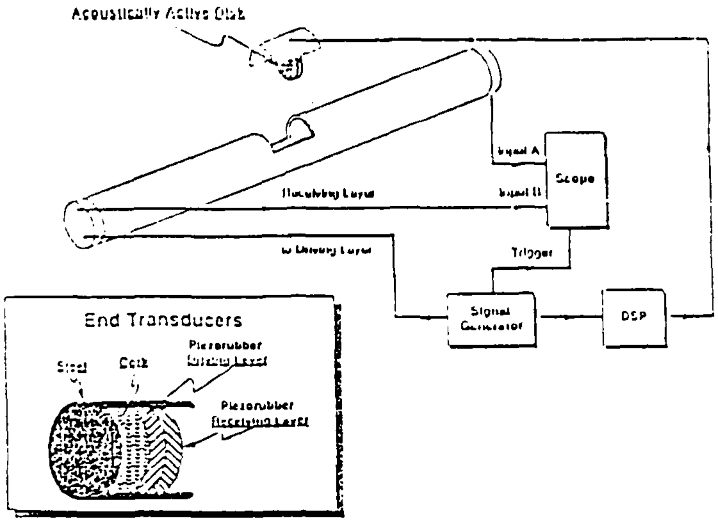


Figure 1.

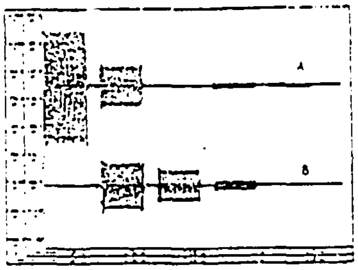


Figure 2 Passive System

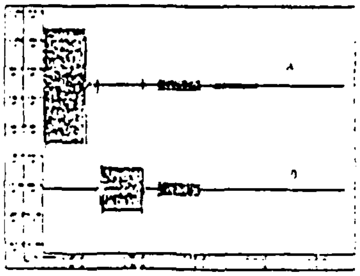


Figure 3 Cancelling Reflections

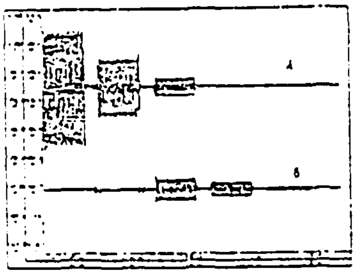


Figure 4 Cancelling Transmissions

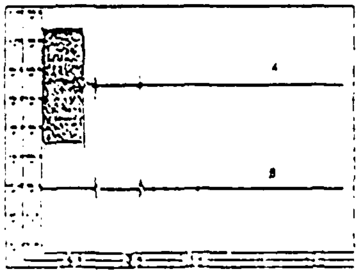


Figure 5 Cancelling Both Waves

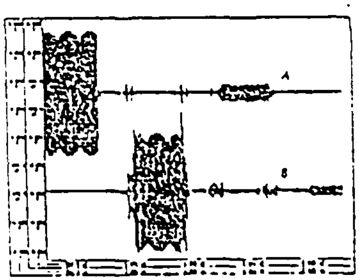


Figure 6 : Smart Cancelling of Reflections

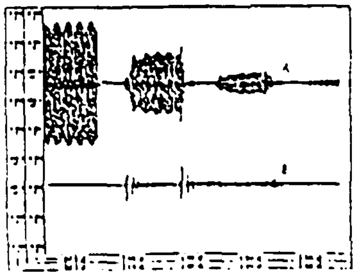


Figure 7 : Smart Cancelling of Transmissions

III. References Cited

1. See, for example, H. Sussner, "The Piezoelectric Polymer PVF$_2$ and its Applications," IEEE 1979 Ultrasonics Symposium Proceedings, edited by J. deKerk and B.R. McAvory (IEEE, New York, 1979), pp. 491-198; R.G. Kepler and R.A. Anderso, "Piezoelectricity in Polymers," CRC Critical Reviews in Solid State and Materials Sciences, 9, 399-447 (1980).

2. See, for example, J.R. Giniewicz, K. Duscha, R.E. Newnham, and A. Safari, "$(Pb_{1-x},Bi_x)(Ti_{1-x},(Fe_{1-y},Mn_y)_x)O_3$.) Polymer 0-3 Composites for Hydrophone Applications," in ISAF '86 Proceedings of the Sixth International Symposium on Application of Ferroectrics (IEEE, New York, 1986), pp. 323-327; T.R. Gururaja, W.A. Schulze, and R.E. Newnham, "Composite Piezoelectric Transducers for Ultrasonic Medical Imaging," Proceedings of the Seventh Annual Conference of the IEEE/Engineering in Medicine and Biology Society, Frontiers of Engineering and Computing in Health Care--1985, edited by J.C. Lin and B.N. Fienberg (IEEE, New York, 1985), pp. 226-230.

3. NTK Technical Ceramics/NGK Spark Plugs (USA), Inc., 99 Morris Ave., Springfield, NJ 07801.

C. SCATTERING BY STRUCTURES

1. Introduction

In recent years, advances in electronics have greatly facilitated the use of active methods of controlling vibration and noise. To apply active (or passive) methods of controlling vibration requires a detailed understanding of the vibrations within the structure. We are concerned here with developing the understanding necessary to control the response of structures to incident sound in water.

In the past interest has centered on the scattered sound field which has been used to infer the nature of the vibrations occuring inside acoustic targets. In particular, there is resonance scattering theory (RST) [1] in which vibrational resonances in the scatterer are determined from analytical poles in series solutions of the scattered sound field. The vibrational modes that are infered from the scattered field have been described in terms of concepts such as Rayleigh waves, whispering-gallery waves and monopole and dipole motions. It seems highly unlikely, however, that such concepts suffice to fully describe the features of the vibrations that actually occur inside an acoustic target. It is necessary, then, to return to the fundamental theory of vibrations excited by incident sound to explore the interior vibrational fields in a more complete manner, in order to develop the understnding needed for control of the vibrational response of an acoustic target.

Another facet that should also be explored is the use of sound intensity (sound-power flow per unit area). Sound intensity is now a routinely measurable quantity in fluids and can be used along with sound pressure measurement to explore the sound field in the vicinity of an acoustic target. Sound intensity in solids can be used to compute sound-power flow and acoustic energy fields within a structure, and hence provide additional information about the elastic response of an acoustic target.

Two papers are used as references to be discussed in relation to the approach that is taken in the proposed research. The first [2] published in 1987 is an application of resonance scattering theory (RST) to vibrational modes occuring inside an acoustic target (in this case a solid cylinder). In this study, experiments were conducted with a phototelastic cylinder which showed that modal patterns observed in the interior of the cylinder agree with predicted modal patterns. In the second paper, published in 1976, the resonant modes inside the acoustic target (in this case a solid sphere) are identified to be the modes of free vibration in a vacuum [4]. This explanation was shown to be consistent with the characteristics of the backscattered form function.

The approaches in these two papers appear to be distinct. The RST method apparently includes the effect of the surrounding fluid on the resonances and has a more complex mathematical formulation. Also the modes are described in terms of surface waves i.e. Rayleigh modes and whispering-gallery modes, with the implication that little of significance can occur further in the interior of the target. Examination of the RST paper [2], however, indicates that this interpretation of the modes is not what is found. The computed modal patterns and those observed with the photoelastic cylinder have major features well inside the acoustic target. In addition, a recomputation of the table of frequencies of the RST resonant modes in Reference 2 shows that they are identical to frequencies of the free modes of vibration in a vacuum. Any differences that occur are at most in the third decimal place. The RST paper [2] and the free-vibration paper [3] are therefore essentially in agreement.

That the vibrational modes excited in a structure by incident sound in water are basically the free modes of vibration of the structure (in a vacuum) would appear to represent a major clarification. Implicit in this is an abandonment of the notion that the modes have to be a type of surface wave. With this clarification, the modes excited by incident sound are the same modes as those excited by other means. Standard methods in structural mechanics can therefore be applied to the excitation of structures by sound. Generally the free modes of vibration of a complex structure such as an automobile body or an engine are obtained using finite-element methods. These methods can be used to obtain the resonances excited by incident sound in a submarine hull or a mine casing. Also the methods that have been used to control vibrations in complex structures can be applied to underwater structures excited by incident sound.

2. Work Performed to Date

The principal outcome of the work performed to date is the identification of the types of waves occurring inside acoustic targets. Previously such waves have been inferred from the scattered sound field and have been described in terms of known wave types, that relate either to planar geometries e.g. Rayleigh waves and Lamb waves, or to rigid curved surfaces e.g. whispering-gallery waves and creeping waves. The waves that have been identified consist of torsional vibrations. In the case of a solid sphere, the torsional motion is centered on an annulus perpendicular to the axis of sound propagation. In the case of a solid cylinder the waves are linear and parallel to the axis of the cylinder. Future work will be concerned with the wave structure in shells. In order to obtain a detailed understanding of the vibrations excited in structures by incident sound, it is necessary to start with simple geometries such as a sphere or a cylinder and to build up to more complex shapes. The first piece of work at NCPA is concerned with the solid sphere.

The mathematical expressions for determining the frequencies of the free modes of vibration in a solid sphere are known and have been given in standard texts [4,5]. These were used, for example, in Reference 3. Little is known, however, of the features of the free modes of vibraion within the sphere and it is the pupose here to develop a knowledge of these features. The material of the sphere was assumed to be aluminum. It is expected that the modes will be similar for other materials, but the frequencies will be different.

The characteristics of the modes are determined principally from the displacement vector field inside the sphere. The direction of the displacement vector is given by streamline patterns and the magnitude by contour patterns inside the sphere. As a first step, a tabulation of the modes in the aluminum sphere was made by computing the frequencies of the modes in terms of ka (where k is the wave number in water and a is the radius of the sphere) up to about ka=60. These are listed in Table I.

Two examples are shown here of the displacement fields inside the sphere, namely the (1,3) and (2,3) modes. Because of the axisymmetry, only a cross section of the displacement field through the axis need be shown to describe the entire field inside the sphere. Figure 1 shows the displacement field for the (1,3) resonance at 15.436. Figure 1(a) shows the streamline plot of the displacement and Figure 1(b) shows the contours of the displacement magnitude. The streamlines show that the motion consists of two annular torsional waves, one inside the other, moving in opposite directions like gears. These are similar to smoke rings. The principal effect of displacement within the sphere occurs at the center as shown in Figure 1(b). Figure 1(a) indicates that the motion is a cycling back and forth along the axis. The magnitude of the displacement dies away at the surface of the sphere. Figure 2 shows the displacement field for the (2,3) resonance at ka=18.350. It is seen that there are now two pairs of annular torsional waves. The greatest displacement is again on the axis, as shown in Figure 2(b). This time the displacement is in opposing directions on either side of the center of the sphere.

The resonances excited in a solid aluminum sphere by incident sound waves in water are shown in Figures 3 and 4 for ka=15.436 and 18.350 respectively. It is seen in both cases the mode that is excited is essentially the free mode of vibration. In Figures 3 and 4 the pattern outside the sphere represents pressure waves incident on the sphere from the left. Positive pressure is indicated by the shaded regions and negative pressure by the unshaded regions. The pressure fields outside the sphere consist of both incident plane waves and scattered waves. It is interesting to observe how the streamline pattern of the displacement vector inside the sphere changes during a cycle of the incident sound.

Table I. Frequencies of Free Modes of Vibration of Solid Aluminum Sphere

n \ l	1	2	3	4	5	6	7	8	9	10	11	12
0	12.442	27.337	41.570	55.683								
1	--	7.691	15.436	19.024	22.725	29.405	33.850	36.222	42.866	48.177	49.610	56.238
2	5.610	10.896	18.350	24.218	26.278	32.511	38.969	40.352	46.034	52.639	54.649	59.440
3	8.371	14.307	21.228	27.903	30.861	35.610	42.189	45.985	49.208	55.788		
4	10.749	17.692	24.107	30.948	35.633	38.836	45.238	51.116	52.767	58.884		
5	12.974	20.961	27.011	33.855	39.829	42.525	48.264	54.737	57.620			
6	15.124	24.083	29.948	36.717	43.241	46.799	51.330	57.821				
7	17.230	27.057	32.912	39.562	46.280	51.139	54.556					
8	19.310	29.898	35.885	42.405	49.188	55.077	58.165					
9	21.371	32.628	38.846	45.253	52.043	58.465						
10	23.420	35.271	41.773	48.108	54.872							
11	25.458	37.845	44.652	50.970	57.688							
12	27.488	40.366	47.475	53.831								
13	29.513	42.846	50.242	56.686								
14	31.533	45.293	52.954	59.524								
15	33.548	47.713	55.618									
16	35.561	50.112	58.239									
17	37.570	52.492										
18	39.577	54.856										
19	41.582	57.208										
20	43.585	59.547										
21	45.586											
22	47.585											
23	49.584											

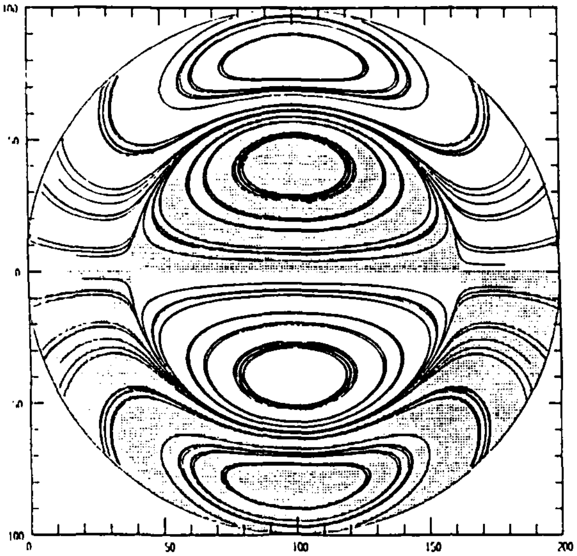


Fig. 1(a). Streamlines of vibrational displacement vector for the (1,3) mode inside the aluminum sphere. Positive direction of rotation is indicated by the shaded area. Negative direction by the unshaded. Essentially the streamlines indicate two annular torsional waves, one inside the other.

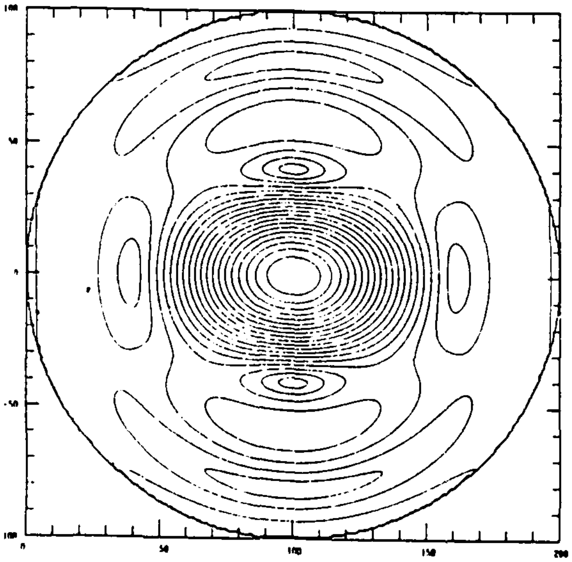


Fig. 1(b). Contour lines of the magnitude of the displacement vector. The peak at the center is due principally to a displacement along the axis cycling back and forth.

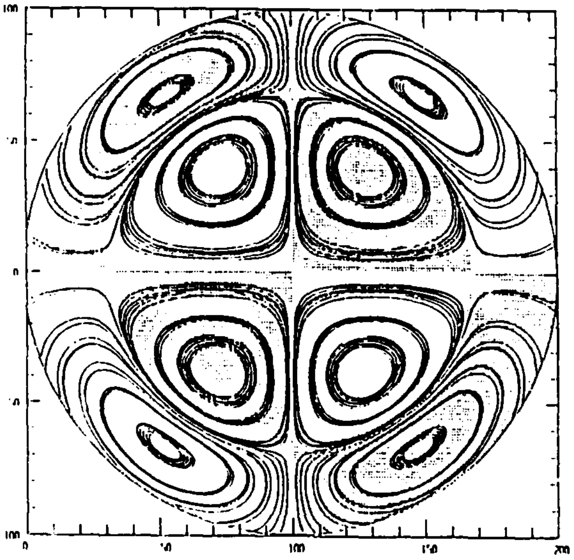


Fig. 2(a). Streamlines of vibrational displacement vector for the (2,3) mode inside the aluminum sphere. Positive direction of rotation is indicated by the shaded area. Negative direction by the unshaded. Essentially the streamlines indicate two pairs of annular torsional waves one inside the other.

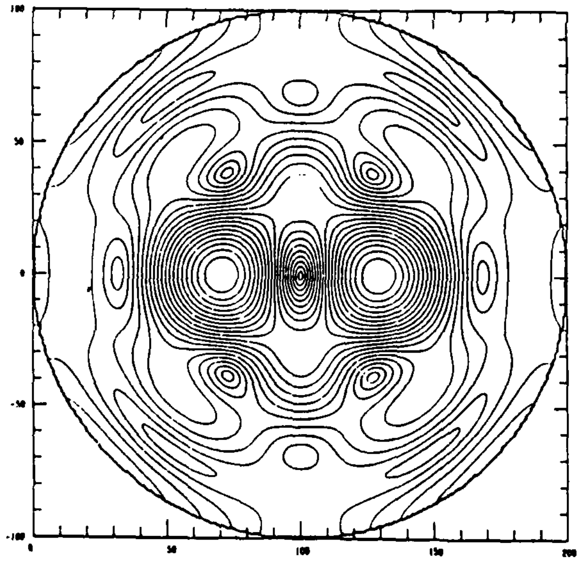


Fig. 2(b). Contour lines of the magnitude of the displacement vector. The peaks on the axis are due to opposing motions of the displacement cycling back and forth on either side of the center.

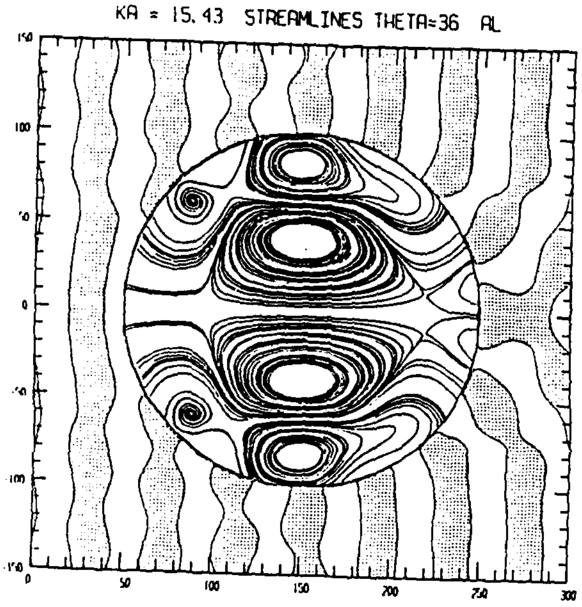


Fig. 3. Streamlines of displacement vector inside aluminum sphere in water, with pressure waves incident from the left. Positive pressure is indicated by shading. This streamline pattern is to be compared with that in Figure 1(a).

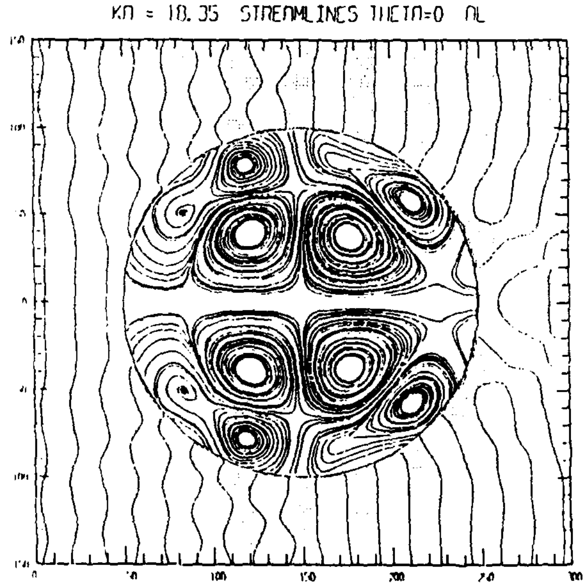


Fig. 4. Streamlines of the displacement vector inside aluminum sphere in water, with pressure waves incident from the left. Positve pressure is indicated by shading. This streamline pattern is to be compared with that in Figure 2(a).

Computations were also performed relating to sound-power flow in and around the spherical target. Some of these results were described in an NCPA report [6]. More complete results will be presented at the International Congress on Structural Intensity at Senlis, France in August, 1990.

III. References Cited

1. L. Flax, G.C. Gaunaurd and H. Uberall, "Theory of Resonance Scattering", Chapt. 3, Physical Acoustics, Vol. XV. W. P. Mason and R. M. Thurston (editors), (Academic Press, New York, 1981).

2. H.D. Dardy, L. Flax, C.F. Gaumond, J.V. Subrahmanyam, S. Ashrafi, P.K. Raju and H. Uberall, "Acoustically Induced Stresses in Elastic Cylinders and Their Visualization". Journ. Acoust. Soc. Amer, 82, 4, 1378-1385 (1987).

3. R.H. Vogt and W. G. Neubauer, "Relationship between Acoustic Reflection and Vibrational Modes of Elastic Spheres", Journ. Acous. Soc. Amer., 60, 1, 15-22 (1976).

4. A.E.H. Love, "Treatise on the Mathematical Theory of Elasticity", Dover Publications, pp. 284-286, (1944).

5. P.M. Morse and H. Feshbach, "Methods of Theoretical Physics", Part II pp. 1872-1874, (1953).

6. R. Hickling, R. K. Burrows and J.F. Ball, "A Return to an Old Acoustics Problem, The Scattering of Sound by a Solid Elastic Sphere", NCPA Report RH-04-89, National Center for Physical Acoustics, University of Mississippi (1989).

D. MACHINERY NOISE

1. Introduction

The development of sound-intensity measurement methods has provided a powerful tool for the control of machinery noise. The early history of sound-intensity measurement has been described, for example, in Reference 1. However, sound-intensity measurement only became practical with the advent of laboratory digital computers and analyzers, and was first applied, in the United States, at General Motors [2-9]. This latter work included development of the cross-spectral formulation of sound intensity, the switching technique for correcting phase mismatch, and the scanning method with simultaneous time and spatial averaging. This was followed by developments at Bruel and Kjaer [10-12]. Subsequently the fundamental theory of sound-intensity fields was investigated at Penn State [13, 14] and elsewhere [15].

Sound intensity methods are ideal for noise reduction in naval vessels. They can be used to identify noise hot-spots on the hull and to relate these to interior sources of vibration. They can also be used to investigate machinery noise inside the hull.

2. Work Performed to Date

Work so far at NCPA has been concerned with investigations of the noise of machinery in air. A major study was performed of the noise of six automobiles provided by the auto industry [16].

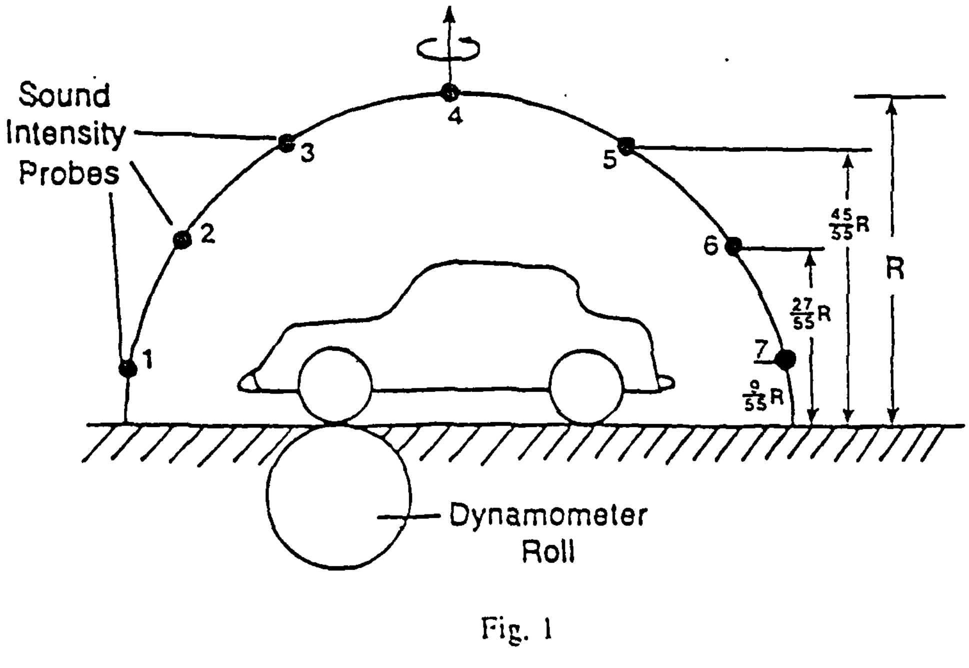


Fig. 1

The sound power of each automobile was measured, as a function of engine speed and load, using a semicircular array of sound-intensity probes, rotated around the vehicle, as shown schematically in Figure 1. A photograph of the structure supporting the array of probes and of a vehicle in the test area is shown in Figure 2. In this work the diagnostic capabilities of sound-intensity methods were demonstrated. The sound-intensity distribution on the measurement hemisphere indicates the location of the dominant sources in the vehicle. For example, in Figure 3, the dominant sources of the vehicle are in the engine compartment. Narrow-band spectra of the sound power are also an important diagnostic indicator. For example, the sound-power spectrum in Figure 4 shows a series of peaks, dependent on the rotational speed of the engine, that are related to different components of the power train. The relative contribution of the different components can be determined from this data.

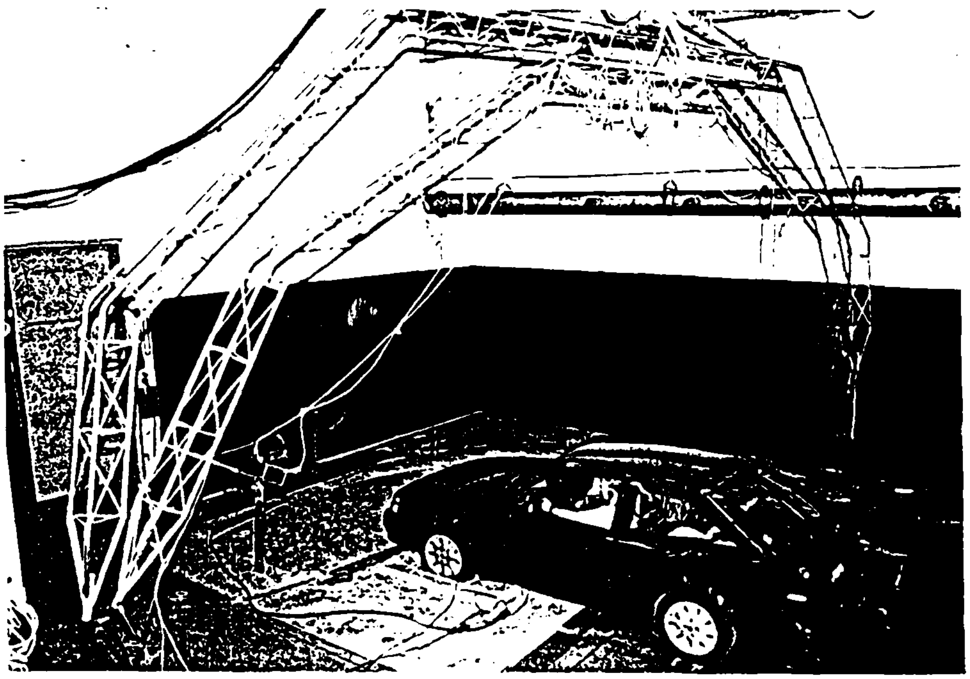
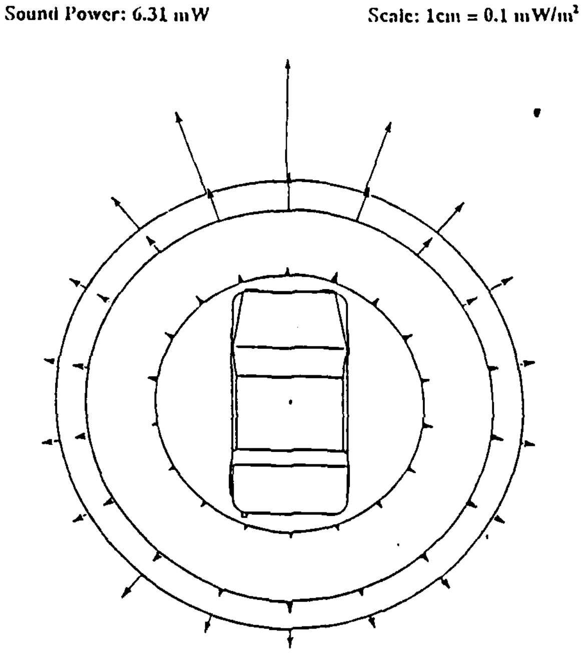


Fig. 2



Sound Intensity Distribution on
Measurement Hemisphere for Car No. 2
at 4300 r/min and 67.8 N.m. Load

Fig. 3

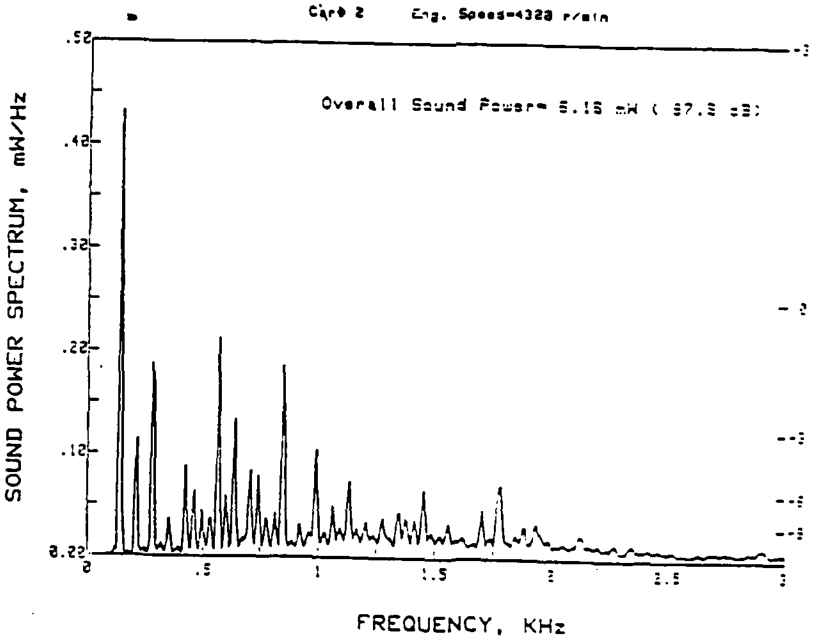


Fig. 4

Similar tests have been performed on other mechanical sources such as power generators, lawn mowers and motorcycles [17]. Figure 5 shows a motorcycle in the test area at NCPA with the

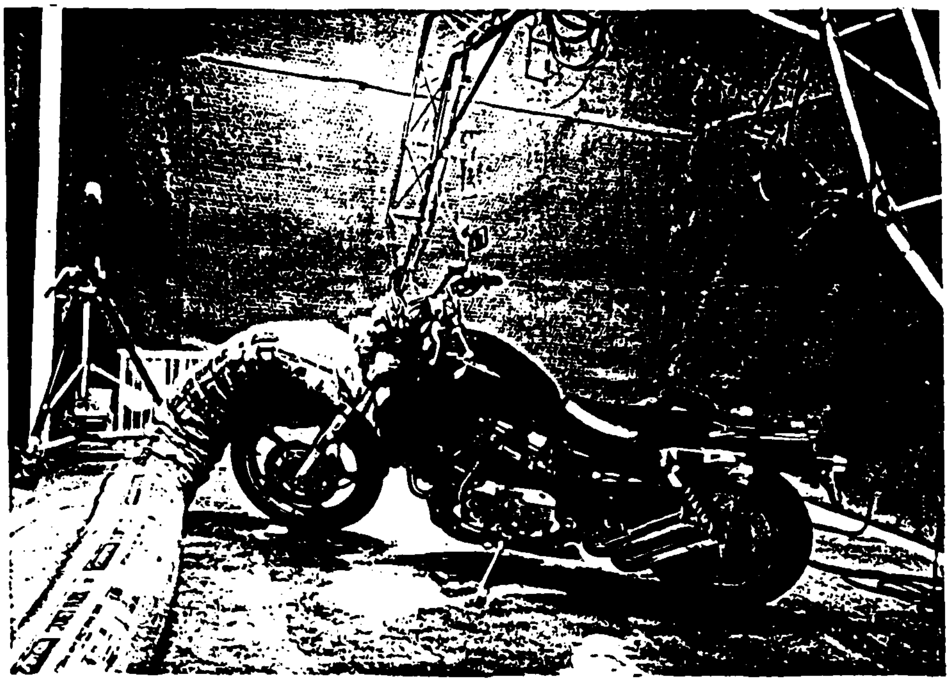


Fig. 5

semicircular array of probes. A part of this work was performed to aid in the development of world-wide sound-power standards for noise sources, as well as for noise-control diagnostics. Sound-power standards are superior to older sound-pressure standards, for a number of reasons.

III. References Cited

1. F.J. Fahy, "Sound Intensity" Elsevier Applied Science, (London and New York, 1989).

2. R. Hickling and M. M. Kamal (editors), "Engine Noise: Excitation, Vibration and Radiation", Plenum Press, New York, (1982).

3. J.Y. Chung, "Cross Spectral Method of Measuring Acoustic Intensity", Research Publication GMR-2617, General Motors Research Laboratories (1977).

4. J.Y. Chung and J. Pope, "Practical Measurement of Acoustic Intensity - The Two Microphone Cross-Spectral Method", Proceedings of the 1978 International Conference on Noise Control Engineering, INTERNOISE 78, San Francisco, CA, May (1978).

5. J.Y. Chung, "Cross-Spectral Method of Measuring Acoustic Intensity Without Error Caused by Instrument Phase Mismatch", J. Acoust. Soc. Amer., Vol. 64, pp. 1613-1616, (1978).

6. J.Y. Chung, J. Pope and D.A. Feldmaier, "Application of Acoustic-Intensity Measurement to Engine Noise Evaluation", Proceedings of Diesel Engine Noise Conference, Society of Automotive Engineers, Paper No. 790502, SAE Publication P-80, (1979).

7. J. Pope, R. Hickling, and D.A. Feldmaier. "Acoustic Intensity Measurements of the Sound-power of a Truck", Research Publication GMR-3272, General Motors Research Laboratories, Warren, MI, April (1980).

8. J.Y. Chung and D.A. Blaser, "Recent Developments in the Measurement of Acoustic Intensity Using the Cross-Spectral Method", Paper No. 810396, Society of Automotive Engineers, (1981).

9. R. Hickling, "Sound-Power Measurement Using the Cross-Spectral Technique", Proceedings NOISE CON 81, North Carolina State University, Raleigh, NC, June (1981).

10. G. Rasmussen, "Intensity Measurements - The Analysis Technique of the Nineties", Publication by Dept. 13, Bruel and Kjaer Inc., August (1984).

11. Anom. "Characteristics of Microphone Pairs and Probes for Sound-Intensity Measurement", Bruel and Kjaer Report, Naerum, Denmark (1987).

12. E. Frederikisen and O. Schultz, "Pressure Microphones for Intensity Measurement with Significantly Improved Phase Properties", Bruel and Kjaer Technical Review No. 4, Naerum, Denmark (1986).

13. G.E. Elko, "Frequency Domain Estimation of the Complex Acoustic Intensity and Energy Density" Ph.D. Thesis, Pennsylvania State University (1984).

14. J. A. Mann, J. Tichy, A. J. Romaro, "Instantaneous and Time-Averaged Energy Transfer in Acoustic Fields", Journ. Acoust. Soc. Amer. 82, 1, 17-30, (1987).

15. J.C. Pascal and J. Lu, "Advantage of the Vectorical Nature of Acoustic Intensity to Describe Sound Fields", Proc. InterNoise '84, 111-114 (1984).

16. R. Hickling, "Narrow-Band Indoor Measurement of the Sound Power of a Complex Mechanical Noise Source", Journ. Acoust. Soc. Amer., 87, 3, 1182-1191, (1989).

17. R. Hickling, P. Lee and W. Wei, "Sound-Power Tests of a Small Engine-Driven Source", International Congress on Recent Developments in Structure-Borne Sound and Vibration, Auburn University, March 6-8 (1990).

E. PROPAGATION PHYSICS

I. Introduction

This project studies the physics of stochastic and deteriministic sound propagation. In both areas the objective is to identify and understand the primary physical mechanisms that govern the propagation of sound, especially for low-frequency, long-range propagation.

A. Stochastic Sound Propagation

The stochastic propagation research, which is a continuation of FY89 research, has focused on the effects of atmospheric turbulence on sound propagation at frequencies below 1000 Hz. Research in FY90 will use results from experimental and numerical studies to develop a single scattering model for sound propagation in a turbulent atmosphere. Future research will apply the methods developed for the atmosphere to stochastic sound propagation in the ocean.

B. Deterministic Sound Propagation

In deterministic sound propagation there are two separate efforts. The first, a study of low-frequency reverberation from the ocean surface, is a new start. The second, a study of a shallow pond as an ocean acoustics test facility, is a continuation from FY89.

The low-frequency reverberation work will investigate scattering from realistic ocean surfaces which include both surface roughness and near-surface bubble distributions. The coupling of the scattered sound to the ocean waveguide will be studied using a recently developed spectral decomposition method. [1]

II. Research Progress in FY89

A. Stochastic propagation

The specific problem addressed in FY89 was the calculation of turbulence effects in an upward-refracting atmosphere. A theoretical study, which was based on a parabolic equation model developed earlier [2,3], has been completed. The results were compared to the extensive measurements of Weiner and Keast who showed that the relative sound pressure level versus range follows a characteristic step function [4]. The strong dependence of the step function on upward refraction and weak dependence on frequency had gone unexplained for over 30 years. The theoretical calculation, which included the effects of turbulence, predicted the step function characteristics both qualitatively and quantitatively. Figure 1 shows the relative sound pressure level versus range for a refracting, turbulent atmosphere. The theoretical predictions with turbulence (solid lines) follow the step function observed by Weiner and Keast (connected dots) while the theoretical prediction without turbulence (dashed line) grossly underpredicts the levels at long range. The theoretical predictions with turbulence were Monte Carlo calculations done for particular realizations ("snapshots") of turbulence. As shown by the two trials, the details of the calculation varied from trial to trial, but the large-scale patterns stayed the same, and agree qualitatively and quantitatively with the measurements of Weiner and Keast. The study showed conclusively that above a few hundred Hertz, sound propagation in an upward-refracting atmosphere is dominated by scattering from turbulence. A paper on the work has been accepted for publication [5]. The journal's peer review of the paper included the following citation: "...This is a very important and pioneering paper, and represents a breakthrough in the field of atmospheric sound propagation."

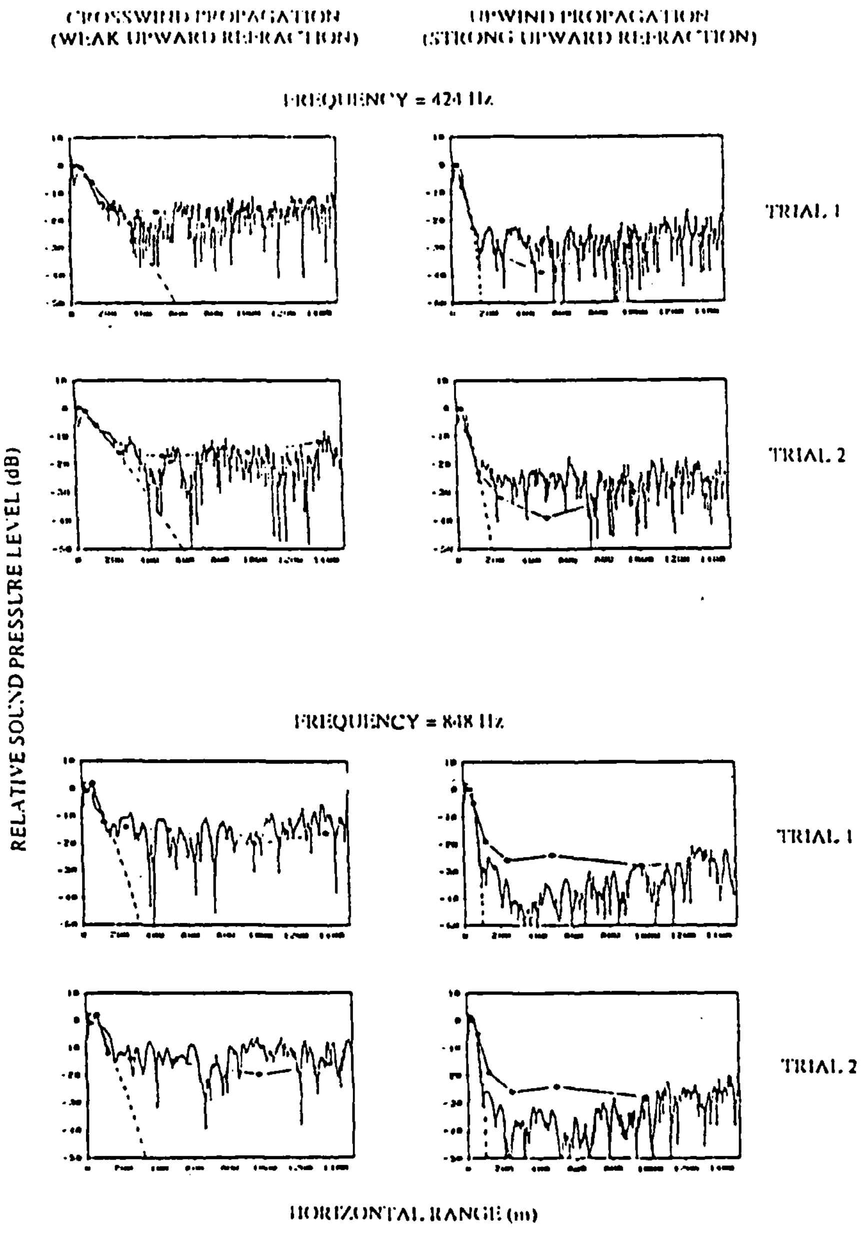


Figure 1. Relative sound pressure level versus horizontal range for a refracting, turbulent atmosphere. The connected dots are the data of Weiner and Keast. The solid lines are parabolic equation calculations with turbulence. The dashed line are parabolic equation calculations without turbulence. Trials 1 and 2 are for two different realizations of the stochastic part of the index of refraction.

B. Deterministic Sound Propagation

Research for FY89 proposed originally to use a vertical array to perform modal decomposition in a shallow pond. The purpose of the array was to resolve ambiguities in the data analysis that arose from using a single receiver. It was found that by imposing physical constraints on the possible values of the amplitude and phase of the bottom reflection coefficient, R, one could carry out the analysis using only a single receiver. Consequently the vertical array was not used. The single-receiver analysis has been completed and will be submitted for publication in 1990. Figures 2 and 3 show some of the results obtained. Figure 2 is a theoretical least-squares fit (dashed line) to the data (solid line) using a normal mode model with an adjustable complex reflection coefficient for the bottom. In earlier studies, the fits could not be determined uniquely and often gave unphysical values for the phase and magnitude of the complex reflection coefficient. By putting additional constraints on R, physically meaningful results could always be obtained. Figure 3 shows the magnitude of R for the first and second modes. As shown in the figure, The value for the magnitude of R is about .9 with little dependence on frequency or mode (angle). These results are in agreement with estimates for R obtained from pulse measurements in deeper water over a gassy-sediment bottom [6].

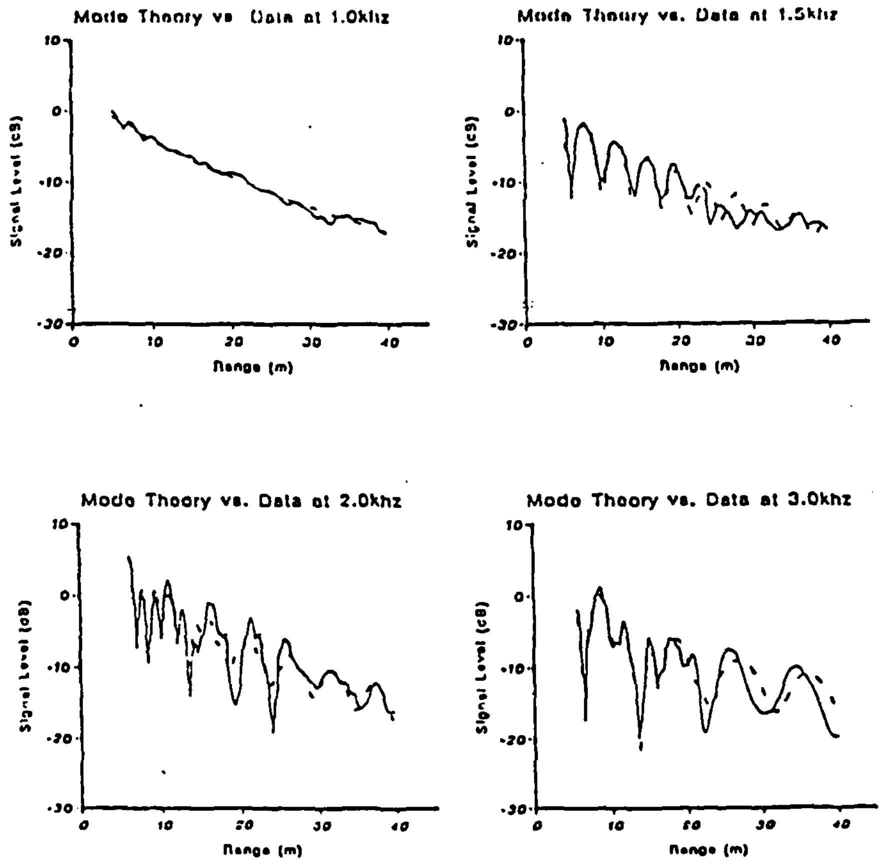


Figure 2. Normal-mode model fit (dashed line) to data (solid line) measured in a shallow, flat-bottomed pond. The magnitude and phase of the bottom reflection coefficient were adjusted to fit the data.

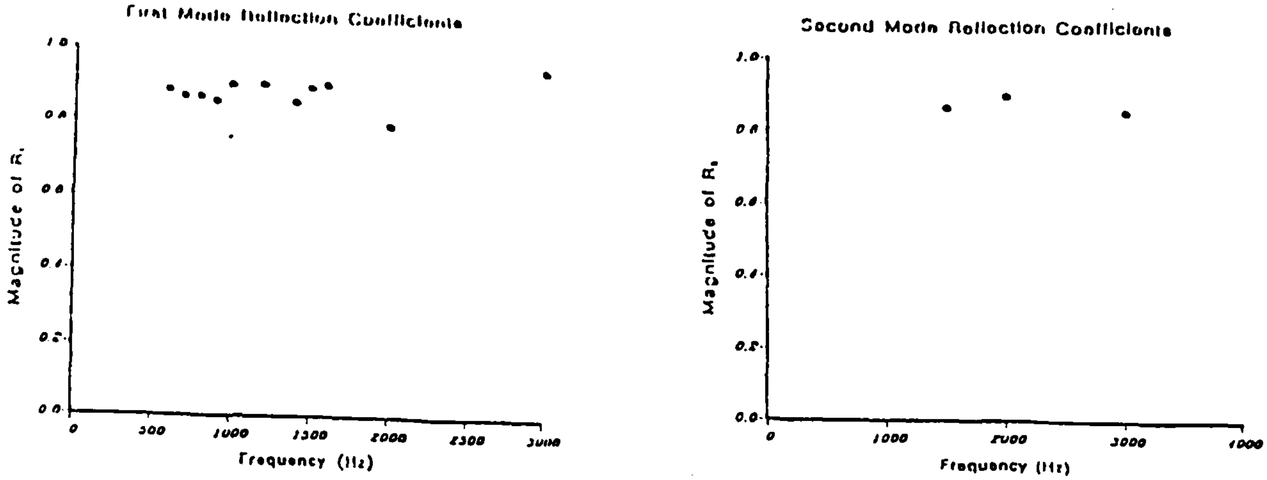


Figure 3. Magnitude of the bottom reflection coefficient obtained from a least-squares normal-mode fit of the data in Figure 2.

III. References Cited

1. Kenneth E. Gilbert and Xiao Di, "Spectral decomposition and propagation of scattered fields in an ocean waveguide," invited paper, Second IMACS Symposium on Computational Acoustics, Princeton University, 1989. To be published in a refereed book.

2. Kenneth E. Gilbert and Michael J. White, "Application of the parabolic equation to sound propagation in a refracting atmosphere," J. Acoust. Soc. Am. 85, 630-637 (1989).

3. Michael J. White and Kenneth E. Gilbert, "Application of the parabolic equation to outdoor propagation of sound," invited paper in Applied Acoustics : Special Issue on "Propagation in Layered Media," edited by Keith Attenborough. [Applied Acoustics, 27, 227-238 (1989)].

4. F. M. Weiner and D. N. Keast, "Experimental study of sound propagation of sound over ground," J. Acoust. Soc. Amer., 31, 724-733 (1959).

5. Kenneth E. Gilbert, Richard Raspet, and Xiao Di, "Calculation of turbulence effects in an upward-refracting atmosphere, to appear in J. Acoust. Soc. Amer., May 1990.

6. J.L. Jones, C.B. Leslie, and L.E. Barton, "Acoustic characteristics of underwater bottoms," J. Acoust. Soc. Amer., 36, 154-157 (1964).

7. Michael J. Buckingham, "Theory of three-dimensional acoustic propagation in a wedgelike ocean with a penetrable bottom," J. Acoust. Soc. Amer., 82, 198-210 (1987).

8. Lambert E. Murray and Kenneth E. Gilbert, Normal mode propagation in a commercial catfish pond." Presented at the 112th meeting of the Acoust. Soc. of Amer., December 1986.

9. Kenneth E. Gilbert and Joe R. Zagar, "The low-frequency reflection coefficient of a gassy sediment." Presented at the 115th meeting of the Acoust. Soc. of Amer., May 1988.

F. SOLID STATE ACOUSTICS

I. Introduction

Over the past several years a series of our publications has made fundamental contributions to the understanding of the relationship between the interatomic potential function on the one hand and lattice anharmonicity and nonlinearity on the other. Initially, it was sufficient to consider the behavior of atoms in a cubic lattice. Based on cubic lattice theory and its experimental confirmation, a technique was developed to measure third order elastic constants and their temperature dependance. This technique has been used to evaluate a large number of cubic solids, especially the floroperovskites, therefore a considerable amount of information is available.

II. Research Progress in FY 89

Expansions of our capabilities were accomplished last year: both experimental and theoretical.

1. Experimental accomplishments:

In the course of examining the nonlinear properties of $KMnF_3$, an extremely fragile fluoroperouskite, Cao and Barsch of Penn State realized that the harmonic generation technique developed at UT was the only way to take third order elastic constants data as a function of temperature. Alternative techniques destroyed the samples. Thus, a collaborative effort was begun which culminated in publication of Reference 1: "Temperature Dependence of Third Order Elastic Constants of Potassium Manganese Fluoride." This publication emphasizes the importance of the technique, as data could not have been taken without it.

During FY 89 we attempted to build on the progress made in 1988. A boule of GaAs was purchased, as well as cutting and polishing apparatus. Much of the time has been spent learning the fundamentals of cutting and polishing of GaAs. As arsenic is poisonous, this is not a trivial matter. The information gained is invaluable, however, both with measurement of GaAs and handling of similar samples in the future.

Learning also is taking place with samples of the high T_C superconductor $YBa_2Cu_3O_{7-\delta}$. A set of samples was purchased and is being studied. We hope to obtain more dense samples in the future; however, data on ultrasonic wave propagation characteristics are being taken with the samples in our possession.

2. Theoretical Accomplishments

It had been evident for some time that there are many samples having lower symmetry than cubic, and that their third order elastic constants would be of interest. The problem was that the tensor analysis was complicated enough that direct mathematical solutions were somewhat impractical. We had solved for hexagonal and rhombohedral symmetry, but had not gone further - nor did we have an independent confirmation of our calculations. During a recent visit to the University of Tennessee, Dr. Gerlich made calculations of harmonic generation of ultrasonic waves propagating in crystals of all known symmetries. The calculation was made using SCHOONSCHIP, a computer program for symbolic evaluation of algebraic expressions. The results are given in Reference 2: "Ultrasonic second-harmonic generation in various crystalline systems: Coupling parameters in terms of elastic moduli and propagation directions," which also examines the possibility of evaluating complete sets of third order elastic constants of cubic, hexagonal, rhombohedral, tetragonal, and orthorhombic crystals.

The continuation of the theoretical work into FY 1989 has involved the use of the same calculation, but introducing piezoelectricity resulting from crystalline assymmetries. By essentially calculating twice: Once with piezoelectric terms and once without, we have been able to evaluate the magnitude of the effect of piezoelectric coupling. But such data often are interpreted by theories which do not correctly account for piezoelectricity. We have calculated the magnitude of the discrepancy caused by the use of inadequate theories. It is noticeable in the third order elastic constant magnitudes. A publication on this subject, Reference 3, has been submitted to the Journal of Applied Physics.

IV. References Cited

1. Cao, Barsch, Jiang and M. A. Breazeale: Temperature Dependence of Third-Order Elastic Constants of Potassium Manganese Fluoride. Phys. Rev. B 38, 10244-10254 (1988).
2. D. Gerlich and M. A. Breazeale: Ultrasonic Second Harmonic Generation in Various Crystalline Systems. Coupling Parameters in Terms of Elastic Moduli and Propagation directions. J. Appl. Physics 63, 5712-5717 (1988).
3. D. Gerlich and M. A. Breazeale: Ultrasonic Second Harmonic Generation in Various Crystalline Systems II. Piezoelectric Materials. Accepted for publication in J. Appl. Phys.

G. SHORT-RANGE ULTRASONIC SENSING

1. Introduction

Focussed ultrasound has been widely used in medical ultrasonics and in non-destructive evaluation. More recently close-range focussed ultrasonic sensors were used for the first time in air, for quality and process control on a production line, to detect missing and out-of-position locking keys in engine valves [1]. Surface features of this type can be readily determined with an accuracy of ± 0.1mm [2]. There are many potential uses for close-range focussed ultrasonic sensing in manufacturing. The most immediate applications involve planar surfaces, examples of which are given below. In addition to scanning planar surfaces, a method has been developed by personnel at NCPA for close-range scanning of arbitrary curved surfaces, where the focussed ultrasonic sensor provides feedback to the device that controls the sensor, enabling it to follow the outline of the surface. This is a new capability not previously available.

In water, it is possible to use close-range ultrasonic sensing to investigate subsurface features as well as surface features. This is standard in non-destructive testing. Generally the procedure is performed with known planar surfaces and simple Cartesian control, with minimal feedback from the sensor. In this project, it is proposed to apply the procedure that has been developed in air, to scan arbitrary curved surfaces underwater using feedback control. It should be emphasized that the scan is controlled entirely from information from a single focussed ultrasonic transducer. This has application to non-destructive testing in tanks, as well as to scanning ships' hulls and other underwater surfaces of interest to the Navy.

2. Research Progress in FY 89

An experimental facility set up in FY 88 has been used in several studies of applications of short-range ultrasonic sensing of planar surfaces in air:

(1) At a range of 25mm, it was shown that a step between two precisely machined blocks could be measured with an accuracy of 15 microns. In air, this amount of accuracy is significant.

(2) It was shown that the flexural motion of a membrane (i.e. a paper sheet) could be measured accurately. The repetition rate of the ultrasonic pulses was 1 kHz and the oscillations of the membrane was several Hz. The oscillations of the membrane are thus easily resolved. The trace of the flexural oscillations obtained with this procedure is shown in Figure 1. The focussed transducer was at a standoff distance from the membrane of 150 mm.

(3) A transducer focussed at 150mm was used to measure the acid levels in the compartments of a battery, through the fill holes. The battery passes under the transducer on a conveyer belt. The operation is shown in Figure 2. The liquid levels in each compartment are shown on the monitor screen in the background of the figure.

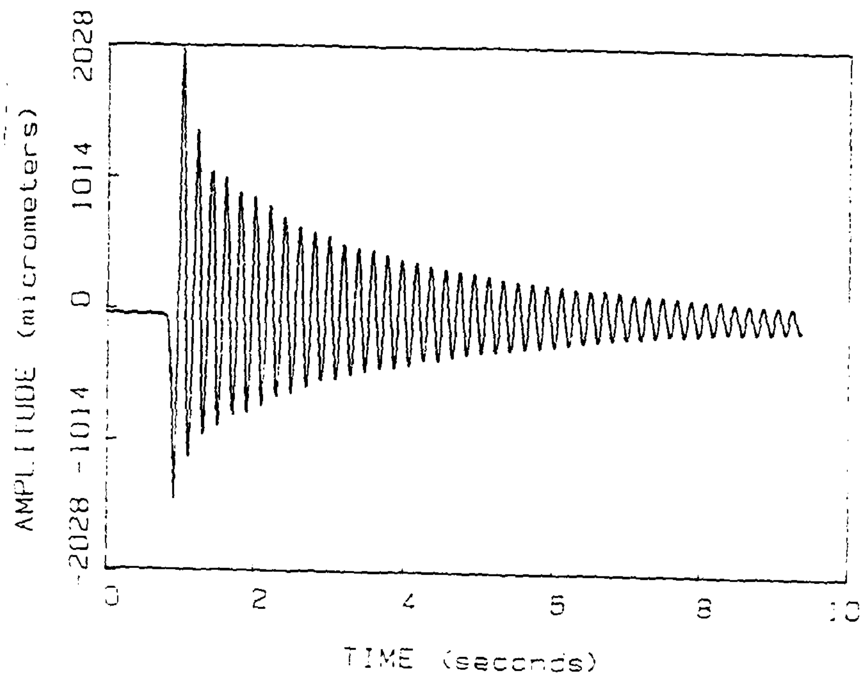


Fig. 1

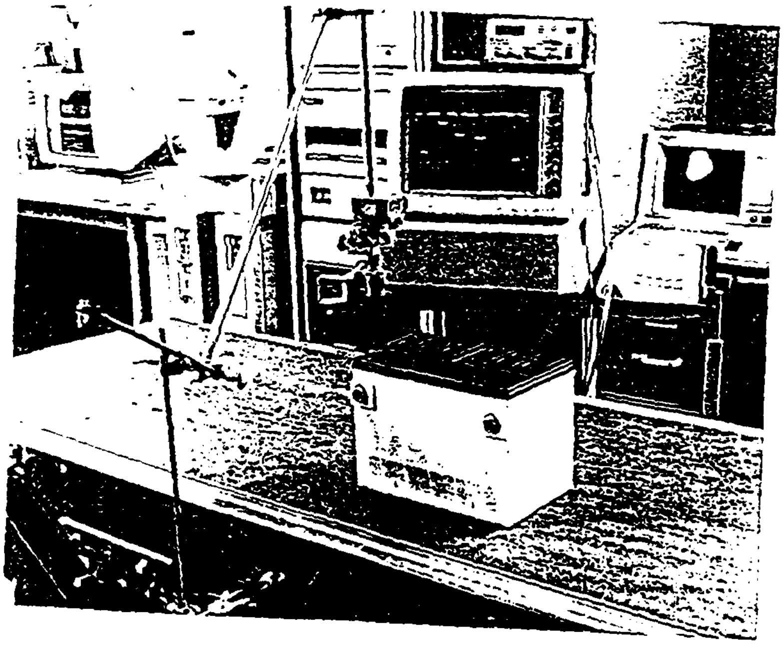


Fig. 2

III. References Cited

1. V. Dahlmann and R. Hickling, "KEYCHECK - The Use of Focussed Ultrasound for Non-Contact On-Line Inspection of Locking Keys in Engine Valves", to be published in Sensors Magazine.

2. R. Hickling and S. P. Marin, "The Use of Ultrasonics for Gauging and Proximity Sensing in Air", Journ. Acous. Soc. Amer., 79, 4, 1151-1160, (1986).

H. ELECTRO-RHEOLOGICAL FLUIDS

I. Introduction

In 1942 a patent was issued to Willis M. Winslow[1,2] which disclosed evidence of an electroviscous effect for a fluid composed of micronized silica gel particles, an oil-based fluid, and water. This fluid had the property of an enormous increase in viscosity when an electric field on the order of 4 kV/mm was applied. Since a fluid with a variable viscosity is a very desirable quantity, especially since this viscosity could be turned on or off in a millisecond, there was considerable interest in this phenomenon.

Modern ER fluids generally consist of a suspension of hydrated, hydrophilic particles in a hydrophobic and electrically insulating base liquid. (There are claims of anhydrous fluids in which an electrolyte replaces the water. The details of these claims are either proprietary or classified.) The particular fluid employed in our studies to date was a simple suspension of corn starch in peanut oil.

Probably the most important experimental observation concerning these fluids is that once a sufficiently intense electric field is applied, the static shear strength and dynamic shear viscosity increases. The effect most likely results from a one dimensional linkage of electric dipoles along the electric field lines. It is more accurate to describe the effect as the introduction of a structural framework that gives rise to an effective increase in viscosity; thus, the term "electrorheological" is to be favored over the term "electroviscous".

The specific details of how these chains are formed are the subject of some disagreement[3], and have been attributed to (a) formation of water bridges[3], (b) orientation of particles[4], (c) deformation of the electrical double layer[5], (d) interelectrode circulation[6], and (e) particle interactions[7]. A plausible scenario for the effect might go as follows: The electric field causes movement of mobile ions in the fluid contained either within or on the surface of the dispersed particles (some particles *ad*sorb the conducting fluid; some *ab*sorb it). This movement of ions leads to the production of electric dipoles that are oriented along the field lines. In the center of each dipole is a solid particle; thus, once the dipoles link together, a one dimensional chain of solid particles is formed that is coupled by electric forces. In one sense, then, a one-dimensional solid has been formed. Since there is little evidence of cross-linking between adjacent chains, the rheological characteristics of the fluid should be different depending upon whether measurements are made either parallel or perpendicular to the field lines. This prediction appears to be borne out by some preliminary observations[8].

At present, there is a paucity of information on the fundamental mechanisms through which these fluids function. Much of the available research has been carried out in the Soviet Union; for example, Deinega[9] has reviewed the state-of-the-art of ER research in the USSR and reports variations in some electrical parameters with water content; Anaskin[10] *et al.* have studied the effect of the external electric field on the amplitude and frequency characteristics of electrorheological dampers--they found that ER fluid-based dampers afforded a significant improvement in isolation characteristics when compared to conventional methods; Vinogradov[11] *et al.* have examined the viscoelastic behavior of ER suspensions and describe the sequences of structures that form the framework of the system-- first chains, then fibers, then dendrites, then rigid bridges; finally, a single paper by Korobko and Chernobai[8] has been written on ultrasound propagation in ER fluids--they find relative increases in velocity when sound is propagated parallel to the electric field lines, but their work is extremely restricted in scope and of limited utility.

II. Research Progress in FY 89

Using the apparatus shown in Fig. 1, we have been successful in obtaining preliminary results giving the dependence of ultrasonic compressional wave velocity through a cornstarch and peanut oil mixture as a function of applied field strength. Our results were limited to measurements at a single frequency, 1 MHz, and in a single direction, parallel to the applied field. Data was obtained for three different concentrations (given as percent solid by weight) and is plotted in Fig. 2 (a-c) below.

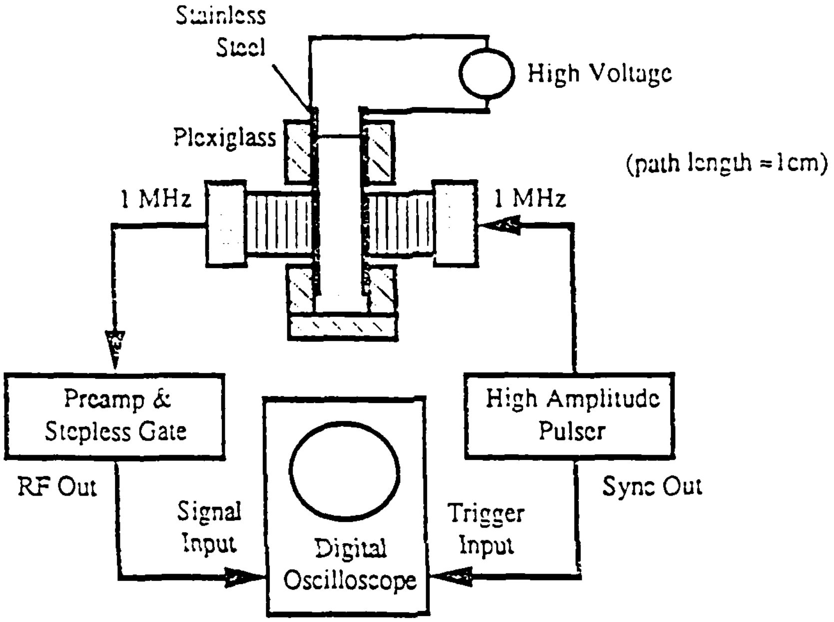


Figure 1: Apparatus for compressional wave sound velocity measurements to quantify the ER effect at one megahertz.

For all the cases studied, we found the changes in sound velocity to be quite small. (≈0.3%) a result which exhibits qualitative agreement with the results of Korobko and Chernobai[11]. We saw no detectable change in attenuation with electric field strength, which is also in agreement with the Soviet study. Although the application of an electric field dramatically alters ER fluid rheology, the high-frequency, compressional bulk modulus does not undergo a dramatic change. None the less, there is a measurable change in sound velocity which begins at the low field strengths and levels off rather quickly. The low and medium concentration data (17% and 29% respectively) exhibited strikingly similar behavior. However, the high concentration fluid exhibited very little change in sound velocity despite the fact that its viscosity increase was much greater than that observed with the less concentrated suspensions. We have a simple (and probably simplistic) explanation for this peculiar result. When the field is turned on, there is a notable migration of particles as the one-dimensional "matrix" is set up in the fluid between the electrodes. This movement alters the particle concentration locally, which may be the cause of the observed changes in sound velocity. It is possible that the 50% suspension is already so concentrated that the small changes induced in the local concentration induced by particle relocation are insignificant. We find this concentration dependence to be interesting; an effect which warrants further investigation.

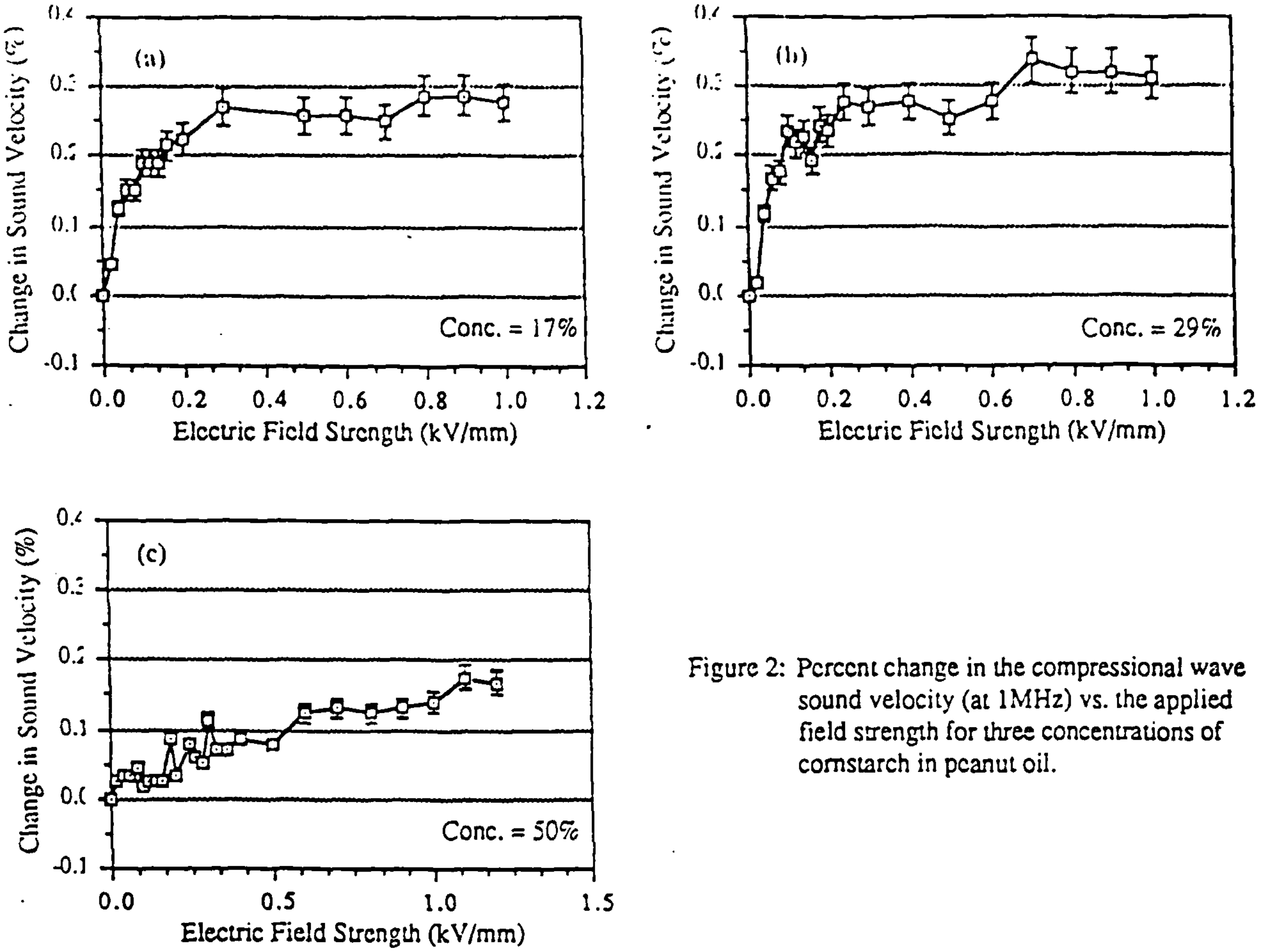


Figure 2: Percent change in the compressional wave sound velocity (at 1MHz) vs. the applied field strength for three concentrations of cornstarch in peanut oil.

III. References Cited

1. W. H. Winslow, U.S. Patent 2,417,850 (March 25, 1947).
2. W. H. Winslow, "Induced fibration of suspensions," J. Appl. Phys., 20, 1137 (1949).
3. J. E. Stangroom, "Electrorheological fluids," Phys. Technol. 14, 290 (1983).
4. C. E. Chaffy, J. Colloid and Inter. Sci., 20, 330 (1965).
5. Yu. F. Dienaga and G. V. Vinogradov, Kolloidn. Zhurn. 24, 688 (1962).
6. V. N. Shilov and Yu. F. Deinega, "The electrorheological effect in interelectrode circulation of particles of dispersed phase," Electron Obr. Mater. 3, 44 (1974).
7. E. E. Bibik and V. E. Skobochkin, "Friction torque in a rotating magneto-rheological effect in colloidal ferromagnets." Inzh. Fiz. Zhurn., 22, 687 (1972).
8. E. V. Korobko and I.A. Chernobai, "Influence of an external electric field on the propagation of ultrasound in electrorheological suspensions," Trans. from Inzhenerno-Fizicheskii Zhurnal, 48, 219 (1985).

9. Yu. F. Deinega, Polimery i Rezinov Smesei, No. 1, 29 (1978); Libr. Trans. No 2092, Roy. Aircraft Est. (1982).

10. I. F. Anaskin, V.K. Gleb, E.V. Korobko, B.P. Khizhinskii and B.M. Khusid, "Effect of external electric field on amplitude-frequency characteristics of electrorheological damper," Trans. from Inzhenerno - Fizicheskii Zhurnal, 46, 309 (1982).

11. G. V. Vinogradov et al., "Viscoelastic behavior of electrorheological suspensions," Trans. from Inzhenerno-Fizicheskii Zhurnal, 50, 605 (1985).

12. E. R. Generazio, "The role of the reflection coefficient in precision measurement of ultrasonic attenuation," Mat. Eval., 43, 995 (1985).

I. TRANSDUCER DEVELOPMENT

I. Introduction

The existence of an unusually precise Ultrasonic Schlieren system in our laboratory has led to the examination of a large number of ultrasonic fields in liquid media. For example, considerable study of the reflection of sound at a liquid-solid interface has taken place. More recently the Gaussian transducer that facilitated these studies has been examined with the Schlieren system and otherwise. Schlieren visualization of ultrasonic fields continues to provide direct results that are unavailable otherwise. The combination of Schlieren results and results from probe transducers allows a complete mapping of the field as well as direct visualization.

II. Research Progress in FY 89

1. Gaussian transducer development

We have fabricated and sent to the University of Texas, Gaussian transducers which operate at 2 MHz and 250 KHz. Although the beam characteristics are not as good as those of our 4 MHz Gaussian transducer, we nevertheless hope that an unambiguous test can be made of the nonlinear theory of scattering of sound by sound developed by Tjøtta and Tjøtta, and others.

2. Diffraction beam field expressed as the superposition of Gaussian beams

The evaluation of the diffraction field of even a piston source becomes complicated as one enters the Fresnel field, and becomes more inexact as the propagation distance becomes smaller and smaller. Until very recently, the problem essentially had ruled out consideration of finite amplitude distortion in a diffraction field. To get around this problem we decided to express the diffraction field as a superposition of Gaussian functions because the evaluation of the diffraction field becomes trivial for Gaussian amplitude distributions. The problem we encountered is that Gaussian functions are not orthogonal functions unless some special mathematical tricks are used.

To overcome the mathematical difficulties we decided to express the diffraction field as the superposition of a small number of Gaussian functions, and to use computer optimization to evaluate coefficients. The procedure gave surprising results. Only a small number of Gaussian functions gave a good fit even of the boundary condition at a piston radiator (with its mathematical discontinuity at its edge). The results are described in Reference 1: "A diffraction beam field expressed as the superposition of Gaussian beams." To study this problem in more detail, the Second IMACS Symposium on Computational Acoustics was organized for March 15-17, 1989 at Princeton University. Reference 2 is a transcription of our contribution to the IMACS Symposium.

3. Acoustical Microscopy

Wedge transducers of Lithium Niobate were provided by David Cheeke of the University of Sherbrooke. These transducers have the characteristic that a beam emerges from the location of a half-wavelength thickness. Thus, a swept frequency results in a sweeping of the beam across the transducer. During FY 89 we have made Schlieren photographs of the emerging beam under at a constant frequency. The Schlieren system is ideally suited for such photographs. Study of the photographs will give considerable information that can be used to improve resolution of the microscope. The inclusion of a Gaussian profile would improve resolution further.

III. References Cited

1. J. J. Wen and M. A. Breazeale: A Diffraction Beam Field Expressed as the Superposition of Gaussian Beams. J. Acoust. Soc. Am. 83, 1752-1756 (1988).

2. J. J. Wen and M. A. Breazeale: Computer Optimization of the Gaussian Beam Description of our Ultrasonic Field, in Proceeding of the Second IMACS Symposium, Edited by D. Lee, A Cakmak, and R. Vichnevetsky, Princton, NJ., March 1989.

II. RESEARCH COMMUNICATIONS FROM PERSONNEL OF THE NATIONAL CENTER FOR PHYSICAL ACOUSTICS

(1989 - 1990)

A. Published papers (including recent submissions) in refereed journals, edited conference proceedings and chapters in books

W. P. ARNOTT

1. Unfolding axial caustics of glory scattering with harmonic angular perturbations of toroidal wavefronts, W. P. Arnott, and P. L. Marston, J. Acoust.Soc. Am. 85, 1427-1440, (1989).
2. In Situ measurements of soil physical properties by acoustical techniques, J. M. Sabatier, H. Hess, W. P. Arnott, K. Attenborough, M. Romkens, E. Grissinger, Soil Sci. Soc. Am. J. 54, 658-672, (1990).
3. Laser-Doppler vibrometer measurements of acoustic to seismic coupling, W. P. Arnott, and J. S. Sabatier, accepted for publication in Applied Acoustics, January 1990.

M. A. BREAZEALE

1. Nonlinear Acoustic Effects in Solids, M. A. Breazeale, Proceedings Ultrasonics International, Madrid, Spain, July, 1989.
2. Whither Nonlinear Acoustics?, M. A. Breazeale, Proceedings QNDE Review, Bowdoin College, Maine, July, 1989.
3. Nonlinear Behavior of NaCl and other Cubic Crystals, M. A. Breazeale, Proceedings of the ICA, Belgrade, August, 1989.
4. Nonlinearity Parameter, Nonlinearity Constant and Frequency Dependence of Ultrasonic Attenuation in GaAs. D. N. Joharapurkar and M. A. Breazeale, J. Appl. Phys. 67, 76-80, (1990).
5. 13th International Congress on Acoustics-Belgrade, August 1989. M. A. Breazeale, J. Acoust. Soc. Am. 87, 453, (1990).
6. Determination of the Fourth-Order Elastic Moduli by Acoustic Harmonic Generation in Stressed Crystals. D. Gerlich and M. A. Breazeale, J. Appl. Phys. 67, 3287-3290, (1990).
7. Whither Nonlinear Acoustics? M. A. Breazeale, Review of Progress in Quantitative Nondestructive Evaluation, Vol. 9, D. O. Thompson and D. E. Chimenti Eds., Plenum Press, New York, 1990.

8. Computer Optimization of the Gaussian Beam Description of an Ultrasonic Field. Jing-Jiang Wen and M. A. Breazeale, Computational Acoustics, Vol. 2 D. Lee, A. Cakmak, R. Vichnevetsky Eds., Elsevier Science Publishers B.V., IMACS, (1990).

9. Nonlinearity Parameter, Nonlinearity Constant and Ultrasonic Attenuation in GaAs, D. N. Joharapurkar and M. A. Breazeale, Frontiers of Nonlinear Acoustics 12th ISNA, eds., M. F. Hamilton and D. T. Blackstock, Elsevier Applied Science, New York, 1990 p 547-552.

10. Second Harmonic Generation of Ultrasound in Piezoelectric Materials, Jeong Kwan Na and M. A. Breazeale, Frontiers of Nonlinear Acoustics 12th ISNA, eds., M. F. Hamilton and D. T. Blackstock, Elsevier Applied Science, New York, 1990 p 571-576.

11. Ultrasonic Nonlinearities of High-Tc Superconductor,W. Jiang and M. A. Breazeale, Frontiers of Nonlinear Acoustics 12th ISNA, eds., M. F. Hamilton and D. T. Blackstock, Elsevier Applied Science, New York, 1990 p 541-546.

12. Ultrasonic Second Harmonic Generation in Various Crystalline Systems II. Piezoelectric Materials: Coupling Parameters in Terms of Elastic Moduli and Propagation Directions, D. Gerlich and M. A. Breazeale, To be published by J. Appl. Phys. Nov. 15, 1990.

13. Temperature Variation of NaCl Nonlinearity, Wenhwa Jiang and M. A. Breazeale, Submitted to J. Appl. Phys.

C. C. CHURCH

1. An explanation for the decrease in cell lysis in a rotating tube with increasing ultrasound intensity, M.W. Miller, C.C. Church, A.A. Brayman, M.S. Malcuit, and R.W. Boyd, Ultrasound in Med. and Biol. 15, 67-72 (1989).

2. A theoretical study of cavitation generated by an extracorporeal shock wave lithotripter, C.C. Church, J. Acost. Soc. Am. 86, 215-227 (1989).

3. Nonmonotonic behavior of the maximum collapse pressure in a cavitation bubble, E.J. Aymé-Bellegarda and C.C. Church, IEEE Trans. UFFC 36, 561-564 (1989).

4. Sister chromatid exchanges in Chinese hamster oavry cells exposed to high intensity pulsed ultrasound: inability to confirm previous findings, M.W. Miller, M. Azadniv, S.E. Pettit, C.C. Church, E.L. Carstensen, and D. Hoffman, Ultrasound in Med. and Biol. 15, 255-262 (1989).

5. Confirmation of the protective effort of cysteamine in *in vivo* ultrasound exposures, M. Inoue, C.C Church, A. Brayman, M.W. Miller and M.S. Malcuit, Ultrasonics 27, 362-369 (1989).

6. Acoustic cavitation and extracorporeal shock wave lithotripsy, C.C. Church and L.A. Crum, Proceedings of the 13th ICA, Belgrade, Vol. 4, 205-208 (1989).

7. Time lapse and microscopic examinations of insonated *in vitro* cells, M.W. Miller, C.C. Church and V. Ciaravino: Ultrasound in Med. and Biol. 16, 73-79 (1990).

8. An alternative explanation for a postulated nonthermal, noncavitational ultrasound mechanism of action on *in vitro* cells at hyperthermic temperature, M. Inoue, M.W. Miller and C.C. Church, Ultrasonics (accepted).

9. Confirmation of ultrasound-induced mutation in two *in vitro* mammalian cell lines, Y. Doida, M.W. Miller, C. Cox and C.C. Church, Ultrasound in Med. and Biol. (submitted).

10. Cavitation produced by short pulses of ultrasound, C.C. Church and A. Calabrese, Proceedings of the 12th International Syposium on Nonlinear Acoustics, Austin, TX, August (1990).

L. A. CRUM

1. Underwater sound produced by individual drop impacts and rainfall, H.C. Pumphrey, L.A. Crum and L. Bjørnø, J. Acoust. Soc. Am. 85, 1518 (1989). The underwater noise of rain, A. Prosperetti, L.A. Crum and H.C. Pumphrey, J. Geophys. Res. 94, 32 (1989).

2. The effect of therapeutic ultrasound on the electrophysiological parameters of frog skin, M.A. Dinno, L.A. Crum and J. Wu, J. Ultrasound in Med. & Biol. 15, 461 (1989).

3. Extracorporeal Shock Wave Lithotripsy, L.A. Crum, C.C. Church and D.T. Blackstock, Physics News in 1988 Physics Today, Jan. (1989).

4. Acoustic cavitation and Extracorporeal Shock Wave Lithotripsy, C.C. Church and L.A. Crum, Proc. 13th ICA, Belgrade, 4, 205 (1989).

5. The role of acoustic cavitation in medical ultrasound, L.A. Crum, Proc. 13th ICA, Belgrade, 4, 153 (1989).

6. The underwater sound of rainfall, R.R. Goodman, H.C. Pumphrey and L.A. Crum, Proc. 13th ICA, Belgrade, 4, 411 (1989).

7. The significance of membrane changes in the safe and effective use of therapeutic and diagnostic ultrasound, M.A. Dinno, M. Dyson, S.R. Young, A.J. Mortimer, J. Hart and L.A. Crum, J. Phys. Biol. Med. 34, 1543-1552 (1989).

8. Sonoluminescence and its application to medical ultrasound risk assessment, L.A. Crum and D.F. Gaitan, Proc. Int. Soc. Opt. Engr. 1161, 125-134 (1989).

9. Free oscillations of near-surface bubbles as a source of ambient noise, H.C. Pumphrey and L.A. Crum, Journal of the Acoustical Society of America 87, 142-147 (1990).

10. Acoustic cavitation and medical ultrasound, Ultrasonics International Proceedings 1, 852-858 (1989).

11. Device for Measuring Violent Stable Cavitation, in ANSI Standards Publication IEEE Std. 7 90 - 1989, Guide for Medical Ultrasound Field Parameter Measurements, p. 80, June (1990).

12. Effectiveness of some physical mechanisms generated by the ultrasonic file in the disruption of root canal bacteria, proceedings of International Association for Dental Research, M. Ahmad, T. Pitt Ford, L.A. Crum, and R.F. Wilson (in press).

13. An investigation of the collective oscillations of a bubble cloud, S.W. Yoon, L.A. Crum, A. Prosperetti and N.Q. Lee, J. Acoust. Soc. Am. (accepted for publication).

14. Acoustic cavitation produced by microsecond pulses of ultrasound: A review of some recent results, L.A. Crum, R. A. Roy, R. E. Apfel, C. K. Holland and S. I. Madanshetty, Journal of the Acoustical Society of America, (submitted for publication).

15. The labor pool of future acousticians--is it adequate?, L. A. Crum, Journal of the Acoustical Society of America, (submitted for publication).

16. Mie scattering resed to determine spherical bubble oscillations, R. G. Holt and L. A. Crum, Applied Optics (in press).

17. Collective oscillations of a bubble cloud, S. W. Yoon, K. J. Park, L. A. Crum, N. Q. Lu and A. Prosperetti, to be published in Natural Physical Sources of Underwater Sound, ed. by B. Kerman (Klu wer Acad. Pub., Pordrecht).

18. The production of high frequency ambient sound by capillary waves, A. Kolaini, R. A. Roy and L. A. Crum to be published in Natural Physical Sources of Underwater Sound, ed. by B. Kerman (Klu wer Acad. Pub., Pordrecht)

19. Observation of sonoluminescence from a single stable cavitation bubble in a water/glycerine mixture, to be published in Proceeding of 12th International Symposium on Nonlinear Acoustics, Austin, TX, August (1990).

20. A theoretical study of cavitation generated by four commercially available extracorporeal lithotripters, C. C. Church and L. A. Crum to be published in Proceedings of 12th International Symposium on Nonlinear Acoustics, Austin, TX, August (1990).

T. G. FORREST

1. Stimulus step size and heterogeneous stimulus conditions in adaptive psychophysics, Green, D.M., V.M. Richards and T.G. Forrest, J. Acoust. Soc. Am., 86, 629-636 (1989).

2. Temporal gaps in noise and sinusoids, Green, D.M. and T.G. Forrest, J. Acoust. Soc. Am., 86, 961-970 (1989).

3. Mole cricket phonotaxis: effects of intensity of synthetic calling song (Orthoptera: Gryllotalpidae: Scapteriscus acletus), Walker, T.J. and T.G. Forrest, Florida Entomol., 72, 655-659 (1989).

4. Sexual selection and female choice in mole crickets (Scapteriscus: Gryllotalpidae): modelling the effects of intensity and male spacing, Forrest, T.G., Bioacoustics, (in press).

5. Mate choice in ground crickets (Gryllidae: Nemobiinae), Forrest, T.G., J.L. Sylvester, Jr., S. Testa III, S.W. Smith, A. Dinep, T.L. Cupit, J.M. Huggins, K.L. Atkins and M. Eubanks, Florida Entomol., (accepted for publication).

6. Power output and efficiency of sound production by crickets, Forrest, T.G., J. Exp. Biol., (submitted).

K. E. GILBERT

1. Application of the parabolic equation to sound propagation in a refractive atmosphere, Kenneth E. Gilbert and Michael J. White, Kenneth E. Gilbert and Michael J. White, J. Acoust. Soc. Amer., 85, 630-637, 1989.

2. Electrical Structure in two thunderstorm anvil clouds, Thomas C. Marshall, W. David Rust, William P. Winn, and Kenneth E. Gilbert, J. Geophys. Res., 94, 1989.

3. Application of the parabolic equation to outdoor propagation of sound, Michael J. White and Kenneth E. Gilbert, Invited paper in Applied Acoustics: Special Issue on Propagation in Layered Media, edited by Keith Attenborough. [Applied Acoustics, 27, 227-238 (1989)]

4. Scattering of sound by atmospheric turbulence: predictions in a refractive shadow zone, Walton E. McBride, Henry E. Bass, Richard Raspet, and Kenneth E. Gilbert, submitted to the Journal of the Acoustical Society of America (1990).

5. Numerical description of sound scattering from small scale atmospheric turbulence, Walton E. McBride, Henry E. Bass, Richard Raspet, and Kenneth E. Gilbert, submitted to the Journal of the Acoustical Society of America (1990).

6. Distorted-wave Born approximation calculations for turbulence scattering in an upward-refracting atmosphere, Kenneth E. Gilbert and Xiao Di, The Fourth International Symposium on Long-Range Sound Propagation, NASA Langley Research Center, Hampton, VA, May 16,17, 1990. To appear as a NASA publication.

7. Calculation of turbulence effects in an upward refracting atmosphere, Kenneth E. Gilbert, Richard Raspet, and Xiao Di, J. Acoust. Soc. Amer. 87 , 2428-2437 (1990).

R. HICKLING

1. Early Work on Calculating and Measuring the Elastic Response of Underwater Acoustics Targets, R. Hickling, Proceedings Symposium on Acoustic Resonance Scattering, Catholic University, 3-12 (1989).

2. Indoor System for Efficient Measurement of the Sound Power of Light Vehicles and for Noise-Control Diagnostics, R. Hickling, L. N. Bolen and R. F. Schumacher, Transactions, Society of Automotive Engineers, Paper No. 891145, (1989).

3. Narrow-Band Indoor Measurement of the Sound Power of a Complex Mechanical Noise Source, R. Hickling, Journ. Acoust. Soc. Amer., Vol. 87, 3, 1182-91, (1990).

4. Rotational Waves in the Elastic Response of Spherical and Cylindrical Acoustic Targets in Water, R. Hickling, R. K. Burrows and J. F. Ball, submitted to Jour. Acoust. Soc. Am., (1990).

5. Power Flow for Sound Incident on a Solid Aluminum Sphere in Water, R. Hickling, R. K. Burrows and J. F. Ball, submitted to Journ. Acous. Soc. Am., (1990).

6. Sound-Power Flow Associated with Sound Scattered by a Solid Acoustic Target, R. Hickling, R. K. Burrows and J. F. Ball, Proceedings 3rd International Congress on Intensity Techniques - Structural Intensity and Vibrational Energy Flow, CETIM, Senlis, France (1990).

7. A Return to an Old Acoustics Problem, the Scattering of Sound by a Solid Elastic Sphere, R. Hickling, R.K. Burrows and J.F. Ball, Engineering Science, Fluid Dynamics, A Symposium to Honor T.Y. Wu, California Institute of Technology 257-268 World Scientific Singapore, (1990).

8. Sound-power Tests of a Small Engine Driven Source, R. Hicking, P. Lee, W.Wei, Proceedings International Congress on Recent Developments in Air and Structure Borne Sound and Vibration," Auburn University, 27-34, (1990).

R. A. ROY

1. The production of high-frequency ambient noise by capillary waves, R.A. Roy, A. Kolaini, and L.A. Crum, In Natural Physical Sources of Underwater Sound, ed. by B. Kerman, Kluwer Acad. Pub., Dordrecht, Netherlands, 1990 (in press).

2. Collective oscillations in a bubble cloud, S.W. Yoon, K.J. Park, L.A. Crum, M. Nicholas, R.A. Roy, A. Prosperetti, and N.Q. Lu, In Natural Physical Sources of Underwater Sound, ed. by B. Kerman, Kluwer Acad. Pub., Dordrecht, Netherlands, 1990 (in press).

3. Cavitation produced by short pulses of ultrasound, R.A. Roy, C.C. Church, and A. Calabrese, In Frontiers of Nonlinear Acoustics, 12th ISNA, ed. by M.F. Hamilton and D.T. Blackstock, Elsevier Applied Science, New York, 1990.

4. An acoustic backscattering technique for the detection of transient cavitation produced by microsecond long pulses of ultrasound, R.A. Roy, S.I. Madanshetty, and R.E. Apfel, J. Acoust. Soc. Am., 87 (6), June 1990.

5. Mechanical characterization of microparticles by scattered ultrasound, R.A. Roy and R.E. Apfel, J. Acoust. Soc. Am., 87 (6), June 1990.

6. Acoustic microcavitation: Its active and passive acoustic detection, S.I. Madanshetty, R.A. Roy, and R.E. Apfel, J. Acoust. Soc. Am., (submitted).

J. M. SABATIER

1. In Situ Measurements of Soil Physical Properties by Acoustical Techniques, James M. Sabatier, Heather Hess, W. Patrick Arnott, Keith Attenborough and Matthew Romkens, Soil Sci. Soc. Am., 54 (3), 68-672 (1990).

2. Laser doppler vibrometer measurements of acoustic to seismic coupling, W.P. Arnott and J.M. Sabatier, accepted for publication in Appl. Acoust., January 1990.

3. Measurement and Calculation of Acoustic Propagation Constants in Arrays of Small Air-Filled Rectangular Tubes, Heui-Seol Roh, W. Patrick Arnott, James M. Sabatier, and Richard Raspet, submitted to JASA, July 1990.

F. D. SHIELDS

1. Timothy H. Ruppel and F. Douglas Shields, Sound propagation in vibrationally excited N2/CO and H2/He/CO gas mixtures, J. Acoust. Soc. Am. 87, 1134-1137 (1990).

2. L. Dwynn Lafleur, F. Douglas Shields, and James E. Hendrix, Acoustically Active Surfaces Using Piezorubber, submitted to J. Acoust. Soc. Am. (1990).

B. Technical Reports and Book Reviews

M. A. BREAZEALE

1. Nonlinear Lattice Dynamics by Morikazu Toda. M. A. Breazeale, J. Acoust. Soc. Am. 87, 461, (1990).

2. Surface Waves and Discontinuities by P. Malischewsky. M. A. Breazeale, submitted to J. Acoust. Soc. Am. (1990).

L. A. CRUM

1. Sources of ambient noise in the ocean: An experimental investigation, with H. C. Pumphrey, NCPA Tech. Rept. No. LC.01.89 for the Office of Naval Research, July (1989).

2. Further studies of the underwater noise produced by rainfall, with P.A. Elmore and H.C. Pumphrey, Tech. Rept. No. LC.02.89 for the Office of Naval Research, August (1989).

3. Thresholds for surface wave generation on air bubbles in water, NCPA Tech Dept. No. LC.OZ.90 for the Office of Naval Research, February, 1990.

T. G. FORREST

1. Huber, F., T.E. Moore, & W. Loher, eds. 1989. Cricket Behavior and Neurobiology", Forrest, T.G. Pan-Pacific Entomol., (submitted).

R. HICKLING

1. Indoor System for Efficient Measurement of the Sound Power of Light Vehicles and for Noise-Control Diagnostics, R. Hickling, L. N. Bolen and R. F. Schumacher: Transactions, Society of Automotive Engineers, Paper No. 891145, (1989).

R. A. ROY

1. R.A. Roy, Book review: Ultrasonics International 87 conference proceedings, J. Acoust. Soc. Am., 85 (2), February 1989.

C. Papers read before Professional Organizations

W. P. ARNOTT

1. P. L. Marston, W. P. Arnott, et. al., "Optics of Bubbles in Water: Scattering Properties, Coatings, and Laser Radiation Pressure," for Proceedings of the Third International Colloquium on Drops and Bubbles, edited by T. G. Wang (AIP Conference Proceedings, 1989).

2. W. P. Arnott and J. S. Sabatier, "Laser-Doppler vibrometry measurements of acoustic-to-seismic coupling and geophone-ground coupling ratios," J. Acoust. Soc. Am. Suppl. 1 85, S82 (1989).

3. W. P. Arnott, J. S. Sabatier, and John O. Messer, "Dependence of the acoustic to seismic coupling ratio on the angle of incidence and geophone depth," J. Acoust. Soc. Am. Suppl. 1 86, S120 (1989).

4. H. Roh, J. Sabatier, R. Raspet, and W. P. Arnott, "Measurement and calculation of acoustic propagation constants in arrays of air-filled rectangular tubes," J. Acoust. Soc. Am. Suppl. 1 87, S139 (1990).

5. W. P. Arnott, H. E. Bass, R. Raspet, "General formulation of thermoacoustics for stacks having arbitrarily-shaped pore cross-sections," accepted for presentation at the November 1990 Acoust. Soc. Am. meeting in San Diego.

6. W. P. Arnott, J. S. Sabatier, R. Raspet, "Sound propagation in capillary-tube-type porous media with much smaller pores in the capillary walls," accepted for presentation at the November 1990 Acoust. Soc. Am. meeting in San Diego.

M. A. BREAZEALE

1. Plenary Lecture, Ultrasonics International, Madrid, Spain (1989).

2. Invited Lecture "Whither Nonlinear Acoustics?" QNDE Review, Bowdoin College, Maine (1989).

3. 13th ICA, Belgrade "Nonlinear Behavior of NaCl and Other Cubic Crystals, Breazeale and Jiang (1989).

4. Sherman Fairchild Lecture Series, Invited Lecture, Lehigh University, February, 1990.

5. Invited Lecture, "What to Do When Your World Turns Nonlinear", Symposium on Physical Acoustics, Kortrijk, Belgium, (1990).

6. Invited Lecture, "Anharmonicity, Piezoelectricity, and Solid State Nonlinearity", Review of Quantitative Nondestrictive Evaluation, LaJolla, CA, (1990).

7. "Nonlinearity Parameter, Nonlinearity Constant and Ultrasonic Attenuation in GaAs", Proceedings of the 12th ISNA, Austin, TX, (1990).

8. "Second Harmonic Generation of Ultrasound in Piezoelectric Materials", Proceedings of the 12th ISNA, Austin, TX, (1990).

9. Ultrasonic Nonlinearities of High-Tc Superconductor ", Proceedings of the 12th ISNA, Austin, TX, (1990).

C. C. CHURCH

1. Nonlinear aspects of the acoustic levitation of compressible spheres, presented at the 117th meeting of the Acoustical Society of America, Syracuse, NY, May (1989).

2. Radial oscillations of gas bubbles in viscoelastic materials, with R. A. Roy, presented at the 118th meeting of the Acoustical Society of America, St. Louis, MO, Nov. (1989).

3. On the nucleation of transient cavitation from stabilized microbubbles, with R. A. Roy and A. Calabrese, presented at the 119th meeting of the Acoustical Society of America, State College, PA May (1990).

4. Cavitation produced by short pulses of ultrasound, with R. A. Roy and A. Calabrese, presented at the 12th International Symposium on Nonlinear Acoustics, Austin, TX, August (1990)

5. Extracorporeal Shock Wave Lithotripsy: Boom and Bust, with L. A. Crum, presented at the Annual Meeting of the American Association of Physics Teachers, Atlanta, GA, January (1990).

L. A. CRUM

Invited Presentations:

1. "Cavitation and Medical Ultrasound," presented at the International Conference on Ultrasound in Medicine, Bath, England, April (1986).

2. "Acoustic Cavitation Produced in vitro by Clinical Ultrasound Devices," presented at the 12th International Congress on Acoustics, Toronto, Canada, July (1986).

3. "Acoustic cavitation and medical ultrasound,"presented as a plenary lecture for Ultrasonics International 1989, Madrid, Spain.

4. "Acoustic cavitation and medical ultrasound", presented at the 13th International Congress on Acoustics, Belgrade, July (1989).

5. "Sonoluminescence and its application to medical ultrasound risk assessment" with D.F. Gaitan presented at the International Society for Optical Engineering, San Diego, CA, August, (1989).

6. "Mechanisms of stone disintegration and tissue damage by extracorporeal shock wave lithotripter", with C.C. Church, presented at Annual Meeting of the American Association of Physicists in Medicine, Memphis, TN, July, (1989).

7. "Demonstrations of underwater noise generation by bubbles", with H.C. Pumphrey, presented at the Spring meeting of the Acoustical Society of America, Syracuse, NY, May, (1989).

8. "Underwater noise due to precipitation", with H.C. Pumphrey, A. Prosperetti and L. Bjorno, presented at the Spring meeting of the Acoustical Society of America, Syracuse, NY, May, (1989).

9. "Acoustic Cavitation generated by Extra Corporeal Shock Wave Lithotripsy", with C.C. Church, presented at the 3rd Drexel Symposium on Medical Ultrasound, Philadelphia, PA, September, (1989).

10. "The potential role of acoustic cavitation in medical ultrasound bioeffects, with R.A. Roy and C.C. Church, presented at 118th meeting of the Acoustical Society of America, St. Louis, MO, November, (1989).

11. "Effectiveness of some physical mechanisms generated by the ultrasonic file in the disruption of root canal bacteria", L.A. Crum and M. Ahmad, presented at the International Association for Dental Research, New Dehli, India, July, (1989).

12. "Acoustic cavitation and medical ultrasound", presented at the 2nd World Congress on Ultrasound in Developing Countries, Kuala Lumpur, Malaysia, November, (1989).

13. "Bubbles in the Body: Cavitation and Medical Ultrasound", with R.A. Roy and C.C. Church, presented in special session on "Frontiers in Physical Acoustics", American Association for the Advancement of Science, New Orleans, LA, February, (1990).

14. "Acoustic cavitation and diagnostic ultrasound", with R. A. Roy, and C. C. Church, presented at a special session on ultrasonics at the Annual Meeting of the American Association of Physicists in Medicine, St. Louis, July, 1990

15. "Bubble-related sources of sea-surface sound", with R. Roy, S. Yoon, A. Kolaini, and M. Nicholas, to be presented at a special session on acoustical oceanography at the 119th meeting of the Acoustical Society of America, San Diego, CA, November, 1990.

Contributed Presentations:

1. "Thresholds for surface wave generation on acoustically levitated gas bubbles", S. Horsburgh, R.G. Holt and L.A. Crum, presented at the 118th meeting of the Acoustical Society of America, St. Louis, MO, November (1989).

2. "Further studies of the underwater noise produced by rainfall", P.A. Elmore, H.C. Pumphrey and L.A. Crum, presented at the 118th meeting of the Acoustical Society of America, St. Louis, MO, November (1989).

3. "An experimental investigation of bubble clouds as sources of ambient noise", S.W. Yoon, L.A. Crum and A. Prosperetti, presented at the 118th meeting of the Acoustical Society of America, St. Louis, MO, November (1989).

4. "The scattering of sound by a cylindrical bubble cloud", M.S. Korman, R.A. Roy and L.A. Crum, presented at the 118th meeting of the Acoustical Society of America, St. Louis, MO, November (1989).

5. "The underwater sound of rainfall", R.R. Goodman, H.C. Pumphrey, L.A. Crum, and L. Bjørnø, presented at the 13th International Congress on Acoustics, Belgrade, Yugoslavia, August (1989).

6. "Acoustic cavitation and Extracorporeal Shock Wave Lithotripsy", C.C. Church and L.A. Crum, presented at the 13th International Congress on Acoustics, Belgrade, Yugoslavia, August (1989).

7. "Sonoluminescence and its application to medical ultrasound risk assessment", L.A. Crum and D.F. Gaitan, presented at the 33rd International Conference on Optical Engineering, San Diego, CA, July (1989).

8. "Collective oscillation of a bubble cloud", with S. W. Yoon, K. J. Park, N. Q. Lu, and A. Prosperetti, presented at the 2nd conference on Natural Physical Sources of Underwater Sound, Cambridge, England, July, 1990.

9. "The production of high frequency ambient noise by capillary waves", with R. A. Roy, and A. Kolaini, presented at the 2nd conference on Natural Physical Sources of Underwater Sound, Cambridge, England, July, 1990.

10. "Observation of sonoluminescence from a single stable cavitation bubble in a water/glycerine mixture", with D. F. Gaitan, presented at the 12th International Symposium on Nonlinear Acoustics, Austin, TX, August, 1990.

11. "A theoretical study of cavitation generated by four commercially available extracorpereal lithotripters", with C. Church, presented at the 12th International Symposium on Nonlinear Acoustics, Austin, TX, August, 1990.

12. "Collective oscillations in a bubble column--higher nodes", with M. Nicholas, R. Roy, A. Prosperetti and N. Lu, to be presented at the 119th meeting of the Acoustical Society of America, San Diego, CA, November, 1990.

13. "The acoustic signatives of laboratory-generated bubble plumes", with A. Kolaini, M. Yi, and R. Roy, to be presented at the 119th meeting of the Acoustical Society of America, San Diego, CA, November, 1990.

14. "Large amplitude radial pulsations of a single, linear gas bubble: Comparison between theory and experiment", with D. Gaitan, C. Church and R. Roy, to be presented at the 119th meeting of the Acoustical Society of America, San Diego, CA, November, 1990.

15. "Cavitation from diagnostic ultrasound", with R. Roy, C. Holland, and R. Apfel, to be presented at the 119th meeting of the Acoustical Society of America, San Diego, CA, November, 1990.

16. "The effect of ultrasound on the ionic conductance across frog skin in the presence of free radical scavengers", with M. Dinno, W. Kennedy, R. Ingraham and B. Idom, to be presented at the 119th meeting of the Acoustical Society of America, San Diego, CA, November, 1990.

T. G. FORREST

Invited Presentations:

1. "Acoustic communication in pest mole crickets", Forrest, T.G., Acoust. Soc. Am. annual meeting, Syracuse May 22-26 (1989).

Contributed Presentations:

1. "Power output and efficiency of sound production by crickets", Forrest, T.G., Acoust. Soc. Am. annual meeting, Syracuse, May 22-26 (1989).
2. "Modelling the effects of source intensity and spacing in acoustic communication", Forrest, T.G., Animal Behavior Society annual meeting, Binghamton, NY. June 10-16 (1990).
3. "Detection of silent temporal gaps in sinusoids", Formby, C. and T.G. Forrest, Acoust. Soc. Am. annual meeting, State College, PA, May 21-25. (1990).

K. E. GILBERT

1. Resonant multiple scattering from bubble clusters, Kenneth E. Gilbert and Lintao Wang, National Center for Physical Acoustics, Minoconference on Cavitation, August 23-25, 1990, University of Mississippi.
2. Spectral decomposition and propagation of scattered fields in an ocean waveguide, K.E. Gilbert and Xiao Di, Second IMACS Symposium on Computational Acoustics, Princeton University, March 15-17, 1989.
3. A two-dimensional downslope propagation model based on coupled wedge modes, Harel Primack and Kenneth E. Gilbert, to be presented at the 120th meeting of the Acoustical Society of America, San Diego, CA, November 1990.
4. Resonant multiple scattering from bubble clusters, Kenneth E. Gilbert and Lintao Wang, presented at the 119th meeting of the Acoustical Society of America, Penn State University, May, 1990.
5. Turbulent scattering in a upward-refracting atmosphere, Kenneth E. Gilbert, Xiao Di, Lintao Wang, Richard Raspet, presented at the 119th meeting of the Acoustical Society of America, Penn State University, May,1990.

6. Parabolic equation starting field for a low-frequency source near an interface, Kenneth E. Gilbert and Dehua Huang, 118th meeting of the Acoustical Society of America, November, 1989.

7. Spectral decomposition of parabolic equation fields, K.E. Gilbert, Xiao Di, and Dehua Huang, 117th meeting of the Acoustical Society of America, May 1989, Syracuse University.

R. HICKLING

1, An Indoor Sound-Power Test for Light Vehicles, R. Hickling and L.N. Bolen, Presented at 117th Meeting of the Acoustical Society of America Syracuse, NY, 22-26 May (1989).

2. Scattering and Transmission of Sound Power Flow by Solid Elastic Spheres in Water, R. Hickling, R. K. Burrows, J.F. Ball and L.A. Redmond, 118th Meeting of the Acoustical Society of America, St. Louis, MO, 27 Nov.- 1 Dec (1989).

3. Sound Power Tests of a Garden Tractor, R. Hickling, P. Lee, W.Wei, 119th Meeting of the Acoustical Society of America, Penn State University, PA, 21-25 May (1990).

4. Sound-Power Flow Associated with Sound Scattered by a Solid Elastic Sphere in Water, R. Hickling, R. K. Burrows and J.F. Ball, Proceedings of 3rd International Congress on Intensity Techniques, "Structural Intensity and Vibrational Energy Flow", CETIM, Senlis, France, (1990).

5. A Practical Sensor for Acoustic Detection of Larvae and Insects in Harvested Commodities, R. Hickling, S.T. Chang, J.C. Webb, 120th Meeting of the Acoustical Society of America, San Diego, CA Nov. 26-30 (1990).

R. A. ROY

Invited Presentations:

1. L.A. Crum, R.A. Roy and C.C. Church, "The potential role of acoustic cavitation in medical ultrasound bioeffects," J. Acoust. Soc. Am., 86 (S1), 1989.

2. R.A. Roy, L.A. Crum, C.C. Church, and R.E. Apfel, "Bubbles in the body: cavitation and medical ultrasound," Presented at the AAAS Annual Meeting, New Orleans, LA, February 1990.

3. L.A. Crum, C.C. Church, and R.A. Roy, "Acoustic cavitation and its application to medical ultrasound," Med. Phys. 17 (3), 1990.

4. R.A. Roy, "Cavitation Inception," Presented at the First Annual National Center for Physical Acoustics Cavitation Miniconference, Oxford, MS, August 1990.

Contributed Presentations:

1. R.E. Apfel, X. Chen and R.A. Roy, "Cell and particle characterization with high-frequency ultrasound," ASME Winter Annual Meeting, San Fransisco, CA, December 1989.

2. R.E. Apfel, S.I. Madanshetty, R.A. Roy and Qihong Xu, "Acoustic scattering from transient, micron-sized cavitation bubbles," J. Acoust. Soc. Am., 86 (S1), 1989.

3 M.S. Korman and R.A. Roy, "The scattering of sound by a cylindrical bubble cloud," J. Acoust. Soc. Am., 86 (S1), 1989.

4. C.C. Church and R.A. Roy, "Radial oscillations of gas bubbles in viscoelastic materials," J. Acoust. Soc. Am., 86 (S1), 1989.

5. M. Ahmad, A. Ghani, L.A. Crum, R.A. Roy, C.C. Church, "Cavitational activity in ultrasonic instrumentation," J. Endodontics, 16 (4), 1989.

6. J.D. Richardson, R.A. Roy and L.A. Crum, "The effect of electric field strength on sound speed in an electrorheological fluid," Presented at the Miss. Acad. Sci. Annual Meeting, Buloxi, MS, February, 1990.

7. R.A. Roy, A. Calabrese, and C.C. Church, "On the nucleation of transient cavitation from stabilized microbubbles," J. Acoust. Soc. Am., 87 (S1), 1990.

8. R.A. Roy and J.D. Richardson, "Ultrasonic propagation in electrorheological suspensions," J. Acoust. Soc. Am., 87 (S1), 1990.

9. A.R Kolaini, R.A. Roy, and L.A. Crum, "Observation of high-frequency ambient noise generated by capillary waves," J. Acoust. Soc. Am., 87 (S1), 1990.

10. R.A. Roy, A.R Kolaini, and L.A. Crum, "The production of high-frequency ambient noise by capillary waves," Presented at the Conference on the Natural Physical Sources of Underwater Sound, Cambridge, UK, July 1990.

11. R.A. Roy, A. Calabrese, "Cavitation produced by short pulses of ultrasound," Presented at the International Symposium on Nonlinear Acoustics, Austin, TX, August 1990.

12. A.R Kolaini, M. Yi, R.A. Roy, and L.A. Crum, "The acoustic signatures of laboratory-generated bubble plumes," J. Acoust. Soc. Am., 88 (S1), 1990.

13. D.F. Gaitan, L.A. Crum, C.C. Church, and R.A. Roy "Large amplitude radial pulsations of a single driven gas bubble: comparison between theory and experiment," J. Acoust. Soc. Am., 87 (S1), 1990.

14. L.A. Crum, R.A. Roy, S.W. Yoon, A.R. Kolaini, and M. Nicholas "Bubble-related sources of sea surface sound," J. Acoust. Soc. Am., 87 (S1), 1990.

15. M. Nicholas, R.A. Roy, and L.A. Crum, "Collective oscillations of a bubble column: higher modes," J. Acoust. Soc. Am., 87 (S1), 1990.

16. R.A. Roy, C.K. Holland, R.E. Apfel, and L.A. Crum "Cavitation from diagnostic ultrasound," J. Acoust. Soc. Am., 87 (S1), 1990.

J. M. SABATIER

Contributed Presentations:

1. The reflection of acoustic pulses from arrays of tubes, Heui-Seol Roh, James M. Sabatier and Richard Raspet, J. Acoust. Soc. Am. 85 (S1), S82 (A), Spring 1989.

2. Laser-doppler vibrometry measurements of acoustic to seismic coupling and geophone-ground coupling ratios, W. Pat Arnott and James M. Sabatier, J. Acoust. Soc. Am. 85 (S1), S82 (A), Spring 1989.

3. W. Pat Arnott, James M. Sabatier and John O. Messer, "Dependence of the acoustic-to-seismic coupling ratio at the angle of incidence and geophone depth," J. Acoust. Soc. Am. 86 (S1), (A), Fall 1989.

4. James M. Sabatier, "Surface impedance measurements as a function of moisture content in porous glass beads," J. Acoust. Soc. Am. 87 (S1), (A), Spring 1990.

5. Heui-Seol Roh, James M. Sabatier, Richard Raspet, and W. Patrick Arnott, "Measurements and calculation of acoustic propagation constants in arrays of air-filled rectangular tubes," J. Acoust. Soc. Am. 87 (S1), (A), Spring 1990.

6. D. Craig, P. Arnott, and J. Sabatier, "Particle size characterization of layers of spherical glass beads from acoustic reflection measurements," Presented at ASA-CSSA-SSSA 1990 Annual Meetings, 21-26 October, San Antonio, TX.

7. H. Roh, P. Arnott, and J. Sabatier, "Acoustic surface impedance measurements on partially water-saturated columns of glass beads," Presented at ASA-CSSA-SSSA 1990 Annual Meetings, 21-26 October, San Antonio, TX.

8. W. Pat Arnott, James M. Sabatier, and Richard Raspet, "Sound propagation in capillary-tube-type porous media with much smaller pores in the capillary walls," to be published in J. Acoust. Soc. Am. 88 (S1), (A), Fall 1990.

9. W. Pat Arnott, James M. Sabatier, and Richard Raspet, "Sound propagation in capillary-tube-type porous media with much smaller pores in the capillary walls," accepted for presentation at the November 1990 Acoustical Society of America meeting San Diego, CA.

F. D. SHIELDS

Contributed Presentations:

1. Smart acoustically active surfaces, F. Douglas Shields, James E. Hendrix, and L. Dwynn Lafleur, J. Acoust. Soc. Am. 85 (S1), (A), Spring 1989.

2. Propagation of sound in vibrationally excited N2/CO and CO/H2 mixtures, Timothy H. Ruppel and F. Douglas Shields, J. Acoust. Soc. Am. 85 (S1), (A), Spring 1989.