

AD-A142 484

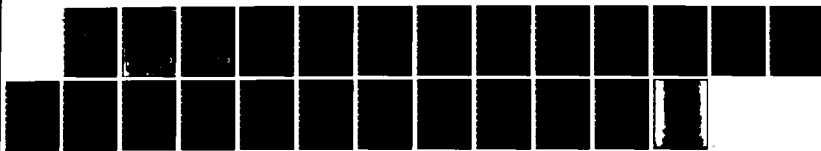
ON MEASURING THE ACOUSTIC INTENSITY OF HYDROACOUSTIC
SOURCES (U) PENNSYLVANIA STATE UNIV UNIVERSITY PARK
APPLIED RESEARCH LAB G C LAUCLHE 25 MAY 84
ARL/PSU/TM-84-91 N00024-79-C-6043

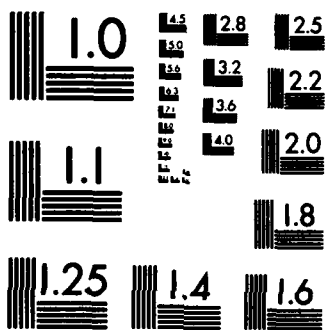
1/1

UNCLASSIFIED

F/G 20/1

NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

6

AD-A142 484

ON MEASURING THE ACOUSTIC INTENSITY
OF HYDROACOUSTIC SOURCES

G. C. Lauchle

Technical Memorandum
File No. TM 84-91
25 May 1984
Contract N00024-79-C-6043

Copy No. 38

FILE COPY

The Pennsylvania State University
Intercollege Research Programs and Facilities
APPLIED RESEARCH LABORATORY
Post Office Box 30
State College, Pa. 16804

DTIC
ELECTE
JUN 27 1984

NAVY DEPARTMENT

NAVAL SEA SYSTEMS COMMAND

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

08 26 125

ON MEASURING THE ACOUSTIC INTENSITY
OF HYDROACOUSTIC SOURCES

G. C. Lauchle

Technical Memorandum
File No. TM 84-91
25 May 1984
Contract N00024-79-C-6043

Copy No. 38

The Pennsylvania State University
Intercollege Research Programs and Facilities
APPLIED RESEARCH LABORATORY
Post Office Box 30
State College, PA 16804

Approved for Public Release
Distribution Unlimited

NAVY DEPARTMENT

NAVAL SEA SYSTEMS COMMAND

DTIC
ELECTE
S JUN 27 1984 D
B

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TM 84-91	2. GOVT ACCESSION NO. AD-A142 484	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ON MEASURING THE ACOUSTIC INTENSITY OF HYDROACOUSTIC SOURCES		5. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) G. C. Lauchle		8. CONTRACT OR GRANT NUMBER(s) N00024-79-C-6043
9. PERFORMING ORGANIZATION NAME AND ADDRESS Applied Research Laboratory Post Office Box 30 State College, PA 16804		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Sea Systems Command, Code NSEA 63R31 Department of the Navy Washington, DC 20362		12. REPORT DATE 25 May 1984
		13. NUMBER OF PAGES 20
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release. Distribution unlimited. Per NAVSEA - 13 June 1984.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) acoustic intensity hydroacoustics		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) → With the recent interest in using the two-microphone technique to measure acoustic intensity, fundamental questions arise when considering this method for hydroacoustic studies. The acoustic intensity generated by a hydrodynamic source is related solely to those pressure components that propagate. The basic questions are then, what influence does the non-propagating hydrodynamic pressure fluctuations have on the intensity probe when used in the nearfield of the source and can their effect be removed		

From: G. C. Lauchle

Subject: On Measuring the Acoustic Intensity of Hydroacoustic Sources

Abstract: With the recent interest in using the two-microphone technique to measure acoustic intensity, fundamental questions arise when considering this method for hydroacoustic studies. The acoustic intensity generated by a hydrodynamic source is related solely to those pressure components that propagate. The basic questions are then, what influence does the non-propagating hydrodynamic pressure fluctuations have on the intensity probe when used in the nearfield of the source and can their effect be removed from a measured intensity spectrum? These two questions are addressed in this paper. An example indicates that the non-propagating pressure fields of a turbulent boundary layer flow can be accounted for approximately. The result is not generally applicable to three-dimensional fields, however.

Acknowledgment: This work was performed at the Applied Research Laboratory of The Pennsylvania State University under contract with the Naval Sea Systems Command, Code 63R31. Partial support for this work has also come from the IBM Corporation, Acoustics Laboratory, Poughkeepsie, NY.

I INTRODUCTION

The development and use of the two-sensor, cross-spectral density method for the measurement of acoustic intensity has proven to be a powerful tool in noise source diagnosis [1-5]. There has also been interest in using this technique in the presence or vicinity of low-speed (Mach number less than 0.1) turbulent flows [4,6-8]. The analysis of Lauchle [8] suggests that an intensity estimate for an acoustical source located outside of a turbulent boundary layer is basically unaffected by the presence of the boundary layer when the measurement is performed under this turbulent layer. This conclusion is founded upon the notion that the turbulent pressure fluctuations of the boundary layer are uncorrelated with the acoustic pressure generated by the source of interest.

A different, but related situation, deals with the measurement of the acoustical intensity generated by a hydrodynamic flow field. The word hydrodynamic is used to remind us that the flow field is of low enough mean velocity that it can be treated as incompressible. This also permits us to define intensity in the usual zero-flow manner [6]. It is further presumed that we would like to make this measurement in the nearfield of the hydrodynamic source. For example, one may need to map out the intensity vectors near the inlet opening of a centrifugal blower. The issues to be addressed then, are related to the interpretation of intensity spectra measured in these types of environments with the two-sensor method. It is the purpose of this paper to examine these issues and to consider, as an example, the measurement of the intensity spectrum generated by a turbulent boundary layer flow.

II. BASIC ANALYSIS

Consider the use of two pressure sensors of radius R in the measurement of acoustic intensity. This measurement requires the cross-spectral density function between the two sensors, where the intensity is then estimated from:

$$I_a(\omega) = - \frac{\text{Im}[G_{12}(\omega)]}{\rho\omega\Delta x} \quad (1)$$

Here, Δx is the separation distance between the two sensors, ρ is the fluid mass density, G_{12} is the cross spectrum, and ω is the radian frequency. Equation (1) is valid at frequencies for which $k\Delta x \ll 1$ ($\Delta x < \lambda/6$ is often-times used, where $\lambda = 2\pi/k$), where k is the sonic wavenumber, ω/c , with c being the velocity of sound.

If the two sensors are placed in a turbulent flow of mean velocity u_0 as generalized in Figure 1, the individual sensors will generate rms signals that contain both propagating and non-propagating components. If we let p_a denote the propagating pressure and p_T be that component associated with the non-propagating turbulent pressure fluctuations, it follows that

$$\hat{p}_1 = p_{a_1} + p_{T_1} \quad (2a)$$

and

$$\hat{p}_2 = p_{a_2} + p_{T_2} \quad (2b)$$

The cross spectrum between the measured rms pressures \hat{p}_1 and \hat{p}_2 therefore contains four terms, i.e.,

$$\hat{G}_{12} = G_{12} + G_{T_1 T_2} + G_{a_1 T_2} + G_{T_1 a_2} \quad (3)$$

The notation used here is standard and follows Bendat and Piersol [9]; e.g.,

$$G_{12} = G_{p_{a_1} p_{a_2}} = \lim_{T \rightarrow \infty} \frac{2}{T} E \{ P_{a_1}^* (\omega, T) P_{a_2} (\omega, T) \} , \quad (4)$$

where P_{a_1} is the finite Fourier transform of p_{a_1} and the ensemble average is over many records. The asterick denotes complex conjugate.

Equation (3) is interpreted as follows: When the two pressure sensors are placed in a turbulent flow, the measured cross spectral density function will have four contributions. The first term, G_{12} , describes the contribution due to the propagating pressure field generated by the turbulence. The second term, $G_{T_1 T_2}$, describes a cross spectrum associated with the non-propagating turbulent pressure field as measured at a sensor separation Δx . The last two terms, $G_{T_1 a_2}$ and $G_{a_1 T_2}$, describe the correlation of the non-propagating pressure at one sensor location with the propagating pressure sensed at the other location.

The objective set forth in this paper is to assess the usefulness of Equation (1) in measuring the acoustic intensity of a hypothetical hydro-acoustic source. From Equation (3) we see that the desired cross spectrum to be used in Equation (1) is of the form:

$$G_{12} = \hat{G}_{12} - G_{T_1 T_2} - G_{a_1 T_2} - G_{T_1 a_2} . \quad (5)$$

Clearly, \hat{G}_{12} is measurable directly, but how do we estimate those cross spectra that need to be subtracted from \hat{G}_{12} ? The answer to this question cannot be given in general because the space-time correlations among turbulent pressure fluctuation components depend strongly on the particular flow field being

studied. It is noted that when the acoustic source of interest is independent of the turbulent motions, the last two terms of Equation (5) are zero. This situation was studied by Lauchle [8] for boundary layer turbulence and by Oswald and Donavan [7] for free-stream turbulence. A detailed examination of Equation (5) for boundary layer turbulence would represent an extension of the previous analysis [8] and is given here.

III. AN EXAMPLE -- TURBULENT BOUNDARY LAYER

Let us consider the use of Equation (5) in Equation (1) when the sensors of Figure 1 are flush-mounted in a planar surface under a low-speed turbulent boundary layer (TBL). We assume that the TBL wall pressure fluctuations at the measurement locations are stationary, homogeneous, and of zero mean. The pressure autospectral density function measured by one of the sensors is given by [10]:

$$\hat{G}_{11}(\omega) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \phi(k_1, k_3, \omega) |H(k_1 R, k_3 R)|^2 dk_1 dk_3 . \quad (6)$$

The wavenumbers k_1 and k_3 are those in the streamwise (x_1) and spanwise (x_3) directions, respectively. The wavenumber/frequency spectrum for the TBL wall pressure fluctuations, $\phi(k_1, k_3, \omega)$ can be estimated using the analysis of Chase [11]. The wavenumber response function for circular sensors is given by [12]:

$$H(k_1 R, k_3 R) = H(\underline{k}R) = \frac{2J_1(\underline{k}R)}{\underline{k}R} , \quad (7)$$

where $\underline{k} = k_1^2 + k_3^2$, and J_1 is the Bessel function of order one. Corcos [13] gives general methods for calculating transducer spatial response functions

for arbitrarily-shaped sensors. He also shows that the cross spectrum $G_{T_1 T_2}$ is sensitive to transducer spatial averaging effects as in Equation (6).

The wavenumber/frequency spectrum modeled by Chase [11] is characterized by a large energy region centered at the convective wavenumber, $k_c = \omega/u_c$, where u_c is the convection velocity given approximately by $0.7 u_0$. This energy is non-propagating for low Mach number flows and represents the p_T -component of the present analysis. The p_a -component occurs at very low wavenumbers $k \ll k_c M_c$, where M_c is the convective Mach number, u_c/c . Inspection of Equation (6) together with Equation (7) shows that the p_T -component would dominate \hat{G}_{11} for measurements using very small pressure sensors [13]. Haddle and Skudrzyk [14] used this same reasoning to show that p_a would dominate a measurement performed with very large transducers. They further showed that a fish-shaped sensor (major length in direction of flow) was less sensitive to the convective wavenumber pressure fluctuations than was a circular sensor of the same area.

The above discussion serves to indicate that the output of a flush-mounted pressure sensor under a TBL depends strongly on its shape and size. One could obtain a crude estimate of $G_{12} \sim \hat{G}_{12}$ by simply using large, fish-shaped sensors. This estimate would also require that $\Delta x > \Lambda$, where $\Lambda = 11\pi/4k_c$ is the streamwise correlation length of the TBL pressure fluctuations [8]. If $\Delta x < \Lambda$, $G_{T_1 T_2}$ would be non-negligible.

An estimate of G_{12} could possibly be improved by measuring, simultaneously, p_{T_1} and p_{T_2} and subtracting them from \hat{p}_1 and \hat{p}_2 , respectively as in Equation (2). A potential method for doing this is sketched in Figure 2. The

fish-shaped sensors are fabricated from piezoceramic material and bored at the center to receive a "pin-hole" type microphone [15] or subminiature crystal. The center sensor would need to be isolated from the larger surrounding sensor by damping material. An analog differencing circuit would be used to form the differences:

$$p_{a_1} \approx \hat{p}_1 - p_{T_1} \quad (8a)$$

and

$$p_{a_2} \approx \hat{p}_2 - p_{T_2} \quad (8b)$$

The cross spectrum, G_{12} , would then be calculated directly from these two difference signals and used in Equation (1) to give a reasonable estimate of the intensity generated by the TBL in the streamwise direction. The concept is not restricted to the flow direction as long as the major length of the fish-shaped sensors align with the flow. Thus, the in-plane intensity vector could be obtained for various directions by re-positioning one element relative to the other, e.g., side-by-side positioning would yield I_a in the x_3 -direction.

IV. CONCLUDING REMARKS

The illustrative example described above is perhaps the "simplest" hydroacoustic source in which a near-field intensity measurement can be interpreted. The fact that the TBL wall pressure field is two-dimensional and reasonably-well understood helps simplify the issues. The interpretation of \hat{G}_{12} as measured by a pair of pressure sensors located in a general three-dimensional flow field is not nearly as well understood as the TBL case. Turbulent pressures generated in such fields are still highly dependent on wavenumber and frequency, but generalized modeling has yet to be accomplished. We would expect that the response of a three-dimensional pressure sensor to a three-dimensional turbulence field depends on sensor shape and size. It is not clear, however, how such sensors, particularly if they need to be large, can be placed in such fields without altering the hydrodynamic flow itself. It is therefore concluded that near-field measurements of the acoustic intensity generated by hydroacoustic sources of sound cannot be interpreted in general. Certain specific cases, such as the turbulent boundary layer, can however be explained.

REFERENCES

1. Chung, J. Y., "Cross-Spectral Method of Measuring Acoustic Intensity," Research Publication, General Motors Research Laboratories, GMR-2617, Warren, MI (1977).
2. Fahy, F. J., "Measurement of Acoustic Intensity using the Cross-Spectral Density of Two Microphone Signals," J. Acoust. Soc. Am. 62:1057-1059 (1977).
3. Chung, J. Y., "Cross-Spectral Method of Measuring Acoustic Intensity without Error caused by Instrument Phase Mismatch," J. Acoust. Soc. Am. 64:1613-1616 (1978).
4. Chung, J. Y. and D. A. Blaser, "Transfer Function Method of Measuring Acoustic Intensity in a Duct System with Flow," J. Acoust. Soc. Am. 68:1570-1577 (1980).
5. Mathur, G. P., "A Stochastic Analysis for Cross-Spectral Density Method of Measuring Acoustic Intensity," J. Acoust. Soc. Am. 74:1752-1756 (1983).
6. Munro, D. H. and U. Ingard, "On Acoustic Intensity Measurements in the Presence of Mean Flow," J. Acoust. Soc. Am. 65:1402-1406 (1979).
7. Oswald, L. J. and P. R. Donavan, "Acoustic Intensity Measurements in Low Mach Number Flows of Moderate Turbulence Levels," Research Publication, General Motors Research Laboratories, GMR-3269, Warren, MI (1980).
8. Lauchle, G. C., "Effect of Turbulent Boundary Layer Flow on Measurement of Acoustic Pressure and Intensity," J. Acoust. Soc. Am. Suppl. 1, 75, Paper A10 (1984). [Also submitted for publication in Noise Control Engr. J. and issued as ARL/PSU TM 84-87, 18 May 1984].

9. Bendat, J. S. and A. G. Piersol, Engineering Applications of Correlation and Spectral Analysis (John Wiley & Sons, 1980).
10. Uberoi, M. S. and L. S. G. Kovaszny, "On Mapping and Measurement of Random Fields," Quart. Appl. Math. 10:375-393 (1953).
11. Chase, D. M., "Modeling the Wavevector-Frequency Spectrum of Turbulent Boundary Layer Pressure," J. Sound Vibra. 70:29-67 (1980).
12. Blake, W. K. and D. M. Chase, "Wavenumber-Frequency Spectra of Turbulent-Boundary-Layer Pressure Measured by Microphone Arrays," J. Acoust. Soc. Am. 49:862-877 (1971).
13. Corcos, G. M., "Resolution of Pressure in Turbulence," J. Acoust. Soc. Am. 35:192-199 (1963).
14. Haddle, G. P. and E. J. Skudrzyk, "The Physics of Flow Noise," J. Acoust. Soc. Am. 46:130-157 (1969).
15. Blake, W. K., "Turbulent Boundary-Layer Wall-Pressure Fluctuations on Smooth and Rough Walls," J. Fluid Mech. 44:637-660 (1970).

LIST OF FIGURES

- Figure 1. Hypothetical arrangement for the measurement of acoustic intensity in a turbulent flow.
- Figure 2. Suggested method for measuring the acoustic intensity of a TBL flow using sensors of special design that are placed under the TBL of interest.

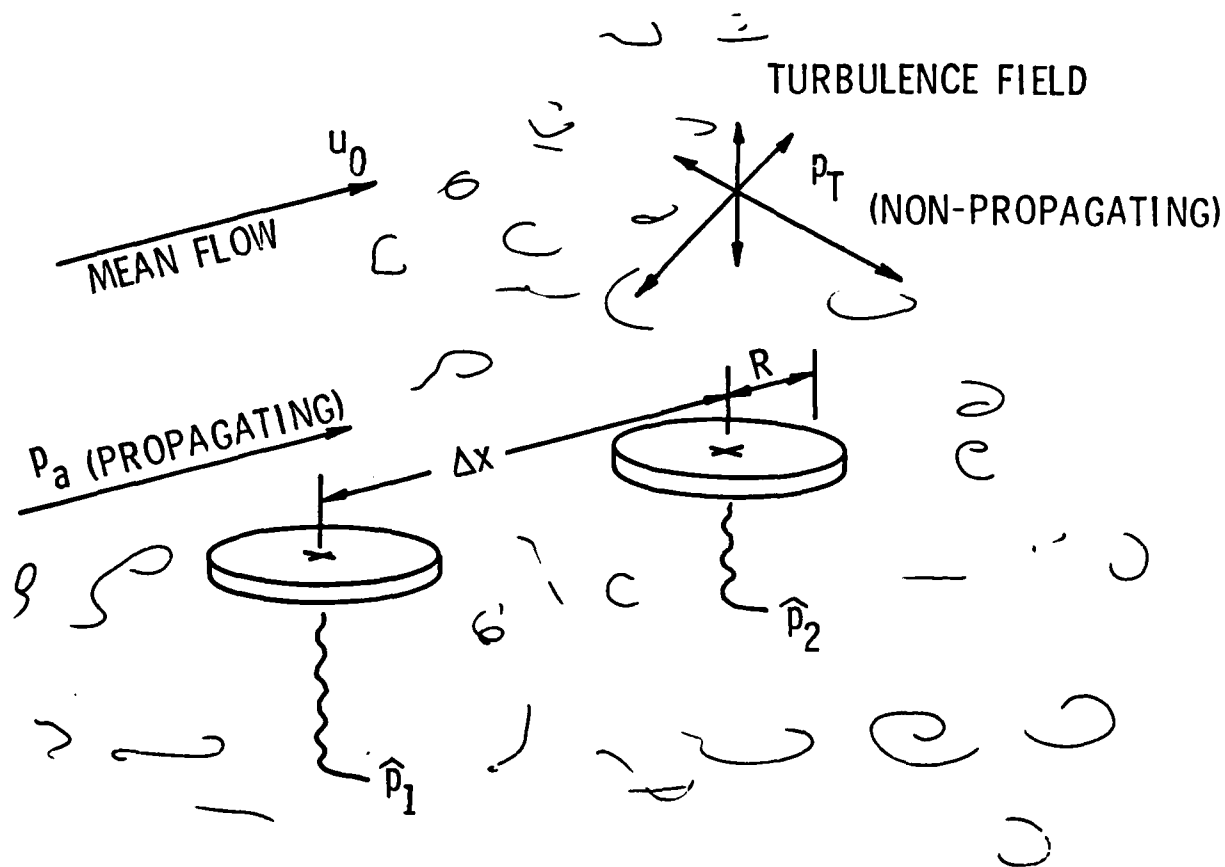
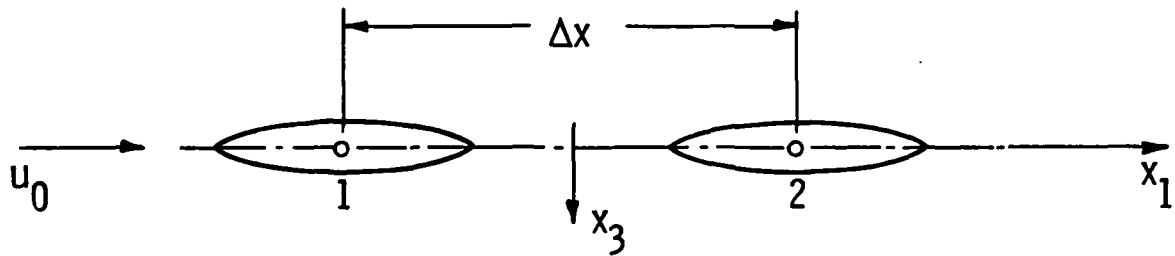


Figure 1. Hypothetical arrangement for the measurement of acoustic intensity in a turbulent flow.



TOP VIEW

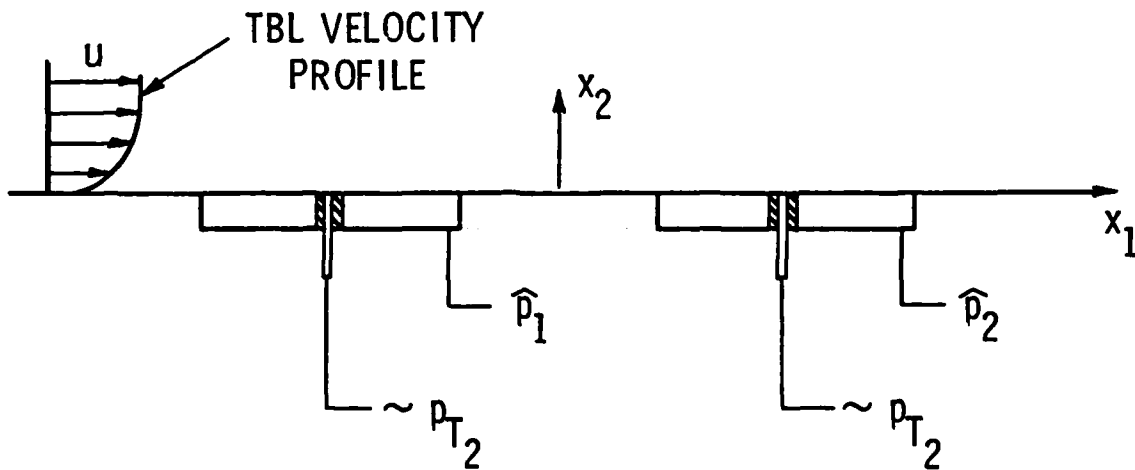


Figure 2. Suggested method for measuring the acoustic intensity of a TBL flow using sensors of special design that are placed under the TBL of interest.

DISTRIBUTION LIST FOR UNCLASSIFIED TECHNICAL MEMORANDUM FILE NO. 84-91,
by G. C. Lauchle, dated 25 May 1984

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: Library
Code NSEA-09G32
(Copies 1 and 2)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: R. Keane
Code NSEA-3213
(Copy No. 3)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: A. R. Paladino
Code NSEA-55N
(Copy No. 4)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: F. B. Peterson
Code NSEA-052P
(Copy No. 5)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: C. D. Smith
Code NSEA 63R
(Copy No. 6)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: D. C. Houser
Code NSEA-63R14
(Copy No. 7)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: F. J. Romano
Code NSEA-63R3
(Copy No. 8)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: T. E. Peirce
Code NSEA 63R31
(Copy No. 9)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: S. Silverstein
Code NSEA-63Y1
(Copy No. 10)

Commander
Naval Sea Systems Command
Department of the Navy
Washington, DC 20362
Attn: E. G. Liszka
Code PMS-406B
(Copy No. 11)

Commanding Officer
Naval Underwater Systems Center
Department of the Navy
Newport, RI 02840
Attn: B. J. Meyers
Code 36311
(Copy No. 12)

Commanding Officer
Naval Underwater Systems Center
Department of the Navy
Newport, RI 02840
Attn: T. A. Davis
Code 36314
(Copy No. 13)

DISTRIBUTION LIST FOR UNCLASSIFIED TECHNICAL MEMORANDUM FILE NO. 84-91,
by G. C. Lauchle, dated 25 May 1984 [continuation]

Commanding Officer
Naval Underwater Systems Center
Department of the Navy
Newport, RI 02840
Attn: D. Goodrich
Code 3634
(Copy No. 14)

Commanding Officer
Naval Underwater Systems Center
Department of the Navy
Newport, RI 02840
Attn: C. Hervey
Code 3634
(Copy No. 15)

Commanding Officer
Naval Underwater Systems Center
Department of the Navy
Newport, RI 02840
Attn: R. H. Nadolink
Code 3634
(Copy No. 16)

Commanding Officer
Naval Underwater Systems Center
Department of the Navy
Newport, RI 02840
Attn: Library
Code 54
(Copy No. 17)

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: V. J. Monacella
Code 1504
(Copy No. 18)

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: Library
Code 1505
(Copy No. 19)

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: J. H. McCarthy
Code 154
(Copy No. 20)

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: M. M. Sevik
Code 19
(Copy No. 21)

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: M. Strasberg
Code 1901
(Copy No. 22)

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: W. K. Blake
Code 1950
(Copy No. 23)

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: D. Feit
Code 1960
(Copy No. 24)

DISTRIBUTION LIST FOR UNCLASSIFIED TECHNICAL MEMORANDUM FILE NO. 84-91,
by G. C. Lauchle, dated 25 May 1984 [continuation]

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: R. A. Rippeon
Code 1980
(Copy No. 25)

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: F. S. Archibald
Code 1942
(Copy No. 26)

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: T. M. Farabee
Code 1942
(Copy No. 27)

Commander
David W. Taylor Naval Ship
Research & Development Center
Department of the Navy
Bethesda, MD 20084
Attn: F. E. Geib
Code 1942
(Copy No. 28)

Commanding Officer
Naval Undersea Warfare
Engineering Station
Department of the Navy
Keyport, WA 98345
Attn: Library
(Copy No. 29)

Commander
Naval Surface Weapons Center
Department of the Navy
Silver Spring, MD 20910
Attn: G. C. Gaunard
Code R-31
(Copy No. 30)

Commander
Naval Surface Weapons Center
Department of the Navy
Silver Spring, MD 20910
Attn: Library
(Copy No. 31)

Office of Naval Research
800 North Quincy Street
Department of the Navy
Arlington, VA 22217
Attn: M. M. Reischman
Code 432F
(Copy No. 32)

Commanding Officer
Naval Ocean Systems Center
Department of the Navy
San Diego, CA 92152
Attn: E. W. Hendricks
Code 6342
(Copy No. 33)

Commanding Officer
Naval Ocean Systems Center
Department of the Navy
San Diego, CA 92152
Attn: D. M. Ladd
Code 6342
(Copy No. 34)

Commanding Officer
Naval Ocean Systems Center
Department of the Navy
San Diego, CA 92152
Attn: Library
(Copy No. 35)

Commander
Naval Coastal Systems Center
Department of the Navy
Panama City, FL 32407
Attn: M. Hyman
Code 4210
(Copy No. 36)

DISTRIBUTION LIST FOR UNCLASSIFIED TECHNICAL MEMORANDUM FILE NO. 84-91,
by G. C. Lauchle, dated 25 May 1984 [continuation]

Defense Technical Information
Center
5010 Duke Street
Cameron Station
Alexandria, VA 22314
(Copies 37 through 42)

Westinghouse Electric Corp.
Post Office Box 1488
Annapolis, MD 21404
Attn: Dr. R. F. Mons
(Copy No. 43)

NASA Langley Research Center
Hampton, VA 22665
Attn: Dr. L. Maestrello
(Copy No. 44)

Dr. R. J. Hansen
Naval Research Laboratory
Marine Technical Division
Washington, DC 20390
(Copy No. 45)

Mr. P. S. Klebanoff
National Bureau of Standards
Aerodynamics Section
Washington, DC 20234
(Copy No. 46)

Professor D. G. Crighton
University of Leeds
Dept. Appl. Math. Studies
Leeds LS29JT
England
(Copy No. 47)

Dr. N. A. Brown
Bolt, Beranek and Newman
50 Moulton Street
Cambridge, MA 02136
(Copy No. 48)

Dr. K. L. Chandiramani
Bolt, Beranek and Newman
50 Moulton Street
Cambridge, MA 02136
(Copy No. 49)

Professor P. Leehey
Dept. of Ocean Engineering
Massachusetts Institute of
Technology
77 Massachusetts Avenue
Cambridge, MA 02139
(Copy No. 50)

Professor J. L. Lumley
Sibley School of Mechanical &
Aeronautical Engineering
Upson Hall
Cornell University
Ithaca, NY 14850
(Copy No. 51)

Dr. R. E. A. Arndt
St. Anthony Falls Hydraulic Lab
University of Minnesota
Mississippi River at 3rd Ave., S.E.
Minneapolis, MN 55414
(Copy No. 52)

Professor V. J. Arakeri
Dept. of Mechanical Engineering
Indian Institute of Science
Bangalore 560 012
India
(Copy No. 53)

Dr. W. W. Haigh
Dynamics Technology, Inc.
22939 Hawthorne Blvd.
Suite 200
Torrance, CA 90503
(Copy No. 54)

Professor M. Pierucci
Dept. of Aerospace Engineering
and Engineering Mechanics
San Diego State University
San Diego, CA 92182
(Copy No. 55)

Professor Eli Reshotko
Case Western Reserve University
Cleveland, OH 44106
(Copy No. 56)

DISTRIBUTION LIST FOR UNCLASSIFIED TECHNICAL MEMORANDUM FILE NO. 84-91,
by G. C. Lauchle, dated 25 May 1984 [continuation]

Dr. W. W. Lang
IBM Corporation
Acoustics Laboratory
Post Office Box 390
Building 704
Poughkeepsie, NY 12602
(Copy No. 57)

Mr. D. Yeager
IBM Corporation
Acoustics Laboratory
Post Office Box 390
Building 704
Poughkeepsie, NY 12602
(Copy No. 58)

Mr. Francois Jouaillec
Office National d'Etudes et de
Recherches Aeronautiques
(ONERA)
Direction de la Physique Generale
BP 72
92322 Chatillon Cedex
(Copy No. 59)

Dr. Massot
Science Industries
22 Avenue Liberation
Montereau 77130
France
(Copy No. 60)

Mr. Glen Steyer
Structural Dynamics Research
Corporation
2000 Eastman Drive
Milford, OH 45150
(Copy No. 61)

Dr. George F. Kuhn
Vibrasound Research Corporation
10957 East Bethany Drive
Aurora, Colorado 80014
(Copy No. 62)

Dr. Eric Stusnick
Wyle Laboratories
The Hayes Building, Suite 404
2361 Jefferson Davis Highway
Arlington, VA 22202
(Copy No. 63)

Dr. Pritchard White
Bolt Beranek and Newman, Inc.
21120 Vanowen Street
Post Office Box 633
Canoga Park, CA 91305
(Copy No. 64)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16804
Attn: L. R. Hettche
(Copy No. 65)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16804
Attn: G. C. Lauchle
(Copy No. 66)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16804
Attn: B. R. Parkin
(Copy No. 67)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16804
Attn: E. J. Skudrzyk
(Copy No. 68)

DISTRIBUTION LIST FOR UNCLASSIFIED TECHNICAL MEMORANDUM FILE NO. 84-91,
by G. C. Lauchle, dated 25 May 1984 [continuation]

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16804
Attn: ARL/PSU Library
(Copy No. 69)

Director
Applied Research Laboratory
The Pennsylvania State University
Post Office Box 30
State College, PA 16804
Attn: GTWT Files
(Copy No. 70)

Mr. Kirby Miller
Advanced Technologies
Western Division
GTE Government Systems
Corporation
100 Ferguson Drive
Post Office Box 7188
Mountain View, CA 94039
(Copy No. 71)

Mr. Alan G. Piersol
Bolt Beranek and Newman, Inc.
21120 Vanowen Street
Canoga Park, CA 91303
(Copy No. 72)

Professor Dr. H. Myncke
Laboratorium Voor Akoestiek
En Warmtegeleiding
Celestijnenlaan 200 D
B-3030 Heverlee
Belgium
(Copy No. 73)

LEND

FILMED

8

74

1974