UNCLASSIFIED

AD NUMBER

ADC017083

CLASSIFICATION CHANGES

TO: unclassified

FROM: confidential

LIMITATION CHANGES

TO:

Approved for public release, distribution unlimited

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Specific authority; Nov 1978. Other requests shall be referred to Commander, Naval Electronic Systems Command, Attn: Code 320, Washington, DC 20360.

AUTHORITY

NRL ltr, 24 Jan 2003; NRL ltr, 24 Jan 2003

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD NUMBER

ADC017083

NEW LIMITATION CHANGE

TO

Distribution authorized to U.S. Gov't. agencies and their contractors; Specific authority; Nov 1978. Other requests shall be referred to Commander, Naval Electronic Systems Command, Attn: Code 320, Washington, DC 20360.

FROM

Distribution authorized to U.S. Gov't. agencies only; Test and Evaluation; Nov 1978. Other requests shall be referred to Naval Electronic Systems Command, Attn: 320, Washington, DC 20360.

AUTHORITY

NAVELEX, per DTIC Form 55, Nov 1978

THIS PAGE IS UNCLASSIFIED

(2) NW LEVEL II

CONFIDENTIAL

NAVELEX Report

AD C017083

DDC FILE COPY

Acoustic Fluctuations: Guidelines for R&D Based on the Acoustic Fluctuation Workshop 22-23 February 1978

[Unclassified Title]

S. Hanish, C. R. Rollins and J. Cybulski

"NATIONAL SECURITY INFORMATION"

"Unauthorized Disclosure Subject to Criminal Sanctions"

November 28, 1978

79 03 08 510

DDC
RECEIVED
APR 3 1979
B

NAVAL ELECTRONIC SYSTEMS COMMAND
Washington, D.C.

CLASSIFIED BY CNO (OP-095)
Review 31 DEC 1999

CONFIDENTIAL

aluation; November 1978. Other requests for this document must be referred to Naval Electronic Systems Command, Code 320, Washington, D.C. 20360.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
NAVELEX Report

2. GOVT ACCESSION NO.
and

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
(6) ACOUSTIC FLUCTUATIONS: GUIDELINES FOR R&D BASED ON THE ACOUSTIC FLUCTUATION WORKSHOP 22-23 FEBRUARY 1978 (U), (8)

5. TYPE OF REPORT & PERIOD COVERED
(9) Final rept,

6. PERFORMING ORG. REPORT NUMBER
NESC 320 see Block 11

7. AUTHOR(s)
(10) S. Hanish, C. R. Rollins [redacted] J. Cybulski

8. CONTRACT OR GRANT NUMBER(s)
(16) F52522

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Naval Electronic Systems Command
Washington, D.C. 20360
(12) 89p.

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
62759N, XF52-522

11. CONTROLLING OFFICE NAME AND ADDRESS
Naval Electronic Systems Command
Code 320
Washington, D.C. 20360

12. REPORT DATE
November 28, 1978

13. NUMBER OF PAGES
87

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Confidential

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
[redacted]

16. DISTRIBUTION STATEMENT (of this Report)

Distribution limited to U.S. Government Agencies only; test and evaluation; November 1978. Other requests for this document must be referred to Naval Electronic Systems Command, Code 320, Washington, D.C. 20360.

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 Fluctuations
Research and Development
Guidelines
Undersea Surveillance
Performance Models

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

(U) A set of Guidelines for Research and Development has been prepared based upon the papers and discussions at the Acoustic Fluctuation Workshop held at NRL and subsequent panel deliberations. Included is a background on acoustic fluctuations research and the considerations in structuring a program in ocean acoustic fluctuation. Specific tasks are itemized, beginning with the use of highest priority to formulate a potentially complete model of SNR. This is followed by those tasks relevant to terms in the sonar equation, namely, source level, transmission loss,

(Continued)

Add F

387 196

79 03 08 510 6

20. ABSTRACT (Continued)

signal gain, beam noise and some in Signal Processing and SNR. For reference, an Appendix contains editorial summaries or synopses of papers presented at the Workshop.

CONTENTS

ACOUSTICS FLUCTUATIONS: GUIDELINES FOR R&D BASED ON THE ACOUSTIC FLUCTUATION WORKSHOP 22-23 FEBRUARY 1978

[Unclassified Title]

I. INTRODUCTION (U)

(U) The detection, localization and tracking of submarines by underwater acoustic signals are greatly disturbed by signal fluctuations. These originate primarily in source/receiver motion, but also are caused by acoustic rays reflected from wind-roughened surface, and by scattering from inhomogeneities randomly dispersed in the ocean. In past years such fluctuations have been spatially and temporally averaged to mean values. However, random variations of signals about mean values have recently taken on significant meaning because they strongly affect target detection methods which use statistical decision, such as is found in receiver operating characteristic (ROC) curves. In addition, a higher order statistical analyses of acoustic fluctuations provides a means to evaluate the reliability of experimental data and can lead to the construction of confidence limits to the mean values currently used in ASW operations.

(U) Research progress in acoustic fluctuations has been reviewed and evaluated in several recently held conferences and workshops. Since 1974 there have been four distinctive but related workshops of this nature, one review panel, and an Acoustic Society of America (ASA) session held which bear somewhat on acoustic signal fluctuations. On 27-28 March 1974 a fluctuation workshop was conducted at Naval Research Laboratory (NRL) hosted by Acoustic Environmental Support Detachment (AESD) and a summary (Ref. 1) is available. An International Workshop (Ref. 2) on Low Frequency Propagation and Noise was sponsored by CNO (OP-95) and supported by Chief of Naval Research (CNR) and held at Woods Hole Oceanographic Institute (WHOI) in October 1974. The David Taylor Naval Ship Research and

(U) Development Center (DTNSRDC) was the host for an Operations Research Models of Fluctuations Affecting Sonar Detection Workshop during 19-21 March 1975. Proceedings were published (Ref. 3) in two classified volumes. On 1-2 October 1975 a workshop (Ref. 4) under auspices of Underwater Sound Advisory Group (USAG) was held on Acoustic Signal Coherence at Naval Underwater Systems Center (NUSC). Next, under direction of chief of Naval Operations (CNO:OP95) a technical review panel for a coordinated Ocean Acoustics Program Plan met 8-10 November 1977 at Naval Ocean Research and Development Acitivity (NORDA) and produced a summary (Ref. 5). Lastly, at the December 1977 meeting of the Acoustical Society of America (ASA) at Miami a session on Underwater Acoustics was devoted to Fluctuations and Signal processing. A review of several of the significant papers presented at that session appears in Ref. 6.

(U) Each of the preceding efforts did not completely address the signal fluctuation problems. For instance the one hosted by AESD was specifically directed to satisfy potential SASS contractors. The International Workshop at WHOI was unclassified and many system applications were omitted. The Operations Research effort at DTNSRDC neglected the environmental effects. The one on Signal Coherence at NUSC was constrained in subject material. The scope of the coordinated plan at NORDA (Ref. 5) examined the contributions of Navy research, exploratory and advanced development programs to the four ocean acoustic subjects of bottom interaction, signal fluctuation, coherence and directional noise. Each of these subjects were divided into segments dealing with modeling, measurement systems and data acquisition programs. Of necessity these elements received a very broad treatment and generally were of a non-technical nature and lacked specificity.

(U) Lastly, the ASA session was instructive but again because of its unclassified nature a proper discussion and exposition of the efforts being made by the exploratory and advanced development workers could not be made.

(C) Current Navy sponsored programs in data acquisition and analytical modeling of fluctuations of received acoustic signals show a great diversity of approach, data collection, signal processing and final display. The ultimate use of the results of research to improve undersea surveillance often falls short of expectations because of a mismatch between the user's understanding of his requirements and the investigator's interpretation of those requirements. There is and has been a need to clarify both the user's and investigator's concept of their requirements. To this end the Chief of Naval Development with the assistance of the Naval Electronic Systems Command sponsored a classified workshop on Acoustic Fluctuations.

(U) The objectives of the Acoustic Fluctuations Workshop were to:

a. (C) Delineate the problem areas associated with modeling of fluctuations of acoustic signals and noise as caused by the medium, its boundaries and motion of the source or receiver platforms. Assess the impact of these fluctuations on system performance models as translated into model input parameters.

b. (U) Examine the current programs addressing underwater acoustic fluctuations. Present program goals, technical approaches to meet the goals, and work currently underway.

c. (U) Recommend adjustments to program goals to meet the input needs of users of acoustic environmental fluctuation models.

(U) On 22-23 Feb. 1978 on Acoustic Fluctuation Workshop was held at NRL and the Agenda was essentially as per Figs. 1 and 2.

(U) Attendance at the Workshop was limited to the principal investigators and managers from the involved sectors of the Navy industry and academic community. Over 50 participated in the presentations that were made and discussions that were held. An editorial summary was made for those papers which were supplied by the authors. A synopsis was prepared for all unwritten papers and combined with a comprehensive technical review on Ocean Science Fluctuations into a separate report (Ref. 6).

0830	Welcome, Workshop Objectives, Navy Unified Program, Prologue, and Filters	Spalding, Miller, Winokur, Cybulski
0900	Key Issues in Fluctuations & Coherence	Sam Hanish
0945	APSURV Model (& Fluctuations)	Ron Larsen
1015	PSEUDO Model (& Fluctuations)	Lyman Fretwell
Movable Break		
1100	APETC (& Fluctuations)	Robert Flum
1130	Beam Noise Fluctuation Models	Ray Cavanagh
1200	Signal Processor (& Fluctuations)	Don Grace
Lunch		
1330	Effects of Fluctuating Signals & Noise on Detection Performance	John Heine
1400	A Working Fluctuation Model with Application to Performance Prediction	Robert Urick
1430	Signals Fluctuations	Ken Flowers
1500	A Model of Acoustic Propagation Thru Internal Waves	Harry De Ferrari
Movable Break		
1545	Single Path — Phase & Amplitude Fluctuations	Terry Ewart
1615	Fluctuations From a Communication Engineering Viewpoint	A. Ellinthorpe

(U) Fig. 1. (U) Agenda — Acoustic Fluctuation Workshop
22 Feb. 1978, NRL., Bldg. No. 43, Rm. 205

0800	Prediction of Detection Performance	Magnus Moll
0820	Acoustic Fluctuation Modeling for System Performance Estimation	Ray Cavanagh
0845	Beam Output Fluctuations	Andy Fabula
0915	Fluctuations Due to Range Rate	Ira Dyer
0945	Importance of Source Motion, Receiver Motion and Ocean Environment	W. Jobst
Movable Break		
1030	Impact of Source Motional Fluctuations on IAP	Al Gerlach
1100	Discussion	
1115	Acoustic Fluctuations	R. Spindel
1145	Range Independent Fluctuations — Pattern Recognition	Fred Fisher
1215	Omni Noise Field Statistics — Depth & Clutter	J. Schooter
Lunch		
1330	Characterization of Acoustic Propagation	Harry De Ferrari
1345	Measurement tools	Dave Keir
1400	Open Forum	
	Adjourn	

(U) Fig. 2. (U) Agenda — Acoustic Fluctuation Workshop
23 Feb. 1978, NRL., Bldg. No. 43, Rm. 205

(U) Subsequently, a working group* was charged with the task of formulating objectives, approaches and specific tasks which could serve to assist in structuring R&D programs on acoustic fluctuations. This document is the result of those effort and has undergone several revisions one as a result of consultation and convening of a special panel** where Navy laboratories and industry were represented.

II. BACKGROUND OF ACOUSTIC FLUCTUATION RESEARCH (U)

(C) About 10 years ago, several developments lead to an awareness of the lack of adequate knowledge about fluctuations in the signals and noise always present in acoustic detection systems. One of these developments was the interest in active undersea surveillance systems. A number of studies and analyses were undertaken to establish performance estimates as a function of source level, frequency, array gain, and other variables. It became clear that, due to the long ranges of acoustic transmission, the data rate would be low, and the fading, or fluctuation, of echo returns could seriously impair performance. In addition, it was recognized that the temporal correlation time was important in determining the effect of ping separation on statistical independence of pings. The frequencies of interest were in the few hundred hertz region, with temporal scales from about 1 to 30 minutes. At that time, very little data was available for use in system performance prediction models.

(C) A second factor which contributed to the interest in fluctuation was the development of a family of passive sonar prediction models, of which Anti-Submarine Warfare Program Surveillance (APSURV) is representative. This model was developed primarily by mathematically oriented operations research analysts. It was known that a fluctuating signal-to-noise ratio was characteristic of long range low frequency detection, and therefore a fluctuation was introduced into the model signal-to-noise ratio through use of a pseudo-normal process. One parameter

---

* Dr Sam Hanish, C.R. Rollins, J. Cybulski of NRL.

** Dr. P. Cable (NUSC), Dr. J. Stewart (NOSC), Mr. C. Spofford (SAI).

(C) τ established the correlation interval or "relaxation time" and a second parameter, σ established a normal distribution of signal excess values. Implementation in APSURV (model 1) was through an Ehrenfest random walk incorporated as part of a Monte-Carlo model. Developers and users of the model asked several questions which could not be adequately answered at that time:

1. (C) Can we isolate the signal, noise, and other fluctuations, or must we treat the net signal-to-noise ratio as one fluctuating process?

2. (C) What are the appropriate (correct) values of relaxation time τ and variance σ for the individual (signal, noise, array gain, etc) processes and for the resultant signal-to-noise ratio?

3. (C) Is the normal distribution an adequate representation of the statistical processes involved, or do we need something different?

(C) A third factor which contributed to interest in fluctuation research was the development of long line arrays with the attendant question of maximum coherence length. This motivated investigation of phase fluctuation as a function of spatial position and time, information needed by signal processors as well as array designers.

(C) The confluence of these questions and the importance for the Navy led to sponsor support and subsequently to several years of effective research into these various areas of fluctuations. In addition, closely related subjects such as target scintillation, ship traffic dynamics, source and receiver motion have been investigated. The result has been the production of a substantial body of information, both data and theory, which at this time appears to be unfocused. Answers to many of the original questions now exist, but in some cases the results have not been compiled and disseminated in a form suitable for the potential user. It must be remembered that for a user, *the most simple, uncomplicated result which is adequate for his use*, is what is needed. Thus, a detailed, mathematically elegant model which may provide great insight into causes and relationships may be completely inappropriate for a performance

(C) prediction model or for a system designer. In other cases it may be necessary to carry a great amount of scientific sophistication into a production model in order to meet the requirements of the task. Some method must be found and implemented in which the results of fluctuation research can be organized, summarized, and in some cases simplified, in terms useful to the users. Who the users are, and what these requirements are, is discussed next.

Acoustic Fluctuation Research—Requirements (U)

1. Prediction of Submarine Detection (U)

(C) Developers and users of detection performance models are primarily interested in amplitude fluctuation of signal, noise, array gain, and in some cases, the variability of operator and hardware performance. Signal variability involves both source characteristics and transmission path characteristics. The performance prediction modeler would like to be able to separate the deterministic, predictable component from the nondeterministic component, and he would like a statistical description of the latter. The statistical description would include the parameters of the distribution and the temporal auto correlation function. With this information for each factor in the sonar equation, the modeler could accurately estimate the detection performance (in a threshold sense) of a submarine detection system.

(U) For many purposes combined statistics are adequate, such as combined source and transmission path fluctuation, array gain and noise fluctuation, and even total signal-excess fluctuations. The passive sonar equation may be written in several forms, combining terms differently to allow use of appropriate data or models. The fundamental form is as follows:

$$SE = SL - TL - N + SG - NG - RD \qquad (1)$$

where

$SE \equiv$ signal excess

$SL \equiv$ source level

(U) $TL \equiv$ transmission loss

$N \equiv$ omnidirectional noise level

$SG \equiv$ signal gain for the receiving array

$NG \equiv$ noise gain for the receiving array

$RD \equiv$ recognition differential or detection threshold

(U) Ideally, the deterministic mean, the statistical variability, the correlation (or dependence) relative to other terms, and the temporal auto correlation coefficient of each term should be known. If the signal gain and noise gain terms are combined, the array performance, including fluctuation characteristics, can be characterized by array gain:

$$SE = SL - TL - N + AG - RD \tag{2}$$

where

$$AG = SG - NG \equiv \text{array gain} \tag{3}$$

(U) Similarly, in many cases, it is convenient to model or measure noise level and fluctuations in noise on a beam. Thus:

$$SE = SL - TL + SG - BN - RD \tag{4}$$

where

$$BN = N + NG \equiv \text{beam noise} \tag{5}$$

(U) For engagement models which must be re-run repeatedly, where running time is a significant consideration, the complexity of the fluctuation processes must be reduced to simplest terms. The performance modeler would like to know the significance of the statistics of individual terms as compared to the statistics of signal excess, and whether a statistical description of signal excess is sufficient, or whether individual terms must be handled separately.

2. System Design (U)

(C) The system designer is interested in acoustic fluctuation processes as they affect the design of signal processors and receiving arrays. Temporal statistics of amplitude and phase indicate the length of integration times which may be utilized for coherent and non-coherent

(C) processing. Frequency, bandwidth and type of acoustic path are important parameters. The "coherence length" of an acoustic field determines the maximum size array which will be effective. Coherence length has statistical properties associated with the fluctuation of phase across an array aperture. Thus phase fluctuation investigations contribute to the design of arrays and to an understanding of the variability of array gain. In addition, the development of inter-array processing (IAP), multi-array processing (MAP), and coherent multi-array processing (CMAP), requires information about the temporal and spatial fluctuations of both phase and amplitude for widely separated sites.

(U) In an effort to place these requirements in perspective and to identify users of the results of fluctuation research, Table 1, on fluctuation parameters has been prepared.

(U) Table 1 — Research in Acoustic Fluctuation Parameters and Potential Users (U)

Parameter of Research in Acoustic Fluctuations	detection performance modeling	signal processing development	receiving array design
Source Level SL (for given submarine)			
1. mean value as function of aspect (deterministic)	x		
2. statistical distribution (over all aspects)	x		
Transmission Loss TL			
1. mean value as function of frequency, range, source and receiver depth	x		
2. statistical distribution of temporal amplitude fluctuation	x	x	
3. statistical distribution of temporal phase fluctuations	x	x	
4. statistical distribution of spatial amplitude fluctuation	x	x	x
5. statistical distribution of spatial phase fluctuation		x	x
6. autocorrelation function of temporal amplitude fluctuation	x	x	
7. autocorrelation function of temporal phase fluctuation		x	
8. crosscorrelation function of spatial amplitude fluctuation		x	x
9. crosscorrelation function of spatial phase fluctuation		x	x
Ambient Noise N			
1. mean level of omnidirectional ambient noise	x		
2. statistical distribution of amplitude fluctuations	x	x	
3. temporal autocorrelation function	x		
4. spatial crosscorrelation function (spatial coherence)		x	x
5. statistical distribution of spatial amplitude fluctuation	x	x	x
Signal Gain SG (for array)			
1. mean value	x		x
2. statistical distribution of temporal fluctuations	x		x
Noise Gain NG (for array)			
1. mean value	x		x
2. statistical distribution of temporal fluctuations	x		x
Array Gain AG (= SG − NG)			
1. mean value	x		x
2. statistical distribution of temporal fluctuations	x		x
Beam Noise BN (= N + NG)			
1. mean value	x		x
2. statistical distribution of amplitude fluctuations	x	x	x
3. temporal autocorrelation function	x		
Signal Excess SE (= SL − TL − N + SG − NG − RD)			
1. mean as function of range	x		
2. statistical distribution of values	x		
3. temporal autocorrelation function (relaxation time)	x		

(U) The three major users of results selected are the performance detection modelers, the signal processing developers and the array designers. In a general sense, all the users are interested in all the results. However, the users indicated are those considered to be the primary and most important for the given fluctuation parameter.

III. STRUCTURING A PROGRAM IN OCEAN ACOUSTIC FLUCTUATIONS (U)

A. Introduction (U)

(U) Underwater sound physicists and systems performance modelers approach acoustic fluctuations in different but complementary ways. A previous report (Ref. 6) has reviewed the propagation of acoustic disturbances (signal and noise) in the ocean in the context of the physicist model of a single communications path between source and receiver, here called a "channel," and symbolically written as,

$$p = T(\mathfrak{E})Q \tag{6}$$

in which Q is the source of sound, T is the transmission, $\mathfrak{E}$ is the matrix of environment factors, and p is the received acoustic pressure. Because of random properties of the medium the entities $\mathfrak{E}$, T, and p are all random variables. At the antenna the received pressure is multiplied by the antenna function $\mathfrak{A}$ to form $\mathfrak{A}p$, and then $\mathfrak{A}p$ is signal processed by the processing function δ to give the final statistic S of the received field. A sum of signals in N such channels caused by the m'th source Q_m of a total of M sources, and received at the j'th hydrophone of an array of I hydrophones is given by,

$$p_{Nm}^{(i)} = \sum_{n=1}^{N} p_{nm}^{(i)} = \sum_{n=1}^{N} [T_n(\mathfrak{E})Q_m]^{(i)} \tag{7}$$

and the final statistic from all I hydrophones and M sources is,

$$S = \delta\left\{\sum_{m=1}^{M}\sum_{i=1}^{I}\mathfrak{A}^{(i)}\sum_{n=1}^{N}[T_n(\mathfrak{E})\,Q_m]^{(i)}\right\}. \tag{8}$$

(U) In summary, research by the underwater physicist in acoustic fluctuations in the ocean involves the following list of studies in the statistical properties of the components of this equation:

1. sources of sound (both signal and noise) Q
2. environmental effects, $\mathcal{E}$
3. transmission functions, T
4. antenna function $\mathcal{A}$
5. signal processing $\mathcal{S}$

(U) Implicit in this listing are the problems of multipath interference (or effects of summing channels at specific space points) and resolution of multipath in time, space and doppler (or isolation of channels). The important measurement is the acoustic pressure transmitted by a single channel and many channels; the final output is some statistic of P_N peculiar to the goals of the research. Statistics in current use are listed in Ref. 6.

(U) Complementary to the study by the physicists of the propagation of sound in the ocean as a physical event is the current research in ocean fluctuations by system performance modelers as they affect sonar system performance. The basics of this research are formulated differently. Consider the detection of submarines first. Acoustic *power* S_s from a distant source (the submarine) undergoes attenuation, A, as it traverses the ocean to the receiver, arriving with power S_s/A. Here it is increased again by the signal gain G_s so that the processed received power is $S_R = S_sG_s/A$. At each hydrophone there is noise power N_R, which becomes N_RG_N for all hydrophones, G_N being the noise gain. If one chooses a minimum signal to noise level $(S/N)_{RD}$ to serve as recognition differential, the signal excess above this level is the ratio of S/N's: In decibel units,*

$$SE = SL - TL - BN + SG - RD \tag{9}$$

---

*Ref. 6

(U) in which, relative to unit reference levels,

$SL = 10 \log_{10} S_x$ (signal level)

$TL = 10 \log_{10} A$ (transmission loss)

$BN = 10 \log_{10} (N_R G_N)$ (beam noise)

$SG = 10 \log_{10} G_x$ (signal gain)

$RD = 10 \log_{10} (S/N)_{RD}$ (recognition differential)

(U) All of the terms of this equation are random variables so that signal excess is itself a sum of random processes. The focal point of research is the characterization by experiment and modeling of each term as a random process, and of the total.

(C) Beside detection, current sonar systems may be required to perform other functions, such as localization and tracking of a target. A usual passive procedure for localizing a target is geometrical triangulation using bearings from two separated receivers. An alternate newer method uses multiarray processing. Two receivers, "widely separated" in the ocean, receive $p(\vec{x}_1,t)$, $p(\vec{x}_2,t)$ from a common source. The time records of these signals are used to form an ambiguity surface $E(\tau,\phi)$ of the time difference of arrival τ between the signals and of their frequency difference ϕ. The three-dimensional plot of E versus τ and ϕ exhibits several maxima of varying height. The center of gravity of all the maxima and the neighboring spread of E over τ and ϕ, indicates the particular values of τ_c and ϕ_c at which the probability that both signals originate at the same source is greatest. The most likely location of the source of the signal can be determined from τ_c and ϕ_c. An extension of the two receiver method sometimes used to determine wavefront curvature is the identification of the wavefront of a common source on two pairs (or a minimum of three) widely separated receivers. Not only does the method locate the target but it also permits estimation of its course and speed. In practice, wavefronts fluctuate in time over great distances. This makes the determiniation of bearing, range and thus localization to be random processes. The focal point of research in localization is to reduce the uncertainties inherent in the statistics of these processes.

(C) Tracking of a distant target is limited by several factors including fluctuations in the ocean. In current practice, knowledge of one, or several identifiable characteristics of the target (such as target bearing, frequency, time difference of arrival at two hydrophones, etc.) are continuously updated. Attempts have been made to improve tracking by introduction of feedback control loop which detect change, and make corrections. A mathematical description of the tracking loop can be reduced to an n^{th} order ordinary differential equation involving signal and noise, which is subject to initial conditions. Solution is effected rapidly by converting this equation into a set of first order differential equations which becomes the state variable matrix equation of signal and noise. Such equations can be solved on digital or analog computers. The entire procedure is equivalent to prediction filtering using a Kalman-Bucy filter. When fluctuations are present the coefficients of the state variable matrix become random variables. The tracking loop thus takes a random character not only because of corrupting noise due to noise sources but also because of the random medium. The focal point of research in the effects of fluctuations on tracking becomes a reduction of the statistical uncertainties of the signal that is being tracked, and of the state variable matrix.

1. Origin of Fluctuations of Acoustic Signals in the Ocean (U)

(U) An ocean which contains random volume distributed inhomogeneities, rough surfaces in motion, and rough bottom, gives rise to perturbations of acoustic signals which appear in various spatial and temporal scales. Extensive records of spatial and temporal sampling of these perturbed fields by stationary or moving sensors allows an approximate ordering of the causes of observed fluctuations. These are:

(1) (C) For observation time of seconds to a few tens of minutes, and for frequencies of less than a few hundred hertz the dominant cause of observed fluctuations is multipath interference generated by source/receiver motion.

(2) (U) Rough ocean surfaces in motion, with surface wavelengths comparable to or larger in size than the acoustic wavelengths cause temporal, amplitude and frequency fluctuations of transmitted signals, with time scales of the order of seconds.

(3) (U) Receiving arrays which receive corrugated wave fronts and beamform as if the wavefronts are planar undergo random shifting of the direction of the principal lobe, and random changes in side-lobe level.

(4) (U) Noise in the ocean caused by shipping, marine life, and wind-surface interaction mixes with the incoming signal and causes fluctuations in S/N ratio.

(5) (U) For observation times from hours to days and for acoustic wavelengths less than or comparable in size to internal (gravity) waves, fluctuations of acoustic signals caused by these internal waves have been observed.

(U) The origin of acoustic fluctuations in the ocean and the current approaches to research noted above both strongly affect future programs in underwater acoustics. This is discussed next.

2. *A Summary of the Aims of This Report (U)*

(U) The following sections present guidelines for research and development in acoustic fluctuations for FY-79 (and thereafter). They are based on the proceedings of the Workshop of Acoustic Fluctuations and discussions held at NRL, February 1978. They represent a composite of all recommendations presented at this Workshop as sifted and interpreted both by the authors of this report and several review panels. Appendix A contains an Editorial Summary and Synopsis of papers presented at the Workshop.

(C) While acoustic fluctuations in the ocean have significance in many Navy tasks, the goal to which this report is directed is the long range undersea surveillance of submarines by

(C) low frequency passive underwater acoustic systems as pursued primarily within program elements 62759N and 62711N. Acoustic fluctuations of high frequency acoustic signals employed in acoustic homing torpedoes, or in short-range localization for weapons delivery, or in high frequency sonar in general, are not explicitly touched upon here.

(U) We proceed now to a listing and elaboration of recommendations in the planning of research, exploratory and advanced development in acoustic fluctuations.

B. Recommendations for Structuring Programs in Ocean Acoustic Fluctuations (U)

1. Preface (U)

(U) The following set of recommendations range in scope from very narrow lines of research to very broad areas. In most cases an effort has been made to avoid recommendations of the type "continue doing what you are doing," since these are already covered by specific contracts to specific organizations, and a rationale for their support has presumably been accepted. Instead, the recommendations focus firstly on the overall goals of research and secondly, on areas of work in fluctuations which promise significant returns for the money invested, and which are currently not being worked on, or are being worked on at insufficient level. Time is not available to review the background state-of-the-art in each recommendation. It is possible therefore that some of the proposed recommendations are receiving attention elsewhere.

(U) The descriptions of the proposed work tend toward brevity. It is understood that a task is only properly qualified when a full statement of frequency, physical range, depth, kind of ocean, temporal scale, etc. is made. To avoid undue repetition a procedure has been adopted of citing only "critical" items in a proposed task with the understanding that there is also a train of additional specifications that belong to the work which can be supplied at a later time.

2. Structuring a Potentially Complete Model of SNR (U)

(U) The recommendations, objectives, approaches and programs appearing in this report refer to the concept of a "potentially complete model of SNR." Since this concept is very important in all that follows, an effort will be made to define it and discuss its significance.

(C) Most current models of acoustic fluctuations concentrate on calculating first order and second order statistics at one physical point, or at two. The actual fluctuating variables are taken to be some aspect of the pressure: its absolute value, phase, quadrature components, etc. Closely allied studies are made on the coherence properties of the field. Here the time series of acoustic pressures at various field points are examined for their temporal coherence, over specified durations; and the "space series" of acoustic pressures, either instantaneous, or averaged over time, are examined for their spatial coherence, over specified distances. Thus coherence and fluctuations are closely allied properties of signals randomized by source motion and a complicated (ocean) transmission medium.

(U) These concepts of the nature of the randomized acoustic field allow the following definition to be made.

(U) Definition: A potentially complete model of the acoustic SNR is one that has the capability of calculating all needed N-point statistics $S_p(i;t)$, $S_p(i,j;t)$, etc., of the received field as functions of the properties of the acoustic sources, transmission paths, and receiving sensors. (See Appendix B for discussion of symbols).

(U) Such a model does not presently exist, although many submodels of components of the sonar equation are currently available (See further discussion under, Highest Priority Task). With this definition we proceed to making a list of recommendations.

IV. RECOMMENDATIONS FOR OCEAN ACOUSTIC FLUCTUATION RESEARCH (U)

A. General (U)

(C) A thorough understanding of the physical basis of acoustic fluctuations is a strong (and ultimately very satisfying) foundation on which to build successful programs for system performance modeling, and for component design in sonar engineering. However, the need for accuracy must be balanced against the need for simplification. In attempting to balance these two we note that current system performance models of APSURV and PSEUDO rely upon simulation of fluctuations which were adopted because of their convenience rather than their physical correctness. This raises a question of confidence in these models. Improvement in confidence can be had by a greater infusion of basic physics of underwater sound into these models. The purpose in making the following general recommendations is to direct attention of program managers toward the necessity of realigning the thrust of current programs so as to insure a greater influx of ocean acoustic physics into systems design, performance modeling and signal processing than is visible today. Closely allied recommendations made at the Workshop are listed in Appendix C.

(C) The recommendations are:

(1) (C) An increased emphasis should be placed on the use of deductive or "first-principle" methods in research on acoustic fluctuations in order to improve the essentially inductive, or ad hoc, procedures now in use in system performance modeling. This implies isolation of a phenomenon for study, establishment from first principles of a hypothesis concerning its underlying physics, conduct of an experiment to test the hypothesis, consumate analysis and publication of results. An iterative interchange between deductive and inductive methodology will of course improve the speed of getting results, and the accuracy of results. But the "first principle" approach should carry a much greater share than is currently allotted.

(2) (C) The goal of ocean experiments should be to test hypotheses deduced from "first principles" using ocean data already available as input. It is believed that an adequate data base of ocean statistics exists to help form analytic hypotheses. However, there may be exceptions in the case of beam noise (Cavanagh I #3, #4).* No justification is in sight for continued support of general sea-going trips whose only achievement is accumulation of more data leading to more empirical models of limited usefulness. (Cavanagh II).

(3) (C) Every effort should be made to supplement Monte Carlo methods currently used in system performance models with mathematical fluctuation models derived from the *potentially complete model of SNR* which predict statistical moments of fluctuation fields (due to all possible causes, multipath, source/receiver motion, convergence zone, surface, bottom, internal waves, etc.) directly from physical data. (See discussion of derived models in the section below on Highest Priority Task). The latter approach while possibly more complicated will not necessarily be less practical since it would furnish the needed statistical moments of fluctuations in one calculation (i.e., one "run"). It would also inspire more confidence in the end product of predicting system performance by furnishing improved acoustic inputs to sonar performance models. This is not to say that Monte Carlo is not a good ad hoc technique; it is only to say that algorithms which supply statistical moments of fluctuations directly (from physical considerations) for single sensors, and for multiple sensors, are better. (Fretwell #1, Flum #4).*

B. Specific Recommendations (U)

1. *Objectives*: (U) The first objective is to frame tasks in immediate response to requests for help made by speakers (Appendix C) at the Acoustic Fluctuation Workshop.

---

*Workshop recommendations listed in Appendix C which are related to or identical with text recommendations.

(U) The second objective in making these recommendations is to introduce a more substantial foundation of ocean acoustic physics into the work of system performance modelers, signal processors, and designers of underwater acoustic antennas.

(U) Specific tasks are intended to fulfill one of these objectives, or both.

2. *Prioritization:* (U) Except for the single "Highest Priority Task", the tasks are listed in arbitrary order so that their relative importance should not be surmised by their position in the listing.

3. *Task Categories:* (C) For convenience, tasks are listed under headings of terms in the sonar equation (i.e., source level, transmission loss, etc.). They are framed so that they can apply to any of the underseas surveillance systems (SOSUS, SURTASS, RDSS, and other Systems), as needed.

(U) Each task recommendation is designated by a category which is designed to give the underlying attitude that the framers of the task envisioned as the main thrust of the research. The chief categories are Ocean Fluctuation Research and System Performance Modeling.

(U) The category of *Ocean Fluctuation Research* is intended to mean that the task is directed toward understanding (in either basic or exploratory sense) the underlying physics of the phenomenon being investigated, and that the results of the research are to be published in a form appropriate to journal papers, containing mathematical derivations, experimental results, etc.

(C) The category *System Performance Modeling* is intended to mean that the task is directed toward direct incorporation of results into system/design/performance modeling, in a format suitable for the current models (APSURV, PSEUDO*, APAIR, APSURF, APSUB) now in use.

---

*Programmed Simulations to Evaluate Underwater Surveillance Systems Dynamic Operations.

4. Two General Observations (U)

(U) The following observations apply to all tasks specifically directed toward studying ocean acoustic fluctuations.

(a) (C) Each term of the sonar equation (or groups of mutually interacting terms) is a function of space/time and is to be treated as a random variable with a known or, surmised probability distribution. The objective of the research is to obtain statistical moments of these distributions. Current values for these moments are based on the assumptions that the ocean is statistically stationary and homogeneous. Because these assumptions are generally not fulfilled during sea experiments, or in theory, there is a real necessity while calculating the fluctuations relative to mean (that is calculating second moments) to monitor the first moment (or mean value) itself. (Heine #1, Larsen #7, Flum #1). Separating fluctuations from their associated mean is a procedure which increases arbitrariness in current performance models. There is a clear need to avoid this procedure.

(b) (U) The accuracy of current measurements technology must enter into any discussion of acoustic fluctuations in the ocean. It is questionable whether assignments of standard deviation of x dB to describe the statistical behavior of beam noise, transmission loss, etc. have meaning unless measurements accuracy is also specified. In this regard the spatial and temporal resolution of measurement arrays in dynamical motion must be kept under close scrutiny. Effects of fluctuating beamwidth, beam direction, antenna gain on resolution must be explicitly allowed for, as well as the time and bandwidth of reception.

5. Key Approach in the Theoretical and Experimental Execution of Listed Tasks (U)

(U) While multipath effects loom large as the chief cause of acoustic fluctuations in long range underseas surveillance, research must begin with the study of single paths. By isolating

(U) single paths and understanding the causes of their fluctuations the scientist can assemble the various paths and predict correctly the statistics of the total.

(U) The resolution of multipath structure can be done in time, in frequency and in space. To resolve in time of arrival one requires large bandwidth signals; to resolve multipaths in frequency (or doppler) one requires long duration signals; finally to resolve multipaths in angle of arrival one requires high resolution vertical and horizontal arrays.

(U) The need to isolate single paths leads then to the following: the key approach for many of the listed tasks is to recognize a multipath structure in the intended task, from which single path isolation can be done in time, frequency, or space as the research requires.

V. SPECIFIC TASKS (U)

Highest Priority Task (U)

(U) The highest priority task is to initiate, under the leadership of an appropriate Project Manager, a new program whose goal it shall be to choose from among all the models of components of the equation for SNR currently available those physically based models which in the best judgment of leading underwater sound scientists constitutes when assembled together a *potentially complete model of SNR*. This model can then serve as the basis for hypothesis testing that is the major feature of the remaining tasks which follow. Because of its significance in plans for 6.1, 6.2 and 6.3 research in underwater acoustics, environmental studies, large aperture arrays, etc., this task must be undertaken as quickly as possible.

(C) The purposes of assembling the potentially complete model of SNR are (1) to document that our understanding of fluctuating ocean acoustic processes appearing in the interrelated terms of the sonar equation is scientifically correct, (2) to provide a benchmark algorithm

(C) from which heirarchy of application oriented models can be derived with certifiable justification to meet various user's needs, particularly with regard to simplification of input, higher running speed, more appropriate output, lower but acceptable levels of accuracy, etc., (3) to give the Navy means of making highly probable predictions of SNR in specific ocean sectors for which the data base is too meagre, or is not available at all, (4) to provide a standard of the relative weight to be attached to the terms of the sonar equation in particular applications and thus justify statement levels of accuracy that can be achieved, or that are required to be achieved. (Larsen #7, Flum #1, Fretwell #1, Flum #3, Cavanagh #6, Fretwell #3).

Source Level Task (U)

Category: (U) System Performance Modeling

(C) From the point of view of the receiver the radiated level and frequency content of submarine signatures vary in a random way as the sub aspect changes in a random way due to random changes in course, speed, etc. The same can be said of surface ships. These fluctuations have a time scale of their own, and a frequency power spectrum. A task should be formed to study the temporal fluctuations of predominant groupings of spectral lines and of the entire signature, and to construct better models than currently available. (Larsen #1, Fretwell #1).

(C) Naturally, fluctuations in the signatures of potentially hostile Soviet submarines should be studied as a first priority in conjunction with Naval Intelligence. But it is equally necessary to study fluctuations in the radiated level of U.S. submarines in order to improve the rational basis for possible tactical decisions in the detection, localization and tracking of targets at low SNR.

Transmission Loss Tasks (U)

(C) There exist today several potentially complete models of transmission of sound in a randomized ocean. The majority emphasize the calculation of mean values. Of the few that specifically address fluctuations (and coherence) two have recently become prominent, namely the family of JASON Models, of Flatte, Dashen, Munk and Zachariasen, (Ref. 7,8,9) and the model of Beran and McCoy (Ref. 10). It is assumed that portions of these models, extended to include bottom and surface scattering, plus range and depth dependent sound speed profiles, and available portions of others, will be incorporated into the overall general *potentially complete model of SNR*, as called for by the "Highest Priority Task." A similar incorporation of a selected features of a family of shallow water models is also needed.

(1) *Category*: (U) Ocean Fluctuation Research

(C) Using those portions of the potentially complete model of SNR which specifically addresses fluctuations, form hypotheses on the statistical properties of groups of spectral lines currently used for detection and classification as a function of depth, range bottom, surface and frequency. Test these hypotheses at sea, first in deep water then in shallow water, in order that all refracted (RSR) and bottom (BB) interacting paths can be encountered. The conduct of this task should be closely coupled to tasks in ambient noise and beam noise cause by distant shipping. Note that while standard deviation and relaxation time can be abstracted from these tests the objective is to confirm a hypothesis on underlying physics rather than to report quantities in sonar equation modeling. (Larsen #2).

(2) (U) System Performance Modeling:

(C) In current models of PSEUDO and APSURV the various fluctuating components of the sonar equation (as well as the total signal excess) are modeled as Gauss-Markov processes

(C) having exponential autocorrelation. A task should be made to compare theoretical predictions of this model with that of the *potentially complete model of SNR*. The short term objective is to improve input to the Monte Carlo model. The long term objective is to eventually replace ad hoc simulation of system performance models with physically based modeling. (Fretwell #1, Flum #4).

(3) (U) Ocean Fluctuation Research

(C) Using the *potentially complete model of SNR* conduct long range, low frequency experiment at sea with point receivers, and with a vertical and horizontal array having beamforming capabilities, to test its predictions on the separation out of pure tone multipaths by measurement of angle of arrival. Calculate the parameters of the $\Lambda-\Phi$ space of the Jason theory. Repeat the experiment with broadband long duration signals to separate out multipaths by time of arrival.

(4) (U) System Performance Modeling

(C) Range and bearing errors increase rapidly when a source and/or a receiver pass through convergence zones in which fluctuations of acoustic signals are a dominant feature of the transmission. This complicates detection, classification and tracking. Much study has been devoted to this problem and several models are now in existence. However, the following difficulties still remain: these are, the structure of these zones vary with geography, season, tides, currents, nature of ocean bottom and surface. There is a spatial and temporal history of the position and magnitude of the zones which must be incorporated on the model. A task should be formed to select out the best model of this phenomenon based on theory and experiment, to improve the model by associating with it the correct spatial and temporal scales, and to incorporate it into the *potentially complete model of SNR*. (Larsen #4).

(5) (U) System Performance Modeling:

(U) Ocean Fluctuation Research:

(C) Fluctuations in received signals can be caused by repeated reflection of sound in a bottom-sloping channel which has a randomly rough bottom and a wind randomized surface. The intensity of such fluctuations depends on the scale sizes of roughness encountered, on the wavelength of the propagating signal, on the slope of the bottom, and on the time scale of surface variability. A task should be formed to investigate this problem in view of the strategic value of the underseas surveillance in bottom-limited acoustic environments. In this task specific attention should be paid to the mean value of the transmitted signals, as well as to the fluctuations.

(U) In addition the application of results of this task to spatial correlation in distributed systems should be studied.

(U) This task is exceptionally large in its scope. Isolation of particular facets in order to accomplish hypothesis-testing may be difficult. It might be useful to consider portions of this task which address themselves to shallow water acoustics as a separate entity in laying out a program for research in acoustic fluctuations. (Flum #2, Ellinthorpe).

(6) (U) System Performance Modeling:

(U) Ocean Fluctuation Research:

(C) Current studies in spatial fluctuations caused by source/receiver motion in a statistically frozen ocean are only beginning to include the very pronounced effects of the ocean bottom. An ideal plane wave reflected from a rough bottom is randomly scattered about some

(C) mean geometric reflection angle. The degree of spatial decorrelation caused by this random reflection over a length of range depends on several factors, chief of which are the scale size of bottom roughness, and the acoustic wavelength. A task should be formed to investigate spatial fluctuations caused by bottom interference in a moving source/receiver experiment. (Ellinthorpe, Flowers).

(7) (U) Ocean Fluctuation Research:

(C) The statistics of acoustic fluctuations in the ocean are closely dependent on the statistics of randomized sound velocity profiles that are present in the path of propagation. Spatial randomization of temperature and salinity may be a feature of a momentarily frozen ocean, and both spatial and temporal randomization may be caused by transport of temperature and salinity by fronts and eddies. The probabilistic nature of these profiles is only partially understood. A more perfect understanding can be obtained by applying currently available data bases to form physically based models which can then be used to make hypotheses for testing at sea. However, there may be instances where the statistics of ocean variability are not available. In these special cases data gathering at sea may be warranted. Thus for the general case of hypothesis testing, and for the limited case of data gathering it is recommended that support of investigation of ocean properties that contribute to acoustic fluctuations be a continuing task.

Signal Gain Tasks (U)

(U) The reception of local signal wavefronts on large aperture arrays is complicated by the possible existence of spatial and temporal fluctuations in the array structure itself. Such fluctuations may be caused by source/receiver (or platform) motion (Ref. 11); or may be caused by dynamic interaction of the array with fluid loads as it is being towed through the ocean.

(1) (U) System Performance Modeling:

(U) Ocean Fluctuation Research:

(C) Using the appropriate portions of a *potentially complete model of SNR* for a selected transmission path predict statistics of spatial coherence of an acoustic field generated by distant narrow band and broad band signals. Next, include temporal fluctuations of this acoustic field caused by source/receiver platform motion. Conduct a sea experiment to check these predictions. Finally, examine the effects of spatial and temporal fluctuations on signal gain of a receiving array and the use of such statistics for detection and tracking. (Fisher).

(2) (U) System Performance Modeling:

(C) Using the best available statistical model of the spatial and temporal fluctuations of a *towed array* predict degradation in array gain, beamwidth, beam directionality, depth and location of nulls, etc. (Larsen #5). Conduct an experiment at sea to validate these predictions using frequency as a parameter together with selected ocean space/time scales. The objective here is to incorporate the results of this task into the *potentially complete model of SNR*.

(3) (U) System Performance Modeling:

(C) Fluctuations in transmission paths and/or antenna characteristics cause the signal to move to adjacent beams in short times. The result is a fluctuation in bearing of distant targets. A task should be formed to apply the statistical theory of antennas (Ref. 12), and construct a mathematical model of this phenomenon of beam jumping. (Cavanagh I #1, Cavanagh II #2).

General Observation on Signal Gain Tasks (U)

(C) Tasks 1 thru 3 emphasize the preponderant effect of environment on the modeling of Signal Gain. Not only do fluctuations of gain require investigation but also the very

(C) important *slow* variation in the mean over the long periods of observation required by tracking. (Larsen #7, Heine #1, Flum #1).

BEAM NOISE TASKS (U)

(1) (U) Ocean Fluctuation Research:

(U) System Performance Modeling:

(C) Beam noise is a combination of noise fields detected by single hydrophones in an array and noise gain of the entire array. A general model of beam noise completely validated by experiment is not now available. (Urick, Larsen #6). Most simulation models have relied on Gauss-Markov processes to describe the fluctuation aspect of beam noise. (Fretwell #1). However, recently newer models have appeared which are more physically based (Ref. 13).

(C) These models must be validated and then incorporated into proposed general model for SNR. A task should be pursued to select out the best model of beam noise (Cavanagh #6, Cavanagh #5) based on physical principles, to validate this model by experiment and to incorporate it into the *potentially complete model of SNR*. In this task attention should be paid to examine the possibility of applying the theory of propagation of mutual coherence which can yield ensemble averages in a single calculation (single run) rather than averaging by numerous Monte Carlo trials. (Larsen #6, Urick).

(2) (U) System Performance Modeling:

(C) The investigation of underlying physics in the above recommendation should be supplemented by system modeling. A suggested program could be to construct a model of the statistical characteristics of beam noise in a beamformer array as a function of beam number,

(C) beamwidth frequency, antenna construction, and array location, as well as a function of the parameters currently under study, namely the number, location and motion of distant sources which generate the noise. This model should include the best features of all models now available. (Cavanagh #6, Shooter).

General Observations on Beam Noise Tasks (U)

(C) These tasks emphasize the statistical nature of beam noise fluctuations. Any effort at validation of current models is frustrated by the difficulty of trying to decide not only when an agreement between model and test has been achieved but also to decide which model is "better". This is because testing generally yields one sample, or realization, of beam noise modeled as a random variable. An investigation is needed to study the problem of validation of statistical models, not only of beam noise, but also of all the other terms in the sonar equation. (Flum #3, Flum #5).

SIGNAL PROCESSING TASKS (U)

(1) (U) System Performance Modeling:

(C) Classification of spectral lines in received signals according to frequency, grouping, stability, and target bearing can be improved by inclusion of fluctuation data particularly the probability distribution and statistics of single line fading. The construction and validation of algorithms to achieve this inclusion must be accelerated. A task should be formed to assess state-of-the-art in classification modeling with respect to acoustic fluctuations and recommend specific areas of research to speed up getting needed results.

(2) (U) System Performance Modeling:

(C) Current tracking procedures are being extended toward use of phase locked loops and minicomputers. However, the statistics of fluctuations must be incorporated into the control, extrapolation and interpolation branches of these trackers in order to smooth out fading and dropouts, and in order to avoid possibility of resuming track on a false line. A task should be formed to update decision making branches of tracking loops particularly in connection with newer tracking methods by separation of multipaths with long vertical arrays. (Fisher).

(3) (U) System Performance Modeling:

(C) The signal processing of signals received on widely separated arrays can be conducted in both coherent and incoherent modes. In the coherent mode the spatial and temporal fluctuations of amplitude and phase of received signals strongly affect interarray correlations, hence correlation time and correlation distance, particularly for moving targets. Spatial decorrelation (alternatively, interfering multipaths arriving on two widely separated arrays) often limits the time available for performing integration on signals from moving targets to less than 10 minutes. This results in poor estimates of sonar parameters. A program should be formed to construct a model of the effects of spatial (meaning multipath) and temporal (meaning random environment) fluctuations on correlation time associated with signals from moving targets in the context of reception on widely spaced arrays, including arrays which themselves are in motion. (Larsen #5, Grace, Gerlach, Larsen #3).

(4) (U) System Performance Modeling:

(C) In all signal processing algorithms used in fluctuation studies, the received field is modeled as a sum of transmitted signal which has been modified by the transmission

(C) path source/receiver motion and additive ambient noise. Standard ROC, or transition curves, based on modeling the additive noise as Gaussian white noise, have been modified to account for the fact that the additive noise in many parts of the ocean over long ranges is not Gaussian, and not white. In all these modifications the noise model has either not accounted for nonstationarity or has assumed a simulation-type conversion of stationary statistics to nonstationary statistics. A task should be formed to compare physically based data sets on ambient noise, and extract from them a physically valid description which has nonstationarity built in. The purpose of this task is to take one step beyond currently available modified ROC transition curves and include the nonstationarity of the ambient noise. In the latter distinction should be made between nonstationary broad-band ambient noise, generally uncorrelated in space and time, and nonstationary narrow band noise which arrives from close-in shipping in the form of space and time correlated spectral lines. A rationale for incorporating these two types of nonstationary noise into ROC curves should be part of this task. (Heine #1, Larsen #7, Flum #1).

(5) (U) System Performance Modeling:

(U) Urick has hypothesized that fluctuations of signal excess appears to be lognormally distributed in consequence of the Central Limit Theorem. The problem of fitting statistical data to sets of theoretical curves requires a discriminator of high resolution which is capable of deciding which curve of several closely spaced ones best represents the physics. What appears to be needed is a more fine-tuned procedure for establishing the validity of currently "accepted" statistics of signal excess. However, the question is posed, if more accurate determination of probability distribution is made could such information be useful enough to pay for the cost of finding it? This question itself should constitute a task. (Urick).

SIGNAL TO NOISE RATIO (SNR) TASKS (U)

(1) (U) System Performance Modeling:

(C) All system performance models presented in the Workshop, APSURV, PSEUDO, APAIR, APSURF and APSUB, have very meagre records of validation by field test (Ref. 14). Two problems account for this. First there is the difficulty of knowing precisely what constitutes a valid field test of the model. Second, there is the very great complexity of the models which makes isolation of field-checkable predictions by them very troublesome. A great need exists for overcoming these problems and proceeding directly with one or several decisive field tests. A task should be formed to formulate specific predictions of SNR behavior of these models, and to devise sea going trips to prove decisively that the predictions are "correct." If such trips show that component terms of the sonar equation are non-gaussian distributed, a major effort will be needed, both experimental and theoretical, to remedy this defect. (Larsen #1, Flum #5, Fretwell #2, Heine #2, Cavanagh #4).

(2) (U) System Performance Modeling:

(C) To date, the components of the sonar equation have generally been treated as independent random variables in most models under review but not all. Two features of this treatment require scrutiny. First is the universal representation of these variables by random processes which have unproven physical bases. Second is the assumption that these variables are independent. The validity of the first assumption is under review. A task should be formed to examine the validity of the second assumption, namely that the components of the sonar equation, particularly target strength, transmission loss, and beam noise, are independent in their fluctuations, especially over time intervals associated with sonar operations. While

(C) some currently used system performance models have an option of introducing physical coupling between components of signal excess, the justification for the values used for this purpose is very thin. In this connection, a case of particular importance is the investigation by experiment to see whether signal in a beam and noise in the same beam are correlated. (Flum #4, Fretwell #1).

(3) (U) System Performance Modeling:

(U) Ocean Fluctuation Research:

(C) Current mathematical models of transmission loss, beam noise, array gain, etc., based on underlying physics are so complicated, require so much computer space, and generate numerical results in such unhandy form that all thought to load them bodily into system performance models used by systems designers is regarded as impractical. Yet somehow, the benefits of these models must be shared with possible users. There may, however, be a way around the difficulty. It is to take the mathematical models and reduce them to simple *curve-fitted* formulas that retain the essential physics, but replace "exact" solutions with approximations based on tables of coefficients needed for curve fitting. A task should be formed to examine candidate math models for both mean value and for fluctuations of transmission loss, beam noise, array gain, etc., with goal of simplifying them into tables of look-up values. This approach is currently used in system modeling on a limited scale in the case of mean value of transmission loss. It should be extended to other components of the sonar equation, and to fluctuations.

PARALLEL AND AUXILIARY TASKS (U)

(U) The first group of objectives, approaches and tasks, noted above was based on the assumption that programs will be designed to help system performance modelers, signal processors and antenna designers. A second group proposed below is designed to improve the general

(U) physical understanding of fluctuations in the ocean. Such improvements help all participating scientists in the field of underwater sound to understand the limits imposed by ocean statistics on their work. They are listed under categories of Physics, as well as Ocean Acoustic Research and System Performance Modeling.

(1) (U) Physics:

(U) A rational basis for understanding the physics of acoustic fluctuations must begin with a physical description of the spatial and temporal scales of perturbations in the physical properties (density, temperature, salinity, etc.) of the ocean. The magnitude of these scales coupled to the wavelengths of the propagating sound determine the corresponding spatial and temporal scales of the perturbations of the acoustic field. For any acoustic wavelength, at given range, in a given part of the ocean, at given calendar date of the year the physical and acoustical scales could be measured. A task should be initiated to survey the present state of available data on spatial and temporal scales of the ocean associated with acoustic fluctuations. Such a survey can eventually replace, and certainly be more useful than, the very bulky collections of "ocean data" currently on the shelves.

(2) (U) Physics:

(U) Ocean scientists in the past, and up to most recent times have proposed to study mesoscales of ocean fluctuations in temperature density, internal currents, tidal motion, layer migration, etc., by means of the perturbations they cause in acoustic propagation. The theoretical base for this is couched in terms of mathematical inversion of differential and/or integral equations. A voluminous literature on inversion in atmospheric acoustics and optics, and underwater acoustic, is in existence (Ref. 15,16). A current proposal (Ref. 17) cites the recent

(U) advent of underwater acoustic propagation models which predict phase and amplitude perturbations of single paths in a multipath field as a function of space/time scales of the scattering object(s). Their success, however, clearly depends on the possibility of isolating single paths. Current techniques for doing this depend on transmission of broadband, long duration signals, and the precise measurement of arrival time and arrival angle. A task is needed to determine an optimal procedure for separating out these single paths from groups of multipaths, to predict from the best transmission submodel of the *potentially complete model of SNR* the perturbations of signals in these paths as a function of the ratio of Fresnel Zone size and the space/time scales of the mesoscales and to test these predictions at sea. A by-product, or bonus, of mesoscale studies will be the validation of predictive models, thereby increasing confidence in their use. (Spindel, DeFerrari I).

(3) (U) System Performance Modeling:

(U) The statistics of received acoustic signals are illuminated by plots in $\Lambda-\Phi$ coordinates (Ref. 14). These can fall anywhere between unsaturated and saturated regimes depending on range, frequency, and severity of the ocean-induced perturbations. From this it can be deduced that a very large number (perhaps infinite?) of experiments can be conducted in the ocean, each purporting to give an increment of "data base", and each permitting some ad hoc model to be constructed which "fits" the data over limited ranges of parameters dictated by geography, seasons, and local space/time environmental scales. This accumulation of data base and narrowly valid models have gone about as far as they should. *There is a compelling need to abstract the best in them and integrate it into the proposed potentially complete model of SNR.* Recognizing, however, that only an interim model of SNR will be available in the near future, it will be essential to concentrate on decisively proving out the prediction of the interim model by

(U) hypothesis testing. Should it not be possible one asks, to generate a once-and-for-all model that definitively covers significant frequency and range regimes in long range surveillance, say 1 to 10 Hz and range 1000 nmi? A second model segment that covers 10 to 50 Hz and a range of 500 nmi, etc.?

REFERENCES (U)

1. Encl (1) to AESD ltr to LRAPP mgr. AESD:PRT:ke Ser: S369 of 8 May 1974.
2. "International Workshop on Low Frequency Propagation on Noise, 14-19 Oct. 1974 (WHOI)," Vol. I and II, 1977. Coordinated at the Navy Center for Ocean Science.
3. Proceedings of the 1st Workshop on Operations Research Models of Fluctuations Affecting Passive Sensor Detection, Jan. 1976, (Vol. I (C), Vol II (S)).
4. Coherence Workshop, J.P. Beam, U.S. Navy Journal of Underwater Acoustics, Vol. 26, No. 3, July 1976.
5. Encl (1), "Planning Summary for Selected Navy Ocean Acoustic Program," to NORDA ltr 200:TM:sgt Serial S002-78 of 17 Jan. 1978 to OP-095.
6. "Acoustic Fluctuations Workshop-Technical Review, Editorial Summary and Papers," (U) S. Hanish, C.R. Rollins and J. Cybulski, NRL Memo Report 3884 (C), (in preparation).
7. S.M. Flatte and F.D. Tappert, "Calculation of the effect of internal waves on oceanic sound transmission," JASA, 58, 1151-1159 (1975).
8. W.H. Munk and F. Zachariesen, "Sound propagation through fluctuating stratified ocean: Theory and observation," JASA, 59, 818-838 (1976).
9. R. Dashen, "Path Integrals for Waves in Random Media," JSR-76-1 (SRI, Menlo Park, CA, 1977).
10. M.J. Beran and J.J. McCoy, "Propagation of Radiation from a Finite Beam or Source Through an Anisotropic Random Medium," J. Acoust. Soc. of Am., 56, 1667 (1974).
11. Discussion of the Performance Loss of a Towed Array Detection System due to Random Hydrophone Motions (U), J.F. Ianniello, NUSC Tech Memo 777 078, 26 April 1977 (C).
12. Y.S. Shifrin, "Statistical Antenna Theory," The Golem Press, 1971.
13. "A Shot Noise Model of the Random Fluctuations in Broadband Ambient Noise Caused by Shipping," J. Goldman, Bell Laboratories Report OSTP-57 JG, 1977.

14. Commentary by R. Larsen, R. Flum and L. Fretwell during Workshop sessions; see Appendix C.

15. "Mathematics of Profile Inversion," NTIS Pub. No. N73-11585, L. Colin (ed), 1972.

16. S. Twomey, "Introduction to the Mathematics of Inversion in Remote Sensing and Indirect Measurement," Elsivier Pub., N.Y., 1977.

17. "Ocean Acoustic Tomography: Can It Work?" W. Munk, JASA, 63, Supplement #1, S71A, Spring 1978.

Appendix A

EDITORIAL SUMMARY AND SYNOPSIS OF PAPERS PRESENTED AT THE ACOUSTIC FLUCTUATION WORKSHOP

[Unclassified Title]

I. Editorial Summary (U)

(U) The editorial summary which follows is in order of the Workshop Agenda and is based upon material submitted by the author; with the Roman I and II after the name for those presenting more than one paper.

Index to Summary Contents

R. Cavanagh I
D. Grace
J. Heine
R. Urick
K. Flowers
De Ferrari I
M. Moll
R. Cavanagh II
A. Fabula
I. Dyer
A. Gerlach
R. Spindel/W. Munk
De Ferrari II
J. Shooter

Workshop Paper: "Beam Noise Fluctuation Models" (U)

Author: R. Cavanagh

Objective: (U) Review beam noise models, and recommend best features of each for specific applications.

Research Approach: (U) Review models in terms of treatment of ships, transmission loss, and receiver characteristics. Consider statistical quantities of each, and recommend types of ensembling.

Models Reviewed: (U) (1) Underwater Systems USI, (2) Bell Lab. BTL, (3) Bolt, Beranek and Neuman, BBN, (4) Wagner, (5) NABTAM, ORI, USI, NORDA, et al., (6) Science Applications DSBN, (7) NORDA (BEAMPL), (8) NRL, SIAM I, (9) NRL, SIAM II.

Chief Output: (U) Summary of each model's prediction of beam-noise statistics ensembled over some specific time (hour, day, week, etc.)

Chief Conclusion: (U) No single model satisfies all requirements.

Outstanding Problems: (U) (1) Need an approach to predict signal plus noise in one frequency bin, and noise in another.

(2) Need to treat a moving array.

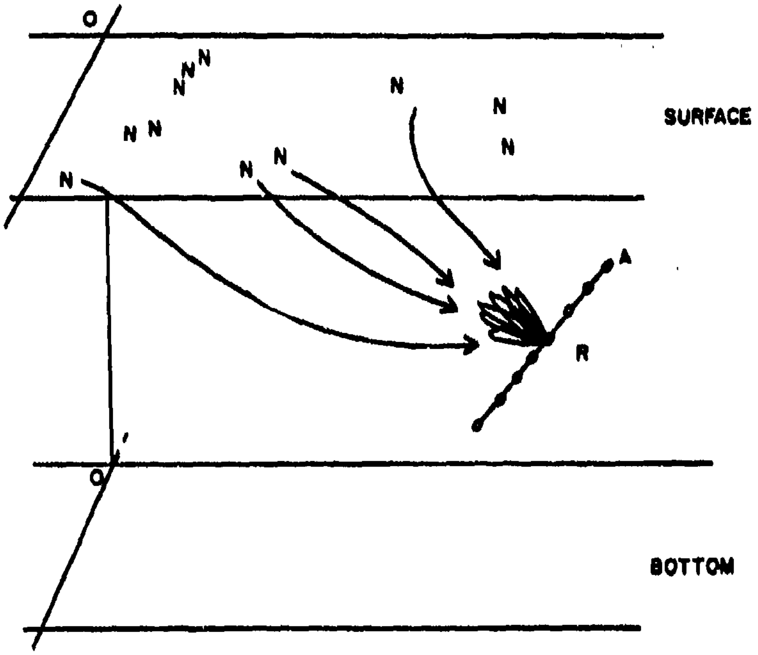
(3) Source levels and locations of ships still not known accurately.

(4) Need evaluation of models, at least for mean values.

(5) Need to understand importance of weak generated noise.

A pictorial representation of this paper is shown next.

Cavanagh*



(C) Comparative Review of Beam-Noise Models

	US1	NABTAM	
	BTL	DSBN	
Analytic	BBN	BEAMPL	Brute Force
	WAGNER	SIAM I,II	

These are tabulated by how they model the noise $N(t)$.

$$N(t) = \underset{\substack{\downarrow\\ \text{intensity}}}{\sum_{u=1}^{J(t)} SL_i(t)} \qquad \underset{\substack{\downarrow\\ \text{transmission}}}{T_i(t)} \qquad \underset{\substack{\downarrow\\ \text{array response}}}{AG_i(t)}$$

Good features of each model are selected and problems presented.

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "Signal Processor and Fluctuations" (U)

Author: D. Grace

Objective: (U) Review the problem of degradation of spatial coherence in multi-array processing with increasing integration time and processing bandwidth. Distinguish on a time difference-Doppler difference plot between peaks caused by platform motion and those caused by multipath.

Research Approach: (U) Review past experiments of Mohnkern, Sloat, Barbour and Grace.

Chief Parameters: (C) Plots of coherence between signals from one source ariving at two widely separated arrays versus time difference of arrival and Doppler difference. Plots of signal coherence versus time-bandwidth product (TW). Spectrum of phase fluctuations.

Chief Results: Mohnkern: (C)

(1) increasing TW product decreases coherence.

(2) increasing the integration time decreases the coherence more than increasing the bandwidths.

(3) the power spectrum of random signal phase modulation falls off at -30 dB per octave as would be expected for internal waves.

Sloat: (C)

(1) Random course and speed produce small effect on coherence.

(2) Constant course and speed produce large effects.

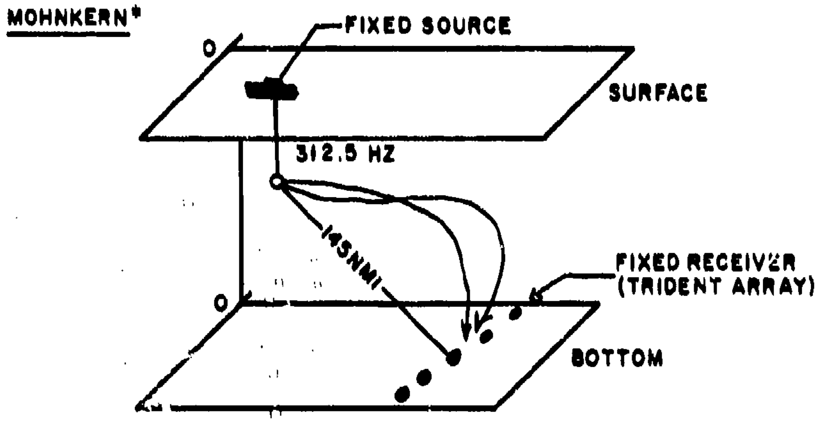
(3) Measured coherence lower than predicted.

Barbour: (C) Standard deviation of fluctuations in peak location on coherence surfaces is greater than expected.

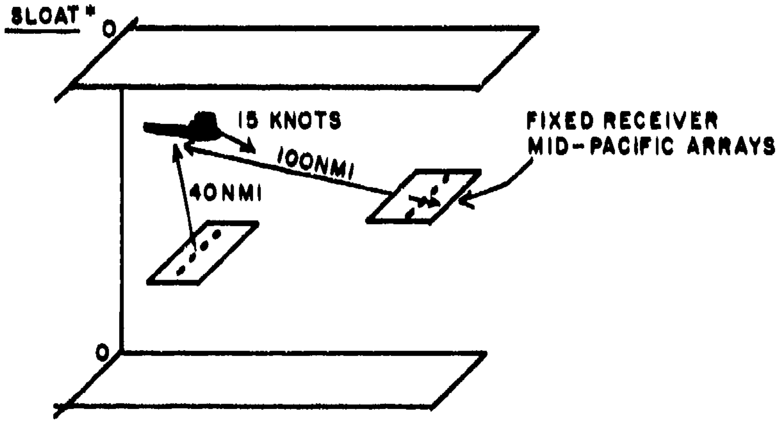
Grace: (C) If platform and medium indicate fluctuations are slow, and if differential Doppler between multipath components is great then coherence peaks due to multipath and due to platform motion can be separated.

Pictorial representations of the work of Mohnkern, Sloat, and Barbour are shown next.

Grace*



(C) Calculate coherence between transmitted PRN carrier (312.5 Hz) and received PRN as a function of integration time and processing bandwidth. Calculate power spectrum of signal phase modulation.

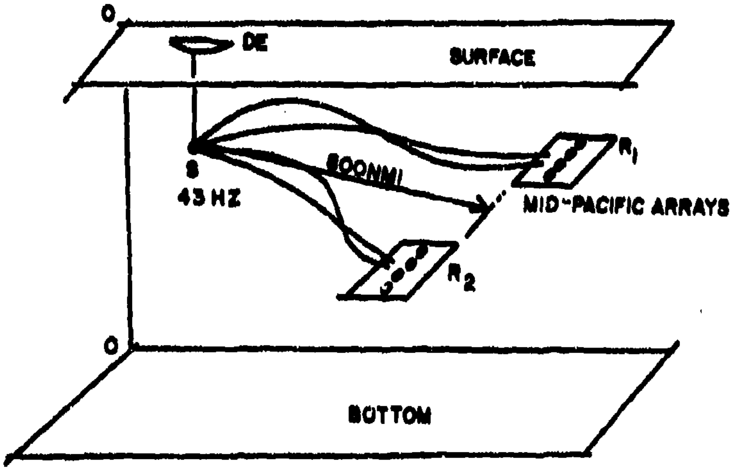


(C) Calculate "coherence surface" ($\Delta\tau, \Delta\Phi$) for processing band 1/4 Hz and integration time 2,4,6,8,16,32 min., using a 12.5 Hz line from sub.

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

BARBOUR*



(C) Calculate coherence surfaces ($\Delta\tau, \Delta\Phi$) for processing band 1/4 Hz and 2 min. integration time, using a 43 Hz signal. Compare actual surfaces with ray trace model and source-receiver geometry. Calculate statistics of fluctuations in peak coordinates of the coherence surfaces as function of time.

Grace: Use Barbour data to distinguish between coherence peaks caused by platform motion and those caused by multipath.

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "Effects of Fluctuating Signals and Noise on Detection Performance" (U)

Authors: J. Heine and J. R. Nitsche

Objective: (U) Analyze effect of fluctuations in noise caused by shipping, and fluctuations in the signal caused by multipath, upon systems ROC curves.

Research Approach: (U) Mathematical analysis, assuming ocean noise is not white Gaussian.

Chief Parameters: (U) Random SNR, Random P_D.

Principal Task: (U) Determine probability distribution of SNR.

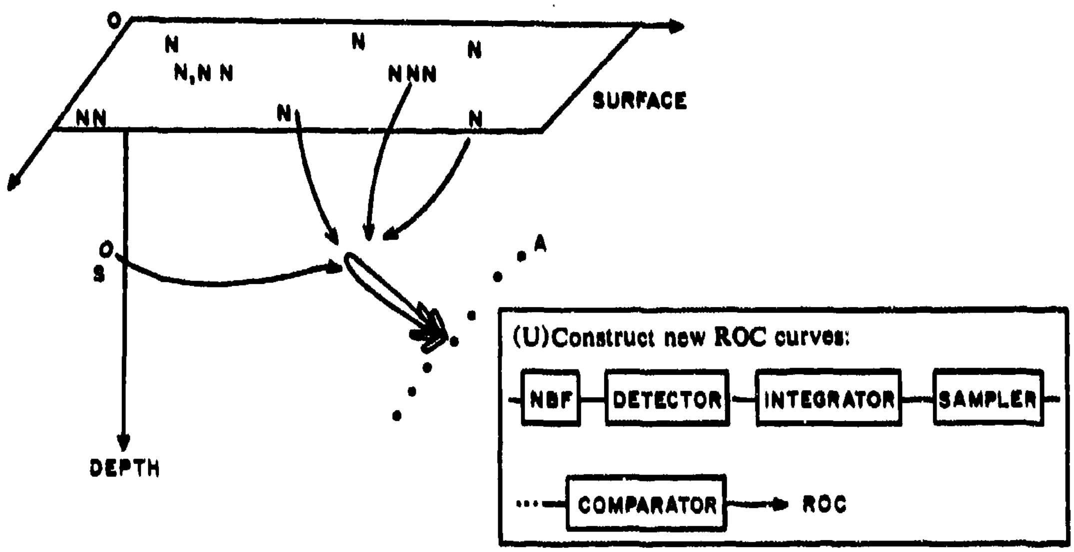
Temporal Scales: (U) Slow fluctuations of characteristic time 2X to 3X receiver integration time.

Principal Result: (U) Presentation of a set of ROC curves modified by fluctuations.

Principal Conclusions: (U) Predicted performance improvements based on non-fluctuating SNR can lead to gross overestimates.

A pictorial representation of this paper is shown next.

Heine and Nitsche*



(U)Construct new ROC curves:

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "A Working Fluctuation Model with Application
to Performance Prediction" (U)

Author: R. Urick

Objective: (U) Review a signal intensity fluctuation model based on Rician statistics. Review the fluctuation time scale parameter. Review noise fluctuations. Discuss effects of fluctuations on detection.

Research Approach: (U) Compare models with data from numerous experiments.

Chief Conclusions: (U)

(1) (U) Many experiments prove that the cumulative probability distribution of intensity of CW signals in a randomizing ocean Rician statistics. It is easier to predict fluctuations of signal level than to predict the mean level itself.

(2) (U) The sea surface is responsible for fast fluctuations in the range 2-20 seconds. Slower fluctuations longer than 10 seconds, and up to 10 minutes appear to be caused by multipath reception.

(3) (U) Fluctuations in ambient noise obey Gaussian statistics (but not always). Samples of noise power are random variables whose statistics depend on the time bandwidth product of the processor. A conventional processor yields chi-square statistics for these samples of noise power, with degrees of freedom equal to twice time-bandwidth product.

(4) (U) Curves of P_D vs. SE have been plotted for Rayleigh, amplitude normal log, and normal signal fluctuations. Comparison with experiment shows that the log normal distribution with standard deviation between 6 and 8 dB best applies to real detection data. (Applies to short range, mobile sonar). This may be a consequence of the Central Limit theorem.

Workshop Paper: Signal Fluctuations (U)

Author: K. Flowers

Objective: (U) To present characteristics of signals propagated over long range deep water paths, for which the data is currently insufficient to permit modeling. In particular, to determine probability density of received levels, and space/time statistics.

Research Approach: (U) Perform the experiments pictured below. From the data gathered remove the average signal level, then determine distribution of fluctuations about the mean. This is a function of frequency and range, but not of receiver position or direction.

(U) Use ray-tracing models to find average signal levels.

Chief Parameters: (U) Received signal level, its probability density and space/time statistics.

Chief Conclusions: (C) RMS fluctuation is directly proportional to average signal level.

(C) Radial (meaning along transmission path) correlation length for a 10 Hz acoustic field is about 1 km near the source, 4 to 5 km at a range from 10 km to 2000 km, and falling off above 2000 km to about 2 km at a range of 3000 km. Depth correlation only a few wavelengths. Transverse correlation quite large (many wavelengths).

(C) Bearing errors range between 1° and 2° over a period of hours. It is possible by removing a nearly linear trend in the data that a reasonably high bearing accuracy is obtained by observing wavefronts with short arrays.

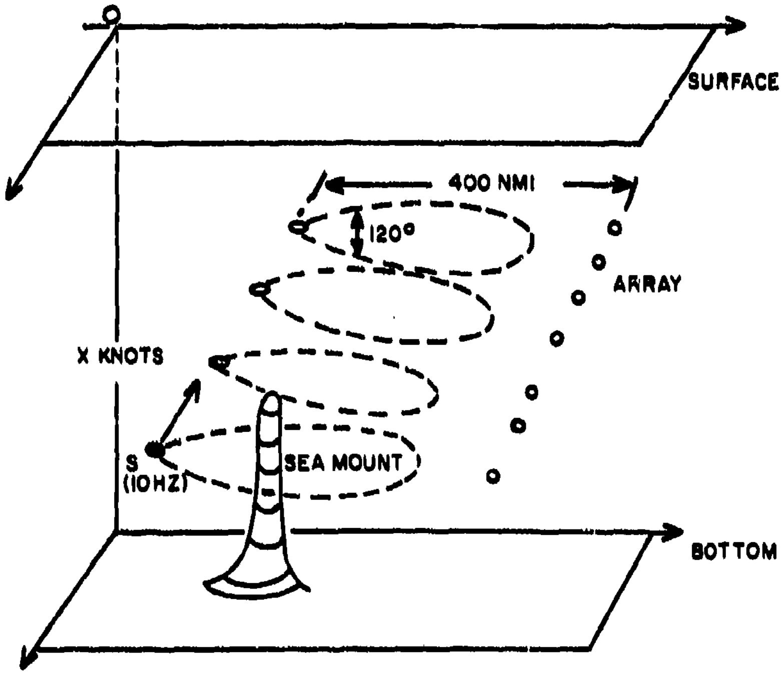
(C) Variations of amplitude and bearing error are very sharp in going through convergence zones. No models are known to predict this effect.

(C) Existing propagation models are capable of providing signal fluctuation statistics in long range, deep water experiments.

(C) For low frequencies bottom mounted arrays see nearly perfect plane waves. However their orientation is not understood.

Pictorial representations of this paper are shown next.

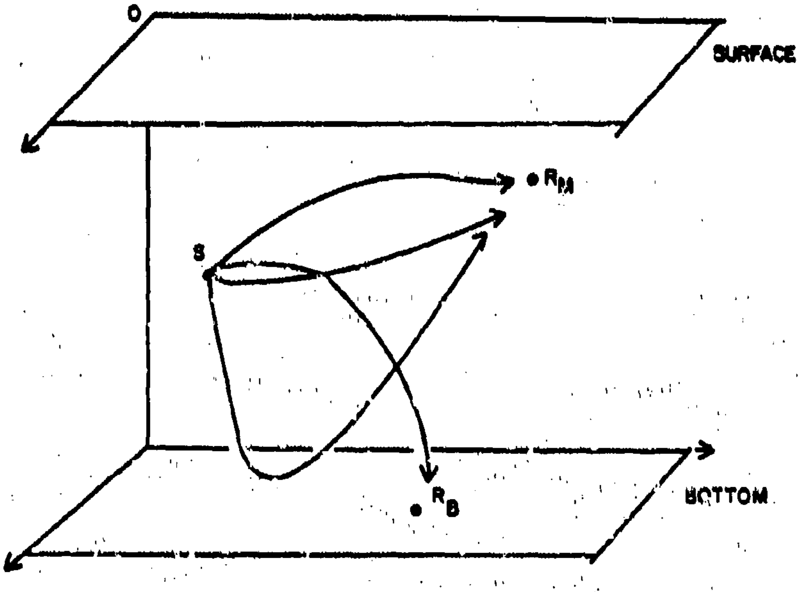
Flowers*



---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Flowers*



(C) Experiment is designed to determine probability distribution of signal at receivers R_M, R_B, and correlation distance in depth, along transmission path and transverse to this path.

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "A Model of Acoustic Propagation
Through Internal Waves" (U)
Author: H. De Ferrari

Objective: (U) Develop numerical methods for computation of long range ocean propagation using the theory of Flatte, Dashen, Munk and Zachariasen, and the Garrett-Munk internal wave model.

Research Approach: (U) Use ray-tracing to get ray paths, then introduce fluctuation.

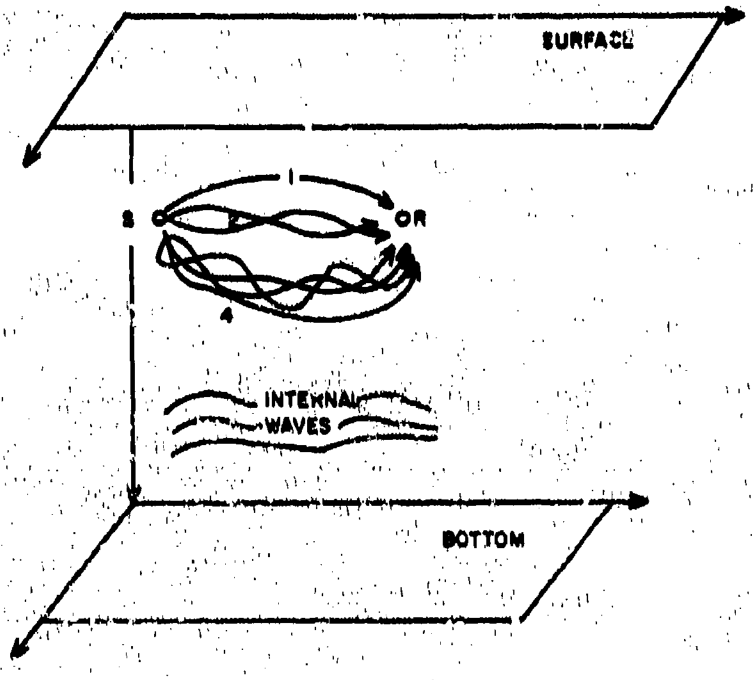
Chief Parameters: (U) Fluctuation strength Φ, diffraction parameter Λ.

Number of Ray Paths: (U) The numerical study of single ray path completed. Next effort is to numerically calculate theoretical propagation with fluctuation for two channels, then four channels.

Chief Conclusions: (U) Λ parameter is very sensitive to ray geometry. Rays having turning points near the surface show less Φ variation than predicted.

A pictorial representation of this paper is shown next.

De Ferrari*



(U) Calculate the quantities,

$$\Phi^2 = q_0 \int\int dx\ dx'\ \rho\left\{z(x),\ z(x')\right\}$$

$$\Lambda = \Phi^{-2} q_0^2 \int\int dx\ dx'\ \rho\ \left[z(x), Z(x')\right]\ (g_0 A L^2)^{-1}$$

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "Prediction of Performance Behavior" (U)

Author: M. Moll

Objective: (U) Predict performance of a passive sonar receiver which has fluctuating acoustic inputs.

Research Approach: (U) Construct an analytical model of a multi-beam receiver with random input. For detection purposes choose a threshold for each beam which is a linear combination of the outputs on all other beams.

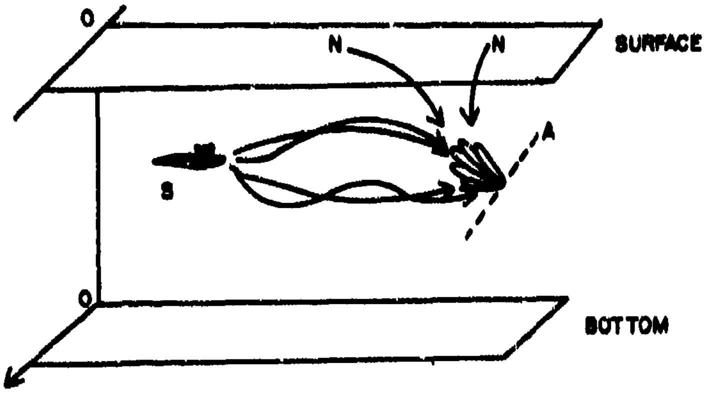
Chief Parameters: (U) Fluctuation is represented as ambient noise of form $N(t) = \sqrt{P(t)}\, G(t)$. Signal is sinusoid.

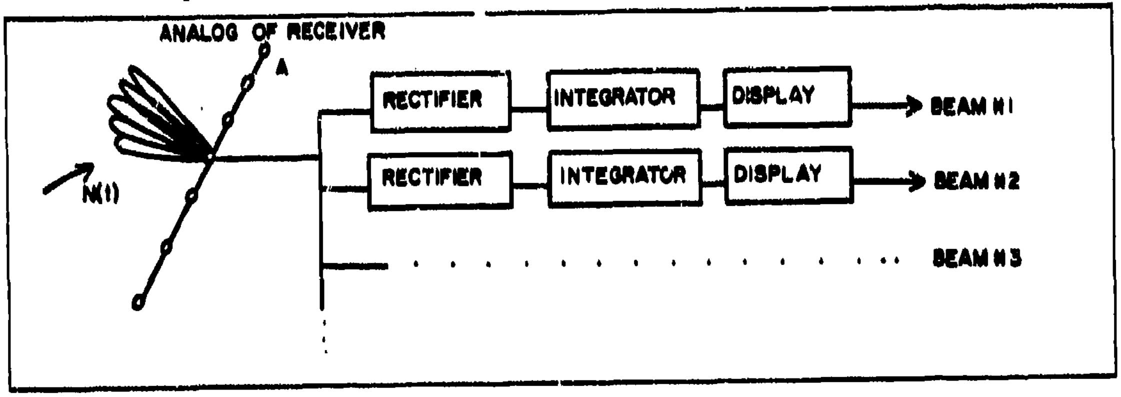
Chief Results: (U) Kurtosis of $N(t)$. Test statistic for detection, Z_0. Probability density of Z_0, its mean, variance, third moment.

(U) ROC plot of SNR vs. P_D with D/T as parameter (D is relaxation time of the envelope of the random process representing the output of a beam, T is the post rectification averaging time).

A pictorial representation of this paper is shown next.

Moll*





(U) Choose THRESHOLD FOR BEAM #X — Linear combination of outputs of integrators on all other channels.

FLUCTUATION MODEL,

$$N(t) = \sqrt{P(t)}\ G(t)$$

$P(t)$ is a non-negative random process

$G(t)$ is a zero mean unit-variance stationary Gaussian process

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "Acoustic Fluctuation Modeling for System Performance Estimation" (U)

Author: R. Cavanagh

Objective: (U) Evaluate the simulation random-process approach for modeling signal excess in system performance prediction.

Research Approach: (U) Construct signal and noise time series of received signal using available acoustic models of transmission loss and ambient noise. Simulate these series by random process models taking needed data from acoustic models. Compare acoustic models with random-process simulation, both as to statistics and as to detection history.

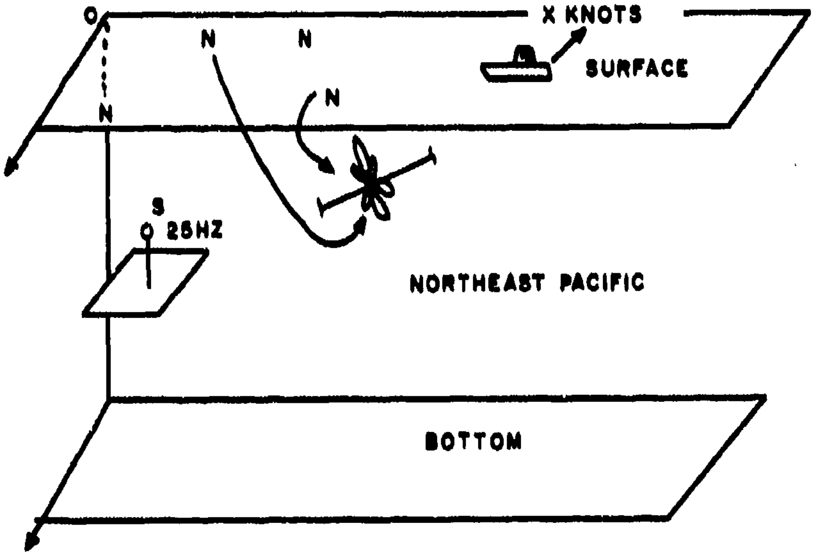
To evaluate, random process simulation model, choose data, one ocean environment (N. Pacific), single 25 Hz source, towed array receiver.

Chief Parameters: (U) Transmission loss, ambient noise, array gain, signal excess, detection threshold.

Chief Conclusions: (U) Given accurate inputs, random process simulation models give adequate simulation. Acoustic input data (statistics of signal excess, etc.) is biggest problem. Method is poor if data is poor.

A pictorial representation of this paper is shown next.

Cavanagh*



(U) Acoustic Models of Above Test Case

To be compared with

Random-Process Simulation using

a. Gauss-Markov

b. Gauss Jump

c. Ehrenfest

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "Beam Output Fluctuations" (U)

Author: A. Fabula

Objective: (C) Investigate the effectiveness of coherent multi-array processing (CMAP) for two towed arrays in a bottom-limited environment. Study the fluctuation characteristics of beam output signals from these arrays.

Research Approach: (U) Conduct an experiment featuring a moving source and two array receivers. Process data using the CMAP algorithms.

Chief Parameters: (U) Interarray signal coherence as a function of time difference of arrival. Beam Survey. Amplitude and phase fluctuations in beams. Doppler difference in beams.

Chief Conclusions: (C)

(1) Maximum coherence between received signals at the two arrays range from 0.62 to 0.93.

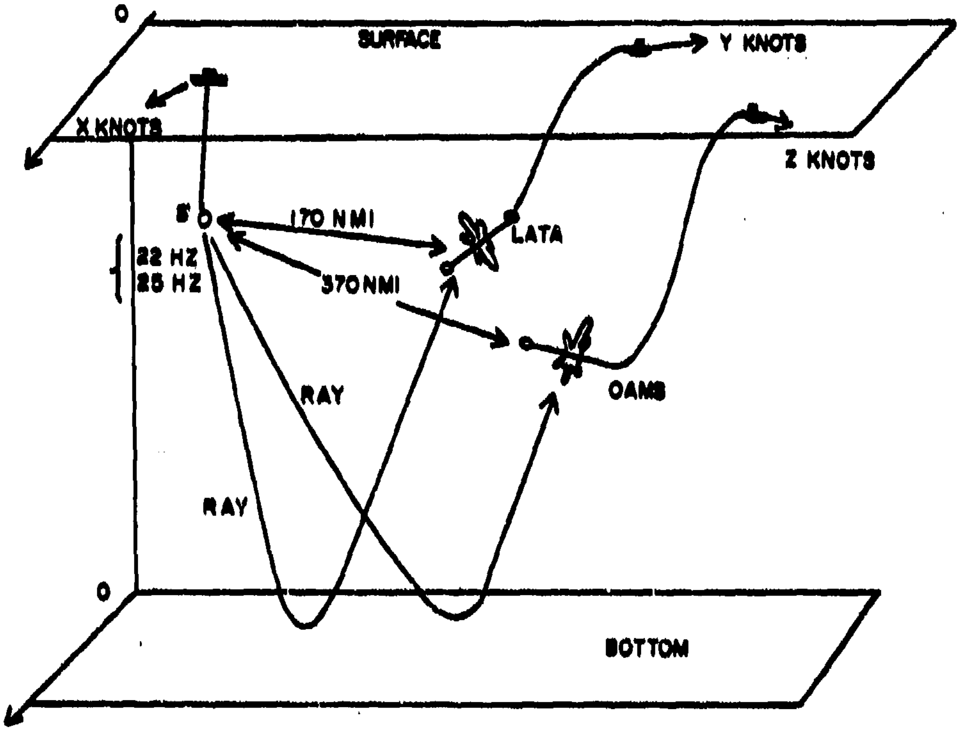
(2) Maximum signals "jump" from one beam to a neighbor beam due to multipath interference. A jump of 7° in 4 seconds has been recorded.

(3) Null, or sharp amplitude fades, also occur, and are attributed to multipath interference. These fades are easily smoothed by making a 1° change in look angle.

(4) Meander in phase is uncorrelated between the arrays. This meander is thought to be due to propagation effects, not platform motion.

A pictorial representation of this paper is shown next.

Fabula*



(C) For digital signal processing of each beam data of LATA use 128 samples/sec, and obtain amplitude spectrum level in 1/4 Hz bins by use of FFT. On OAMS data use 125 samples/sec, and obtain spectrum level by use of DFT.

Plot coherence surface $E(\Delta\tau, \Delta\Phi)$ using CMAP algorithm (Coherent Multi Array Processor).

Make a "beam survey" by finding the loudest bin-beam pair (of beams) and record the relative levels of the signal s in the beam. To obtain alignment between arrays the projector signal is switched between two distinct frequencies (22 or 25 Hz).

Calculate fluctuations in relative amplitude and phase of the received signals as a function of beam number.

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "Fluctuations Due to Range Rate" (U)

Author: I. Dyer

Objective: (U) By analysis construct a model of the power spectrum of fluctuations in a sinusoidal signal caused by platform motion. Compare this model with the power spectrum of fluctuations due to internal waves.

Research Approach: (U) Take a length of a single ray path and give it a velocity at each end. The frequency shift at each point in the path can be determined as a function of ray angle with the horizontal. *Assuming fluctuation saturation*, choose a sound speed profile, determine the energy of the ray in it, from it calculate its temporal correlation, and finally, by Fourier transformation determine the power spectrum of fluctuations.

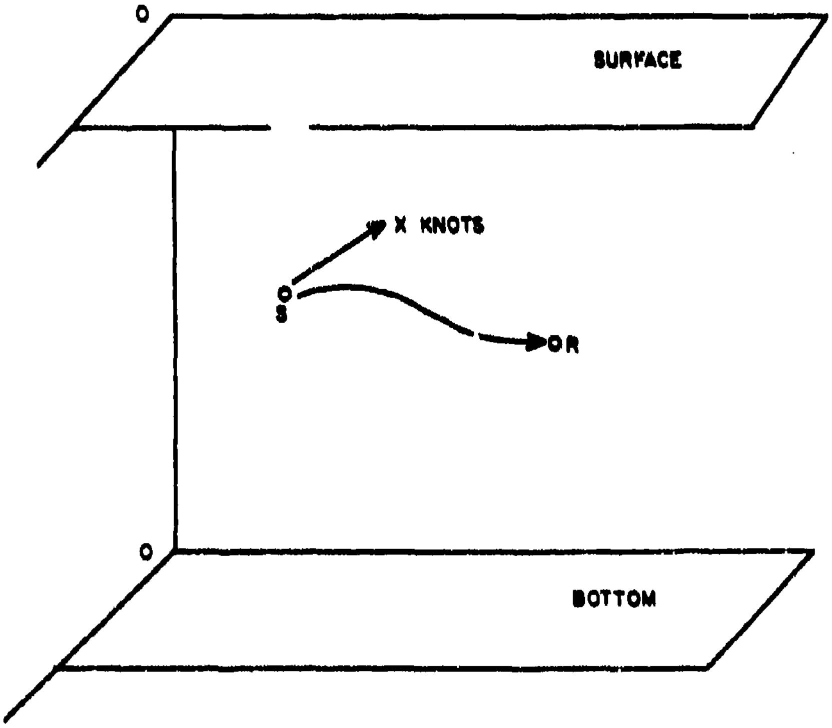
Chief Parameters: (U) Power spectra for range rate with the following choices of sound speed profiles (a) isospeed channel (b) bilinear channel, (c) Munk channel.

Chief Results: (U) Three power spectra are derived for the saturation fluctuation of sinusoids caused by platform motion, conforming to the three choices of sound speed profile.

Upon comparing fluctuations caused by phase rate with fluctuations caused by internal waves one can construct a *critical range rate* at which the frequency shift due to internal waves and that due to platform motion in a frozen ocean are equal.

A pictorial representation of this paper is shown next.

Dyer*



(U) Analytic modeling of range rate statistics, particularly the power spectrum of fluctuations of frequency of a sinusoidal signal in the saturation regime.

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "Impact of Source Motional Fluctuations on IAP" (U)

Author: A. Gerlach

Objective: (U) Determine correlation degradation between signals at two widely separated arrays caused by the motion of a transiting submarine and provide an estimate of the optimum integration time for use in passive correlation detection.

Research Approach: (U) From test data determine phase-difference fluctuations between the signals received at two remote sensors. Calculate from this the degradation of correlation coefficient between the two received signals.

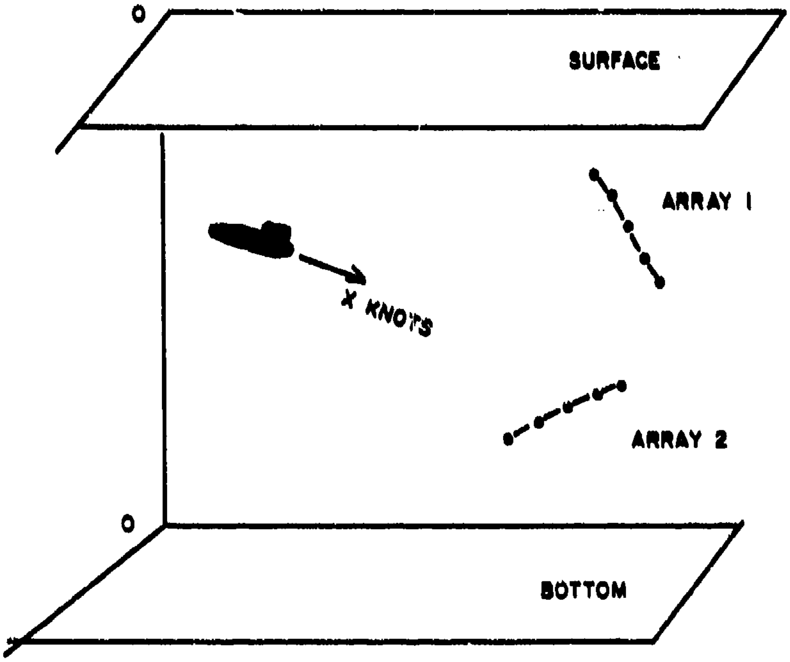
Chief Parameters: (U) Variance and Power Spectra of Target Speed and Course. Standard deviation of phase-difference fluctuations. Analysis time *T*. Cross correlation of signals at the two arrays.

Chief Conclusions: (1) (C) Temporal cross-correlation between signals at two arrays undergoes degradation as signal frequency, aperture angle between the sensors (taken at target location) target speed and integration time (*T*) increase. Standard deviation of phase-difference fluctuations increases *linearly* with *T*. Detailed data are available which give optimum integration time when signal frequency, target speed and course, and source-sensor angle are specified.

(2) (C) For received signals of time duration less than 30 minutes the dominant cause of fluctuations is platform motion (alternatively, multi-path interference).

A pictorial representation of this paper is shown next.

Gerlach*



(C) Calculate standard deviation of phase-difference fluctuations as a function of integration time. Calculate temporal cross-correlation of signals at arrays 1,2 and determine correlation degradation with course, speed, source-sensor angle and integration time.

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "Acoustic Fluctuations" (U)

Author: R. Spindel

Objective: (U) The WHOI (Woods Hole) program is designed to study effects of oceanic variations on acoustic propagation, and determine limits on signal coherence in space and time, with concentration on narrowband (nominally 10 Hz) low frequency (100-400 Hz), long range (10-1500 km). The IGPP (Scripps) program is designed to study mesoscale processes in the ocean by acoustic means, concentrating on high frequency (2250 Hz), wideband, short range (25 km).

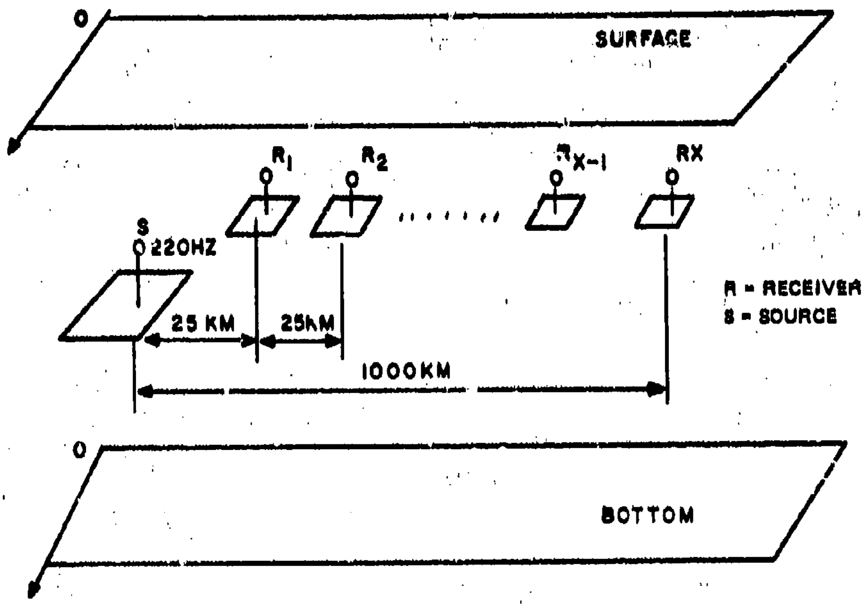
Research Approach: (U) Conduct experiments at sea. Show by calculation that study of mesoscales by acoustic signals is feasible.

Chief Results: (U) (1) Study of mesoscales by acoustic means is feasible.

(2) Experiment still is to be conducted, or if conducted, to be reported.

A pictorial representation of this paper is shown next.

Spindel*



(U) WHOI—IGPP Proposed Experiments. (See paper.)

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "Omni Noise Field Statistics Depth and Clutter" (U)

Author: J. Shooter

Objective: (U) Identify and understand the dominating source and environmental mechanisms that govern the ambient noise field as a function of depth, frequency and bandwidth. In particular, identify ambient noise caused by ships, and noise caused by wind.

Research Approach: (C) Use data of the vertical ACODAC sensor in the Church Opal experiment. Process the data into narrow band spectra, and obtain statistics of noise level spectra and false alarm rate.

Chief Parameters: (U) Ambient noise spectrum SPL db re $\mu Pa/Hz^{1/2}$. Dynamic range of noise level. Covariance of broadband and narrowband spectral components of noise. "False alarm lines" in the noise field. Cell groups or "clutter."

Chief Conclusions: (C)

(1) (C) If environment is stationary and homogeneous (limited to 3 to 6 HR) the noise obeys chi-square statistics.

(2) (C) Noise levels varied from 65 dB to 105 dB re $\mu Pa/Hz^{1/2}$.

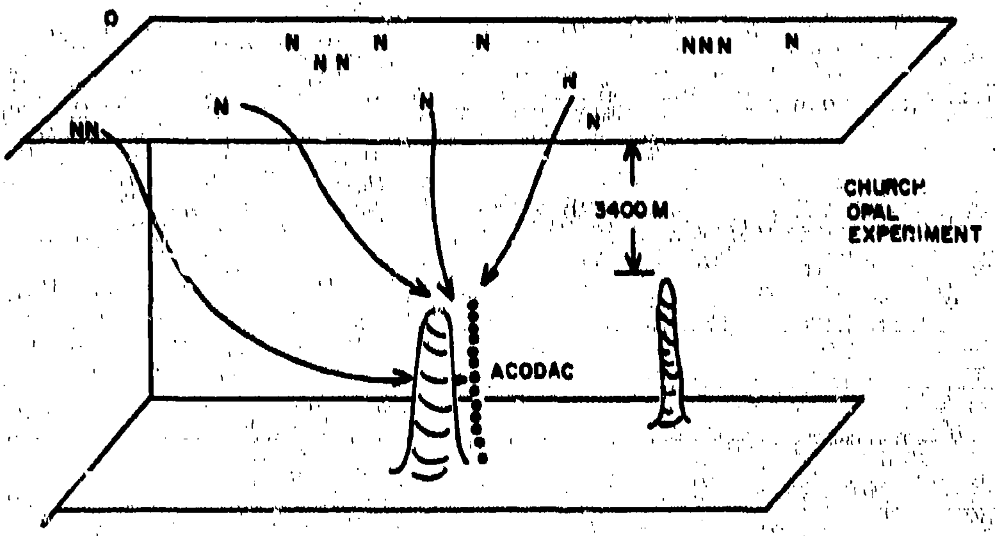
(3) (C) Spectral components of broadband noise are uncorrelated in time or frequency for homogeneous conditions (3 to 6 HR); spectral components of narrowband (ship) noise are highly correlated across frequency band, High correlation between adjacent frequency bins also observed for wind generated noise.

(4) (C) The number of single frequency bin false alarms during a "quiet period" is about 50 in 5 to 55 Hz range with 0.015 Hz resolution. Threshold at 10^{-3} probability of false alarms. When a ship passes number of false alarms rises to 200 over same period.

(5) (C) Number of single bin false alarms is greatest for near-critical depth receiver.

A pictorial representation of this paper is shown next.

Shooter*



(C) 13 hydrophones provided 13 data records in the form of time series. System dynamic range 80 dB. Process bandwidth was 0.147 Hz for frequencies 10 to 500 Hz and 0.018 Hz in band 5 to 75 Hz. Averaging time was one minute. Calculate ambient noise spectrum, covariance betwen spectral lines, false alarm statistics in single and multiple frequency bins, statistics of noise field "clutter."

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

Workshop Paper: "Characterization of Acoustic Propagation" (U)

Author: H. DeFerrari

Objective: (U) Characterize the transfer characteristics of a propagation channel rapidly in real time using a small computer and FFT.

Research Approach: (U) Using examples I,II,III pictured below, divide the spectrum of the received signal by the spectrum of the transmitted signal to find channel transfer function. From this by integration obtain the impulse response.

Chief Parameters: (U) Channel transfer function, channel impulse function.

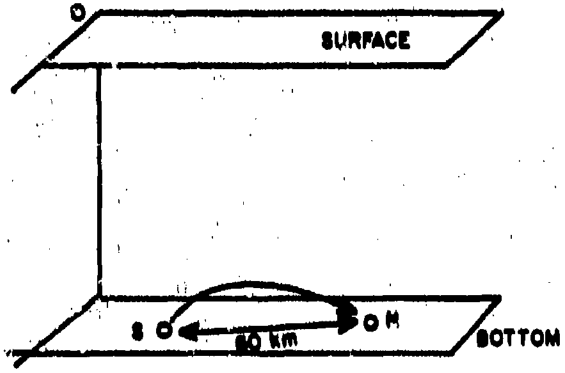
Special Feature: (U) Source transmits pseudo random sequences to permit separation of multipaths, and to overcome noise at low end of spectrum.

Principal Result of Research: (U) Inverse filtering on received pseudo-random sequences (examples I,II,III) has been used with success.

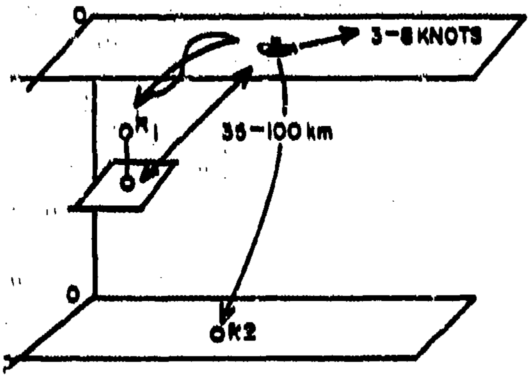
A pictorial representation of this paper is shown next.

De Ferrari*

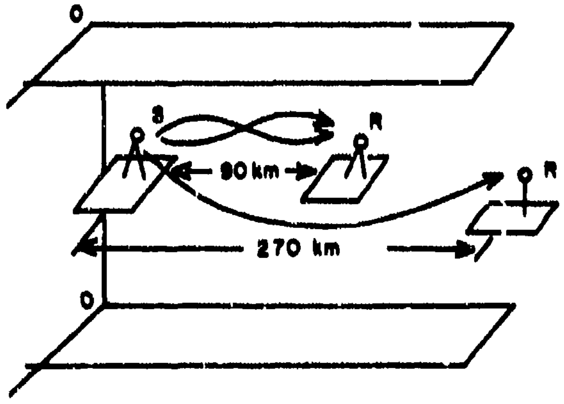
EXAMPLE I



EXAMPLE II



EXAMPLE III



(U) Evaluate

$$\frac{R(W)}{S(W)} = H(W)$$

$$p(t) = \int_{-\Delta W}^{\Delta W} H(W)\,dW$$

---

*This sketch is either (1) the editor's concept of the underlying experimental situation of the paper, presented for convenience of the reader or (2) an actual experiment conducted by others. In all cases the material boxed in heavy lines is the author's contribution as reported at the Workshop.

II. SYNOPSIS OF PAPERS NOT SUBMITTED FOR PUBLICATION (U)

(U) Of the 23 papers presented at the Workshop three were discussed in some detail in Section II of 6, while 14 have been editorially summarized in the preceding section and for five of these a synopsis was prepared because at the time no additional information was available. The one by Mr. Keir on latest arrays is included in its entirety together with all the other papers submitted for publication as Appendix A [Ref. 6].

R. Flum (U)

(C) APETC consists of a group of engagement models devoted to detection of submarines by sonobuoys. The fluctuation aspects of the models are treated as random "draws" from a statistical population whose probability distribution simulates (but does not duplicate) the fluctuation behavior of signal excess. Three component models are APAIR, APSURF, and APSUB. In practice a particular model is run some 50 to 200 times, each run being different from the next by a Monte Carlo trial of the fluctuation of a sonar parameter. The first model, APAIR, is devoted to air launched sonobuouys It has for each replication four Monte Carlo "draws": (1) an operator degradation factor which accounts for fluctuation in operator recognition differential (2) an environment draw, which accounts for long term fluctuation of acoustic signals, modeled as a zero mean normally distributed random variable (3) a second environment draw which accounts for the short term fluctuations in acoustic signals (4) a buoy variation draw which accounts for deployment fluctuations of buoy to buoy. The second model, APSURF, is devoted to surface launched sonobuoys. It has several Monte Carlo draws for each replication of both active and passive modes. In the active mode the draws are: (1) fluctuations in source level of a single buoy from ping to ping (2) fluctuation of sonar performance

(C) from sonar, say 3 sonars per convoy (3) fluctuation of acoustic signals with long term duration. In the passive mode the Monte Carlo draws for each replication provide estimate of standard deivation of target strength and relaxation time. The draws are: (1) an environment draw to account for long term fluctuations, (2) an environment draw to account for short term fluctuations within the duration of an integration time, (3) a similar short term environmental fluctuation associated with helicopter launched sonobuoys. The third model, APSUB, is devoted to submarine launched sonobuoys. It too has both active and passive modes. In the active mode a Monte Carlo draw provides an estimate of the standard deviation in source level from ping to ping based on transmission path. In the passive mode attention is given to fluctuations in signals propagating in paths near the surface out to convergence zones, for the geometry of one hostile submarine facing one friendly submarine. A Monte Carlo draw provides an estimate of standard deviation for this type fluctuation.

(C) As an overall comment on APETC it is important to realize that there is little justification for the numbers used to correct for fluctuations. The basis of the Monte Carlo trial is the Markov chain which remains an arbitrary choice. More work is needed to help APETC. In particular, present models assume all components of the sonar equation are statistically independent. There is need to investigate the correlations between components.

(U) Concerning validation, all models have been tested. However, they have been found to be very sensitive to certain sonar parameters, particularly range of detection.

T. Ewart (U)

(U) An objective of project MATE is to study oceanographic phenomena by use of "high frequency" sound. In such studies it is important to work with a single refractive path. Hence

(U) there is a necessity to develop techniques for extracting one Fermat path from a group of multipaths. The limit on resolution of paths is the size of the Fresnel zone. To explore path isolation we have devised two experiments, both in the unsaturated regime, and have assumed that the perturbations in sound transmission are caused by internal waves. The first experiment is in a local fjord, source on one side, receiver on the other. The transmitted signal is a known waveform (narrow band, broad band, pulsed tone, etc.). The received signal is assumed to be a random time-delayed version of this waveform with random amplitude, to which ambient noise has been added during transmission. In the signal processing the techniques of inverse filtering, matched filtering and maximum likelihood have been used to obtain estimates of fluctuations in amplitude and time of arrival. It is found that maximum likelihood yields the best results. The resolution into multipaths is obtained by the technique of sequential pulsing. Data has been obtained for frequencies at 4, 8, and 16 Hz. A noticeable feature of the data is the dominating effect of tides which is clearly evident. Theoretical analysis compared with experiment showed that geometric optics gives best agreement with data on phase fluctuations, but fails to agree with data on amplitude fluctuation. The latter should be calculated from the JASON diffraction parameter Λ.

(U) The second experiment is at the Cobb seamount, at a range of 18 km where the ocean at the depth of the experiment does fit the Garrett-Munk model of internal waves. A moored sensor was used in conjunction with a 12 Hz signal to obtain reasonable estimates of internal wave phenomena.

A. Ellinthorpe (U)

(C) The objective of our research is to develop an underwater communication system in which the sensors are to be mounted on the hull of warships. The intended range is 100 nmi. and the frequencies in question span 500 to 5000 Hz. Our present concern is the degrading

(C) effect of ocean-induced fluctuations. Since communication signaling is a sequence of pulses we must study the transmission of transients. A typical transient is a delta function. After transmission it is no longer a delta but appears spread out in amplitude. The amplitudes are randomly distributed. It is found that the probability distribution is more like Rayleigh than log-normal; however, both are hypotheses.

(C) Our approach is to do experiments at sea. Formerly we used the AFAR range, but we now use submarines for our communications experiments, particularly the Nautilus. When the path of the communication signal is near the surface of the sea we think we understand the propagation well enough. It is a random modulation process. Actually we use the Pierson-Moskowitz model of surface waves, and deal with a modulation of a carrier that results in two side bands. We experimented and signal processed the data to find an empirical probability distribution for amplitude of received signal. We compared this with the log normal and Rayleigh distributions, and found that the data for surface paths more nearly agrees with the Rayleigh distribution. We next undertook to study fluctuations due to internal waves. We isolated a single ray path and performed towed array experiments. In particular, we measured the variance of sound speed fluctuations with depth and found that portions of it roughly agree with the Garett-Munk model. We then made plots of $<\mu^2(z)>$ vs depth, correlation time vs. frequency, and roughness scales of the bottom. Several conclusions were drawn from our work. (1) transmitted signals along direct paths which fall into the category of unsaturated statistics fits the log normal distribution, while saturated paths fit the Rayleigh distribution. (2) Bottom effects on fluctuation associated with ship motion are much stronger than volume effects. (3) Most of the experiments present evidence of good direct path propagation followed by strong randomization of received signal caused by bottom roughness. Understanding bottom effects remains to this day our chief problem.

W. Jobst (U)

(U) When source-receiver pairs are in relative motion the acoustic field can be regarded as momentarily frozen, during which time the receiver moves through the field. The received pressure waveform is sampled by individual hydrophones of an array of hydrophones, and the spatial coherence between pairs of hydrophones can be calculated for the specific moment of freeze. In the following moment a new portion of the frozen field is sampled, and a different spatial coherence is measured. Thus the spatial coherence matrix which accounts for all pairs of hydrophones in the array becomes a function of time. A critical parameter in determining the statistics of this spatial coherence matrix is the time-bandwidth of the signal processor. Particularly, if the integration time is too long the statistics become nonstationary.

(U) It is the purpose of this study to use data from recent experiments in the Atlantic and Pacific to characterize the coherence of signals in the context of moving source/receiver.

(C) The experiment actually considered had a source centered at 88.8 Hz, and a moving receiver of conventional type. The range was 200 nmi. and reception was both on omni and on beamform. From the received data a plot of transmission loss vs. time was made, and its mean and variance calculated. Then the data was used to calculate coherence in space, time and frequency. To calculate spatial coherence we took the averaging time to be 40 minutes. Although one expected (and found) quite a bit of change in path structure with range, the data showed that the spatial correlation index in deep ocean paths is near unity. The data was also calculated to produce plots of temporal coherence vs. time, and it was found that the decorrelation time was about 80 sec. A plot of correlation envelope vs. time was also made. The results pointed up the importance of projector motion, hence the importance of placing an accelerometer on the projector to monitor its motion.

(U) As a result of the data reduction exercise reported here the *spatial coherence* of the received field was obtained as a function of array orientation, arrival angle of the multipath and spread in arrival angles over different multipaths; the temporal coherence was obtained as a function of the source ship speed; and the frequency coherence was obtained as a function of time spread.

F. Fisher (U)

(C) We pose the question, can one track arrival angle as a function of range? We know that multipath interference causes the signal received on the tracking array to fluctuate as the source/receiver geometry changes. The goal we set for ourselves is to try to make the multipath structure work for us. This effort was discussed with Adm. Waller and we feel we have made an advance in the tracking and holding of submarines by this technique of tracking angle of arrival.

(U) We tried the following experiment: a towed source at depth of 100 m radiated two frequencies, 400 Hz and 195 Hz at 172 dB re 1μPa level. The receiver was a vertical array of length 532 ft, and the range between source and receiver varied from 10,000 yds to 200 nmi. The data was processed to give vertical angle of arrival (in degrees) on a beamformer (total of 240 beams), versus range.

(U) We found that at long range only two arrivals were prominent; and we didn't need great angular resolution to find them. We concluded that the statistics of fluctuation of angle of arrival across the array were independent of range and that our ability to track these arrivals was encouragingly good. However, the medium variability does impose a limit on detection and measurement of these angles of arrival. All calculations of spatial coherence depend on the energy density of the ray in the direction of arrival of the selected path. Currently we use average energy densities. Naturally it is desirable to know the energy density at each range increment for each angle of arrival rather than the average. We are currently working on the problem of book-keeping actual energy densities of selected angles of arrival as a function of convergence zone increments.

Appendix B

N-POINT STATISTICS-NOTATIONS
[Unclassified Title]

(U) The acoustic pressure p at time t measured by an array of L point hydrophones centered at point $X(1)$ is

$$p(\vec{x}(1),t) = \sum_{l=1}^{L} A(l)\, p(\vec{x}(l),t)$$

$$p(x(l),t) = \int dt_o \int d\vec{x}_o\, T\left[\vec{x}(l),t\,|\,\vec{x}_o,t_o;E\right] Q(\vec{x}_o,t_o)$$

(U) in which $p(x(l),t)$ is the received pressure at the lth hydrophone, Q is a distribution of source functions, T is the transmission function; $\mathcal{E}$ is the environment; and $A(l)$ is the antenna function.

(U) When acoustic fluctuations are present the measured field pressure is taken to be a random variable of space and time. The objective of research in acoustic fluctuations is to determine the probability distributions of $p(X(l),t)$ and $p(X(1),t)$, and as many of the statistics of this distribution as are needed for practical use in underseas ocean surveillance systems. These statistics are the averages of the acoustic field over N physical points at a particular time,

$$< p(\vec{x}(l)\; p(\vec{x}(J) \cdots p(\vec{x}(N)) >, \quad t = t_1$$

(U) or, if these averages vary with time, a average over time of these averages. Here each pressure is a random variable and the brackets indicate averages. To identify statistics let $Sp(l)$ be the collection of all orders of statistics as the single spatial point l, that is, the listing,

<u>$Sp(l)$</u>

1st order, or mean: $< p(l) >$

2nd order, or intensity: $< p(l)p(l) >$

.
.
.
.

(U) In acoustics the theory and measurement of fluctuations in intensity was the chief concern in the investigation of ocean acoustic fluctuations for several decades. In more recent times, and at an accelerated pace, the study of the statistics $Sp(i, j)$ of two physical points have become prominent. This is a collection of the average products of the pressures at all pairs of physical points i, j in the region of interest,

$$Sp(i, j) = \left\{ < p(i) p(j) > \right\}, \quad \begin{array}{l} i = 1, 2 \ldots \\ j = 1, 2 \ldots \end{array}$$

(U) where the curly brackets means collection or set.

(U) Statistics among 3 or more physical points are rarely used, but their formulation is straightforward.

$$Sp(i, j \cdots Z) = \left\{ < p(i p(j) \cdots p(Z) > \right\}$$

$$\begin{array}{l} i = 1, 2 \ldots. \\ j = 1, 2 \ldots. \\ Z = 1, 2 \ldots. \end{array}$$

(U) In many investigations, both past and present, these statistics have been assumed to be stationary in time and homogeneous in space. However, this assumption must be modified to accomodate different space and time scales, so that it is more appropriate to write the statistics on the forms $Sp(i;t)$, $Sp(i, j;t)$ .... .

Appendix C

SPECIFIC RECOMMENDATIONS FOR FURTHER RESEARCH IN FLUCTUATIONS MADE BY WORKSHOP SPEAKERS

[Unclassified Title]

Speaker: R. Larsen

Paper: APSURV Detection Model (U)

Implied, or Explicitly Stated, Recommendations:

1. (C) Research is required to improve our understanding of source level variations, and the justification for using current values in APSURV. (page 10).*

2. (C) Transmission loss fluctuations of temporal character should be investigated in the light of internal wave theory. A global description of environmental conditions yielding saturated and unsaturated regions is required (page 11). Internal wave theory must be extended to include BB and RSR paths. (page 11).

3. (C) The integration time for passive incoherent processing (10 to 30 min.) is larger than the relaxation time of spatial fluctuations due to source motion so that the latter has no effect on the detection process. But coherent interarray processing does suffer from spatial decorrelation effects associated with spatial fluctuations. (page 12).

4. (C) Deterministic transmission loss variations associated with convergence zones at ranges less than roughly 150 nmi should be considered. (page 12).

5. (C) Signal gain variations in SURTASS due to array motion have not yet been modeled, nor has the effect of wavefront coherence. (page 13).

---

*All page numbers refer to original Workshop papers.

6. (U) It is expected that generalized descriptions of the characteristics of beam noise fluctuations will be forthcoming (page 13). Quantitative descriptions of beam noise fluctuations are not available (page 14).

7. (U) "We don't even know mean values, how can we worry about fluctuating values?" (remarks from the floor during discussion).

Speaker: L. Fretwell

Paper: PSEUDO, Surveillance System Performance Simulator (U)

Implied or Explicitly Stated, Recommendations:

1. (C) Each component of the sonar equation is modeled as a GM (Gauss-Markov process) (page 3). Despite this actual temporal correlation of S/N does not appear to be described by GM (remark made during speech). More work is needed in the correlation structure of the components of the sonar equation in time, frequency and space (page 2).

2. (U) Modeling and data gathering are too disconnected (implied by speech). More data from prime sites are needed to develop and check models (page 2). Individual models of components should be run in a multitude of cases (page 2).

3. (U) The impact of fluctuations on new system components should be studied, particularly in new shore-based processors and new array systems (page 2).

Speaker: R. Flum

Paper: APTEC and Fluctuations (U)

Implied, or Explicitly Stated, Recommendations:

1. (C) The nature of long term and short term fluctuations of signals are yet unknown and require further study, especially for active sonar (page 5).*

---

*All page numbers refer to original Workshop papers.

2. (C) In the active sonar model (ASONAR) the subroutine PFLUCT-1 is limited to deep water transmissions. Shallow water environments may require a different model (page 6).

3. (C) It must be realized that PFLUCT2 is only a rough approximation of observed fluctuations (page 6). It is assumed that signal fluctuations are uncorrelated in time, which may not be adequate for a frequently sampled sonar.

4. (C) There is little justification for the numbers used to account for fluctuations (remark made during speech). A Monte Carlo trial remains an arbitrary way of handling fluctuations (remark made during speech). More work is needed to help APETC. In particular, present models assume all components of the sonar equation are statistically independent. There is need to investigate the correlations between components (remark made during speech).

5. (U) Validation of APETC models have been tried. However, the results of these tests are very sensitive to sonar parameters, particularly range of detection (remarks made during speech). There is also a difficulty of knowing what constitutes a validation in view of the statistical nature of APETC (discussion from the floor).

Speaker: R. Cavanagh

Paper: review of Beam-Noise Fluctuation Models (U)

Implied, or Explicitly Stated, Recommendations

1. (U) An approach is needed to predict signal plus noise in one bin and noise in another (Slide #9).*

2. (U) Research is needed into the statistics of time-dependent arrays since none of the beam-noise models treat a moving array (Slide #9).

---

*All slides and page numbers refer to original Workshop papers.

3. (U) More work is needed in compiling source levels and locations of ships (Slide #9).

4. (U) The evaluation of models, particularly for mean noise, requires attention (Slide #9).

5. (U) Research is needed into array-system-response to wind-generated noise (Slide #9).

6. (U) No single model of beam noise will satisfy all requirements, a careful combination of the best of each type seems the best approach.

Speaker: O.D. Grace

Paper: The Effect of Acoustic Fluctuations in the Ocean Upon Coherence (U)

Recommendation:

(U) Coherence peak value and peak location between two sensor arrays as determined by CMAP algorithms are strongly affected by acoustic fluctuations due to target motion and medium variation. Research is needed into the second order statistics of the fluctuations of phase and amplitude modulations of signals arriving at differently located arrays (page 7).*

Speaker: J. Heine

Paper: Effects of Fluctuating Signals and Noise on Detection Performance (U)

Recommendations:

1. (U) If the signal is constant in white Gaussian noise the transition curve is very sharp for a small change in SNR. Strong emphasis must then be placed on accurate measurements of mean values (page 18).*

2. (U) Fluctuations in SNR give improved detection performance as long range, and decreased detection at short range. It is implied that the statistics on SNR are vital to performance prediction (page 18).

---

*All page numbers refer to original Workshop papers.

Speaker: R. Urick

Paper: A Working Fluctuation Model (U)

Implicit, or Explicitly Stated, Recommendations:

(U) Amplitude fluctuations of CW signals and ambient noise have field-data-verified models. Other quantities in the sonar equation (beam noise, target strength, etc.) do not appear to have similar models (page 2). Performance modeling is based on assuming fluctuations in signal excess, or SNR, to be log-normal distributed (page 3).

Speaker: K. Flowers

Paper: Signal Fluctuations (U)

Implicit, or Explicitly Stated, Recommendations:

(C) For deep water, long range passive surveillance existing propagation models are capable of providing required signal fluctuation statistics. However, the orientation of nearly perfect plane wave fields at low frequency near bottom mounted arrays is not completely understood (page 8).*

Speaker: H. De Ferrari I

Paper: Numerical Models of Acoustic Propagation Through Internal Waves (U)

Implicit, or Explicitly Stated Recommendations:

(U) The objective is to extend the $\Lambda-\Phi$ calculation (or JASON model) from the single ray case to the special cases of two and four paths (page 3).*

---

*All page numbers refer to original Workshop papers.

Speaker: A. Ellinthorpe

Paper: Fluctuations from a Communication Engineering Viewpoint (U)

Recommendations:

(U) Understanding bottom effects remains to this day our chief problem (remark made during speech.)

Speaker: M. Moll

Paper: Prediction of Detection Performance (U)

Implicit Recommendations:

(U) The mean and variance of the test statistic (signal power minus averaged noise power) is not enough for performance prediction. Calculation of the third moment of the test statistic is being investigated to provide a more realistic basis for performance prediction.

Speaker: R. Cavanagh II

Paper: Acoustic Fluctuation Modeling (U)

Recommendations:

(U) The stochastic process approach can produce adequate simulations of signal and noise. However, the accuracy and utility of this approach are greatly dependent on the availability of accurate input data. (e.g., the variance of beam noise fluctuations). Without them predictions are poor. Accuracy of simulations also depend on the particular process used. Significant improvement over "just adequate" results can be realized when the random process selected is tailored to the case at hand (page 3).*

---

*All page numbers refer to original Workshop papers.

Speaker: R.C. Spindel

Paper: Acoustic Fluctuations (U)

Implicit Recommendations:

(U) It is the goal of the collaboration between IGPP and WHOI to demonstrate the feasibility of monitoring mesoscale processes via acoustic methods.

Speaker: F.H. Fisher

Paper: Range Independent Fluctuations and Pattern Recognition
of Vertical Angle of Arrival Structure (U)

Implicit Recommendations:

(C) The principal questions are the ultimate capability of vertical arrays for detection and tracking, the utility of pattern recognition as a means of discriminating between submerged and surface sources, and the apparent independence of amplitude fluctuations over the array as a function of range. We expect to detect and hold low level targets out to 1000 mi. and more. A critical test is planned (page 7).*

Speaker: J. Shooter

Paper: Omni Noise Field Statistics (U)

Implicit Recommendation:

(U) Data from an acoustic exercise in mid-Northeast Pacific in 5000m of water has been analyzed to understand the dominant source and environmental mechanisms that govern ambient noise fields. The next step to link cell groups in the time domain and study line frequency and amplitude stability in the background noise (page 8).*

---

*All page numbers refer to original Workshop papers.

UNITED STATES GOVERNMENT

Memorandum

7100-005

DATE: 24 January 2003

REPLY TO ATTN OF: Burton G. Hurdle (Code 7103)

SUBJECT: REVIEW OF REF (A) FOR DECLASSIFICATION

TO: Code 1221.1

REF: (a) “Acoustic Fluctuations: Guidelines for R&D Based on the Acoustic Fluctuation Workshop 22-23 February 1978” (U), S. Hanish, C.R. Rollins and J. Cybulski,NRL, NAVELEX Report, November 28, 1978 (C)

539935

ADC017083

1. Reference (a) is a description of a Navy-wide workshop on the fluctuation of underwater acoustic signals. It includes the program of the workshop, a discussion of previous workshops on fluctuation, and the resulting recommendations.

2. The technology and equipment of reference (a) have long been superseded. The current value of these papers is historical.

3. Based on the above, it is recommended that reference (a) be declassified and released with no restrictions.

Burton G. Hurdle

BURTON G. HURDLE
NRL Code 7103

CONCUR: Edward R. Franchi 1/23/2003

E.R. Franchi Date
Acting Superintendent, Acoustics Division

CONCUR: Tina Smallwood 1/27/03

Tina Smallwood Date
NRL Code 1221.1

```
--   1  OF    1
-- 1 -  AD NUMBER: C017083
--48 -  SBI SITE HOLDING SYMBOL:     NRL539935
-- 2 -  FIELDS AND GROUPS: 17/1, 20/1
-- 3 -  ENTRY CLASSIFICATION:   UNCLASSIFIED
-- 5 -  CORPORATE AUTHOR: NAVAL ELECTRONIC SYSTEMS COMMAND WASHINGTON D C
-- 6 -  UNCLASSIFIED TITLE:     ACOUSTIC FLUCTUATIONS: GUIDELINES FOR R AND
--      D BASED ON THE ACOUSTIC FLUCTUATION WORKSHOP 22-23 FEBRUARY 1978.
-- 8 -  TITLE CLASSIFICATION:   UNCLASSIFIED
-- 9 -  DESCRIPTIVE NOTE: FINAL REPT.,
--10 -  PERSONAL AUTHORS: HANISH,S. ;ROLLINS,C. R. ;CYBULSKI,J. ;
--11 -  REPORT DATE:      28 NOV 1978
--12 -  PAGINATION:    89P   MEDIA COST:  $  7.00 PRICE CODE:   AA
--16 -  PROJECT NUMBER:   F52522
--20 -  REPORT CLASSIFICATION:  CONFIDENTIAL
--22 -  LIMITATIONS (ALPHA):    DISTRIBUTION LIMITED TO U.S. GOV'T.
--      AGENCIES AND THEIR CONTRACTORS; SPECIFIC AUTHORITY; NOV 78. OTHER
--      REQUESTS MUST BE REFERRED TO COMMANDER, NAVAL ELECTRONIC SYSTEMS
--      COMMAND, ATTN: CODE 320. WASHINGTON, DC 20360.
--23 -  DESCRIPTORS:     *UNDERWATER ACOUSTICS, *REVERBERATION, *SONAR
--      SOUND ANALYZERS, CONFIDENCE LEVEL, ACOUSTIC DETECTION, UNDERSEA
--      SURVEILLANCE, SUBMARINE DETECTION, STATISTICAL PROCESSES, SIGNAL
--      PROCESSING, TRANSMISSION LOSS, GAIN, SIGNAL TO NOISE RATIO, SONAR

-
--      EQUIPMENT, WORKSHOPS
--24 -  DESCRIPTOR CLASSIFICATION:   UNCLASSIFIED
--27 -  ABSTRACT:   A SET OF GUIDELINES FOR RESEARCH AND DEVELOPMENT HAS
--      BEEN PREPARED BASED UPON THE PAPERS AND DISCUSSIONS AT THE ACOUSTIC
--      FLUCTUATION WORKSHOP HELD AT NRL AND SUBSEQUENT PANEL DELIBERATIONS.
--      INCLUDED IS A BACKGROUND ON ACOUSTIC FLUCTUATIONS RESEARCH AND THE
--      CONSIDERATIONS IN STRUCTURING A PROGRAM IN OCEAN ACOUSTIC
--      FLUCTUATION. SPECIFIC TASKS ARE ITEMIZED, BEGINNING WITH THE USE OF
--      HIGHEST PRIORITY TO FORMULATE A POTENTIALLY COMPLETE MODEL OF SNR.
--      THIS IS FOLLOWED BY THOSE RELEVANT TO TERMS IN THE SONAR EQUATION,
--      NAMELY, SOURCE LEVEL, TRANSMISSION LOSS, SIGNAL GAIN, BEAM NOISE
--      AND SOME IN SIGNAL PROCESSING AND SNR. FOR REFERENCE, AN APPENDIX
--      CONTAINS EDITORIAL SUMMARIES OF SYNOPSES OF PAPERS PRESENTED AT THE
--      WORKSHOP. (AUTHOR)
--28 -  ABSTRACT CLASSIFICATION:     UNCLASSIFIED
--29 -  INITIAL INVENTORY:    2
--32 -  REGRADE CATEGORY: C
--33 -  LIMITATION CODES:  2
--34 -  SOURCE SERIES:    F
--35 -  SOURCE CODE:      387196
--36 -  ITEM LOCATION:    DTIC
--37 -  CLASSIFICATION AUTHORITY:     CNO (OP-095)
```

UNCLASSIFIED

APPROVED FOR PUBLIC
RELEASE - DISTRIBUTION
UNLIMITED

```
--38 - DECLASSIFICATION DATE:  OADR

-
--40 - GEOPOLITICAL CODE:     1100
--41 - TYPE CODE:  N
--43 - IAC DOCUMENT TYPE:
--49 - AUTHORITY FOR CHANGE:  LIMITATION CHANGED PER DTIC FORM 55









--END          << ENTER NEXT COMMAND >>          END --
```