KEYNOTE ADDRESS
UNDERWATER ACOUSTICS — MODELLING

by

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INTRODUCTION

I have entitled this address "Underwater Acoustics — Modelling", believing that this Conference provides a timely opportunity to review the field of underwater acoustics in some totality and certainly at three important interfaces that it encompasses, namely:

a) Oceanography — Acoustics

b) Experiment — Theory

c) Scientific Knowledge and Research — Application

For this reason I consider the present Conference is potentially one of the most important the Centre has sponsored, although its conduct at an unclassified level may limit its scope in terms of the application of underwater acoustic knowledge and technology.

My task in this address is to provide a viewpoint as possible guidance to the business of the Conference which, as I see it, should result in

1. A review of earlier and current efforts.
2. Inputs as to where we currently are in the modelling field.
3. Views as to where we should be going.

I intend to approach my task by a résumé of some earlier reviews of underwater acoustics and some comment on highlights of underwater acoustic development related to the modelling problem.

1. THE REVIEWER — LIMITATIONS ON AVAILABLE INFORMATION

Before doing so, however, I wish to express my personal thanks to those amongst you who have undertaken the difficult task of preparing review papers. Never easy, this task is becoming increasingly

difficult in underwater acoustics, first as a result of the growth of the field, but more importantly because of limitations on the availability of both information and data in all but the most basic areas.

Following World War II, particularly in the U.S., substantial efforts were made to make basic scientific data and background information developed during the war available, both to promote scientific interest in defence research and to permit exploitation outside the defence area in the public domain. The "Red Books", [Refs. 1,2,3], of which more later, are a fine example. By the early 1950s the situation was somewhat improved, and by the late 1950s it was relatively good, as a result of strong interest on the part of the Acoustical Society of America and indeed of the U.S. Navy [Refs. 4,5]. An excerpt from Reference 4, an address by the then Assistant Secretary of the U.S. Navy for Research and Development, is particularly pertinent:

> "The Acoustical Society's Committee on Underwater Acoustics is already alert to the problem of classification, and has opened an exchange of letters between the Society and the Navy on this matter. I want to state that I am in complete accord with this desire to increase the amount of unclassified published material in this field. I have, I am quick to admit, a somewhat selfish viewpoint. The Navy is anxious to encourage more scientists to engage in this area of research. We would like to convince them of the intriguing challenges that await them in this fascinating field. The best and simplest way to do this is to spread the news of what is being accomplished through open professional meetings and publication in the open literature."

Unfortunately, with the further passage of time, availability appears to be deteriorating under the impact of security classification, need-to-know, multi- and bi-lateral agreements and, indeed, industrial security — a situation by no means unique to any single nation. In consequence, the reviewer's task is becoming increasingly difficult and complex but, by the same token, more important and responsible.

2. UNDERWATER ACOUSTIC REVIEW EFFORTS

Table 1 presents a listing of some important review efforts across the field of underwater acoustics.

TABLE 1

SELECTED REVIEW EFFORTS

1937-38	"Afternoon Effect"
1940-46	NDRC Wartime Research "The Red Books"
1947-48	NRC.CUW. Panel on U/W Acoustics "Basic Problems in U/W Acoustic Research
(1950)	"The Green Book"
Mid-50s	ONR Unpublished Summaries Urick "Principles of U/W Sound for Engineers"
1962	U/W Sound Transmission Marsh & Schulkin
Mid-60s	Maury Center Oceanography - U/W Acoustics
1970	Acoustical Society of America, Special Sessions Technical Committee on Underwater & Engineering Acoustics 20-year Review of Underwater Acoustics
1975	? ? ? ? ?

I should say, for the benefit of my NATO colleagues, that my selection of U.S. reviews is intentional as representing a historical background with which I am most familiar. I well recognize the important rôle of other national efforts and of the series of NATO Advanced Study Institutes in underwater acoustics and related topics held under the auspices of the Science Committee but feel that particulars of the latter are better known and more readily available to all attendees.

My inclusion of the long known "afternoon effect" in this listing again is intentional. Its explanation represents to my mind initial progress in modelling in the field. The Guantamano (Cuba) experiments that provided the explanation of the phenomenon were conducted in 1937/38 jointly by Steinberger of the U.S. Naval Research Laboratory, Iselin and Spillhaus of Woods Hole and Batcheldor of the Submarine Signal Co. [Refs. 6,7]. For the first time a direct relationship between the sharp temperature gradients in the top layers in the medium and echo detection ranges was demonstrated. The need for the bathythermograph, invented shortly afterwards by Spillhaus, was clear. This device was to prove a most valuable tool in extending understanding of the relation between the medium and sonar performance, only partially supplanted by the Greenspan-Tschiegg sound speed meter in the mid 50's [Ref. 8].

During the period 1940/46, alongside the extensive US ASW development efforts, the National Defense Research Committee and its later parent, the Office of Scientific Research and Development, supported an extensive research effort across the oceanographic-acoustic-ASW boundaries. Fortunately these efforts were extremely well documented and relatively rapidly made public, providing a firm basis for post-war development of underwater acoustic research and application. The two principal volumes, "Physics of Sound in the Sea" and "Principles (and Applications) of Underwater Sound", the "Red Books" [Refs. 1,2], have been reprinted at least four times in the U.S. under various auspices*. A third text, concerned with military oceanography [Ref. 3] is less well known in the acoustic community.

The U.S. National Research Council, Committee on Underwater Warfare followed these efforts in the late 40s by establishing a Panel on Underwater Acoustics which set about identifying problems in the field as a guide for future research efforts. The resulting report, which appeared in an unclassified version in 1950 as the "Green Book" [Ref. 9], was an outstanding effort and it remains a valuable document.

In the early 1950s the U.S.N. Office of Naval Research undertook a summary of underwater acoustic data in terms of the so-called "Sonar Parameters". The aim was to provide across the whole frequency range of potential underwater acoustic application, in addition to basic data, background information and models pertaining to their use by sonar scientists, engineers, designers and equipment users. Although these summaries, completed in the mid-50s, were never formally published, much of their content was reflected and amplified subsequently in Urick's "Principles of Underwater Sound for Engineers" [Ref. 10]. At the time of the initial undertaking perhaps 10 000 documents dealt in some way with underwater acoustics and its use and 1000 provided acoustic data or were concerned with their rational interpretation. Summarizing the state of knowledge of the sonar parameters at the conclusion of the initial summaries it was stated that: [Ref. 11];

> "Underwater sound has grown beyond its infancy to the point where we possess some knowledge and some conceptual understanding of most of its major phenomena..... Perhaps the state of knowledge about the parameters can be summarized in this way. With the exploratory phase over, and with a knowledge of mean values and the underlying physical phenomena, some sort of turning point appears to have been reached. The most urgent need now is for more accurate numerical values useful to the design engineer and the performance analyst. In order to meet this need, future measurements of the parameters must concentrate not only

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** They have also been printed at least once in the USSR in a Russian translation. A copy of this translation coming into the hands of one U.S. scientist was misinterpreted as being Soviet work and taken as demonstrating great progress in the field by the USSR, as distinct from interest.*

> on mean or average values, but on the variations from the mean with a view to improving our ability to make better statistical predictions for a given set of conditions. By a study of variations, and by attention to effects that were once neglected, we may be able one day to use the sonar equations with a high degree of confidence."

At the time of these summaries, the study of transmission loss had been covered in a series of papers by different authors concerning various aspects of underwater sound transmission. In a revision undertaken by Marsh & Schulkin and published in 1962, an attempt was made to achieve unity and a measure of completeness. The authors, commenting on the state of the art at that time, noted: [Ref. 12]

> "Today, the questioners are pounding on the door, seeking information vital to the problems of present operational performance and future design. They are concerned for the most part with features of the sound field which are simply not contained in the sonar parameters. There are two ways in which answers to such questions can be sought at this time. One is the direct way, going to sea again, with new kinds of instrumentation, making new analyses and building up a new picture of the kind that seems important. The second way is synthetic, using a physical description of the ocean as the basis for the necessary equations to describe the required features of the sound field. Both ways are useful; both are being employed today.
>
> "Unfortunately, the kind of experiments being conducted today cannot be regarded as satisfactory. On the "synthetic" side, considering the very large expenditures of effort in the past, future results cannot be expected to provide more than marginal increases in knowledge, except in special cases. On the "direct" side, there is the inescapable dilemma that vastly increased detail is required, on a subject which is already almost unmanageable because of detail. The fact is, new ideas and concepts for characterizing the sound field are sorely needed. What are the essential features of the sound field, which both must and can be determined?"

they proceeded to provide some insight into possible approaches, stressing that many properties of the sound field are not conveniently or practically related to the mean acoustic field and its variability.

My next entry in Table 1 is the Maury Center and its associated activities, which have played major roles in co-ordinating oceanographic research across the underwater acoustic boundary and in modelling for various types of sonar application and particularly for very long range propagation.

In 1970 the Acoustical Society, through its Underwater Acoustic and Engineering Acoustics Technical Committees, undertook a review of the previous twenty years in underwater acoustics in special sessions organized at its 80th meeting.* A number of review articles took as their starting point the problems outlined twenty years earlier in the "Green Book" and pursued subsequent progress. I will refer to two only. Berman & Guthrie, in an excellent general review on the substantial progress in understanding the medium from the underwater acoustics point of view [Ref. 13], noted a principal deficiency of the fifties as

> "....the ability to handle a mathematical model of the ocean which would give a prediction of the acoustic field in detail.

They concluded that, despite some gaps and uncertainties,

> ....intensive efforts of many investigators over the last twenty years have yielded a computational capability which now allows a general specification of propagation in relatively great detail".

Williams, in a companion paper [Ref. 14], again noted much progress in understanding propagation but that variability of the medium and its boundaries still imposed limitations. Commenting on the "Green Book", he pinpointed its failure to mention at all the coming influence of large computers, despite the fact that by 1947 the first true digital computers had been in action for some time. He proceeds:

> "....Everything that I say in the rest of this talk has, hanging over and permeating it, the influence of large computers.
>
> Nevertheless, with great blessings there always come small curses. These computers make possible, in all sorts of fields, the solution of problems that previously were too complex for us to solve. True — but they also make all too possible the solution of problems that were never worth solving. Moreover, they seduce us away from possible compact analytical solutions and lead us to vast piles of print-out paper.
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> Perhaps we are in only a temporarily awkward situation, much as we are with household appliances. In an earlier day we repaired broken appliances or got someone else to do it. Some time in the future, we are told, it will be cheaper to throw away the broken gadget and buy a new one. Meanwhile, now, we find it expensive to buy a replacement and impossible to arrange for repairs. It may be that

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See Jnl Acoustical Society of America 51, 1972: 992-1065.

> computers are in a somewhat similar stage of transition. Further development of graphic outputs may give us much the effect of analytic solutions, as we turn knobs and scan from one possible result to another, instead of having to look at one graph after another, one print-out after another."

and later:

> ".....The interrelation of experiment and theory is emphasized deliberately. In so complicated a field as propagation, anyone who ventures far into theory without keeping a constant eye on experimental data is simply crazy. The problems are far too complex, the answers too unsure, to allow any divorce between theory and experiment."

Both are surely sobering thoughts and questions for this Conference.

3. THE 70s

And now to 1975 and the present Conference. In comparison with earlier periods the 70s in underwater acoustics (as in many other environmental and applied sciences) are characterised by:

a) Large-scale experiments.

b) Large data bases.

c) An increasing number of fixed sites for the conduct of major and long period experiments.

d) Greatly-increased computational and analytical facilities.

e) Potentially increased precision in measurement, although this depends even for automated systems on adequate calibration.

f) The need for increasingly realistic concern in the financial area.

g) Increasing pressure to solve the user's immediate problems.

h) Modelling.

The implications of this listing are I believe obvious and I will not discuss these items further except for the omni-present "Modelling".

4. MODELLING

The questions tabulated below are important to all modelling efforts and will I'm sure be addressed in this Conference

a) What is one trying to model?

b) What is actually being modelled?

c) To what purpose is the modelling being undertaken

- To provide a description?
- To provide understanding?
- To permit analysis?
- To permit performance prediction?
- As a guide to use of equipment?

Clearly models can be of a widely differing variety and may run from simple rules of thumb, through empirical and analytical ones to physical models of varying complexity involving increasingly large-scale computation. They may be completely deterministic in nature or stochastic. Indeed a major question is how may we introduce variability of a model parameter without complete recomputation. Further we may approach a modelling problem by refinement of an existing model or attempt new approaches to the problem. All these topics will undoubtedly arise in the ensuing papers and discussion, and need no further elaboration except perhaps to state a belief that wherever possible our aim should be for simple solutions.

Solutions of scientific problems, and certainly the most elegant ones, usually revolve around simple concepts. A model must be responsive to its purpose, and one for the final user may well be substantially simpler than for an intermediary user (e.g. the system analyst). It may be reached by a completely different path.

5. LIMITATIONS

Some comment on the impact of models of underwater acoustic and acoustically-related phenomena may be of value. Two examples from many possible ones demonstrate I believe that it is the difference between expected and observed that is important in further understanding of phenomena, and that established "models" should not be used beyond the limits of the input parameters on which they are based. One must always be clear as to the particular purpose of a given model and the range of inputs upon which it is based.

My first example, ambient noise in the deep ocean, is illustrated in Fig. 1. As originally published, the so-called Knudsen curves for deep water [Ref. 15] based on examination of considerable

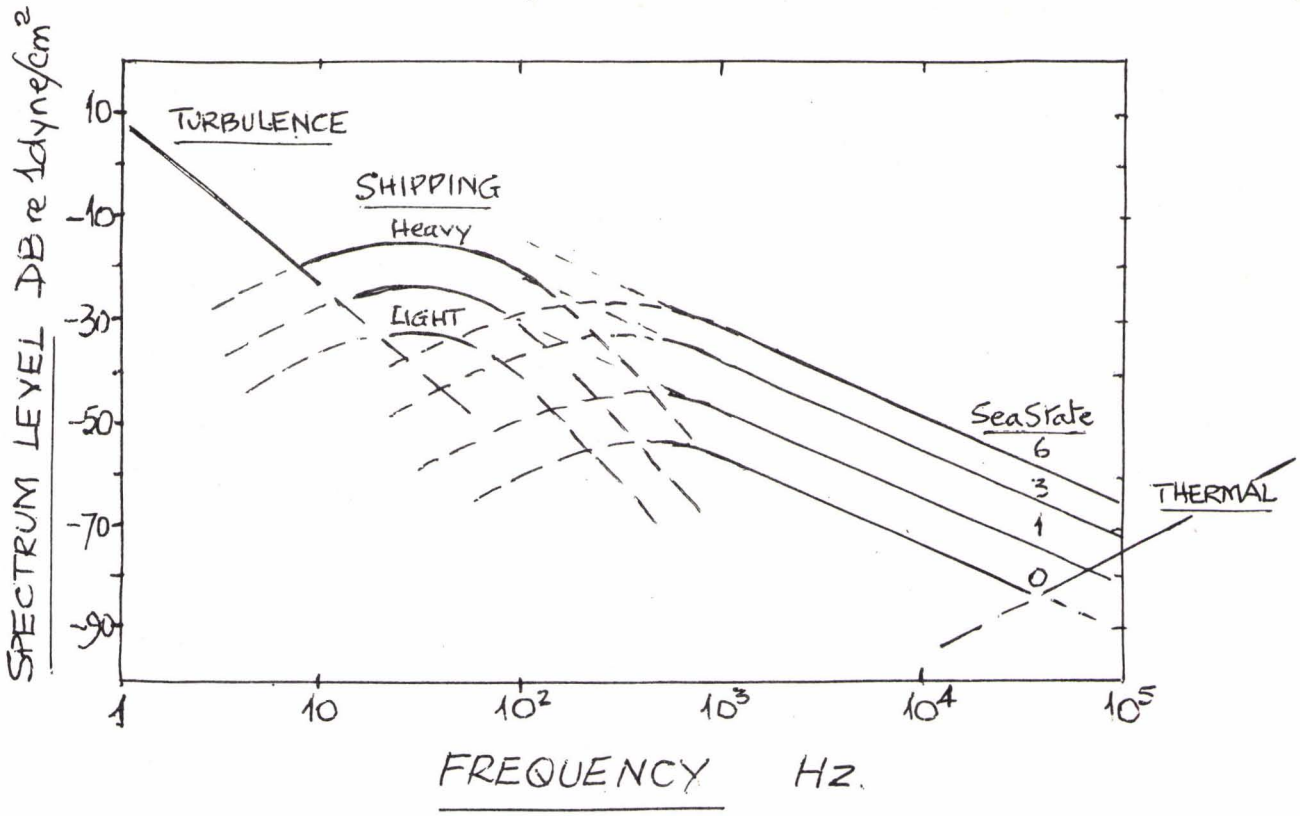

FIG. 1 DEEP WATER AMBIENT NOISE
based on Knudsen [Refs. 15,16], Wenz [Ref. 17] and Urick [Ref. 10, p.168]

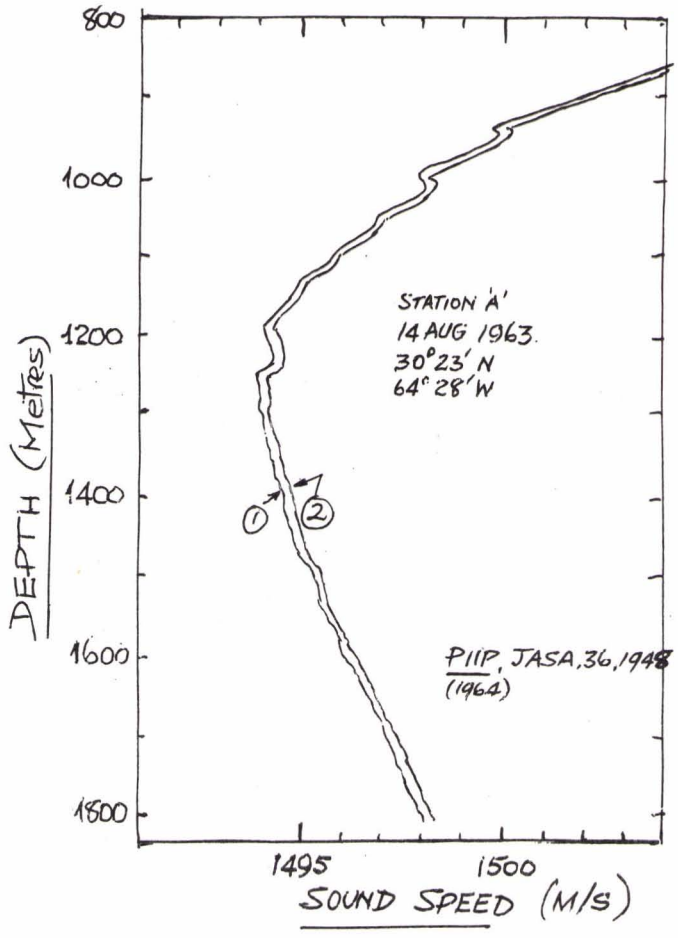

FIG. 2 FINE STRUCTURE IN THE DEEP OCEAN
Tracking of two independent sound speed meters

WW II data, were extended down to 100 Hz. By the early fifties they were well established — and accepted — to the extent that they were frequently offered as a possible means of calibrating hydrophones at sea. On the other hand, measurements made by both the east and west coast activities at low frequencies suggested a plateau in the noise curves below 1000 Hz with little sea-state dependence. Faith in the Knudsen model and its low-frequency extension tended to restrict acceptance of this new knowledge in a frequency range of growing application interest.

The second example concerns fine structure in the deep ocean. For many years the accepted model of the ocean, particularly for underwater acoustics purposes, was one in which there was considerable variation and stratification in the surface layers, but below the thermocline conditions were stable, there being a continuous variation of properties with depth, deep sound-speed profiles being smooth. While deep stratification was suspected and by the late fifties had indeed been measured, its acceptance had to await further verification by much improved instrumentation [Ref. 18]. Figure 2 is indicative of early "acoustic" observations of deep structure in the Bermuda area [Ref. 19]. Rapid and short-term variations had also been observed by Hersey and others in this area [Ref. 20]. This work was largely generated by acoustic interest in prediction of travel times through the sound channel for other than ASW purposes. The possible impact of such phenomena on "Sonar" will undoubtedly be discussed during the Conference.

CONCLUDING REMARKS

Now let me return to the current conference — some five years down the line from the review conducted by the Acoustical Society in 1970. In the forthcoming papers and discussion we may expect to hear what the facilities available to us in the 70's and our accompanying modelling efforts have contributed to our knowledge, understanding and capabilities. We may expect, in part,

1. A review of earlier and current efforts.
2. Inputs as to where we currently are in the modelling field.
3. Views as to where we should be going.

To conclude I am tempted to refer back to Hunt's 1970 "Introductory Retrospection" [Ref. 7] delivered when he chaired the Acoustical Society's special review sessions. He opened

> "It is no accident that the helmsman of a boat sits in the stern facing forward, whereas the oarsmen, who do the real work of making the boat move ahead, face aft with their foreground filled with the view of where they have just been."

and concluded by turning

> ".....at last to the assigned task of introducing
> our backward-looking speakers....."

I am prompted in a similar vein to await our speakers who will acquaint us with the product of their endeavours and will advise us of our progress and future course in sailing upon an ocean of data and computation.

THE PERFECT MODEL

[**Courtesy, Hindustani Times, circa 1968**]

SERVES PURPOSE (JUST)

SUPPORT ADEQUATE (JUST)

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