PROPAGATION STUDIES FROM THE USERS POINT OF VIEW

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1. INTRODUCTION

1.1 Good afternoon, ladies and gentlemen, my name is Commander Ian Gallett. I am the Oceanographic Staff Officer to the Royal Navy's Director of Naval Oceanography and Meteorology (DNOM) and as such I am responsible for recommending the Royal Navy's policy for all aspects of oceanography. My colleague Lieutenant-Commander Graham Woodworth is also a DNOM Staff Officer and is responsible to me for the acoustic aspects of oceanography. Our presentation today is aimed at giving the Royal Navy's perspective of the requirement to understand the transmission of sound through the ocean and how through this understanding it attempts to exploit the acoustic environment.

2. THE IMPORTANCE OF ACOUSTIC PROPAGATION TO THE ROYAL NAVY

2.1 Background.
One of the primary requirements of the Royal Navy in any future period of tension or war is its capability to detect, track, localise, and ultimately, destroy or disable hostile submarines. Therefore to achieve this it is necessary to be able to assess the oceanographic environment within which your sensors are operating and understand how this then effects the propagation of sound. It is important to note however that it is equally as important in certain situations to avoid being detected and thereby deny the enemy a firing solution. Indeed avoiding detection may be the primary task of the unit. A first class example of this is that throughout 21 years of continuous nuclear deterrent patrols at sea, the submarines have remained undetected.

2.2 The Detection/Evasion Process.
How then, do we go about this process of detection or evasion? The answer lies in assessing the environment and then attempting to predict quantatively the effect the environment has on sound by range predictions. Consider, firstly then the environment. It is essential that an assessment of the prevailing oceanographic conditions is undertaken of the area of interest. This may be achieved using own ships data, third party information, archived climatology or remote sensing data. Armed with this oceanographic analysis of the prevailing conditions pertaining to your

operational area, which may encompass many 100s of square miles, decisions can be made on the optimum deployment of the available sensors in the water column to maximise detection probabilities. This must then be balanced, in the case of submarines, against, the optimum depth to minimise the effect of own ships radiated noise. Figures 1a, b and c illustrate these possible alternatives. The assessment must not only consider the sound speed profile and bottom conditions, but must also consider fronts and eddies, bottom topography and variations in ambient noise directionality to mention but a few.

2.3 The Sonar Equations.
It is interesting to note that correct exploitation of the environment can offer an advantage of some 6 - 20 dB. When this is considered against the large financial investment used in designing and procuring sonars which only offer an improvement in the order 3 - 6 dBs it is imperative that the Command at sea has a good environmental appreciation. Now I shall turn to the other process of range prediction. This is where the current oceanographic acoustic conditions are summarised in a simple numerical form. The range corresponding to direct path, bottom bounce path, surface duct, convergence zone and sound channel modes of propagation must all be considered. These should be assessed, compared where possible with previous results actually achieved and then combine with the assessments made of the environment to give a full tactical appreciation of the prevailing or predicted oceanographic conditions. The range prediction process uses the following sonar equations.

For Passive detections: PFOM = TN - (BN - DI) - DT - DF
For Active detections: AFOM = SL + TS - BN + (DI - DT - BW) -DF
For Passive intercept of Active transmissions:
PIFOM = SL - BN + (DI - DT - BW) - DF

where
TN = Target Radiated Noise
BN = Background Noise
DI = Directivity Index
DT = Detection Threshold (Based on 50% probability of detection, 0.01% probability of false alarm)
SL = Source Level of the sonar
TS = Target Strength of the target
BW = Bandwidth
DF = Degradation Factor

2.4 Most of the terms in these equations are, I think, familiar to you. However, I will expand on just two terms, DT and DF. The mathematical equation to calculate DT has been included as an Annex to this paper in the Proceedings, as experience has shown that there exist several different approaches to this calculation.

The Annex therefore represents the Navy's approach. The Degradation Factor has been added to the sonar equations in an attempt to relate predicted ranges to achieved ranges, and perhaps can be considered as a term representing a process or processes as yet unknown to us. As you might expect the DF varies for each of the sonar equations.

2.5 Variability.
The FOM calculations derived from the sonar equations represent a probability of detection of 50% and a probability of false alarm of 0.01% for a signal excess of 0dBs. However, variations in probability of detection tend to be fairly symmetrical about a signal excess of 0dB and a signal excess of ± 5 dB corresponds to a change in probability of detection of ± 25% (Figure 2). Hence, the range represented between FOM - 5 dB and FOM is the 25 - 50% probability of detection and that represented between FOM and FOM + 5 dB is the 50 - 75% probability of detection. Therefore the range bracket represented by FOM - 5 dB to FOM + 5 dB can be considered to be range within which 50% of detections will occur (Figure 3). It is this approach of range brackets that has replaced the almost meaningless concept of "range-of-the-day".

2.6 This approach is most appropriate when each of the terms of the sonar equation displays unpredictable variability and where this variability is of a similar magnitude for each term in the equation. However when only 1 or 2 terms in the sonar equation show much greater variability than the rest a more useful statistical approach is to produce an overall system standard deviation. If the variability associated with these terms is also deterministic to some extent the meaningful range brackets are more easily obtained and interpreted. Consider the case of an active sonar for example. The target strength parameter could vary from 30 dB on the beam to 10 dB on the bow. This degree of deterministic (predictable) variability is likely to exceed the random (unpredictable) components of the other terms. It is therefore useful to calculate 2 FOMs: one for a beam aspect target, and one for a bow aspect target. The range bracket derived can then be interpreted as:

2.6.1 The range within which detection is likely (> 50%) even for a bow aspect target.

2.6.2 The range beyond which detection is unlikely (< 50%) even for a beam aspect target.

2.7 Benefits of Acoustic Analysis and Range Prediction.
From the oceanographic analysis and range prediction process the following advice can be given to the Command.

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2.7.1 Predict the effect of any changes in the local oceanographic conditions (eg. increase sea state, weather, ambient noise).

2.7.2 Modify the sonar line-up to make optimum use of available sensors and signal processing equipment.

2.7.3 Refine search/evasion/transit plans and tactics.

2.7.4 Provide initial guidance for TMA ranges.

2.7.5 Forewarn the command of expected counter detection ranges.

2.7.6 Optimise disposition of forces in co-ordinated operations (Screen design).

2.7.7 Active/Passive policy.

2.7.8 Determine best search/evasion depths and frequencies.

2.7.9 Determine optimum/maximum sonar speeds.

2.7.10 Select best operating area.

2.7.11 Assess likely weapon performance and tactics.

2.7.12 Predict likely threat tactics.

2.8 As you can see a very impressive list of advice that can determine a successful or non-successful mission. However, for the range predictions to be valuable it is necessary to have a suite of acoustic models to cover all the environments Naval units can be expected to operate in. I will now give some of the background to the present in-service models, those proposed for the near future and a brief word on the long term aims.

3. PROPLOSS MODELS

3.1 Background.
Up until the mid 70's the navy hade few problems with respect to acoustic modelling. The sensors we had were at best medium range in capability and in the majority of cases at frequencies where a simple ray treatment of the problem in a range independent environment would suffice. The few sensors such as sonobuoys which had low frequency capability detected at such short ranges that energy spreading laws were all that were needed.

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3.2 In the last 15 years, however, technological advances have pushed the frequency limits out so that in the Navy we are now interested all the way from a few hertz to some hundreds of kilohertz. Also ranges, instead of being a few miles can in many instances be some hundreds of miles and so, instead of being able to assume a constant environment between target and sensor we now have to try and take account of the constantly varying ocean. With the prime area of interest shifting to lower frequencies more complex solutions to the propagation problem were required.

3.3 The Present Situation.
So where are we now? The answer, regrettably, is a long way from the ideal but with optimism for the future. At sea in the UK we work to the policy of maximum usage of on-board expertise for analysis, forecasting and tactical advice with a minimum reliance on communication from land based centres. To assist our on-board forecasters a system called SEPADS (Sonar Environmental Prediction and Display System) was developed and is the subject of the lecture to follow. SEPADS was based acoustically around the FACT model initially but semi-empirical models have been added for shallow water and high frequencies.

3.4 Future Requirements.
So what would we like for the future? In simple terms a suite of range dependent acoustic propagation loss models covering shallow water, deep water, MIZ and under ice environments capable of running in operationally acceptable timescales using the on-board environmental computer support to an operationally acceptable degree of detail.

3.5 To expand on this, by a suite we mean a small number of models, covering the Frequency domains and environments required, which could produce a complete scenario calculation using MICROVAX technology in 1 hour. It is of prime importance that all the models are operationally easy to use (not needing expert tuning or selection of inputs). Earlier I said we were optimistic. This is because we have identified nearly all the models we wish to have in our suite:

3.5.1 Shallow Water. [1] SUPERSNAP (Normal mode low frequency)
[2] MOCASSIN (Ray Theory high frequency)

3.5.2 Deep Water. [1] SUPERSNAP (Normal mode low frequency)
[2] HODGSON (Ray Theory high frequency)

3.5.3 MIZ and Under Ice. ?

3.6 Although no model has been identified for the MIZ and Under-Ice environments specifically as yet, we are greatly encouraged by work being undertaken by Barry Uscinski at the Department of Applied Mathematics and Physics at Cambridge University and we hope to have a model ready for use at sea within the next 2 - 3 years. Our major concern now is to determine if we have the comprehensive gridded databases that these range dependent models require to use as inputs. Without them or good real time data sets, the more sophisticated models may not yield a significantly better result in a range dependent environment than those that they are replacing. In the long term we hope to be able to model the ocean thermal structure and predict more effectively the thermal make up of the ocean before running our acoustic models. This aspect of coupling acoustic modelling to ocean models is of course the subject of the final presentation by Tony Heathershaw from ARE.

3.7 One final area of growing importance to us for the future is to either incorporate a new, or extend an existing model to deal with the problem of pulse distortion which affects those sounds which are transmitted as discrete packages in the time domain such as active transmissions. This ability will be required to support low frequency active sonar (LFAS) if and when we should ever deploy such a sonar.

3.8 It should of course be remembered that in such a volatile subject area new models are continually being developed and we would not expect our intended suite of models to have a life of more than 5 to 6 years before new and we hope better models replace them.

3.9 Configuration.
Before summarising, a quick word about configuration. A few years ago it became apparent that using "the same model" with "the same input files" unfortunately did not yield the same output files. Over the last 12 months we have had a contract running with DOWTY MARITIME to produce configured versions of our more commonly used propagation loss models. FACT9H, PAREQ and recently SUPERSNAP have been configured with HODGSON and MOCASSIN to follow in the next 12 months. This will ensure that all those people involved in using Proploss Models on behalf of the Navy will be using the same model. If you are engaged on work outside the defence field and using Proploss Models which have not been configured, I would commend you attaching as an Annex to your paper example input and output files with as much detail on the version of the particular model you have been using. This will allow the recipient to make constructive comments on the conclusions and recommendations which may pertain to the particular choice and version of model used.

4. SUMMARY

4.1 As Soviet submarines become quieter and faster, and operate deeper than ever before, the significant advantage held by UK ASW forces for so many years is decreasing. One way to ensure the advantage remains with the UK lies in the intelligent use of the environment; the side exploiting the environment to the best advantage may gain the decisive edge in a tactical engagement. This paper has therefore emphasised the importance of understanding the environment and its effect on the propagation of sound in trying to optimise the Navy's deployment of ASW units at sea.

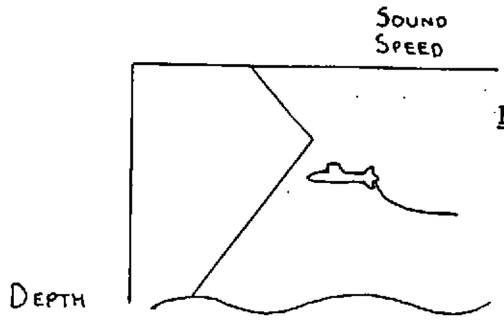


FIGURE 1.a

Submarine's self-radiated noise is refracted down into the ocean floor.

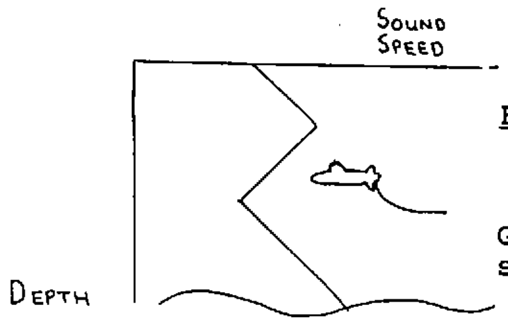


FIGURE 1.b

Good depth for detection, but submarine's self-radiated noise also propagates well.

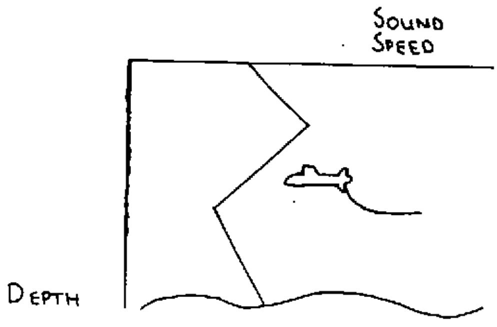


FIGURE 1.c

Good depth for detection and submarine's self-radiated noise is refracted down into the ocean floor.

FIGURE 2

P (d) vs Signal Excess for a fluctuating signal

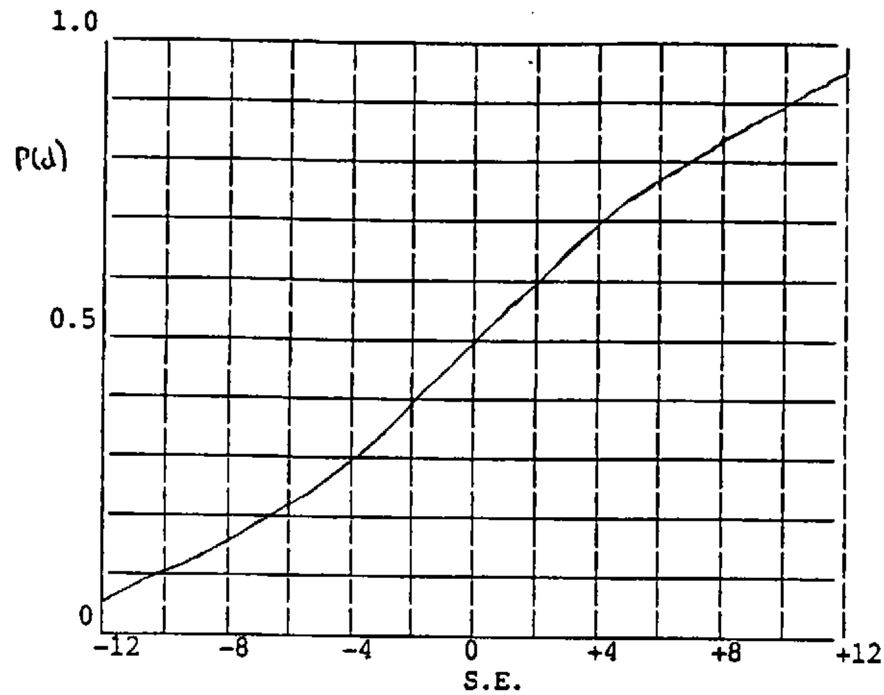
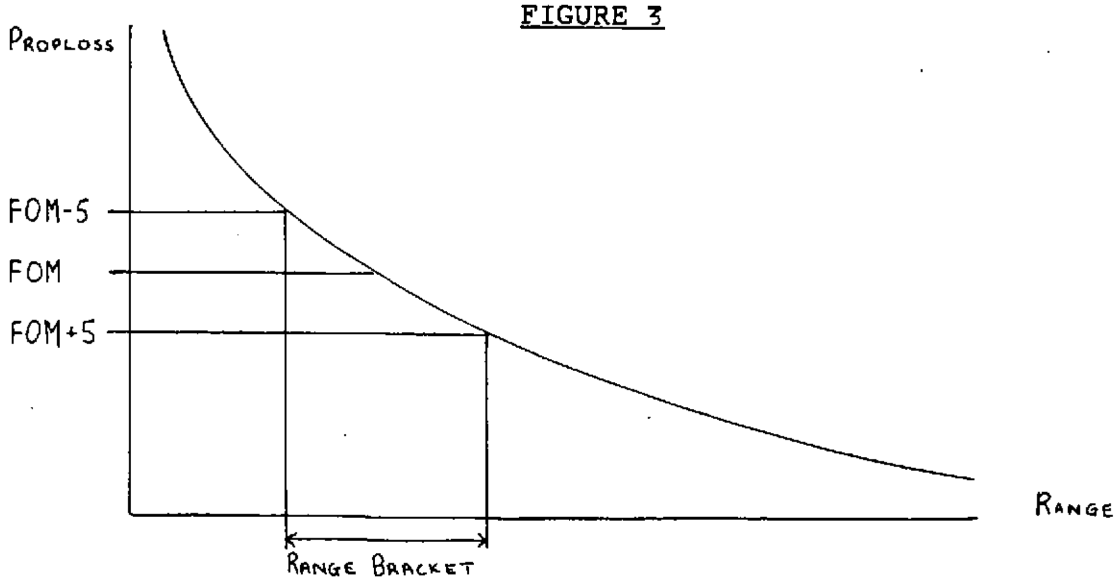


FIGURE 3



50% RANGE BRACKET DERIVED FROM A PROPLOSS CURVE