*Proceedings of the Fifth European Conference on Underwater Acoustics, ECUA 2000*
*Edited by P. Chevret and M.E. Zakharia*
*Lyon, France, 10-13 July 2000*

# LONG-RANGE PROPAGATION PREDICTION IN SHALLOW WATER

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*The crux of the project is to explore the extent to which acoustic returns from the sea bed received at short propagation ranges may be used to build geoacoustic models suitable for longer range acoustic propagation. Progress to date has focussed primarily on information retrieval from reflection data achieved at short range where the sea bed properties are not well known. Exploratory data was obtained during an air-gun experiment conducted in water of approximately 500m depth off the Perth metropolitan coast during April 1999 and to a lesser extent an experiment using implosive sources conducted in 110m of water off the Perth metropolitan coast during December 1999. Imploding acoustic sources offer potential advantages over air-gun devices for shallow reflection purposes in terms of reduced pulse duration. Results of both experiments are presented here with an analysis of the suitability of implosive sources for shallow water reflection studies.*

## 1. INTRODUCTION

The objective of the project is to try to determine to what extent "long-range" propagation may be modelled from comparatively short-range propagation measurements. This has involved modelling source/receiver geometry with respect to horizontal separation, which forms the basis for what has been termed the "aspect ratio", *n*, of an experiment [1]. Thus this project concerns both reflection and refraction information retrieval.

Low aspect ratio experiments are those where horizontal source/receiver separation is small in comparison to the water depth – high aspect ratios are the converse. Fig. 1 illustrates the theoretical aspect ratio, which must be exceeded for head waves to arrive before bottom reflections, plotted against the ratio of sea bed and water column compressional velocities ($c_p$ and $c$ respectively). Provided a suitable high velocity layer exists, a measurable refraction

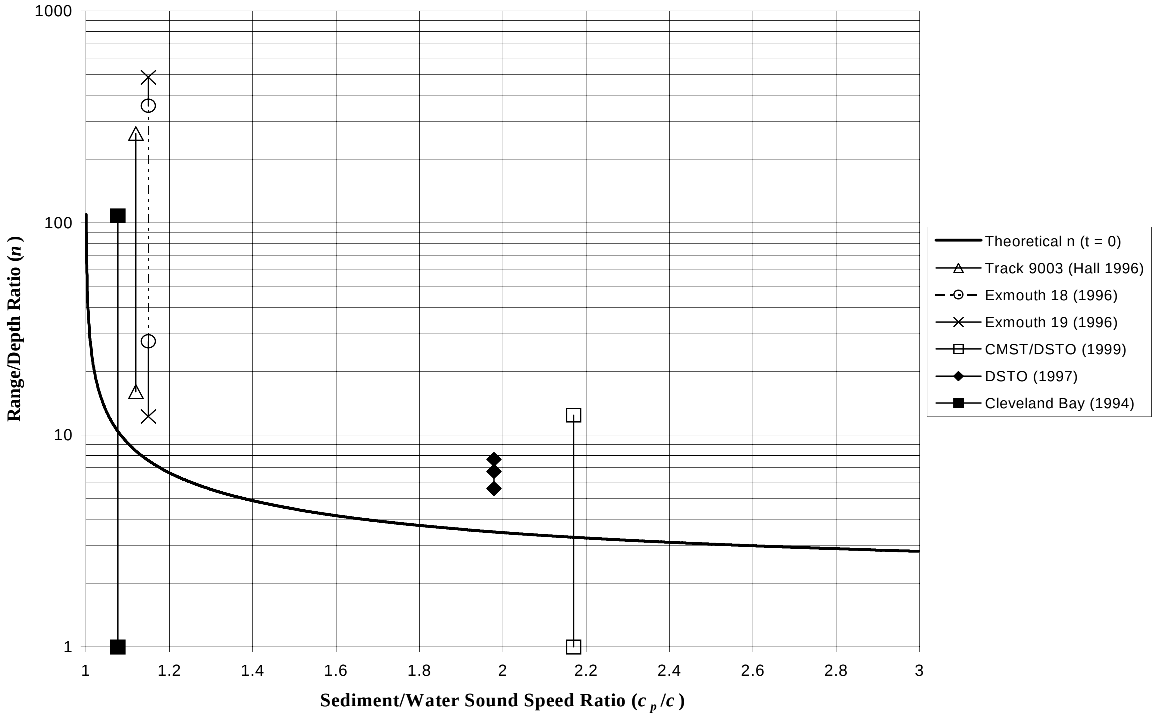


*Fig.1: Minimum aspect ratio for refraction. Aspect ratios above the curve allow in principle the time-separation of head wave arrivals from the direct arrival.*

signal requires that the experiment provide conditions corresponding to the area above the line shown on Fig. 1. A point below the line means that the refracted signal will not be time-separable from the direct signal. Ideally an experiment would incorporate an experimental geometry capable of obtaining low and high aspect ratio measurements. Fig. 1 also includes information drawn from a number of experimental work programs [2]—[5]. Due to the particular combination of operating range and water depths a range of aspect ratios (*n*) and associated grazing angles ($\theta_i$) are involved for each of the data sets. In each case $c_p/c$ values are derived from best estimates of sea bed and water column compressional velocities. Aspect ratios which fall both above and below the line furnish the possibility of observing refraction at larger aspect ratios (low grazing angle) and sub-bottom reflectivity (higher grazing angle) respectively. The relationship to be expected between these two regimes has been addressed [6], where field data gained at $\theta_i < 20°$ and $28° < \theta_i < 50°$ were compared and it was noted that there were significant difficulties in extrapolating between the two regimes.

## 2. DECONVOLUTION

Data sets presently being processed pertain primarily to the retrieval of reflection information. One such data set concerns an air-gun experiment conducted in approximately 500m of water off the Perth metropolitan coast during April 1999 [2]. Data was obtained at ranges between 100m and approximately 6km. The air-gun was situated 4m below the sea surface and two hydrophones, fixed at 22m and 46m below the sea surface respectively, were allowed to drift.

Due to the source/receiver geometry and the duration of the air-gun's pulse (approximately 0.5s at 4m source depth), certain propagation path arrivals were convolved. Figure 2 illustrates an example of the time series recorded at the deep hydrophone (depth = 46m) for one shot. Fig. 2(a) is a zoom of the results of deconvolution of the direct signal from the surface reflected arrival and Fig. 2(b) is a zoom of the bottom reflection deconvolved from the surface-bottom reflected arrival.

### 2.1. Earth Impulse Response

In theory it is possible to obtain the Earth's impulse response from the received signal to help infer the sea bed properties. This is best achieved from near normal incidence measurements where the source pulse is relatively short in duration. Mathematically, the received signal is a convolution of the source signal and the Earth's impulse response:

$$s(t) = w(t) \otimes e(t) + n(t) \quad (1)$$

where "⊗" denotes the convolution operation, $s(t)$ is the recorded time series, $w(t)$ is the original source signal (direct path signal), $e(t)$ is the Earth's impulse response, and $n(t)$ is additive noise. The source signal $w(t)$ may be either the deconvolved direct signal as shown in Fig. 2(a) or the near-field air-gun signature, which was recorded at 0.874m from the air-gun. The near-field signature however would be a better descriptor of the source output since

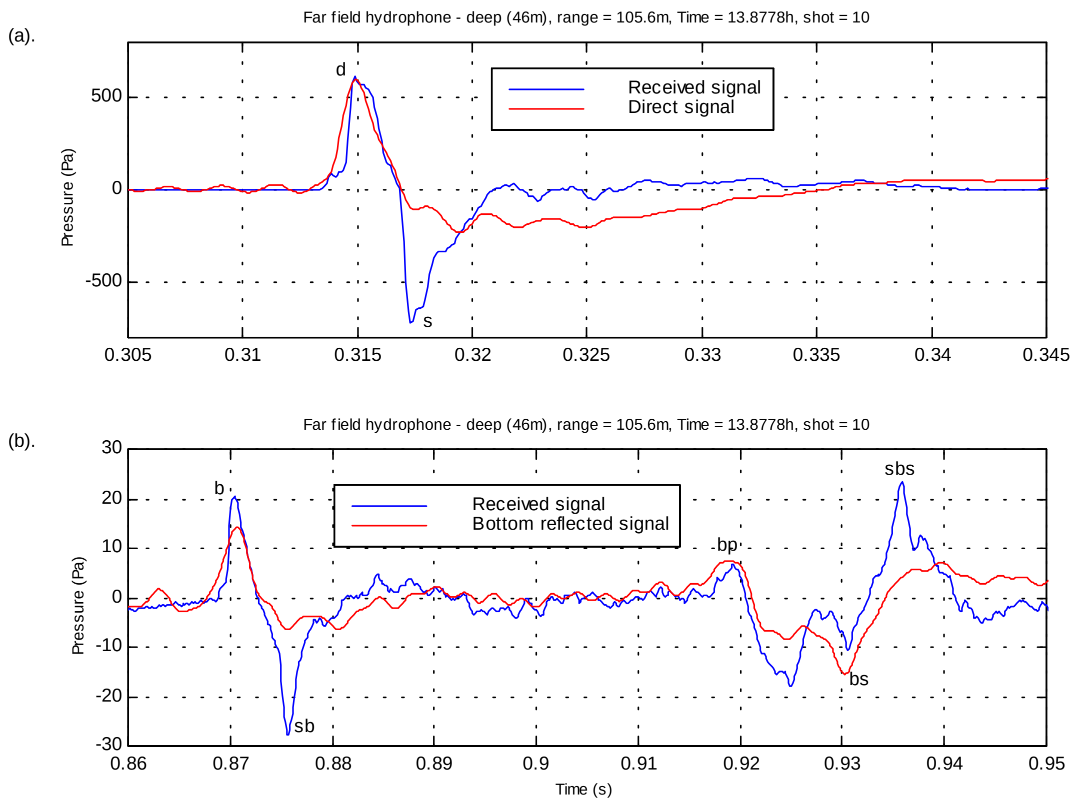


*Fig.2: Deconvolved signals (a). direct, and (b). bottom reflection compared with the original received signals. "d" is the direct arrival, "s" is the surface reflection, "b" is the bottom reflection , "sb" is the surface-bottom reflection, "bp" is the bubble pulse reflected from the sea bed, "bs" is the bottom-surface reflection, and "sbs" is the surface-bottom-surface reflection.*

there are not as many factors influencing this signal. This aspect is still under review, but it appears that the long air-gun signal may not be optimum for resolving sub-surface signals at depths of interest.

## 3. SOURCE-TYPE COMPARISON

A significant factor concerning the ability to receive time-separated arrivals is the nature of the signal produced by the acoustic source. Ideally the acoustic source pulse would be of short duration, thus reducing the likelihood of having to resort to deconvolution. A recent investigation [7] has discussed the acoustic characteristics of two source types, the C.M.S.T. air-gun and imploding spheres, with the view of establishing the usefulness of each in resolving sub-bottom reflections. The implosive sources, consisting of light globes and purpose-built evacuated spheres, have been tested in two recent implosion experiments [7]. The light globes were standard 60W and 75W household incandescent units. Their internal gas pressure was found to vary widely, where the average was 55% of atmospheric pressure. Heard *et. al*. [8] determined internal pressures for similarly sized light globes in the vicinity of 70% and 80% of atmospheric pressure. The evacuated spheres were built at Curtin University. Their internal pressures were almost negligible.

Fig. 3 illustrates the received pressures and energy spectral densities, referred to a distance of 1m, for the C.M.S.T. air-gun, a light globe, and an evacuated sphere.

### 3.1. Air-gun

The direct arrival, deconvolved from a sample time series for the C.M.S.T. air-gun recorded at 4m depth and at 0.874m range, is illustrated in Fig. 3(a). To the right is the corresponding energy spectral density. From Fig. 3(a) it is clearly seen that the pulse duration is approximately 0.5s. This pulse includes the bubble pulse, which can be seen in the energy spectral density as a peak occurring at approximately 22 Hz. The air-gun is relatively broad-band, where significant roll-off begins at approximately 400 Hz.

### 3.2. Implosive Sources

The direct arrivals and corresponding energy spectral densities for both the light globe and evacuated sphere are presented in Fig. 3(b) and (c) respectively. The pulse duration of both the light globe and evacuated sphere may be observed to be much shorter than that of the air-gun, 26ms and 1.5ms respectively. A bubble pulse presence is still observed for the light globe however, which is due to an internal pressure approximately 55% of atmospheric pressure, as mentioned previously. The bubble pulse presence in the evacuated sphere time series is almost negligible, due to a very small internal gas pressure. The resonant frequency of the light globe was calculated to be 418 Hz using an expression developed by Minnaert [9], which is comparable to approximately 450 Hz observed from Fig. 3(b). Beyond 450 Hz there is considerable energy roll-off. However, the energy spectrum of the evacuated sphere is in contrast to that of the light globe and the air-gun. Significant energy decay does not occur until approximately 4 kHz, which is a concern with respect to sub-bottom reflection measurement. The resonant frequency of the evacuated sphere was calculated to be 1376 Hz using Minnaert's resonant frequency equation, which is not easily observed from Fig. 3(c).

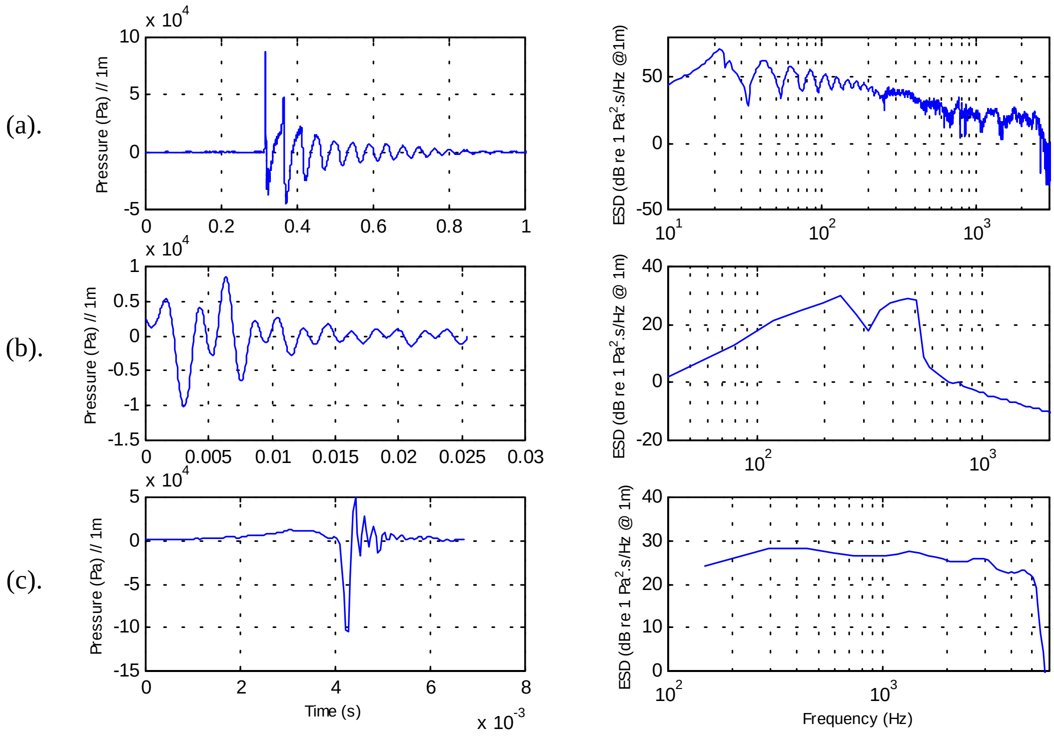


*Fig.3: Received pressures and corresponding energy spectral densities referred to 1m for three acoustic sources (direct arrival only). (a). deconvolved direct arrival from air-gun at 4m depth, (b). deconvolved direct arrival from new light globe at 40m depth, and (c). evacuated sphere at 40m depth.*

## 4. MODELLING TIME SERIES

At present a simplistic approach based on plane-wave reflection and transmission at interfaces is being developed to produce a synthetic time series of propagation path arrivals for low aspect ratios i.e. reflection conditions. The model incorporates compressional attenuation, but does not include shear velocity or shear attenuation at this stage. The aim is to establish, albeit roughly, the magnitude of sub-bottom reflections that may be received for a particular source/receiver geometry in the region chosen for the next experiment. A spherical wave approximation will be incorporated in the near future. To complement this work propagation modelling using OASES is being undertaken to determine the sensitivity of transmission loss in this environment for varying layer properties and thicknesses.

## 5. DISCUSSION

The advantages of using implosive sound sources, in comparison to an air-gun, are that the primary pulse and bubble pulse duration are relatively short. Therefore implosive sources have the added advantages of being “broad-band” and increase the possibility of reception of sub-bottom reflections with increased time resolution, thus potentially eliminating the need to deconvolve certain propagation path arrivals. The major disadvantage of the implosive sources used here is that the received peak pressure is comparatively low and there is concern that these sources do not output sufficient energy for sub-bottom reflections to be distinguished from noise in the water column. One other disadvantage, which is dependent upon the internal gas pressure, is that the pulse duration is so short that the output energy is spread across a very large region of the frequency spectrum (up to 6kHz) before sufficient energy drop-off occurs. This is observed with respect to the evacuated sphere implosion in Fig. 3(c). With a significant amount of this energy situated at 1kHz and above, reception of sub-bottom reflections would be difficult where the upper sediment layers of the sea bed offer significant absorption. However it may be worthwhile investigating the possibility of tailoring the internal gas pressure of the evacuated spheres in order to produce a pulse which is short enough for time separation of arrivals, but not too short in that the majority of the output energy may be contained below 1kHz. This would unfortunately be at the cost of reduced peak pressure and an increased bubble pulse presence.

From Fig. 3 it may be seen that there is not a *significant* difference in ESD below 500 Hz between the light globe and the evacuated sphere. It has already been discussed that the high-frequency energy content of the evacuated spheres may be a limiting factor for reception of sub-bottom reflections. With these factors in mind and considering the cost of the evacuated spheres in comparison to the light globes (~AUD$20 per sphere), it would appear that the light globes may be the more appropriate implosive source to use. However, from a recent analysis [7] the light globes have been found to have somewhat greater output variability than the evacuated spheres. This factor, along with the capability to model any frequency *and* having a known internal gas type make the evacuated spheres an attractive option in comparison to the light globes.

## 6. ACKNOWLEDGEMENTS

The authors wish to thank Robert McCauley and Kim Klaka for their assistance in carrying out the recent implosion experiments.

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