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PREDICTED DETECTION OF AN EMERGENCY UNDERWATER LOCATOR BEACON

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Substantial media interest has been shown in the difficulty experienced in the detection of emergency underwater locator beacons from aircraft lost at sea in remote ocean regions. An original system detection testing report indicates that the beacon was specified and designed to be detected at short range in shallow water. Locator beacon system parameter values are available in published documentation. Prediction of sonar detection ranges in remote ocean locations is relatively straightforward. Three locations have been selected in three different oceans – North Atlantic Ocean, South Atlantic Ocean and Indian Ocean. The results of the calculations indicate that the detection ranges are short such that detection is predictably difficult in remote locations. Keywords: Underwater, Acoustics, Sonar, Detection

1. Introduction

Substantial media interest has been shown in the difficulty experienced in the detection of emergency underwater locator beacons from aircraft lost at sea in remote ocean regions [1, 2] compared to the successful search for a previous aircraft [3]. An original system detection testing report indicates that the beacon was specified and designed to be detected at short range in shallow water [4]. Nevertheless analysis conducted during one search indicated an expectation of detection in deep water and ascribed lack of detection to failure of the beacon [5]. Problems associated with detecting beacons that meet the existing standard have led to proposals for an amended standard [6]. The aim of this paper is to conduct a systematic assessment of the detectability of underwater locator beacons in remote ocean locations by conducting sonar range prediction using published methods [7, 8].

2. System description

The requirements for an emergency Underwater Locator Beacon (ULB) are specified by the International Civil Aviation Organisation [9]. System descriptions of underwater locator beacons can be found on several manufacturers' websites, for example [10, 11, 12]. The receiver employed will depend on the assets available, varying from general purpose systems designed to detect a variety of signals over a wide band of frequencies, to bespoke systems designed to detect a specific signal.

2.1 Source

The ULB sound source is monotone pulse at a frequency of 37.5 kHz, pulse-length of 9ms, a pulse repetition interval of 0.9s and a source level of 160.5dB re 1 µPa at 1m [10, 11, 12].

2.2 Receiver

The typical baseline receiver, assumed in the following calculations, is an omnidirectional hydrophone with no directivity gain and a conventional broadband energy detector with a 10 kHz analysis bandwidth. Detection is also evaluated for the case of an ideal bespoke narrowband detector.

The detection threshold for the case of an energy detector and a signal with unknown frequency and unknown length is [7]:

$$DT = 5log_{10}\left(\frac{dw}{t}\right) + \left|5log_{10}\left(\frac{T}{t}\right)\right| \quad (1)$$

Where:

d is the detection index for a specified probability of detection (PD) and false alarm (PFA)
w is the processing bandwidth (Hz)
t is the pulse length (sec)
T is the processing integration time (sec)

Some DT calculations of relevance to the energy detection of the ULB signal are shown in Table 1:

Table 1: Detection threshold for energy detection of an unknown signal

t	PD	PFA	D	w	T	DT
0.009	50%	0.01%	13	111	1	36.2
0.009	50%	0.01%	13	1000	1	41.0
0.009	**50%**	**0.01%**	**13**	**10000**	**1**	**46.0**
0.009	50%	0.01%	13	30000	1	48.4

The default option for the energy detection DT used in further calculations is 46dB.

Given that the ULB signal is known, it is theoretically possible to design a bespoke detector with the correct frequency and pulse length. In this case the detection threshold is given by a set of equations from [8]:

$$DT = 10log_{10}(R_{50}) \quad (2)$$

$$R_{50} = log_2\left(\frac{1}{2p_{fa}}\right) \quad (3)$$

$$p_{fa} = \left(\frac{n_{fa}}{\Delta f . N_{beams}}\right) \quad (4)$$

Where:

R_{50}	is the signal-to-noise ratio threshold for a 50% probability of detection
n_{fa}	is the number of false alarms per second
N_{beams}	is the number of beams
Δf	is the pulse bandwidth (Hz)
p_{fa}	is the probability of false alarm

DT calculations of relevance to the bespoke detection of the ULB signal are shown in Table 2. The false alarm rate is set at 1 per hour following the worked example in [8].

Table 2: Detection threshold for bespoke detection of a known signal

n_{fa}	Δf	N_{beams}	p_{fa}	R_{50}	DT
2.50E-06	**111**	**1**	**2.25E-08**	**24.4**	**13.9**
2.50E-06	111	10	2.25E-09	27.7	14.4
2.50E-06	111	100	2.25E-10	31.0	14.9
1.11E-02	111	1	0.0001	12.3	10.9

For the base case of an omnidirectional sensor, with one false alarm per hour [8], the DT of a bespoke detector is 13.9dB. The equations in [8] indicate that the number of false alarms per hour would be very high in the 0.01% p_{fa} case consistent with the approach from [7].

The difference in gain between the general broadband energy detector [7] and a bespoke detector [8] is 32.1dB; which could make a substantial difference to the detection range.

2.3 Sonar equation

The sonar equation for the detection of the ULB can be expressed as [8]:

$$SE = SL - PL - NL + AG - DT \tag{5}$$

Where:

SE	is the signal excess
SL	is the source level
PL	is the propagation loss
NL	is the noise level
AG	is the receiver array gain
DT	is the receiver detection threshold

Setting signal excess to zero, we can define the figure of merit (FoM) by:

$$FoM = SL - NL + AG - DT \tag{6}$$

Setting the noise level to ambient noise at Sea State 3 results in a value of 35dB re 1µPa/√Hz [7]; leading to the following cases:

Table 3: Figures of merit for energy and bespoke detectors

	SL	*NL*	*AG*	*DT*	*FoM*
Energy detector	160	35	0	46	79
Bespoke detector	160	35	0	13.9	111.1

3. Oceanography and Propagation

Three locations have been chosen in oceanic locations near to sites where aircraft have been lost or suspected to have been lost and profiles from the Argo database [13] are available:

- North Atlantic 50.3ºN 12.6ºW 2000m
- Equatorial Atlantic 3ºN 30.5ºW 4000m
- Indian Ocean 31.8ºS 108.4ºE 5500m

The profiles from Argo database extend to a depth of 2000 metres. The profiles have been extrapolated to the full depth of the ocean in the Equatorial Atlantic and Indian Ocean cases by considering the deep ocean isothermal and isohaline. The sound speed profiles for the three cases are shown in Figure 1:

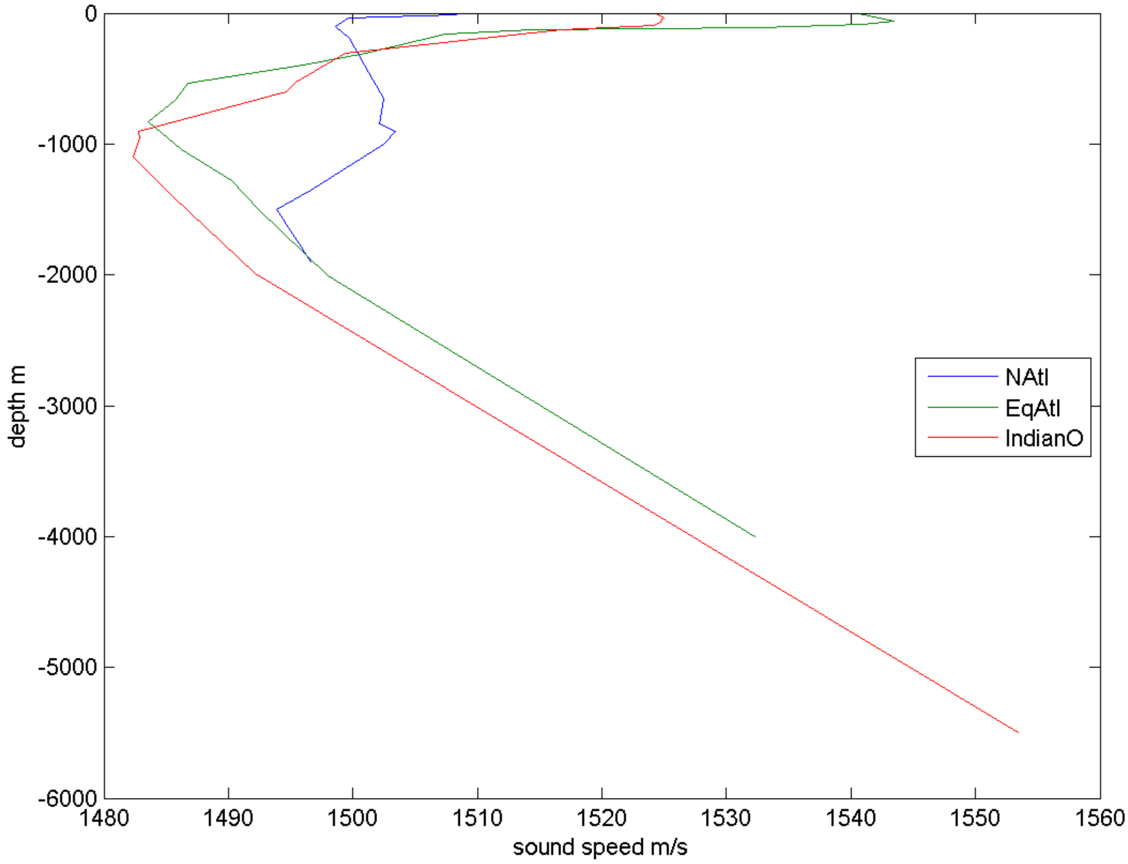

Figure 1: Sound speed profiles from Argo data in North Atlantic, Equatorial Atlantic and Indian Oceans

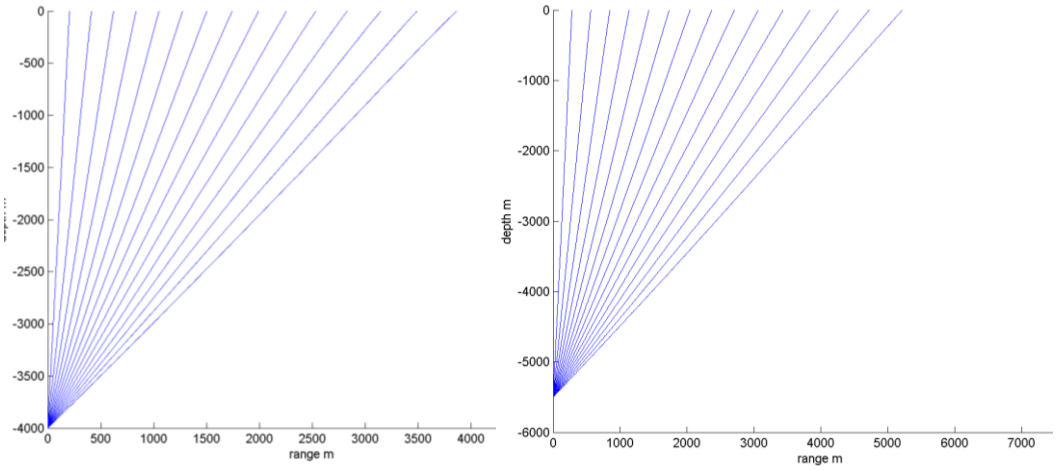

Figure 2: Ray plot for seabed source in Equatorial Atlantic environment (left) and Indian Ocean environment (right) – Ray angles from 45° to 87°

Inspection of Figure 2 shows that for angles greater than 45° the rays are nearly straight lines; such that spherical spreading is a reasonable approximation. Absorption at the ULB frequency of 37.5 kHz is substantial at these ranges. The absorption has been calculated using the Ainslie-McColm formula [8]. A key feature of the absorption formula is the decrease in absorption with depth, such that it would be misleading to adopt a single value from the seabed to the sea surface, as shown in Figure 3:

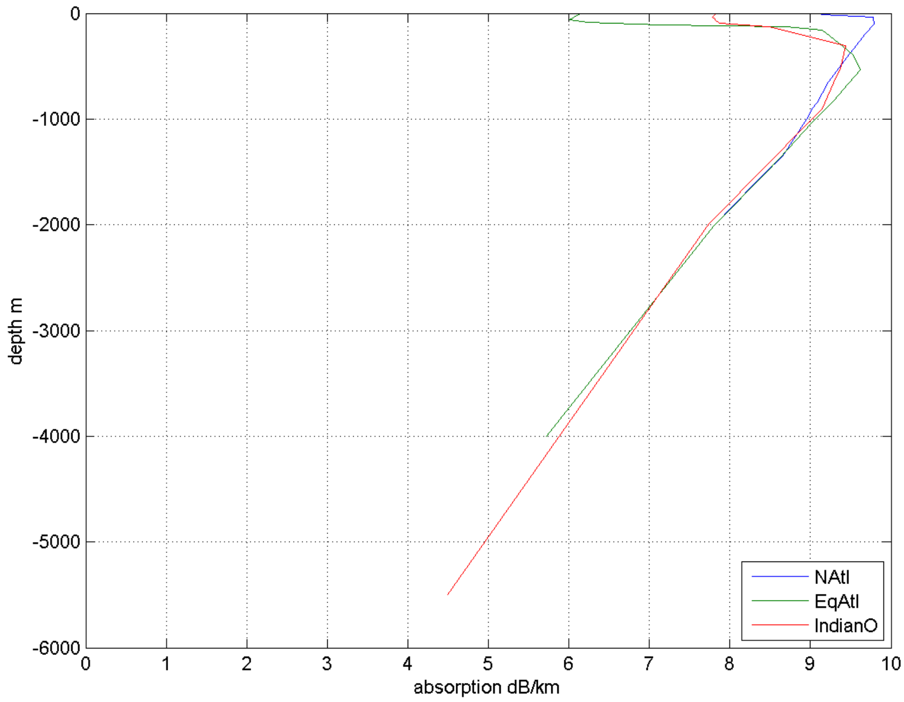

Figure 3: Absorption versus depth and environment

The modelling priority was to ensure correct treatment of absorption as a function of depth, so a simple algorithm for calculating propagation loss was created in preference to using a standard modelling tool. The iterative ray tracing approach is described in Eq. 7.

$$PL(\theta) = 20log_{10}\left(\sum_{z} \delta s(\theta)\right) + \sum_{z} [\delta s(\theta). a(z)] \tag{7}$$

Where:

θ	is the ray launch angle relative to horizontal
z	is the depth (m)
δs	is the ray path step (m)
$a(z)$	is the absorption as a function of depth (dB/m)

The resultant loss at the surface is shown in Figure **4** for the three environments.

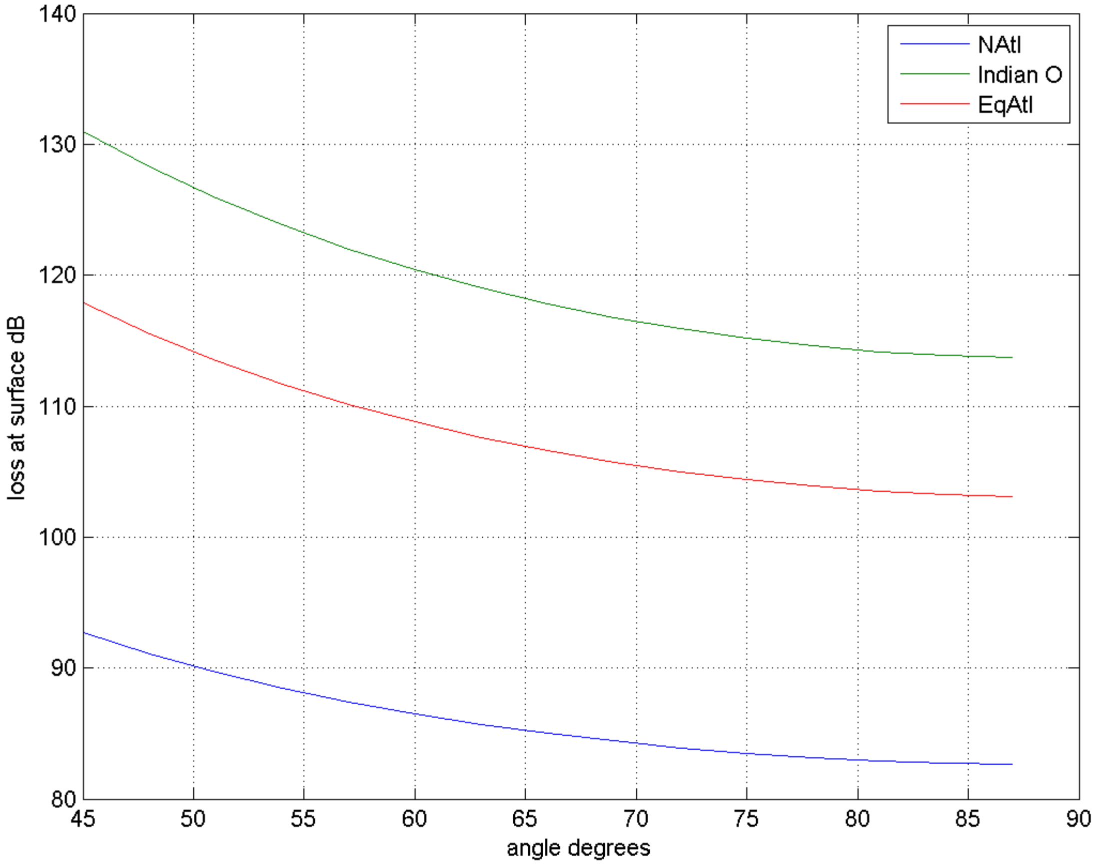

Figure 4: Propagation loss for a receiver at the sea surface versus ray launch angle

Comparison between the propagation loss at the surface shown in Figure **4** and the values of Figure of Merit in Table 3 indicates that an omnidirectional energy detector, with a 10kHz analysis bandwidth and a FoM of 79dB, at the surface would have nearly no chance of detecting the ULB in the deeper cases (Equatorial Atlantic and Indian Oceans) and a poor chance of detection in the shallower North Atlantic case. Note that the accident report [3] describes the use of a "SCARAB" vehicle with a sensor at depth for the North Atlantic case, when the location of the crash appears to have been known from other sources of information. An energy detector with some receive directivity or a narrower analysis bandwidth would have a realistic chance of detection in the North Atlantic case but little chance of detection in the other cases. An omnidirectional ideal bespoke detector, with a FoM of 111dB, would have a high probability of detection in the North Atlantic case, a reasonable probability of detection in the Equatorial Atlantic case and a low probability of detection in the Indian Ocean. An ideal bespoke detector with some receiver directivity could have some detection opportunities in all cases, but the search range is likely to be small in the remote Indian Ocean environment due to the high absorption loss at the ULB signal frequency.

4. Conclusions

Conventional energy detection using an omnidirectional broadband receiver has a poor chance of detecting an ULB signal apart from shallow water cases. Bespoke detectors would help in some deep open locations however the deeper and more remote locations will prove an ongoing challenge for the current ULB. Absorption loss at the ULB frequency is a substantial reason for the poor detectability such that the planned reduction of the ULB to lower frequency should improve the probability of detection.

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