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MATLAB MODELLING OF SHALLOW WATER SOUND FIELDS TO EXPLAIN THE AVERSIVE BEHAVIOUR OF A HARBOUR PORPOISE.

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1. INTRODUCTION

Large numbers of small cetaceans are caught each year as incidental catch in gill-net fisheries around the world, Donovan[1]. The 1994, EC ASCOBANS agreement stresses the importance of reducing marine mammal bycatch, in particular of the harbour porpoise (*Phocoena phocoena)*. With the uncertainty of the severity of the problem in other fisheries it has become necessary to research into the scale of the problem in the different fishery types. Two 3-year EC (AIR DG XIV) projects have been initiated to analyse the scale of the problem in the pelagic trawls and to advise on possible methods of reducing cetacean bycatch in this fishery, one with the remit to analyse the scale of the problem in commercial fisheries (BIOECO), Morizur et al.[2], the other to analyse the reasons for cetacean bycatch and suggest methods of reducing it (CETASEL), De-Haan et al.[3].

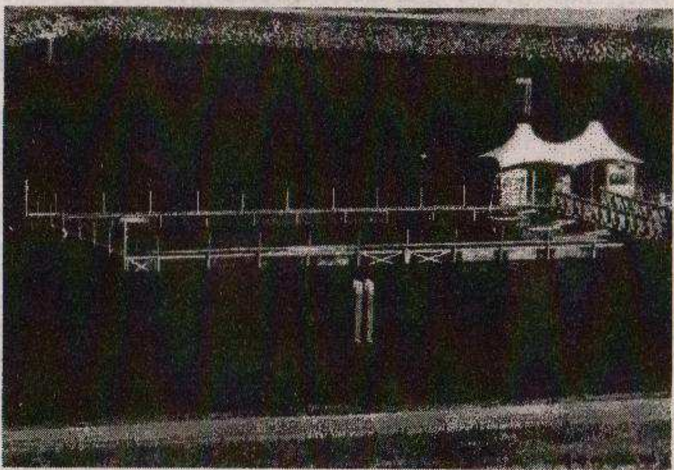
As part of CETASEL, trials have been taking place both at sea with pelagic trawls and in dolphinaria in Europe. A cetacean rehabilitation centre in Neeltje Jans, Holland, has been used to examine the behaviour of a single wild harbour porpoise to different forms of acoustic disturbance produced by electronic means, Kastelien et al.[4]. The results of such tests provide valuable information as to the animal's tolerance to sound pressure levels at various frequencies and to different signatures. This information can be used further to design effective deterrents which only produce the signals which are known to deter the relevant species, Newborough et al.[5]. The porpoise was housed in a floating net pen in minimum (tidal) of 4 metres of water providing a shallow, controlled environment in which the animal can be monitored as it re-acclimatises to the open sea. Signals introduced to the animal via four transducers produced the required aversive effect, however patterns of behaviour emerged which could not easily be explained. Mathematical modelling of the propagation of the signal in the water, showed a possible reason for the behaviour.

2. METHODOLOGY

The harbour porpoise was housed in a floating pen (34m x 19.5 m ; 3.2 m deep at the sides, and up to 4.7m deep in the centre). The water depth is 6m at high water and 4m at low water. The harbour in which the pen is located is horse-shoe shaped (500m x 280m). The mouth faces North East and is situated in Zeeland in the Netherlands on the island of Neeltje Jans. Because of high currents near the barrier ships are not normally allowed within 2 km and so there were no external disturbances during the tests. Occasionally, research vessels were allowed into the area, and tests were halted during these periods.

The animal behaviour was observed during the test by observing the positions and frequencies of surfacings (95% of which are thought to be for respiration) using an overhead video camera. Acoustic signals from the porpoise were recorded on Racal Store-4 (max 300 kHz) and Racal V-Store (max 100 kHz) recorders, using an Sonar Products HS70/100 reference 25mm ball hydrophone. Recordings were also taken from a low frequency pre-amplified Dowty SSQ904 'bender' hydrophone (band limited to 50 Hz-15kHz) which was installed for audible spectrum monitoring purposes. A Benthos AQ4 element with Loughborough University (LU) envelope detector circuit to make the high frequency click spectrum (60 kHz - 140 kHz) audible. Two Sonar Products HS150 (50 Hz to 180 kHz) hydrophones were also deployed, one with a click detector and one with a low noise wide-band pre-amplifier.

Figure 1 The floating net enclosure at Neeltje Jans used for the porpoise tests.(photo de Haan)



The trials at Neeltje Jans were made as objective as possible, whilst working around the daily procedures of the porpoise rehabilitation programme. Each test was preceded by a 15 minute acclimatising period where the gear was inactive in the water to allow the porpoise to familiarise itself. The test lasted 15 minutes to allow habituation effects to show. After which there was a 15 minute "cooling off" period allowing the porpoise to resume its normal behaviour before the next acclimatisation period.

Tests were performed to study the reaction of the porpoise to different frequencies, waveforms and intensities. These included tones (Figure 2a), clicks (Figure 2b) and wide band frequency sweeps (Figure 2c) which, at low frequencies were intended to simulate a dolphin whistle (Figure 2d).

Figure 2 Spectrograms of a) Clicks b) Tones c) Sweeps d) Dolphin whistle.

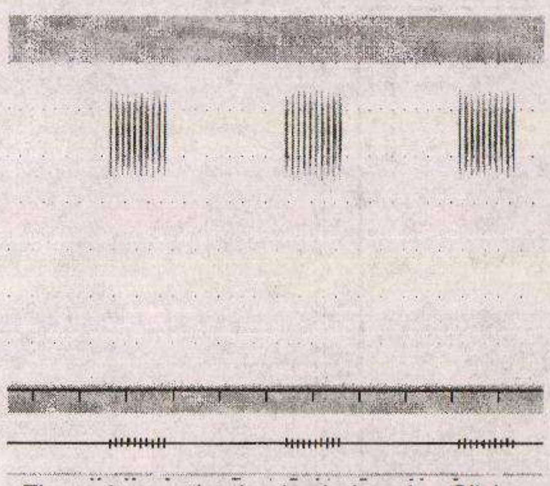


Figure 2a: synthesised echolocation Clicks

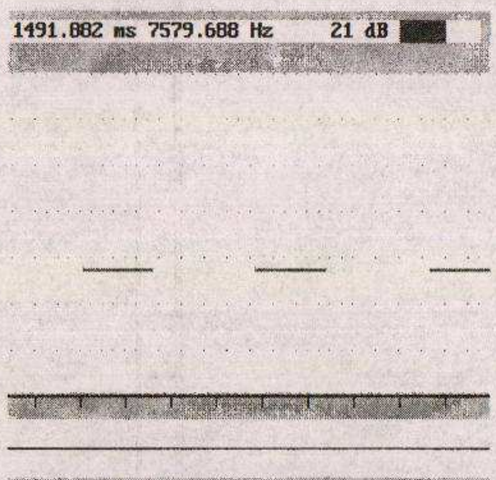


Figure 2b: Tones

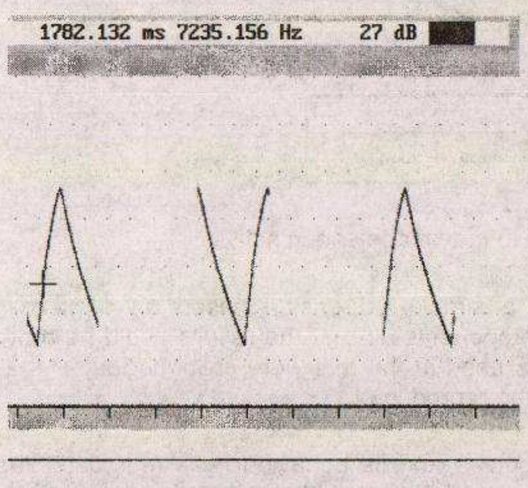


Figure 2c: Sweeps

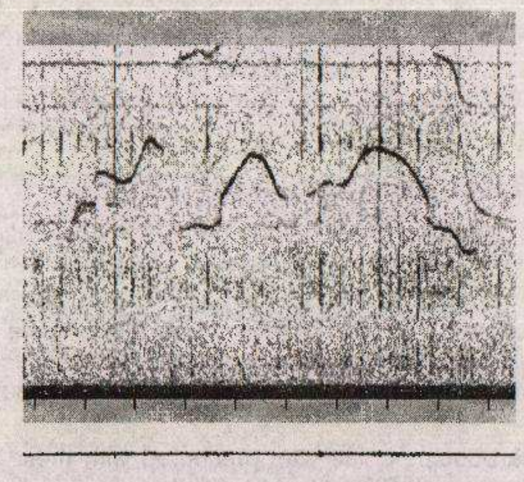


Figure 2d: Dolphin whistles

Sources 2a-c were played through an array of four transducers positioned as shown in Figure 3, and the behaviour of the animal was monitored with hydrophones and video cameras.

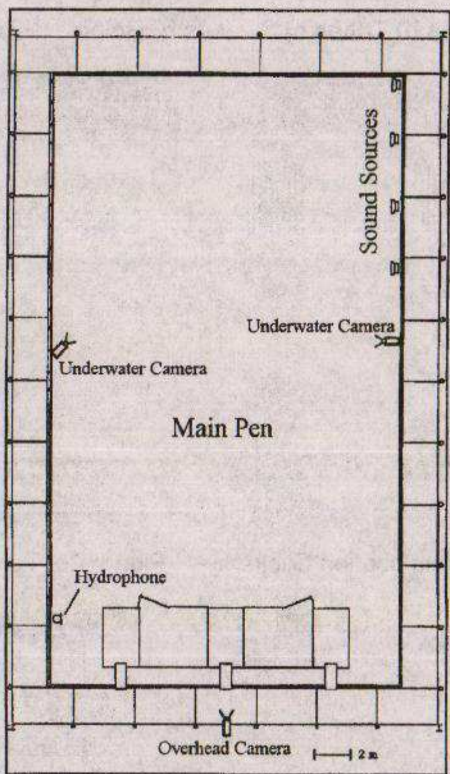


Figure 3 Figure of pool, showing the equipment used to monitor cetacean activity.

Each transmitting transducer was constructed to a simple LU design based on a piezo 'bender' hydrophone, Goodson et al.[6] using inexpensive components so that the results could be replicated in the field as an economic deterrent. The transducers used in the trial were calibrated later in a tank at Loughborough so that accurate Source Levels could be reproduced.

The harbour porpoise was presented with these sources and its behaviour was recorded. The Signal Pressure Level (SPL) was recorded at 3m spacings around the pen with the intention of charting the SPL distribution so that the sound levels the porpoise would tolerate could be quantified.

3. RESULTS

The signals presented to the porpoise had differing results, from *no effect* to a *strongly aversive*. The most effective sounds proved to be frequency sweeps or chirps, which forced the animal into the corner of the pen. Observers were initially surprised that the animal did not show a preference for the opposite corner, which is furthest away from the source, but instead stayed in the corner in line with the transducers. Figure 4 shows the surfacings and breathing rates before (Fig 4a), during (Fig 4b), and after (Fig 4c) the test.

Figure 4 Surfacings and breathing rates when chirps were presented to the animal. (Project Cetasel)

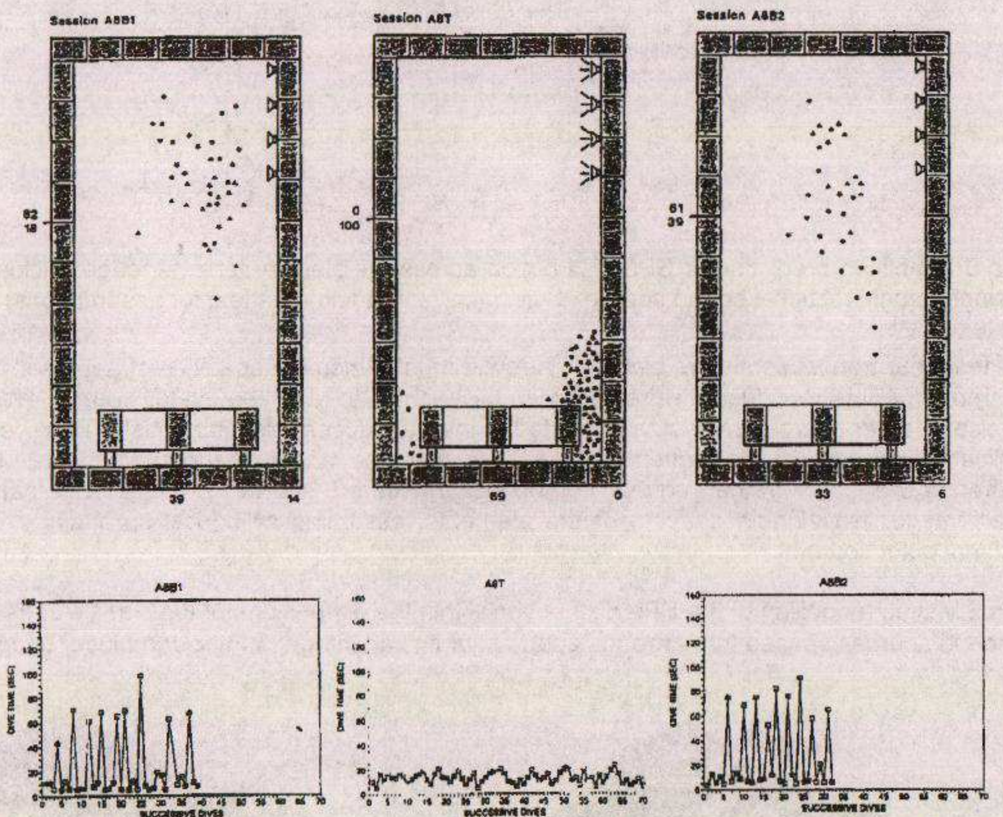


Figure 4a Before the Test Figure 4b During the Test Figure 4c After the test.

It can be clearly seen that the harbour porpoise preferred the South East corner to the South West corner, which was the furthest point from the source. The reason for this is not immediately clear but can be explained with the aid of simulation of the propagation of the sound.

4. SIMULATION

In post analysis of the data taken from different parts of the pool, the SPL was found to vary rapidly between adjacent sampling points suggesting some interference was present and that the sound field was more complex than had been appreciated. Since the frequency sweep signals had a slow rate of change, a continuous wave signal has been assumed, and signal interference due to the shallow nature of the pool makes 'cylindrical' spreading more likely. A simple model of the pool (Figure 5) shows that, by assuming cylindrical spreading from a single omni-directional source, a relatively smooth result should be obtained with a general trend showing that the point of lowest SPL should be, as expected, at the furthest point from the source.

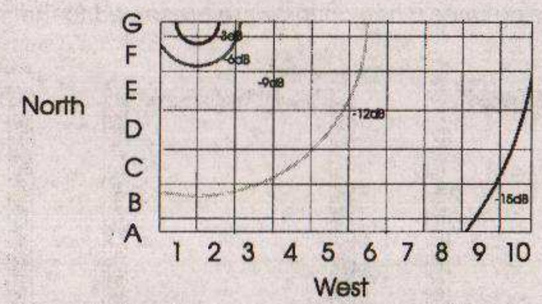
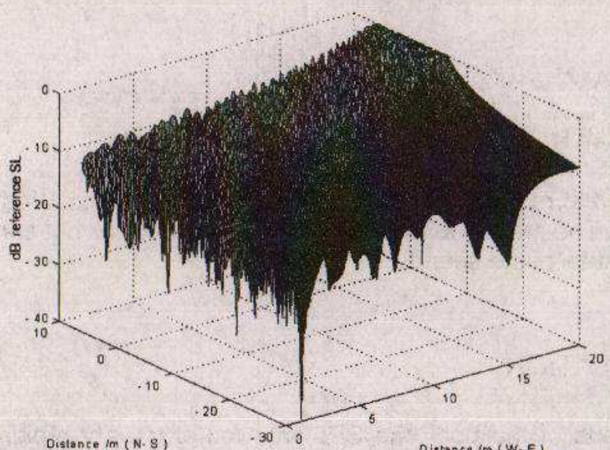


Figure 5 Simplified prediction of SPL distribution across the Neeltje Jans net cage enclosure generated by a single omnidirectional sound source. 'Cylindrical' spreading (see text for assumptions)

In the test, four transducers were placed in a row with inter-element spacings of approximately 3m and at a depth of 2m. The transducers were placed in this fashion to raise the overall source level, and to make a physically larger source. Each signal was fed to the transducers simultaneously. This presented a more complicated interference and attenuation pattern than the above diagram suggests, The pattern of interference changes with the frequency of the signal. Figure 6 shows the interference pattern generated with an integer wavelength spacing of the elements, assuming cylindrical spreading from four omni-directional point sources.

Figure 6 Matlab modelling of the SPL distribution within the dimensions of the Neeltje Jans enclosure with four sound sources spaced three metres apart assuming an integer λ inter-transducer spacing.



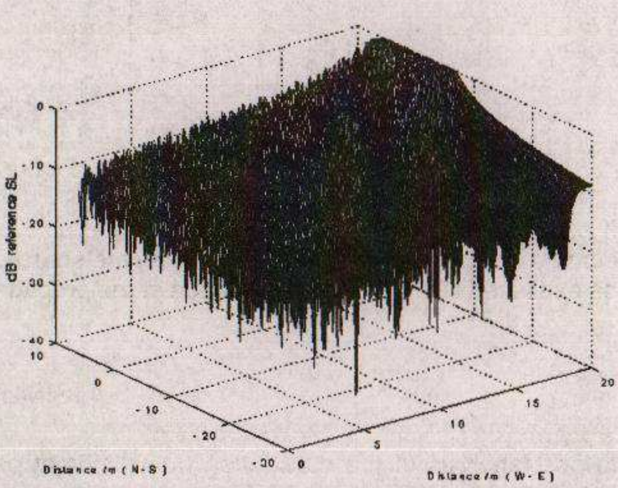
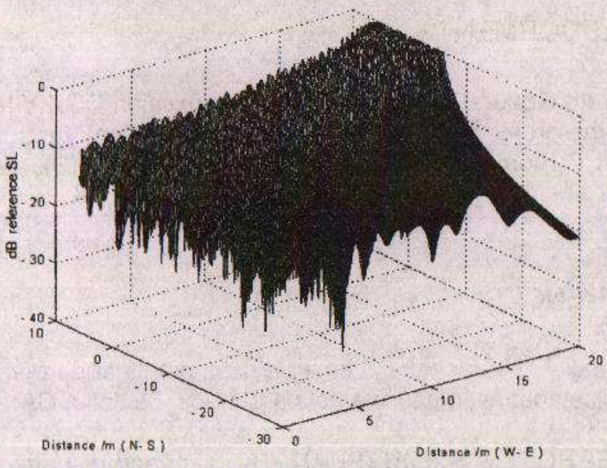


Figure 6a Integer λ transducer spacing at 8.75 kHz Figure 6b Integer λ transducer spacings at 70 kHz

The pattern generated around the transducers demonstrates a near-field pattern of a sparse array, with a strong end-fire side-lobe, and a main lobe beginning to form in front of the transducers. If the transducers were not an exact number of wavelengths apart the signals become incoherent, and the end-fire pattern changes dramatically, Figure 7 demonstrates the pattern generated with alternate anti-phase signals.

Figure 7 Matlab modelling of the SPL distribution within the dimensions of the Neeltje Jans enclosure with four sound sources spaced three metres apart assuming a non-integer λ inter-transducer spacing.



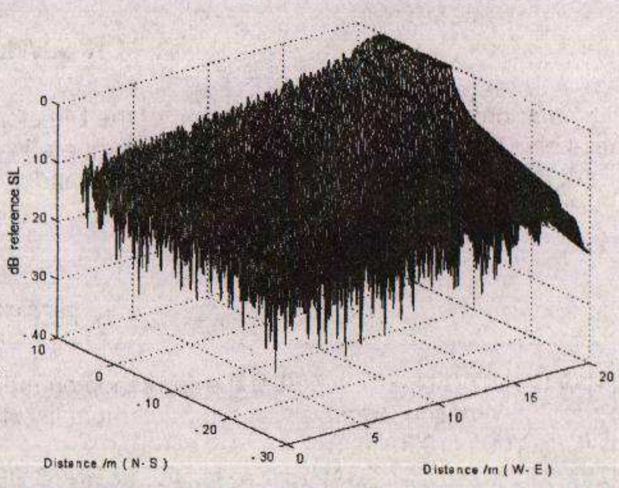


Figure 7a Non-integer ½λ transducer spacing at 8.75 kHz Figure 7b Non-integer ½λ spacing at 70 kHz

5. DISCUSSION

Since the transducers could not be placed accurately, as they were attached to the net wall, the non-integer inter-transducer spacing probably approached the condition modelled in figure 7. In this case the end-fire axis develops a null which would certainly help to explain the porpoises preference for this section of the pool. Although the actual SPL within this null will vary with the changing frequency, these conditions are relatively stable as at end fire far field conditions are already established. In other directions the complex interference phenomena of the near-field will be more sensitive to frequency changes and the SPL will vary between peaks and nulls within the body dimensions of the porpoise.
It is important to recognise some major limitations of this model. The model has assumed omni-directional sources and has ignored the transducer directivity. At low frequencies this is a fair assumption, however at the higher frequencies the transducers become more directional, reducing the intensity of the signals interaction in the end-fire direction, Tucker and Gazey[7]. This model does not take the effects of the shallow water column into consideration. In reality the signals would reflect from the surface and the bottom, producing a vertical array of virtual sources. This further complicates the patterns produced, Stothard et al.[8].

6. CONCLUSIONS

As can be seen from the complexity of the simulated SPL patterns shown in the previous section, it is not practical to make direct measurements at the perimeter of the enclosure and expect to extrapolate SPL's at other positions within the pool. It seems very unlikely that these four transducer elements can contribute constructively to form a peak in the end-fire direction, for this to happen all four signals need to arrive in phase. If the transducer directivity is also taken into account then the actual SPL at end-fire will be lower than either modelled condition. It therefore seems certain that a relatively wide null in the beam pattern will form in the direction of the South East corner of the pen. This form of modelling assists in visualising the complexity of the sound field, and as a harbour porpoise has sensitive hearing at these frequencies, Anderson[9], its movement to this position during the test period would appear to indicate the point off least disturbance.

7. ACKNOWLEDGEMENTS

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