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EXPERIMENTAL EVIDENCE OF BANDGAP STRUCTURES IN THE LOWER JAW OF THE BOTTLENOSE DOLPHIN (*TURSIOPS TRUNCATUS*).

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1 ABSTRACT

Previous studies using the TLM numerical modelling technique have demonstrated the potential existence of bandgap structures within the lower jawbone of the Atlantic Bottlenose dolphin (*Tursiops truncatus*). The study presented here shows experimental evidence of the existence of these bandgaps within a 2-D structure that mimics the principle dimensions of the lower teeth and jawbone of the Bottlenose dolphin. The bandgap present is due to the tooth structure in the lower jaw forming a periodic array of scattering elements, which results in the formation of an acoustic stop band that is angular dependent.

2 INTRODUCTION

For more than half a century sonar designers have been fascinated by the capabilities and the performance of the echolocation systems in marine mammals. This work has shown that a number of dolphins have very versatile sonar systems with excellent target discrimination in shallow water, highly reverberant, environments. An animal that has been measured extensively is the Atlantic Bottlenose dolphin, *Tursiops truncatus*. This animal's sonar system is often quoted as outperforming man made systems (Dobbins *et al.* 2004). There is an increasing body of work which suggests that the lower jaw of the Bottlenose dolphin is the main echolocation reception source (Au 1993). However there has been some debate over the role of the lower jaw in the reception process, and more specifically whether or not the teeth have an impact on echolocation capability. This paper presents the case for the teeth being involved as a passive beam forming structure. Specifically the argument is made that the individual teeth form a periodic filter.

Acoustic band gaps or stop bands are formed when periodic arrays of scattering elements are present in a geometric space. It is well known that in certain frequency bands dispersive behaviour can be observed (Brillouin 1953). It is possible to design such a structure so that for certain frequency bands, wave propagation is heavily attenuated, and hence the term 'band gap' is often applied. Band gap structures are a familiar concept to solid state physicists and, more recently, to designers of electromagnetic band gap (EBG) materials (Engheta and Ziolkowski 2006) and acoustic engineers (Robertson *et al.* 1998). This band gap property is also highly dependant on the direction of the incident sound field.

Robertson, demonstrated that if an array of rods is placed in a square or triangular lattice with a volume filling factor of greater than 0.3 then an acoustic band gap can be sustained. The filling factor, F for a square lattice can be calculated using Equation 1, where a is the separation between centres of adjacent elements and d is the diameter of the cylindrical rods. Furthermore it has been demonstrated experimentally that the centre frequency f_c of the acoustic band gap can be predicted from the periodicity of the lattice geometry by using Equation 2, where u is the speed of sound propagation in the medium surrounding the rods.

$$F = \frac{\pi d^2}{4a^2} \quad (1)$$

$$f_c = \frac{u}{2a} \quad (2)$$

Previous work (Dible *et al.* 2009) has demonstrated the existence of acoustic band gaps within the jaw geometry of the Bottlenose dolphin. These band gaps were observed within the frequency band in which dolphins are known to echolocate (Au 1993). In the current paper the simplified model used for numerical simulations has been scaled and manufactured so that it can under go acoustic testing. The experiment examines how sound propagates around the replica lower jaw of the bottlenose dolphin and the resultant sensitivity patterns. The experiments were carried out in the Loughborough University test tank that is 10 meters long 8 meters wide and 1.8 meters deep.

3 EXPERIMENTATION

The lower jawbone was simplified into a 2-D structure and *all dimensions were scaled by a factor of 1.25* to simplify the manufacturing process. To further simplify the experiment, only one half of the lower jawbone was modeled. The experimental setup can be seen in Figure 1 and 2. M5 (5mm diameter) steel rods measuring 30cm in height were used to replicate the teeth of the dolphin. 1mm thick aluminium plating was used to replicate the hard inner boundary of the jawbone. The steel rods where held in position at the top and bottom by wood, that had been drilled with a rod separation of 15mm and a channel separation of 15mm. The outside of the steel plating was covered with anechoic rubber tiles, to prevented sound from entering the centre channel through the side. The receiving hydrophone was a HS150 and was located at the rear of the structure to measure the sound transmission through the channel. Anechoic rubber tiles were placed over the opening for the hydrophone to prevent sound being measured from outside the channel. A replica broadband dolphin click was transmitted using a Hameg function generator through a power amplifier with a HS70 omni-directional ball hydrophone at a repetition rate of 200 ms, to prevent the reception of multiple signals. The source was maintained at a fixed position whilst the replica array was rotated through 180 degrees using a pan and tilt system in 1 degree steps. The receiving hydrophone was connected to a +60 dB pre-amplifier with a high-pass filter of 10kHz and a low-pass filter of 160 kHz. The signal was captured on a techtronics digital storage scope at a sample rate of 2MHz. The experiment was then repeated with the steel rods removed from the array but with the steel plates,, source and receiver still in the same positions. The transmission after propagation was then analysed and subsequently transformed using a Discrete Fourier Transform (DFT). The peak signal for each source position was subsequently plotted at several frequencies for analysis.

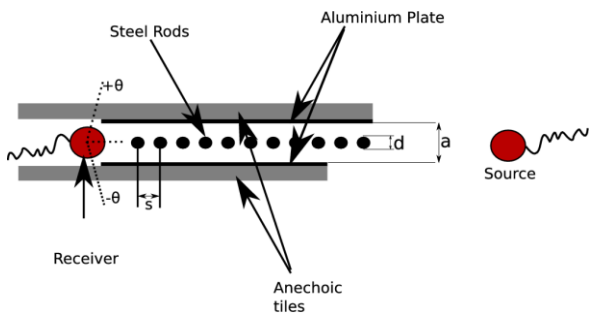


Figure 1. Experimental setup

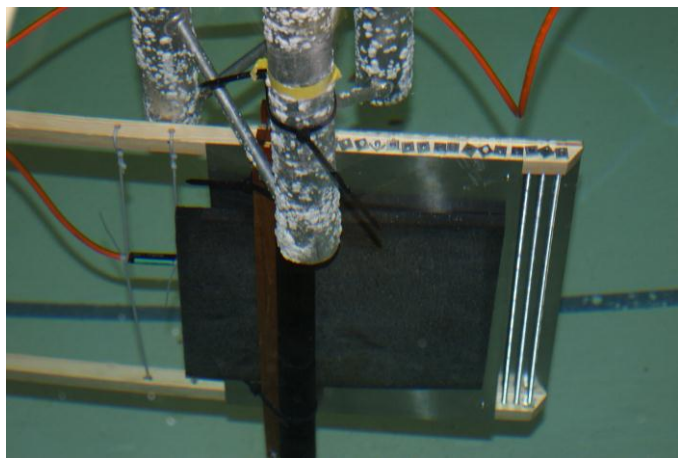


Figure 2. Side view of tooth array

4 RESULTS

Figure 3 shows the normalized (with and without rods) spectral response for a 0° incidence signal . At normal incidence the effect of the band gap response from the semi-infinite rods is demonstrated with a primary bandgap at around 50 kHz This closely matches the primary band-gap expected from the array dimensions and equation 2 with a centre frequency of 50 kHz.

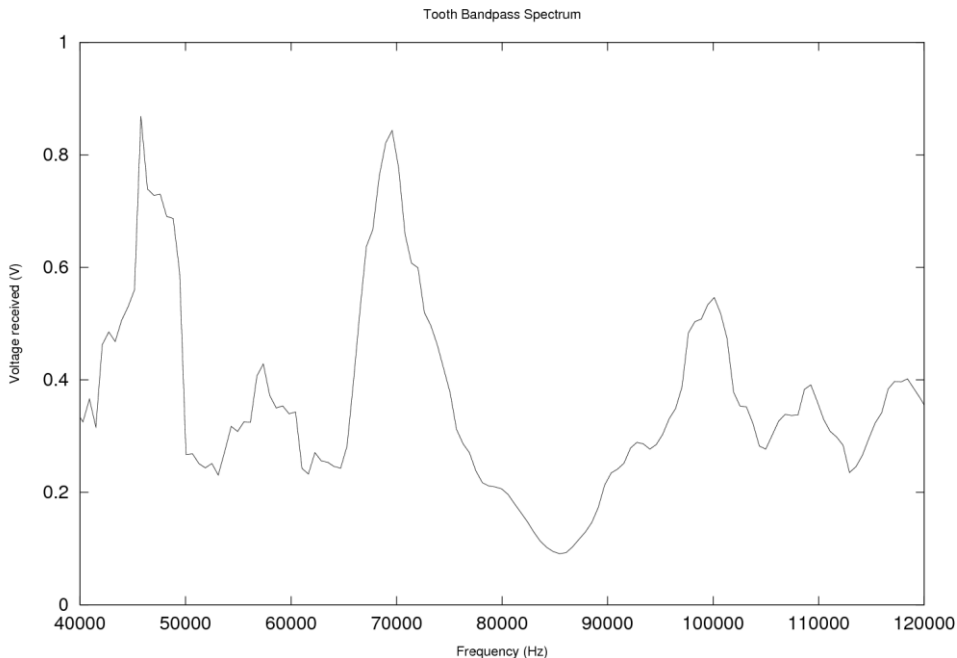


Figure 4: Normalised 2D acoustic band gap formed from a line array of 15, 5mm diameter, circular rods(steel) with a separation of 15mm placed in a 15mm wide hard boundary (aluminum) channel. The primary band stop can be seen at 50 kHz Normalized normal incidence (0°) response with and without teeth

By comparison using modeled data the beam patterns presented in Figure 5 show only a minor difference at 60 kHz with the left and the right ear signals providing almost the same information. However above this frequency the band gap region of the array begins to influence the results and differences begin to appear. Notably in the with-tooth simulation the left and the right signals are isolated and have a notch on the centre axis.

This effect becomes more pronounced with the increasing frequency. At 100 kHz the presence of the teeth appears to provide both isolation and beam narrowing compared to the no tooth model. The toothed beam patterns at high frequency are therefore more favorable for short range target location where the target is a short distance to the left or the right of the jaw.

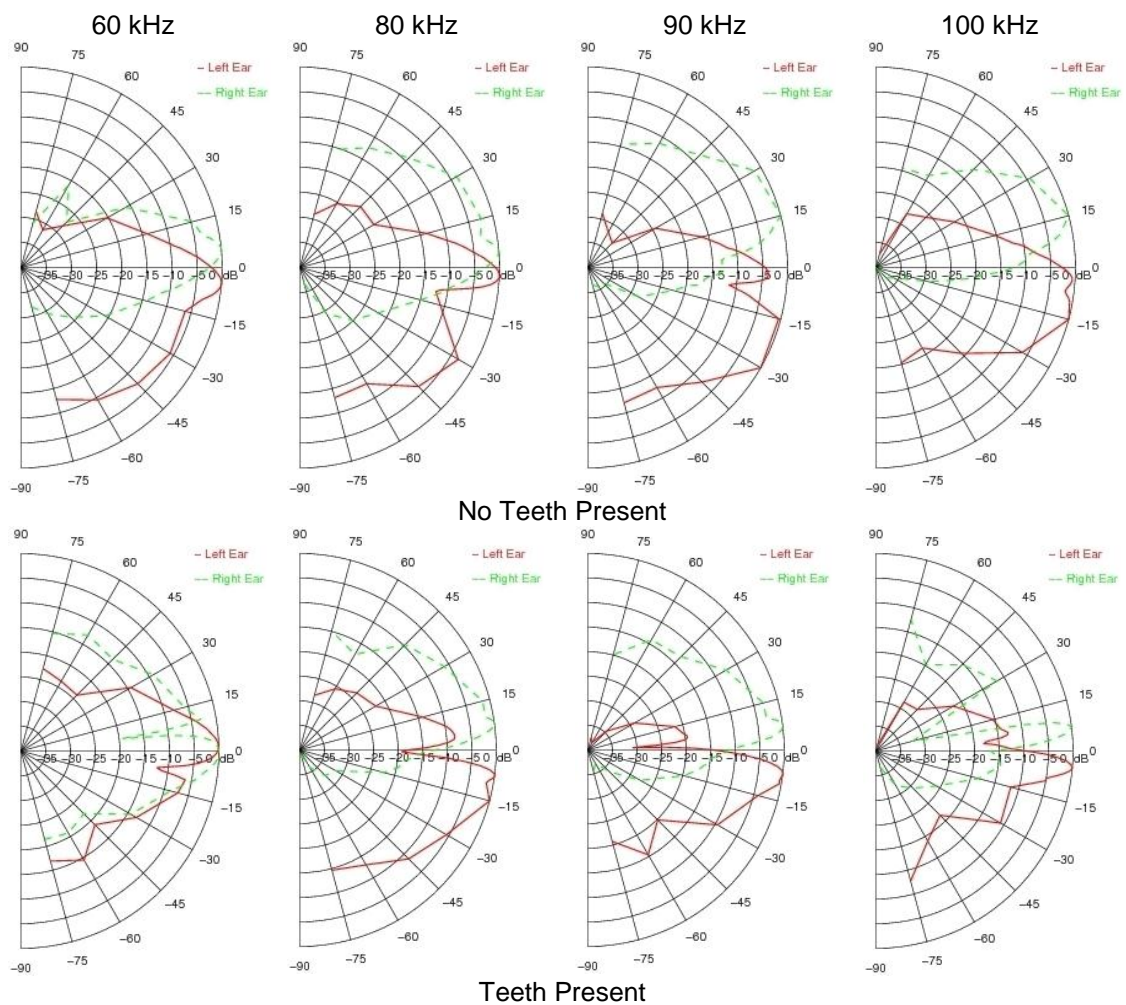


Figure 5. The beam patterns produced from the replica dolphin jaw with and without teeth present.

CONCLUSIONS

A band-gap filter effect has been demonstrated both theoretically and in measurements using 14 semi-infinite rods within a wave guide at normal incidence. However the associated energy levels did not allow demonstration of the band-gap response of the array observed in models. The use of higher levels and individual tones may allow this assessment in future trials.

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