MEASUREMENT OF THE UNDERWATER NOISE FOOT-PRINT OF A VESSEL

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The Impacts of man-made underwater noise on the marine environment have received increased attention over recent years, primarily resulting from recognition of the increased pressures placed on the oceans by human activities. A main source of such anthropogenic noise is shipping. In order to understand the underwater soundscape considerable effort is being placed on generating underwater noise maps, based on using AIS data to provide details of vessel locations and operational characteristics. A key input for noise mapping models is an adequate knowledge of the source strength and characteristics for each vessel. Currently the sources are usually assumed omnidirectional, given the limited data on the true vessel radiation pattern. This paper presents the result of a trial undertaken on a small survey vessel, operating under realistic conditions at sea in shallow water, as part of the SONIC project. This trial used an autonomous recorder to measure the sound pressure as a function of range and azimuth. The vessel made a repeated runs past the autonomous recorder for a variety of different ranges. This has enabled the vessel noise footprint to be measured as a function of frequency and speed for the vessel, showing how the azimuthal characteristics change with frequency.

Keywords: no more than five words (e.g. Underwater Acoustics, Noise, Vessel, Footprint)

1. Introduction

The increased demands placed on the marine environment by, for example, the oil and gas, renewable energy and transport industries, as well as an improving understanding of the sensitivity of marine fauna to underwater noise pollution, has led to an increased interest in the extent of underwater noise and its potential environmental effects.

Many studies have identified radiated underwater noise from merchant ships, predominantly resulting from propeller cavitation, as a major contributor to ambient noise levels in the oceans (e.g. [1] and [2]), while more recent studies have presented data indicating that shipping noise levels are increasing [3] [4], although the most recent data presented in [3] indicate that this trend may be levelling off. Consequently, there is a need to understand shipping noise and its impact on the marine environment.

In recent years, a number of studies have undertaken measurements of radiated noise from ships (e.g. [5], [6] and [7]), often using proprietary mobile deployed measurement systems. This is in contrast to the majority of historical measurements that have been undertaken at fixed noise ranges by military researchers. While these mobile system measurements have been a valuable contribution to the field, most measurements have simply attempted to measure the broadside radiated noise level.

Following the publication of the Marine Strategy Framework Directive (MSFD) by the European Union (EU), the EU has funded a number of projects through the Seventh Framework Programme

(FP7) to investigate underwater noise from shipping and its mitigation (for example the SILENV, AQUO and SONIC projects). The SONIC project covered a broad range of approaches to investigating ship radiated noise [8]. These included the development of experimental procedures at model scale to improve the prediction of radiated underwater noise from new vessels, the investigation of engineering solutions to mitigate the impacts of noise, and the development of numerical modelling tools to improve the estimation of underwater noise generated by the current shipping fleet. Due to the lack of available, good quality ship radiated noise data in the literature, measurements of underwater radiated noise from a vessel operating at sea were also undertaken in order to validate some of these techniques and procedures. It is the data from one of these trials that is the subject of this paper.

In order to understand the underwater soundscape considerable effort is now being placed on generating underwater noise maps, based on using AIS data to provide details of vessel locations and operational characteristics. A key input for such mapping models is an adequate knowledge of the source strength and characteristics for each vessel. Currently the sources are usually assumed to be omnidirectional, given the limited data on the true vessel radiation pattern. An improved knowledge of vessel source strengths and radiation patterns would be of considerable help in constructing such noise maps. This paper addresses this issue by attempting to measure the noise around a vessel, not just in the broadside direction, but as a function of range and direction. This data is combined to produce a map of the noise around a vessel, a noise footprint.

2. Measurement Trial Details

2.1 Target Vessel

The target vessel used was the Princess Royal operated by the University of Newcastle, pictured in Fig. 1. A specification of the vessel is provided in Table I. This vessel was ideally set up to allow the running conditions to be carefully controlled and logged and extensive on-board data to be collected in addition to off-board measurements as part of the SONIC trials. It was also readily available for the time required to make detailed measurements. However, in terms of hull design and size it is not particularly representative of the current merchant shipping fleet. The radiated noise characteristics may, therefore, not be a good indicator of those generated by merchant ships.

Figure 1: The target vessel Princess Royal.

Prior to measurements of radiated noise and detailed on-board cavitation observations were undertaken to determine the cavitation inception point for the vessel and also to record the extent of cavitation on the propeller for a range of running conditions. The vessel running conditions were defined in terms of the nominal engine speed in revolutions per minute (rpm) as this could be easily controlled by the master of the vessel. In order to measure the radiated noise level for a range of propeller cavitation conditions runs had been taken on a previous trial for engine speeds of 600, 700, 900, 1200, 1500 and 2000 rpm.

Table 1: Specification of the Princess Royal.

Classification	MCA Cat 2
Length / Beam	18.9 m /7.3 m
Design draft	At AP: 1.845 m; at FP: 1.745 m
Displacement	44 tonnes (approx.)
Max speed / Cruising speed	20 knots / 15 knots
Engines	2 x 602 BHP
Propulsion	2 x 5-bladed, fixed pitch propellers
Propeller diameter	0.75 m
Approximate source depth	1.15 m
Cavitation inception point (engine rpm/speed)	800 rpm/6.5 kn
Gearbox ratio	1:1.75

2.2 Measurement Location

The trials were undertaken in Cambois Bay, just north of the port of Blyth, Northumberland, UK. The water depth over the trials area varied between approximately 18 – 37 m LAT (Lowest Astronomical Tide). The site was selected in order to give an approximately flat bed with constant seafloor for associated modelling activities that were to be undertaken by TNO. Ideal conditions were defined as a site with a sandy seabed and uniform water depth of approximately 50 m. The possible locations were limited by the logistics of getting to and from the trials area on each day and the deployment and retrieval of the autonomous systems. On this basis, the Cambois Bay site was selected as it was very close to Blyth port, minimising transit time, had a sandy seabed, and provided slightly shallower water facilitating the safe deployment the equipment.

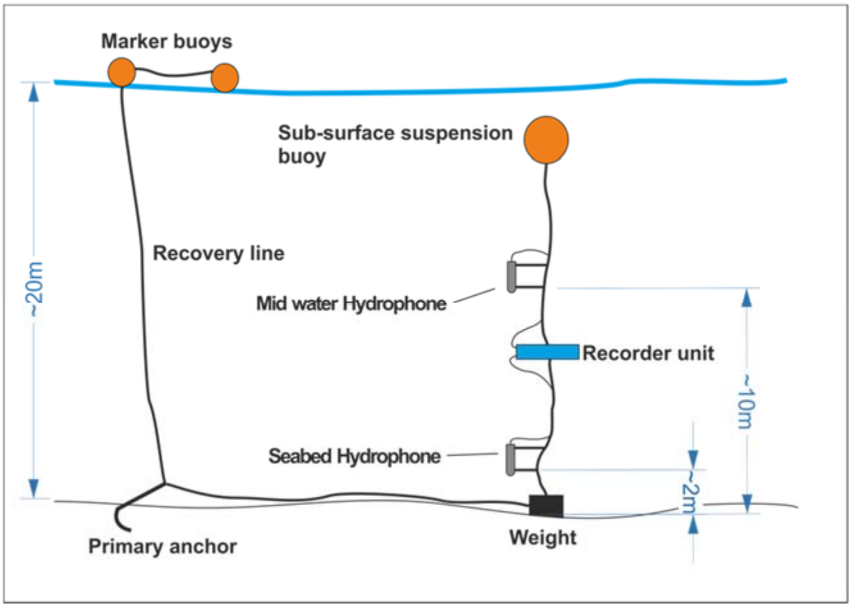

Figure 2: Autonomous recorder deployment arrangement.

2.3 Acquisition System

The measurement systems used for the trial comprised of two bottom mounted autonomous recorder systems. These were deployed along a North-South track about 200 m apart. The general deployment setup of both systems was the same and is shown in Fig. 2. Only the results obtained with one of the systems are presented here. Details of the system are given in Table 2. The two hydrophones were suspended vertically in the water column by a sub-surface buoy. One hydrophone was approximately 2 m above the seabed and the second was at approximately mid-water (depth 10 – 13 m).

2.4 Trial sequence

After deployment of the autonomous recorders the target vessel proceeded to the start of the measurement run, generally about 3 km from the recorder. The vessel's engines and electronic equipment were then switched off for approximately 10 minutes to allow for background noise recordings. The generators on-board had to remain on during this period but all other systems were switched off.

Table 2: Specifications of the autonomous recorder system used to obtain the data reported in this paper.

Acquisition Unit	RTsys EA-SDA14
Number / type of hydrophones	2 x Reson TC4032
Frequency range	5Hz – 120kHz
Resolution	24 bit
Sample rate	312.5kHz
Hydrophone depths	2 m above seabed and approximately mid water (10 – 13 m depth)
Power requirements	Battery operated
Deployment requirements (e.g. winch, hand portable, etc)	Hand deployable, small winch/pot-hauler to recover

Once sufficient background noise recordings had been made the target vessel then commenced the footprint trial sequence. The vessel was requested to follow the predetermined track pattern as shown in Fig. 3 to generate a series of passes by the autonomous recorder at different ranges.

For days 1 – 3 the nominal track length, L (as shown in Fig. 3), was defined as 6 km and the CPA ranges, R_i were 50 m, 100 m, 200 m, 500 m, 1000 m and 3000 m. On Day 4 a "higher resolution" footprint was undertaken for which L was defined as 3 km and R was 25 m, 100 m, 200 m, 400 m, 600 m, 800 m, 1000 m. Days 1 to 3 undertook measurements at 1500, 2000 and 1200 rpm; the high resolution data was collected for 1500 rpm.

2.5 Signal Processing

During the footprint trials, underwater noise data were recorded constantly on the autonomous recorders and stored as .wav files. In order to calculate the footprint the radiated noise levels needed to be synchronised to the distance and bearing of the vessel relative to the recorder. This was achieved by synchronising the internal clock of the recorder to GPS time prior to deployment. The GPS position of the vessel was also logged continuously at 1 s intervals along with various other parameters including speed, heading, time-stamp and position accuracy information. These two datasets were then combined to provide the levels of underwater noise measured at the receiver in terms of one-third octave bands for each second of the run.

3. Results

3.1 Radiated Noise Levels

Previous measurements of the radiated noise level for the Princess Royal, collected as part of the SONIC programme have been reported previously [9]. For these measurements the measured noise levels were measured for a closest point of approach of 100 m and corrected for spherical spreading only to give a radiated noise level (an affected source level) in accordance with the ISO standard [10]. Although this is a deep water standard these measurements were actually made in water with a depth of approximately 100 m but a mud bottom, so the effect of the seabed was significantly reduced.

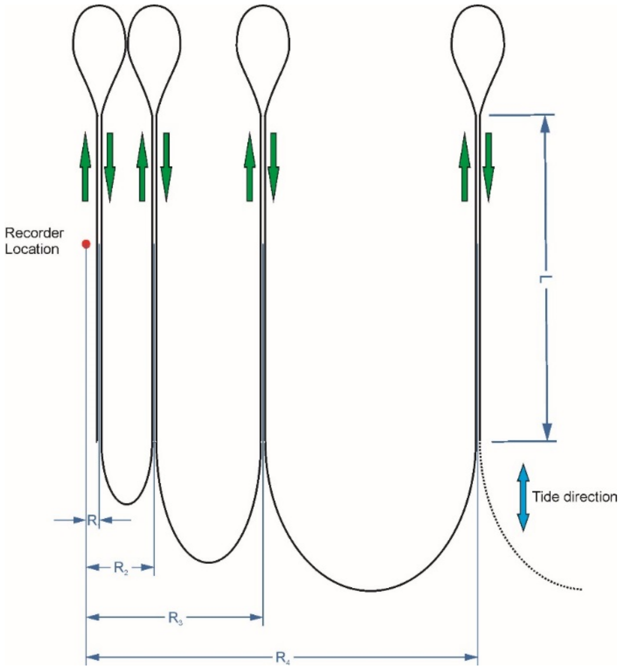

Figure 3: Track pattern for noise footprint measurements.

The results for the one-third octave band radiated noise levels (Fig. 4) show how the noise level rapidly increased as a function of engine rpm above 900 rpm with a broad spectrum above 100Hz. The noise level can be seen to peak at about 200 Hz. The low frequency rise below 80 Hz is associated with other extraneous noise sources not associated with the vessel.

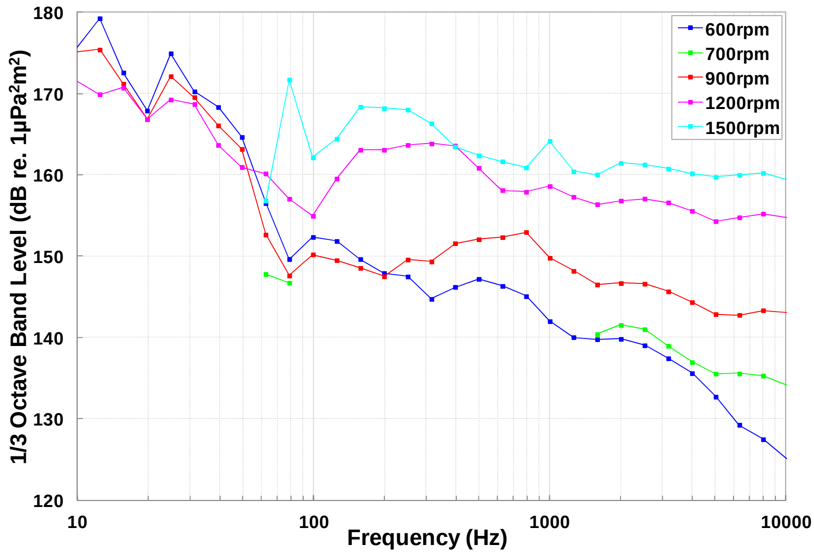

Figure 4: One-third octave band Radiated Noise Levels for the Princess Royal for various engine speeds.

3.2 Footprint measurements

The data for the measured noise pressure as a function of range and angle to the vessel track was mapped on to a rectangular grid and interpolated to provide input for a contouring programme. The resulting plots of radiated noise are shown as a footprint; in practice the vessel moved while the hydrophones were stationary, but the plots effectively show the sound field around the vessel while in motion. The plots give the radiated noise for an area 6 km by 6 km centred on the vessel. The vessel direction of motion is normally vertically upwards.

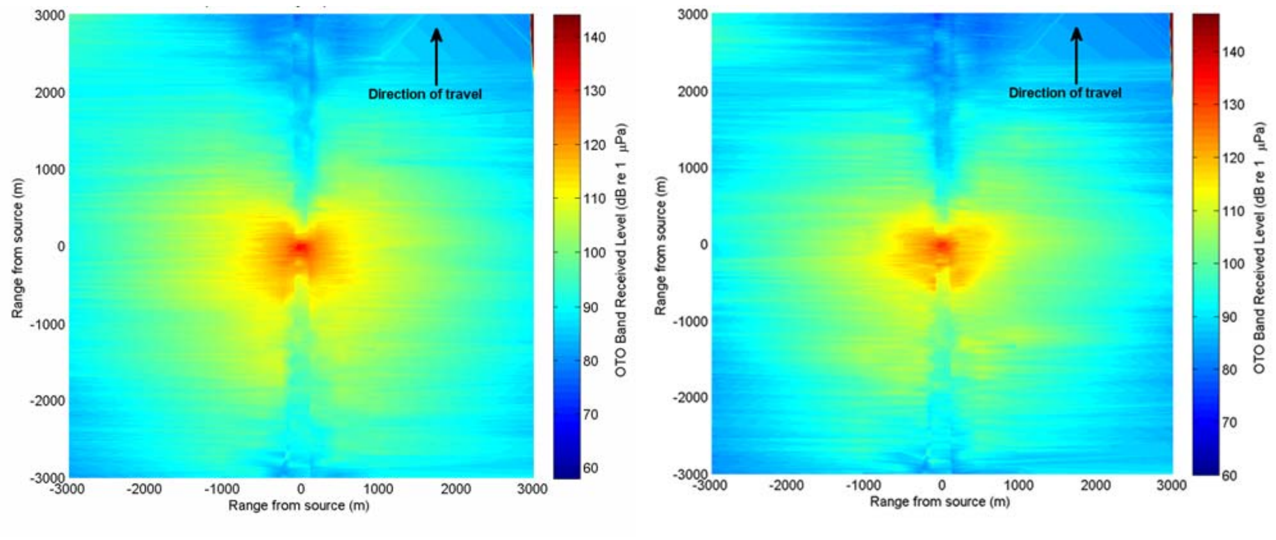

Figure 5: Measured footprint for the 10 kHz third-octave band on mid-water hydrophone and near-bottom hydrophone.

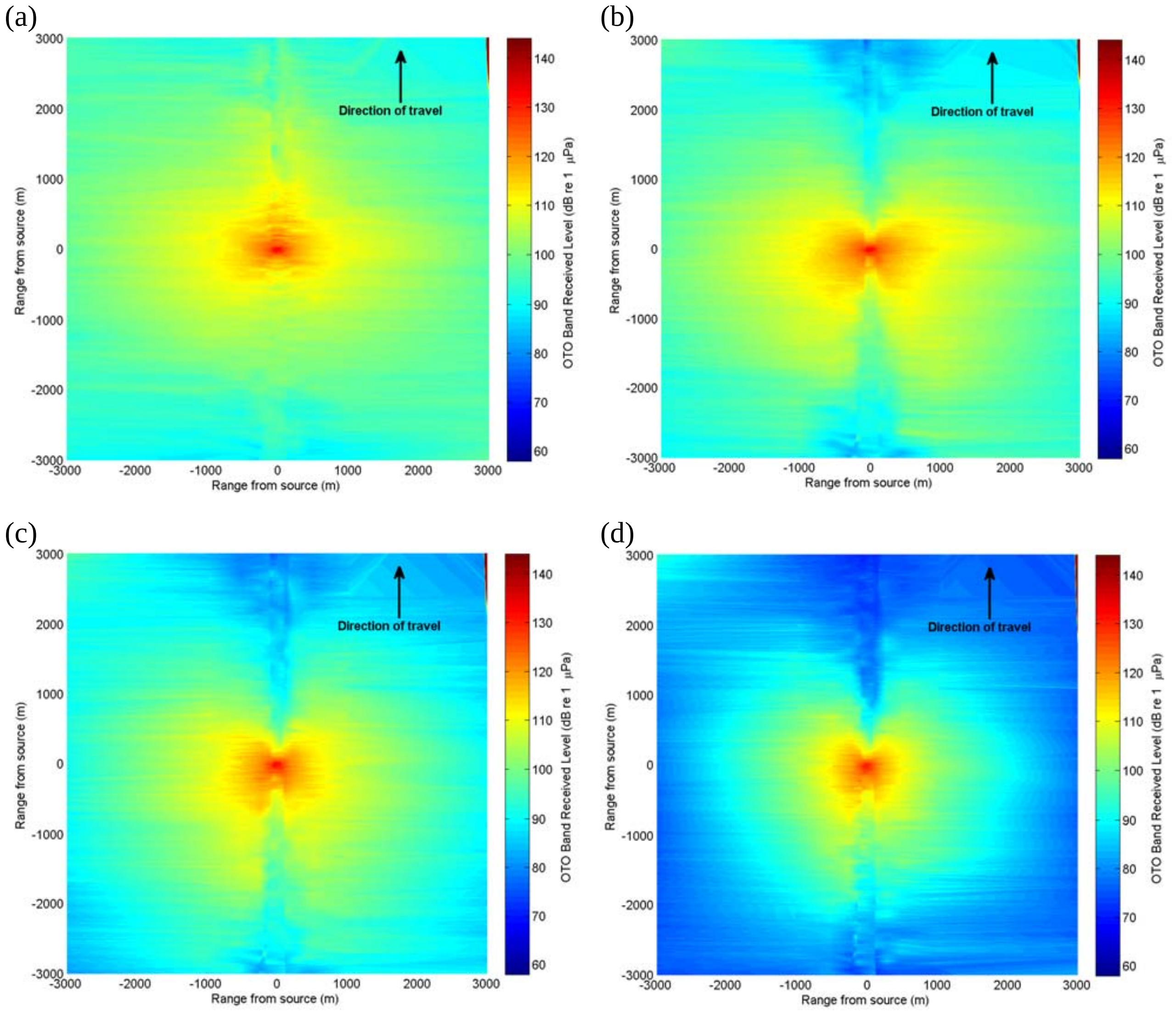

Figure 6: One-third octave band measured footprint for 2000 rpm at (a) 1 kHz; (b) 5 kHz, (c) 10 kHz and (d) 25 kHz.

Figure 5 shows results obtained with both the mid-water hydrophone and near-bottom mounted hydrophone for the 10 kHz third-octave band. These show the similarity of the measured footprint at the two depths and the extent of the noise field produced by the vessel. In addition at this frequency the characteristic lobed shape with distinct shadow regions in both the forward and backward directions is visible.

Figure 6 shows the results obtained for a range of different frequencies for a vessel engine speed of 2000 rpm. At 1 kHz (and below) the footprint doesn't show the pronounced notches in the forward and aft directions, but with higher levels in the broadside directions. For the 5 kHz one-third octave band and above the forward and aft notches become apparent. In addition, at 5 kHz an asymmetry is present with higher levels in the aft direction than the forward direction. At 25 kHz the more limited range of the noise, due to attenuation and absorption, becomes apparent.

Figure 7 presents a typical graphical representation of the noise footprint from the target vessel for three running conditions; 1200, 1500 and 2000 rpm. Each plot is for data in the 10 kHz one-third octave band, and is plotted on the same amplitude scale. These plots clearly show that the radiated noise from the target vessel has a directional dependence at 10 kHz, and how the level of the noise, and the extent of the footprint increases with frequency. This is in line with limited data presented in the literature although it represents one of the most detailed representation of vessel noise directionality available to date

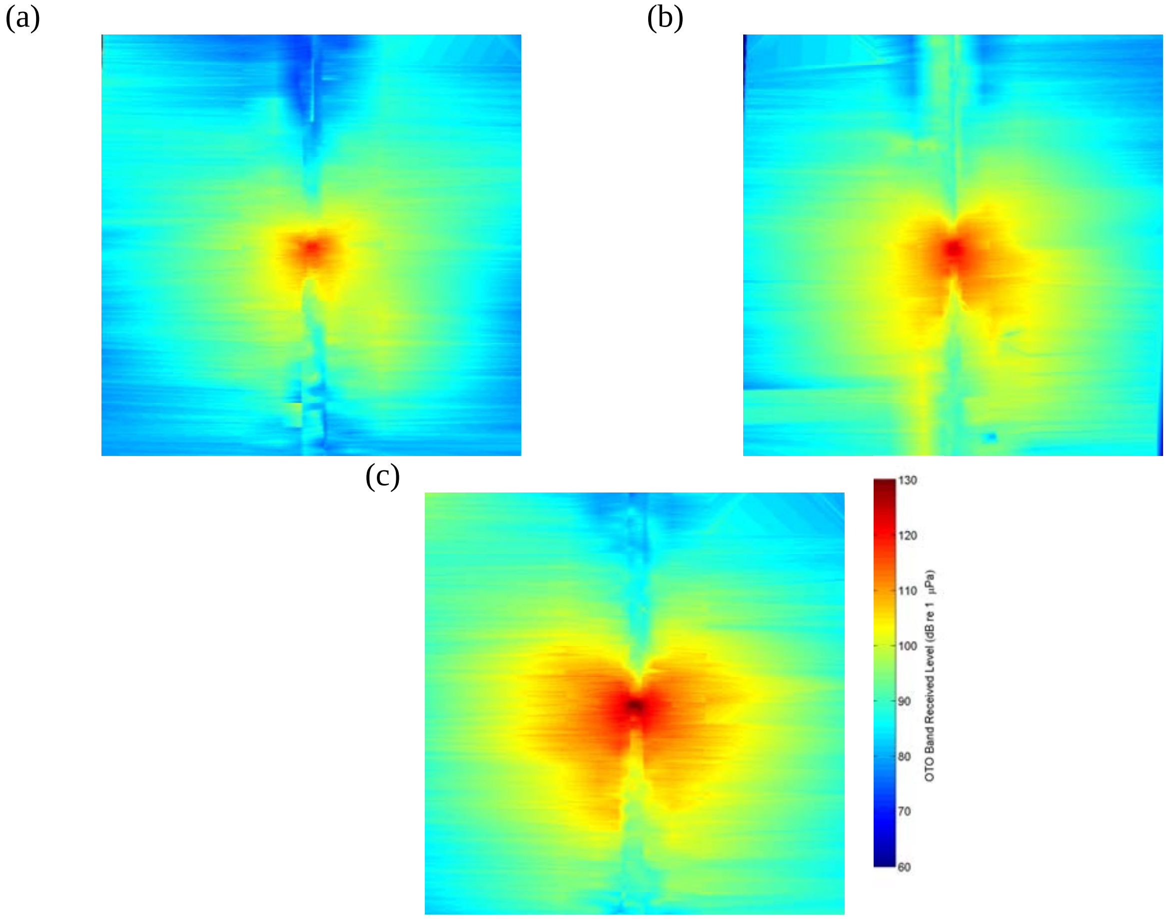

Figure 7: Measured footprint for the 10 kHz third-octave band; a) for 1200 rpm case; b) 1500 rpm case and c) 2000 rpm case.

4. Discussion and Conclusions

The results show that it is possible to measure the noise footprint of a vessel underway given sufficient time. The results show the complex character of the footprint which changes significantly with engine (and vessel) speed. An improved understanding of these characteristics will facilitate the development of improved noise mapping techniques for the underwater environment.

5. Acknowledgements

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