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Measurement of Radiated Underwater Noise from a Small Research Vessel in Shallow Water

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Abstract: The impact of man-made underwater noise on the marine environment has in recent years received increased attention from regulatory authorities, as evidenced by its inclusion in the Marine Strategy Framework Directive (MSFD) of the European Union (EU). Radiated underwater noise from ships, primarily resulting from propeller cavitation, has for many years been understood to be one of the major contributors to ambient ocean noise. Civilian research in this area has to date been relatively limited; standards covering the measurement of radiated noise from ships in deep water and data analysis procedures have only recently been published by national and international standards institutes. Less attention has so far been paid to the measurement of radiated noise from ships in shallow water environments. This is of interest as shallow water areas are more likely to be used by civilian researchers due to the logistical problems involved in undertaking trials in deep water. The issue of shipping noise has been identified as one requiring further research, indicated by the recent funding of several large collaborative projects by the EU (see for example the SILENV, AQUO and SONIC projects). This paper presents ship radiated noise data measured using a three hydrophone array during a recent sea trial undertaken as part of the SONIC project.

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Keywords: Underwater radiated noise, SONIC project, shipping noise, propeller cavitation

1 INTRODUCTION

Interest in the environmental impact of man-made underwater noise has increased considerably in the last two decades driven by a recognition of the increasing 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. The inclusion of underwater noise as a key indicator of environmental status in the European Marine Strategy Framework Directive (MSFD) is testament to this interest.

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. Wenz (1962), Urick (1975), Ross (2005)). While more recent studies have presented data indicating that shipping noise levels are increasing (Andrew et al. (2002)). Consequently, any effort to determine the current status of the marine environment should consider shipping noise in detail.

The measurement of radiated noise from ships has historically been undertaken for military purposes using fixed acoustic noise ranges. More recently, researchers from both military (e.g. Wales and Heitmeyer (2002), Scrimger and Heitmeyer (1991)) and civilian (e.g. McKenna et al. (2012), Merchant et al. (2014), Hallett (2004)) backgrounds have used short or long term mobile deployed systems to measure shipping noise. While these have been a valuable contribution to the field, the lack of a standardised methodology for measurement, data analysis and reporting often hinders the comparison of different datasets.

The recent publication of internationally agreed standards (ANSI/ASA (2009b) and ISO (2012)) is the first step towards rectifying this issue and it is encouraging to see many researchers adopting these methods as closely as possible (Bahtiarian and Fischer (2006), De Robertis et al. (2012), Peña et al. (2011)). The fact that these researchers appear to have found it challenging to meet some of the requirements for the highest measurement precision methodology set out in the standards highlights the difficulty in undertaking these measurements in the real world.

This paper concentrates on the results of full scale trials to measure radiated noise from a vessel following, as closely as possible, the methodology recommended in the sndards cited above. As well as presenting some of the results of the trials the methodology used is discussed in detail highlighting any necessary departures from those in the standard and discusses some of the issues encountered when undertaking trials of this type.

2 THE SONIC PROJECT

Funded under the European Union (EU) Seventh Framework Programme (FP7) the SONIC (Suppression Of underwater Noise Induced by Cavitation) project commenced in October 2012 and will run until October

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2015. It is a multinational collaborative project involving thirteen organisations from five European countries including universities, classification societies, and naval, marine engineering and technical research institutes.

The aim of the project is to investigate radiated noise from ships, primarily concentrating on underwater noise from propeller cavitation as this is the main source of noise generation when the ship is operating at design conditions. It is the most recent demonstration of the commitment of the EU to reduce the environmental impact of human activities on the seas.

The project involves developing techniques for the accurate prediction of ship radiated noise levels from scale model tests and numerical modelling techniques. A number of approaches to improve the accuracy of these predictions are being explored. These include novel techniques for the measurement of cavitation noise in cavitation tunnels and towing tanks, taking into account the acoustically reverberant nature of these environments and developing tools to separate out cavitation noise from machinery noise.

These predictions will be informed by and validated against measurements of radiated noise from full scale sea trials involving the research vessel Princess Royal operated by the University of Newcastle. The first of these trials was undertaken in September 2013 and aimed to measure radiated noise using a deployed hydrophone array using similar methodology to recently published international standards (Section 2). In addition, multiple on-board sensors including hull pressure pulse sensors, hull and engine mounted accelerometers, microphones, torque and shaft speed gauges and ultrasonic transducers were installed on the vessel.

The third aspect of the project focusses on mitigation. It aims to develop an underwater noise propagation model to estimate the "noise footprint" of an individual vessel and a "noise map" showing the contribution to the overall underwater noise levels in an area of ocean from multiple vessels transiting through the region over a period of time. Other than the noise propagation model itself, the inputs to this final stage include an empirical ship source level model that is based on a database of existing ship radiated noise level data compiled for the SONIC project. In addition, other mitigation measures relating to design and operation of propellers and the reduction of machinery noise are being investigated.

3 ISO PUBLICLY AVAILABLE SPECIFICATION FOR SHIP RADIATED NOISE MEASUREMENTS

The American National Standards Institute (ANSI) standard (and the ISO Publicly Available Specification (PAS) subsequently based upon it) provides recommendations covering environmental conditions, suitable locations, specification and setup of measurement equipment, behaviour of the target vessel, post processing of data and the metrics by which to report the data. It also provides three grades of measurement standard from Grade A, which provides the most stringent set of conditions, to Grade C which allows for a reduced degree of measurement detail and estimated accuracy. It is, therefore, a very comprehensive guide for researchers undertaking ship radiated noise measurements which takes into account a number of common issues.

Figure 1 shows the recommended hydrophone setup geometry relative to the target vessel for Grade A measurements. The depths of the hydrophones are defined in relation to the distance at Closest Point of Approach (CPA) of the vessel and the elevation angles specified by the standard of 15º, 30º and 45º. Assuming a vessel of less than 100 m in length (as is the case for the present study) the depth of the shallowest hydrophone, d_1, is recommended as 27 m, d_2 = 58 m and d_3 = 100 m. This, however, is based on the trials being undertaken at a location that meets the minimum water depth requirements, that is the greater of 300 m or 3 x ship length for Grade A measurements, 150 m or 1.5 x ship length for Grade B measurements and 75 m or 1 x ship length for Grade C measurements.

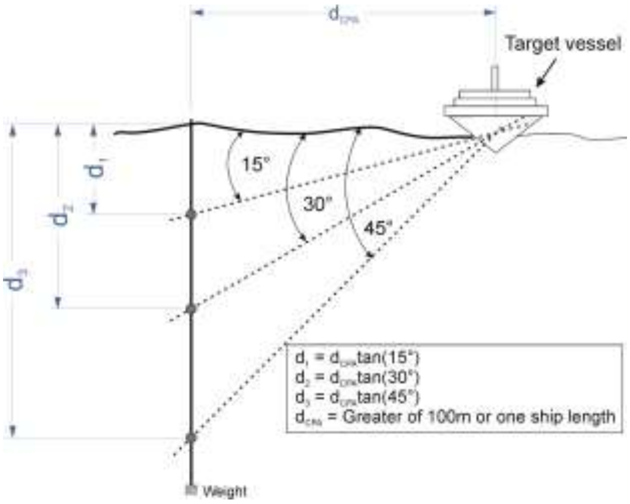

Figure 1 Hydrophone array geometry recommended by the ANSI/ISO Standards

The Standard also covers the manoeuvring of the vessel during the measurements, shown in Figure 2 for the measurement of radiated noise from the starboard side of the vessel. The procedure requires the vessel to run along a track such that it passes the hydrophone array at CPA, perform a Williamson turn and return along the same track so that measurements of radiated noise from both port and starboard sides are made. The Data Window Length (DWL) is the distance between two points along the track either side of the CPA point defined by a ±30º angle about the hydrophone array position. The COMEX and FINEX points define the start and end of the run respectively with each point a distance 2DWL either side of the CPA point. Between the COMEX and FINEX points the vessel must maintain constant speed and running conditions with minimal use of rudder to maintain course along the track.

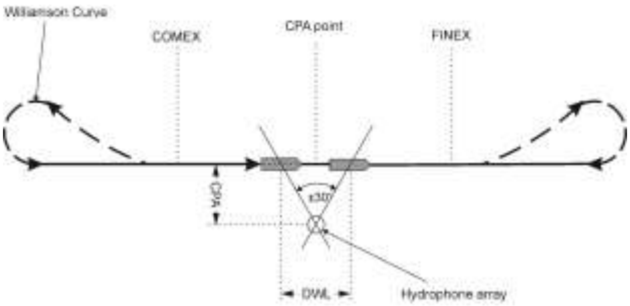

Figure 2 ANSI recommended vessel manoeuvre during trials for starboard side measurements

4 SONIC FULL SCALE TRIALS: MEASUREMENT AND DATA PROCESSING METHODOLOGY

4.1 Measurement system

During the SONIC full scale trials undertaken in September 2013 the University of Southampton deployed a vertical hydrophone array from a moored support vessel. The array consisted of three Reson TC4032 hydrophones and associated Reson cables, input modules and battery supplies. The acquisition system consisted of a National Instruments USB-6251 DAQ device sampling at 240 kHz on each channel and proprietary acquisition software running on a standard laptop PC. A diagram of the basic setup is presented in Figure 3.

The influence of surface wave motion on the array was mitigated by use of a spar buoy to control motion due to the array surface suspension and by using an elastic tether to decouple the array from the movement of the support vessel.

The hydrophones were attached to a central rope using a custom built stainless steel protective cage and mounting setup. As well as preventing damage to the hydrophones during deployment and recovery, this provided a solid mounting on to the central rope to maintain the separation distance between hydrophones. In addition, the mounting fixed the hydrophones away from the central rope and cables, reducing unwanted system self-noise from turbulence around the array. The maximum hydrophone depth of the array was 50 m, a departure from the specifications of the ANSI standard. However, the hydrophone depths within the 50 m maximum were fully adjustable in order to allow the deployment of all three hydrophones even in shallow water areas (the selected location for the trial is discussed below).

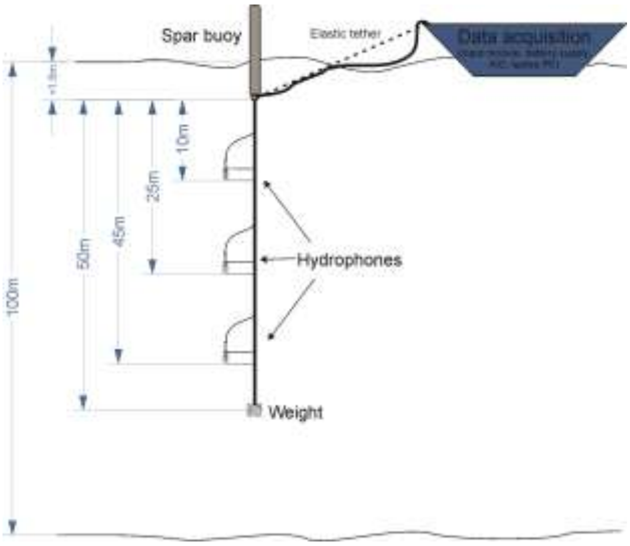

Figure 3 University of Southampton hydrophone array setup

4.2 Additional Measurements

In addition to the hydrophone array a differential GPS system was set up on the target vessel and the support vessel from which the hydrophone array was deployed. This GPS data was subsequently used during data post-processing to define the CPA distances for each run (and therefore the range correction used for “source level” estimation, discussed below) and the data window used for analysis corresponding to the period of the recorded files when the target vessel was transiting through the data window.

In total, thirty transducers were installed on-board the target vessel measuring hull pressure pulses, engine and hull vibration, airborne noise, propeller shaft speed and torque, engine power and a boroscope and several cameras to carry out detailed propeller cavitation observations. As well as providing extremely detailed information for on-board noise and vibration generated by the propeller cavitation and engines this also allowed detailed records of vessel operation during each run to be made in addition to the ships own readouts.

In addition to the above, for each run a record was made of wind speed, wave height, vessel speed over ground (SOG) and speed through water (STW), rudder angle and water depth from observations and the vessels own equipment.

4.3 Target Vessel and Running Conditions

The target vessel used during the trials was the Princess Royal operated by the University of Newcastle pictured in Figure 4. Table 1 provides a specification of the vessel. In terms of access to the vessel, control over its operation during the trials and existing facilities to install on-board sensors, this vessel offered the ideal platform for the trials. The location of the trials could be dictated by the requirements of the measurements rather than the commitments or operating restrictions of the vessel. Additionally, vessel running conditions could be carefully controlled and logged and extensive on-board and off-board data to validate the scale model and numerical modelling results could be obtained. The disadvantage of the vessel is that in terms of hull design and size it is not particularly representative of the majority of the current merchant shipping fleet. The radiated noise data may therefore not be a good indicator of the typical levels of underwater noise generated by merchant ships.

Figure 4 The target vessel Princess Royal

Table 1 Specification of the target vessel Princess Royal

Classification	MCA Cat 2
Length	18.9 m
Beam	7.3 m
Design draft	At AP: 1.845 m At FP: 1.745 m
Displacement	44 tonnes (approx.)
Payload	5 tonnes
Max speed	20 knots
Cruising speed	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
Max operational sea state	4 – 5
Range	400 Nautical Miles
Cavitation inception point (engine rpm/speed)	800 rpm/6.5 kn
Gearbox ratio	1.75

In total, thirty eight vessel runs undertaken broadly in line the ANSI standard guidelines were completed during the 2013 SONIC full scale trial. The vessel running conditions for each run were defined based on nominal engine revolutions per minute (rpm) values that could easily be controlled by the master of the vessel. During the initial phases of the trial, detailed 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 each running condition. Subsequently, several rpm values were chosen for the remainder of the trial; these were 600, 700, 900, 1200 and 1500 rpm, with additional runs at 2000 rpm as time allowed. Two runs at each rpm value (one port side aspect and one starboard side aspect) have been used for the analysis presented in this paper.

4.4 Trials Location

Three locations were selected for the trials, one preferred location and two backup locations, all off the north east coast of England. The backup locations were chosen to allow options for the measurements to continue in the event of poor weather conditions, albeit at a less ideal location to fulfil the aims of the trial. The preferred location was located approximately 28 km from the coast. The water depth at this location was approximately 100 m and the seabed type consisted of soft mud. The other two locations were in shallower water and closer to shore in slightly more sheltered areas. All of the data presented in this paper are from measurements undertaken in the preferred deep water location.

4.5 Data Analysis Procedures

Typically, data acquisition for each run was started when the target vessel team confirmed to the off-board measurement team via VHF radio that they had reached the COMEX position and stopped when the target vessel reached the FINEX position. The first stage of the analysis procedure was therefore to define the time window in the data corresponding to ±30º either side of CPA for each vessel run. This was achieved using GPS data to calculate the speed of the vessel, v (in this case Speed Over Ground, SOG) and defining the data window period, DWP:

$$DWP = {}^{DWL}/_{v} \tag{1}$$

The measurement system was synchronised to GPS time and hence the analysis window for each run can be defined from the above.

The same analysis procedure was used for recorded data from each of the three hydrophones. The section of data corresponding to the DWP for each run was split into 1 second samples and a Hanning window applied to each sample. The Power Spectral Density (PSD) of each sample was then calculated to obtain the received levels (RL) at the hydrophones in terms of dB re 1µPa^2/Hz. The PSD of the entire acquisition run was then calculated by averaging across all 1s samples (with no overlap of windowed data). One Third Octave (OTO) band levels are then calculated from the narrowband data by integration of the narrowband frequency points across each OTO band in accordance with the ANSI S1.11-2004 (ANSI/ASA (2009a). Data are presented over the frequency range from 10 Hz to 10 kHz.

In order to determine radiated noise levels (RNL) of the vessel in terms of dB re 1μPa^{2}m^2 a range correction must be applied. The correction applied to the data in this paper is of the form:

$$RNL = RL + 20\log_{10}\left({}^{r}/_{r_{ref}}\right) \qquad (2)$$

where RL is the received level, r is the CPA range and r_{ref} is the reference range (1 m).

The RNL is also referred to as the dipole or "affected" source level. This terminology reflects the fact that this quantity has not been corrected for interference effects caused by the interaction of sound propagating along direct paths between the source and receiver and indirect paths that are reflected from the sea surface and seabed. The series of peaks and troughs in received level resulting from reflections from the sea surface are often referred to as the Lloyd's Mirror Interference Pattern (LMIP) and may be approximated by the expression: (Ainslie (2010))

$$LMIP = 10\log_{10}\left(4\sin^2\left(\frac{kd_sd_r}{r}\right)\right) \qquad (3)$$

where k is the wavenumber, d_s and d_r the source and receiver depths respectively, and r is the source-receiver range. Further discussion on this can be found in Ainslie (2010) and De Jong (2009).

The ANSI standard requires that data are presented as affected source levels and much of the data in the literature is also in this form. To allow comparison with the literature the spectral source level data presented in this paper are presented as "affected" source levels unless otherwise stated. However, as discussed by De Jong (2009), the analysis procedures described in the ANSI standard, in particular averaging across three hydrophones and across the DWP, mitigates to some extent the influence of this interference. This is due to the fact that the locations in the frequency spectrum of the peaks and troughs caused by the interference are highly dependent on the geometry of the measurements such as measurement range, source depth and receiver depth (as well as many other factors related to the environment during the measurements).

Figure 5 presents the results of LMIP predictions using the above expression for the trial geometry shown in Figure 1 and using the given source depth for the Princess Royal target vessel of 1.15 m. The figure demonstrates that while the peaks and troughs associated with the interference pattern are still evident after averaging, they are reduced when compared to those of a single receiver.

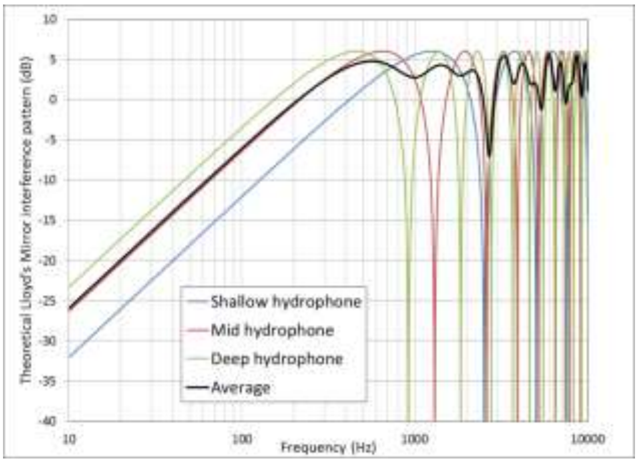

Figure 5 Theoretical Lloyd's Mirror interference pattern. Horizontal CPA range = 100m, Source depth = 1.15 m, d_1 = 27m, d_2 = 58m and d_3 = 100m

Analysis of recorded data as the vessel passes a receiver array presented as a spectrogram clearly demonstrates the LMIP effect in practice, as shown in Figure 6. These data are for a single pass of the target vessel at a nominal CPA range of 100 m. The point at which the vessel passes the hydrophone location can clearly be identified by the increase in received underwater noise levels at around 60 seconds into the recording (a smaller section of this file corresponding to the DWP has been used for detailed analysis). The "U-shape" that can be seen in the figure is the result of the LM effect and shows that the location in the frequency spectrum of the peaks and troughs changes as the vessel passes the receiver. In a similar way to averaging across multiple receivers, averaging the data across a vessel transit therefore further reduces the prevalence of the interference pattern in the data.

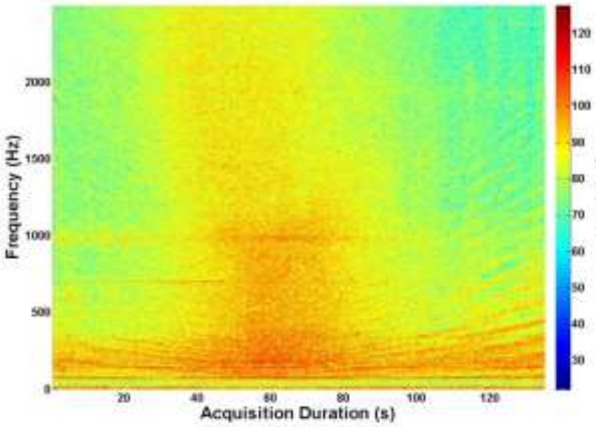

Figure 6 Spectrogram of vessel radiated noise for a pass at 100 m CPA and a speed of 11kn

In addition to multiple receiver and position averaging, the presentation of the measured data in terms of one-third-octave (OTO) bands rather than as narrowband (NB) spectral levels further reduces the prevalence of the interference pattern in the data, but does not reduce the significance of the low frequency fall off evident in Figure 5.

5 RADIATED NOISE DATA

5.1 Variation with Receiver Depth

Figures 7 and 8 present typical examples of the radiated noise levels measured on each of the three hydrophones in the vertical array during the SONIC trials. These data are dipole source levels, corrected for range assuming spherical spreading as in Equation 2, using the slant ranges between the source and each receiver. Figure 7 presents data for a low speed run at 600 rpm (4 kn) and Figure 8 shows data for a run at 1500 rpm (10.5 kn). The comparison indicates a clear increase in underwater noise levels between approximately 80 Hz – 10 kHz. Also evident in the higher speed run data in Figure 8 are the lower measured levels on the shallowest hydrophone which is a consistent feature in the data for all runs above 700 rpm. This is expected as indicated by the LMIP in Figure 5, the propagation losses are greater the closer the receiver is to the sea surface. The fact that this is less evident in the lower speed run data in Figure 7 reflects the fact that at low frequencies (below a few hundred Hz) the radiated ship noise is below the ambient underwater noise levels.

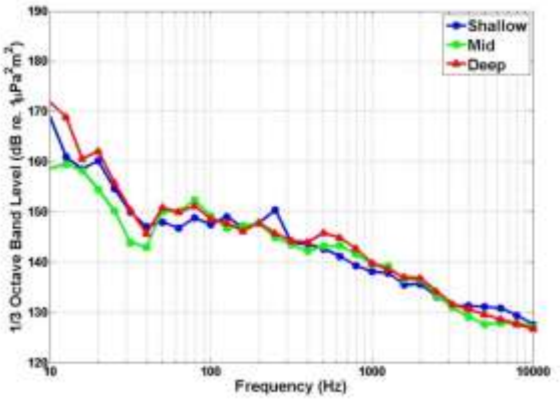

Figure 7 OTO band "affected" (dipole) source levels for target vessel at 600 rpm (5kn) calculated from measured pressures on individual hydrophones

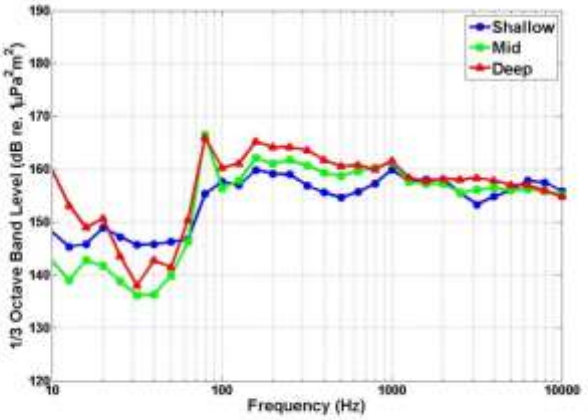

Figure 8 OTO band "affected" (dipole) source levels for target vessel at 1500 rpm (11kn)

Figure 9 presents data from the same acquisition as in Figure 8 but in terms of narrowband Power Spectral Density (PSD) levels.

This plot shows a number of important features of the radiated noise data. Firstly, the spectrum is characterised by a number of high amplitude narrow peaks in the frequency range from approximately 70 Hz – 400 Hz with the highest level peak at approximately 70 Hz. The target vessel has a gearbox ratio of 1.75 giving the propeller Revolutions Per Second (rps) at an engine speed of 1500 rpm as:

$$RPS_{prop} = \frac{1500/1.75}{60} = 14.3. \qquad (4)$$

With a 5 bladed propeller this would give a blade passing frequency (BPF) of 71.4 Hz, corresponding to the highest amplitude peak in the narrowband spectrum with lower level peaks indicating harmonics of the ~71 Hz fundamental. The other lower amplitude peaks in the spectrum at frequencies greater than this fundamental occur at approximately 14 Hz intervals and are most likely a combination of higher harmonics relating to BPF, propeller shaft speed and engine firing rate.

Another important feature of the data shown in Figure 9 is the high levels of low frequency noise below about 20 Hz, particularly evident on the data measured on the deepest hydrophone which is consistent across the majority of the acquisitions. It is likely that this is associated with self-noise of the hydrophone array, probably from movement of the hydrophone vertically in the water column due to surface wave motion or laterally due the effects of the current. There may also be contributions from turbulent flow around the rope, protective cage and hydrophone itself. The analysis of spectral data indicates that this does not consistently affect the higher frequencies. While this source of noise in the system does not prevent further analysis of the data in terms of spectral levels it is very likely to influence the overall broadband radiated noise level data and hence further processing is required prior to undertaking this analysis (discussed in Section 4.3 below).

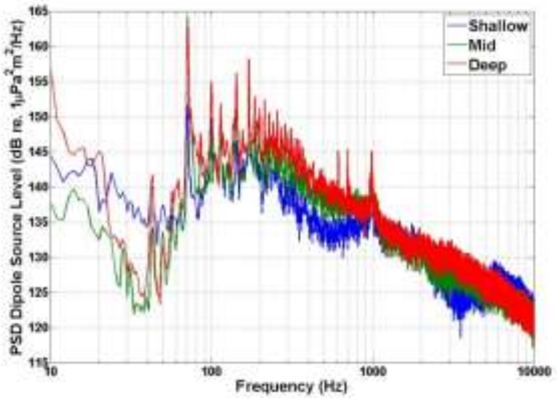

Figure 9 "Affected" (dipole) source level in terms of narrowband Power Spectral Density for target vessel at 1500rpm

5.2 Variation with Engine Speed – Spectral Data

Figure 10 presents RNLs for a number of vessel speeds from starboard aspect. This plot clearly demonstrates the increase in radiated noise as the vessel speed increases. The nature of this increase in RNL is similar to that attributed by other researchers to propeller cavitation noise (e.g. Wittekind (2014)). At lower ship speeds it is first evident in the higher end of the frequency spectrum, in this case above approximately 1 kHz when the speed is increased from 600 – 700 rpm. Clear increases are then seen above about 300 Hz between 700 – 900 rpm, 100 Hz between 900 – 1200 rpm and about 70 Hz from 1200 – 1500 rpm.

Figure 11 presents the corresponding dataset from the port side aspect runs. The measured RNL and spectral characteristics are in general very similar to the starboard side runs. The maximum increase in radiated noise is slightly greater for the port side aspect runs at approximately 33 dB while the corresponding value for the starboard side runs is approximately 28 dB.

In order to provide a comparison with what may be considered typical levels of underwater noise generated by a commercial ship the data may be compared to an adapted average ship source level model based on a large ensemble of measurements reported in Wales and Heitmeyer (2002). The model presented is in terms of the monopole source level for a ship. Therefore, in order to provide a valid comparison the dipole RNL data from the Princess Royal may be converted to an approximate monopole source level using equation 3. These data are presented in Figure 12. The comparison indicates that the radiated noise from the Princess Royal running at higher speeds is similar to typical underwater noise levels from a commercial ship operating at service speed.

The model does appear to overestimate the source level at frequencies below approximately 70 Hz. The Wales and Heitmeyer model is based on measurements of radiated noise from ocean going merchant vessels, likely to be considerably larger than the Princess Royal. Larger merchant ship engines and propellers tend to operate at a lower rpm than the target vessel in this study. Therefore, the peaks in spectrum level shown in Figure 9 associated with the blade passing frequency, engine speed and associated harmonics would be at lower frequencies in the spectrum. This may partly explain why the measured levels of underwater noise for the Princess Royal are lower than the model predictions in this part of the frequency spectrum.

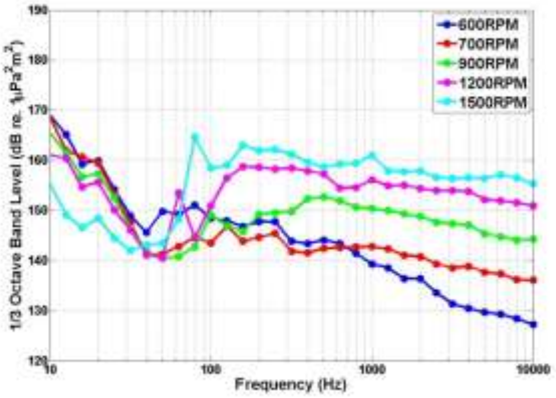

Figure 10 Radiated noise at several engines speeds measured in starboard aspect (averaged over three hydrophones)

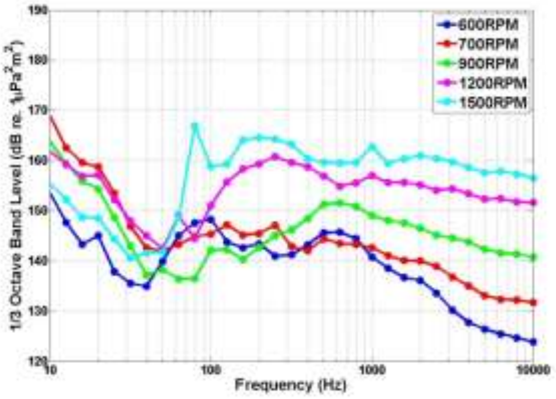

Figure 11 Radiated noise at several engines speeds measured in port aspect (averaged over three hydrophones)

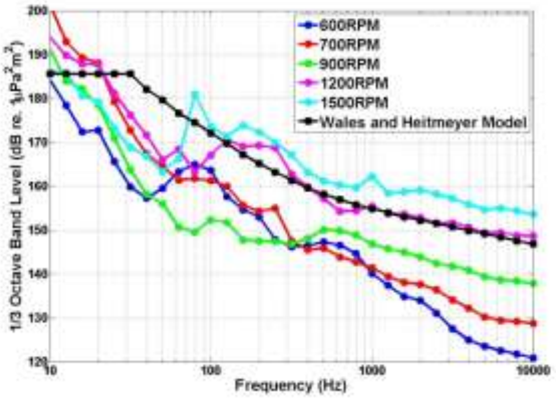

Figure 12 Approximated monopole source levels at several engines speeds measured in port aspect (averaged over three hydrophones)

5.3 Variation in Radiated Noise Level with Ship Speed – Overall Broadband Levels

As discussed above, the spectral data indicates that a considerable amount of low frequency noise, below approximately 20 Hz, is present in the recordings which is likely to be self-noise of the hydrophone array. Analysis of the raw data in terms of overall broadband RMS Sound

Pressure Levels (SPL) does not suggest a clear correlation between vessel speed and radiated noise levels. To investigate whether the low frequency components of the measured data are dominating the broadband analysis the data were reanalysed using a High Pass (HP) filter with a cut-off frequency (-3 dB) at approximately 24 Hz. It is appreciated that components of vessel noise are likely to extend to frequencies below 24 Hz and hence this filtering is not ideal. However, it is applied here to demonstrate the issue of system noise and to present further characteristics of the measured data.

Figure 13 presents the overall broadband RMS Source Levels as a function of ship speed for 16 vessel runs under various running conditions. This plot also includes data for a number of runs during which only the port side engine was running (whereas the preceding data has been for normal running conditions with both engines running).

Also shown in the figure is an historical speed dependence model (black solid line) first proposed by Ross (1976) based on extensive data from radiated noise trials undertaken during World War II. This model is of the form:

$$SL = A + c_v 10 \log_{10} \left({}^{v}/_{v_{ref}} \right) \qquad (5)$$

where A and c_v are given constants, v is the ship speed and v_{ref} is a ship reference speed.

The purple dashed line shows a least squares fit to the SONIC measured data using the form of the Ross model. This is a fit to the normal running condition (both engines operational) data only, excluding the data from runs where only one engine was operational. The difference between the historical model and the fit to the measured data ranges between approximately 2 – 6 dB over the range of vessel speeds tested indicating that the model may underestimate the radiated noise levels from the target vessel over the range of vessel speeds tested.

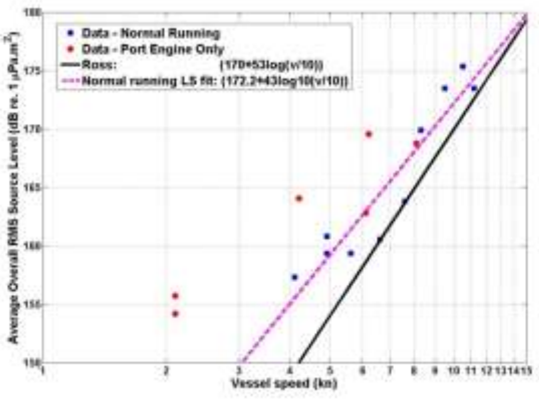

Figure 13 Overall broadband RMS Source Level vs. vessel speed. Also shown is the classical model from Ross (1976) and also a non-linear least squares fit to the measured data

6 DISCUSSION AND CONCLUSIONS

The measurement of radiated noise from ships to meet the recently published international standards is a challenging undertaking. In the absence of a fixed noise range, a vessel deployed mobile hydrophone array is the most viable alternative. The design and deployment methodology of such an array will inevitably have significant implications on the quality of the measured data due to possible self-noise of the array. The data presented in this paper provide an indication of some of the practical issues encountered with the deployment of a typical array.

Undertaking these measurements in Northern European waters is also particularly demanding due to the relatively shallow water depths and the presence of other vessel traffic (and hence generally high ambient noise levels). However, as a region incorporating some of the busiest shipping lanes in the world it is important to investigate and develop tools and techniques to accurately measure or monitor shipping noise under these conditions. The SONIC project aims to contribute to this understanding using a range of approaches of which these full scale trials are one.

While improvements to array design and deployment would certainly enhance the quality of the measured data, the results presented in this paper show that the radiated noise characteristics of a vessel operating under trials conditions can be ascertained in some detail using a relatively simple hydrophone array. Comparison of radiated noise level data with a widely used ship source level model indicates that the target vessel used in this work is fairly typical in terms of the levels of underwater noise generated by a commercial ship. A further comparison with another widely used model for variation in ship source level with speed has indicated that there is a clear positive correlation between radiated noise level and ship speed, although there is some disagreement between the measured data and model predictions.

(The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n°314394).

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