CHARACTERISTICS OF MERCHANT SHIP ACOUSTIC SIGNATURES DURING PORT ENTRY/EXIT

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Abstract

Results are presented of underwater acoustic radiated noise measurements of 10 merchant ships during port entry or exit. The speed of the vessels ranged from 7-15 knots and the displacement of the vessels between 3500–200000 deadweight tonnes. All measurements were taken in very shallow water (~20 m) and at very close range (~100 m) while the ships were transiting narrow shipping channels. The source level dependence on ship length and ship displacement is examined and compared with an empirical model developed by Ross (1976). Results from this limited dataset suggest that for port entry/exit, the acoustic source level is not dependent on ship speed or displacement. Using this observation, an average spectrum level is calculated that can be taken to be representative of a wide variety of merchant ships during port entry and exit.

Introduction

Historically, a common practice when studying the acoustic radiated noise of merchant ships has been to formulate an empirical model of the noise spectrum by performing a statistical analysis of measurements from a large number of ships. Ross [1] and Urick [2] quote a number of WWII-era empirical models used to estimate an overall spectrum level as a functions of speed, displacement tonnage, propeller tip speed and number of propeller blades. Scrimger and Heitmeyer [3], and Wright and Cybulski [4] investigated the source spectra for samples of 50 and 14 ships respectively and performed comparisons with the Ross model. More recently Wales and Heitmeyer [5] investigated a number of different models used to estimate the sound spectrum for merchant ships based on measurements of 54 ships.

Throughout these studies a common method of measuring ship spectra is through the use of air-dropped sonobuoys at intermediate-long ranges (~kilometres) with hydrophones at shallow-medium depths (~hundreds of metres). The data acquisition limitations of a sonobuoy mean that spectra are measured only in a limited band (tens of hertz up to several kilohertz).

This paper will focus on a somewhat different situation; the measurement of merchant ship radiated noise in very shallow water (~20 m) and at very short ranges (~100 metres) using a portable acoustic range deployed in the approach channel of a shipping port. In this case a seafloor hydrophone is cabled directly to a data acquisition system onboard a support vessel. This enables a much larger frequency range to be recorded than is available with sonobuoys.

The merchant ship signature data was measured and analysed as part of a series of experiments that aimed at better understanding the variation of the acoustic source level of large ships as a function of their size. Further, the data gives insight into the impact on the measured signal of the local environment particularly in shallow water choke points such as harbour entrances and shipping channels.

In the "Measurements" section, the setup of the experiments and the data acquisition equipment used is outlined and details of the ships are given. In the "Results" section, the source level measurements of the ships are presented and an *"average merchant ship"* spectrum for the port entry/exit scenario is computed. This spectrum is compared to data and models of other authors and the relationship between ship speed, displacement and total acoustic power is examined.

Measurements

In this paper, data is presented from two different measurement trials:

1. **Dampier, WA in May 2000** {Matthews, et al. [6] have already examined some interesting aspects of the acoustic signatures from this trial, such as the difference in the measured sound field between an approaching and a receding ship}
2. **Gladstone, Qld in April 2002**

The purpose of each trial was to measure the underwater acoustic signatures of the merchant shipping traffic entering and exiting the harbours. Acoustic data was collected using a lightweight, portable range, which is deployed on the seafloor. The range is attached, via cable, to a measurement vessel anchored a few hundred metres away. Onboard the vessel the raw acoustic data is bandpass-filtered between 3 Hz and 20 kHz before being recorded onto a standard PC. Data is measured for about five minutes either side of the closest point of approach during which time the ships travel several kilometres. Table 1 shows some characteristics of the ships that were measured.

The Ship Type, Tonnage and Length values are taken from Lloyd's Register of Shipping [7]. Values for the speed of each ship were calculated using data from a portable laser rangefinder that was used to track each ship during its transit.

Table 1: Type, tonnage, length and speed for each ship

Ship Name	Type	Measurement Location	Tonnage (dwt)	Length (m)	Speed (kts)
Hyundai Olympia	Bulk carrier	Dampier, W.A.	186300	291	7.5
Kuanyin	Bulk carrier	Dampier, W.A.	15600	143	9.3
Jiao Zhou Hai	Bulk carrier	Dampier, W.A.	57700	223	10.8
Orient Trust	Bulk carrier	Dampier, W.A.	118000	262	8.7
Tai Ping Yang	Bulk carrier	Dampier, W.A.	26300	168	14.6
Sincere Gemini	Bulk carrier	Dampier, W.A.	25400	160	10.4
Shinzan Maru	Ore carrier	Dampier, W.A.	201000	320	9.1
Philippine	Liquefied gas tanker	Gladstone, Qld	3500	89	12.8
Kowulka	Bulk carrier	Gladstone, Qld	23300	168	8.9
Admiralengracht	Container carrier	Gladstone, Qld	12200	130	7.7
		Mean	66930	195.4	10
		Std Dev	74424	75.2	2.2

Results

Acoustic Source Level Spectra

Results are presented as third-octave spectrum levels between 5 Hz and 16 kHz averaged over 5 seconds around the closest point of approach. The measured sound pressure level is corrected assuming spherical spreading propagation to represent a Source Level (SL) referenced to one metre (units of dB re 1μPa^2/Hz at 1m).

Figure 1 shows the measured acoustic source level spectra of the 10 ships and the average of these curves. Average values quoted in this paper are calculated as decibel averages rather than power averages, as explained in Ref. [5]. Statistically, this dataset of 10 signatures is small. However the ships measured represent a variety of types and speeds and cover displacements from some of the smallest to largest merchant ships. Therefore it is plausible that many merchant ship spectra (if measured during port entry or exit) would fall into the range observed. Likely exceptions to this suggestion would be any ships with mechanical defects or peculiarities in the propeller, drivetrain or engine.

A number of characteristic features of ship radiated noise are evident in Figure 1. At high frequencies (above several hundred hertz) there exists an approximately 20 dB per decade roll-off (as indicated) associated with cavitation bubbles created at the propeller (see Ref. [2] p334). At lower frequencies it is evident that line structure associated with engine machinery noise exists in the 10–100 Hz band. This structure is more evident in a higher than third-octave resolution spectrum (not shown).

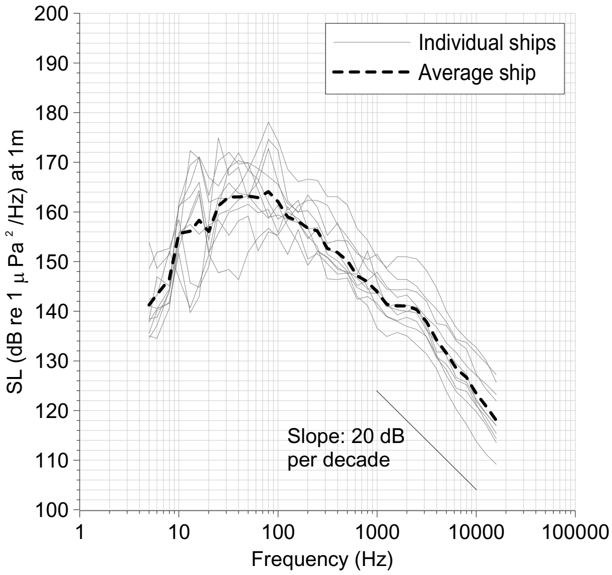

Figure 1: Individual merchant ship source levels, plus average

Interestingly the spectra in Figure 1 do not show significant levels in the blade-rate frequency band (typically 5–15 Hz). This observation may be a result of the ship's engines being subjected to a lighter load (i.e. applying less forward thrust) when they are navigating a shipping channel compared to when they are steaming in open seas. Alternatively there may be a damping of the low frequency sound in the unique bathymetry of a shipping channel. Measurements of a single ship in shallow and deep water at different speeds would be desirable in resolving this issue.

Figure 2 shows the same average merchant ship curve as Figure 1, as well as indications of the standard deviation in the measurements at each third-octave frequency. A standard deviation of between 5–10 dB (across the 5 Hz–16 kHz frequency range) is seen for the 10 ships measured.

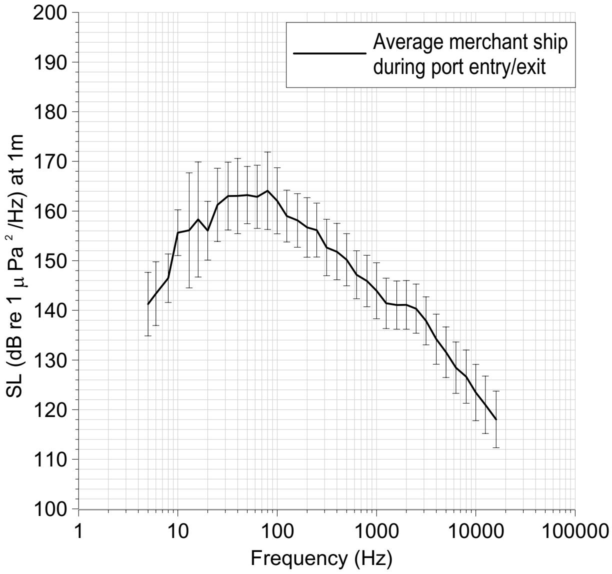

Figure 2: Average Merchant Ship source level during port entry/exit showing one standard deviation

As a comparison, Scrimger and Heitmeyer [3] presented data from 50 ships and found standard deviations in source level values in three frequency bands of interest (70–200 Hz, 240–340 Hz and 400–700 Hz) of between 5–7 dB. These values are consistent with the above results.

Source Level as a function of Displacement or Speed

Wales and Heitmeyer [5] claim there is a "*negligible correlation between the source level and the ship speed and the source level and the ship length*". In stating this assertion, they are not refuting the well known phenomenon of a ship producing more sound at higher speeds than at lower speeds. Instead they claim that this dependence on ship speed (or displacement) does not necessarily hold for the average spectrum of a large sample of ships.

Figure 3 is a plot of ship displacement versus speed for the 10 ships studied. The values adjacent to each point represent the total acoustic power integrated across the 5 Hz–16 kHz band for each ship.

Not surprisingly there is a tendency for the very large ships to travel more slowly (7–9 knots) and the possibility for the some of the smaller ships to travel faster (> 12 knots). It is interesting to note the lack of any correlation between acoustic power and ship speed, and acoustic power and displacement. The results of this small sample of ships entering or exiting a port are consistent with Wales and Heitmeyer's claim.

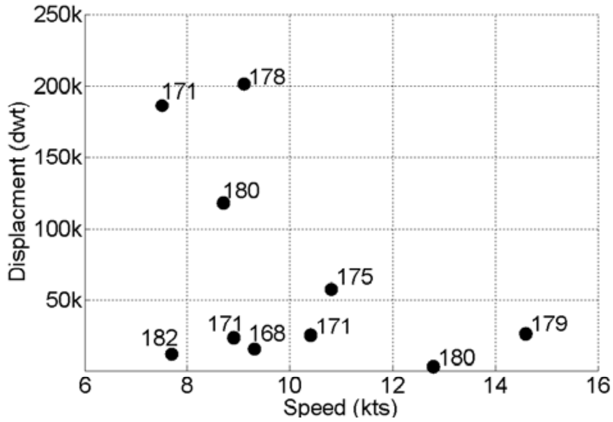

Figure 3: Displacement vs Speed for measured ships (labelled values denote the total acoustic power between 5 Hz–16 kHz)

Comparison with the empirical model by Ross

As mentioned previously, a number of authors have formulated empirical models to predict the sound spectrum of merchant ships as a function of particular ship characteristics. These models are created by compiling statistics on large numbers of different ships. An interesting exercise is to examine whether these models hold for the close range encounters in question.

A widely used model is that by Ross [1], which calculates an overall level above 100 Hz, L_S', and adds it to a "POST-WWII" baseline spectrum (Figure 8.20 in Ross). Equation 8.33 from Ross is used to calculate L_S', which is a function of ship speed and displacement tonnage:

$$L_S' = 112 + 50\,log\left(\frac{U_a}{10\,kt}\right) + 15\,log\left(DT\right) \qquad (1)$$

where U_a is the ship speed and DT is the displacement tonnage.

Values of L_S' were calculated for each of the 10 ships studied and were added to the "POST-WWII" spectrum to create a model prediction for each ship. The decibel average of these was taken to produce the Ross prediction curve in Figure 4. A quite good agreement is seen between the measured average ship spectrum and Ross' model prediction.

It was not possible to use the more widely quoted equation 8.35 from Ross, since data on the tip speed of propeller blades or the number of blades was not available for the ships in this study.

Also plotted in Figure 4 is data presented by Scrimger and Heitmeyer [3], which is an average spectrum from measurements of 50 merchant ships in the Mediterranean. The agreement between the three curves is good, with the largest difference being about 6 dB over the frequency band of comparison.

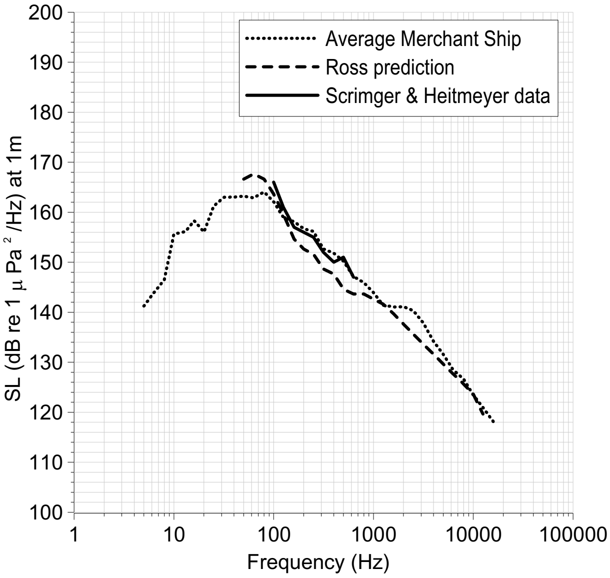

Figure 4: Average Merchant Ship source level compared to model by Ross and Scrimger/Heitmeyer data

Conclusions

Third-octave acoustic source level spectra are presented for 10 merchant ships measured while entering or exiting shipping ports. The use of a portable seabed range, cabled directly to a support vessel, allows measurement over a wider spectrum than is usually available from sonobuoy data. Investigations show that there is little or no source level dependence on ship speed or displacement for the ships measured. Based on this result, an average merchant ship spectrum is derived. It is expected that acoustic spectra of most merchant ships entering or exiting ports would fall within one standard deviation of this curve. The resulting average spectrum is found to be in good agreement with an empirical prediction model by Ross [1] and with average data from 50 ships by Scrimger and Heitmeyer [3].

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