Research Note

Radiated Noise Generation

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Introduction

The standard modes of signal transmission underwater are acoustic waves [1,2]. A large majority of marine life uses sound waves for regular movement, migration, mating,[3] and communication.[4] Keeping this in mind, the classification and analysis of sources of underwater noise becomes imperative. Out of the variety of sources of noise, the one of utmost importance is Radiated Noise from Ships. The first step towards dealing with noise is to estimate its sources and level. While most direct methods of measurement of radiated noise are rather expensive, a variety of simulation models exist which estimate the level based on a variety of inputs from a number of sources (such as AIS data). This work aims to present a high level view on the sources of noise, and then focus on Underwater Radiated Noise (from human shipping activities) and present various existing models for its estimation.

Noise

Noise is described as the ‘unwanted sound that interferes with the normal functioning of a system [5]. Noise in the ocean is the result of both natural and anthropogenic sources. Natural sources of noise include processes such as earthquakes, wind-driven waves, rainfall, bio-acoustic sound generation and thermal agitation of the seawater. Anthropogenic sources include shipping, oil and gas exploration, naval operations, fishing etc [6]. Anthropogenic sources are dominant at lower frequencies (10Hz to 500Hz). Especially at frequencies around 300 Hz, shipping noise interferes with the natural marine sound propagation considerably [7, 8]. Sources of anthropogenic noise are becoming both more pervasive and more powerful, increasing oceanic background noise levels as well as peak sound intensity levels. Thus, this report mainly focuses on noise generated by human shipping activities.

In the context of ships, noise can be classified into the following three types [9]:

1. Underwater radiated noise
2. Noise onboard the ship
3. Self-Noise

Of these, the most important class, which will also be the subject of our discussion, is underwater radiated noise. For commercial ships at service speeds, the main source of noise radiation is the phenomenon of cavitation at the propeller [10]. In his book, Donald Ross defines cavitation as the rupture of a liquid or of a liquid-solid interface caused by reduction of local static pressure. A rupture is the formation of a macroscopic or visible bubble [5]. Cavitation noise includes both broadband noise due to bubble collapse, and tonal components (components in a very narrow frequency band) that are related to blade passage frequency and higher harmonics. Additional factors such as machinery noise, vibrations in the hull and flow noise also contribute to the radiated noise level of the ship [6]. Peak levels for individual commercial ships is in the 10-50 Hz band at range from 195 dB re μPa2/Hz @ 1 m for fast moving ships (>20 knots) to 140 dB re μPa2/Hz @ 1 m for small fishing vessels [11]. Broadly speaking larger ships radiated more noise, and an increase in vessel speed increases noise radiated [6].

Noise Level Estimation Models

In this section we discuss a few existing models that estimate radiated noise levels based on various available parameters of the ships:

The Ross Model: The model proposed by Donald Ross, in his book *Mechanics of Underwater Noise,* assumes that the radiated spectra of surface ships are primarily due to the phenomenon of propeller cavitation. Thus, for speeds greater than that required for cavitation inception, the source level of noise as a function of ship parameters is given by

$$S(f) = S_0(f) + S'$$

Here, S_0, the base spectral level, applies to all ships moving at service speeds regardless of their type. The second term S' is the scaling term that takes into account various ship parameters [5]. The value of the base level can be calculated from the following expression

$$S_0(f) = 20 - 20log_{10}(f)$$

Where, f is the frequency at which the level is desired. In his book, Donald Ross cautions that this formula works only for frequencies over 100Hz. For the scaling term S', Ross gives the following two expressions

$$S_0 = 134 + 60log_{10}\left(\frac{V}{V_{ref}}\right) + 9\ log_{10}D_T$$
$$S_0 = 112 + 50log_{10}\left(\frac{V}{V_{ref}}\right) + 15\ log_{10}D_T$$

Where, D_T is the displacement tonnage, V is the speed of the ship and V_{ref} is taken to be 10 knots. As recommended by Ross, the scaling formula should not be used for ships over 30,000 tons [5].

The RANDI Model: This model is a modified form of the classical model proposed by Donald Ross. It was designed to predict the response of low- to mid-frequency sonar receivers to the ocean acoustic noise field in locations with highly variable bathymetry and range-dependent sound speed structure. Such environments are common of shallow water areas. This model uses parabolic equation propagation loss models to propagate energy from individual ships to the receiver array [12].
For this report, we consider an adopted version devised by M Liefvendahl et.al., in their paper [9]. According to this model the noise level comprises of the following three terms:

$$S_{RA}(f) = S_0(f) + S'(V, L) + S''(f, L).$$

The qualitative discussion of these terms is given below:

S_0 is the base spectrum of the RANDI model.
S' is the ship parameter based scaling term.
S'' is a correction term that is applicable only to frequencies below 200Hz.

The exact mathematical details of the model and its terms can be obtained from the paper by M Liefvendahl et.al. [9].

The Wales-Heitmeyer Model: The model proposed by Wales and Heitmeyer seeks to reduce the rms error of the classical Ross Model. The paper argues that the Ross model cannot describe the surface interaction propagation effects observed in the radiated noise spectrograms for some of the larger ships. Instead of using ship parameters as inputs, the Wales-Heitmeyer model uses extensive noise data of ships.

Wales-Heitmayer divide the source spectrum into two parts: 50-400 Hz and 400-1200 Hz. The justification given for this is that for frequencies above 400 Hz the source spectra showed a simple power law dependence, conversely, for frequencies less than 400 Hz many of the source spectra exhibited a more complex frequency dependence and there was a much greater variability in the spectra across the ensemble.

It uses a rational spectrum model whose parameters are determined by the statistical analysis of the collected noise data. The rational spectrum model provides a ship dependent spectrum that consists of linear combination of approximating functions. This model gives a better estimation of both the individual spectra and the variability than the Ross Model, as claimed by Wales and Heitmeyer in their original paper [13].

Wittekind Model: This model breaks down shipping radiated noise into three components namely:

- Low frequencies from propeller cavitation;
- Medium to high frequencies from propeller cavitation; and
- Medium frequencies from four-stroke diesel engines.

Hence the following parameters of the ship are considered in the model

- Displacement;
- Speed relative to cavitation inception speed;
- Block coefficient as an indicator for wake field variations;
- Mass of diesel engine(s); and
- Diesel engine resiliently mounted yes or no.

Source levels in the Wittekind model are given in terms of 1/3 octave band levels instead of source spectrum levels:

$$SL = 10log_{10}(10^{\frac{SL1(f_k)}{10}} + 10^{\frac{SL2(f_k)}{10}} + 10^{\frac{SL3(f_k)}{10}})$$

The first contribution, SL1(f_k), represents the low-frequency cavitation noise, SL2(f_k) represents the high-frequency cavitation noise, and SL3(f_k) the diesel engine noise.
SL1 and SL2 take the speed (V), the ship hull block coefficient, and the gross tonnage as inputs. The engine noise term SL3 takes in various parameters which take into account the Engine mass, no. of engines, and a measure of how rigidly the engines are mounted.
The terms SL1 and SL2 are derived by fitting a curve through experimentally obtained data. Details of SL1, SL2, and SL3 can be obtained from the paper by Wittekind [7].

AIS Data and its use

The input parameters to the various models described above can be obtained from the AIS data of the ship. Automatic Identification System (AIS) was developed in the 1990s by the IMO technical committee as a high intensity, short-range identification and tracking network. The information transmitted by the AIS can be categorized into Dynamic and Static. The dynamic category include information related to ship's navigational status, position, speed and course and is transmitted every 3 minutes if ship is underway and 6 minutes if the ship is anchored. The static category includes information such as ship's unique ID, name, dimensions, source, destination and estimated time of arrival and is manually fed into the AIS system by the ship's officers and transmitted on request [14, 15, 16]. As a tool, AIS can be used for many different functions such as [17]:

- Maritime Safety: Collision Avoidance
- Fishing Fleet Monitoring and Control
- Maritime Security (Suspicious vessel identification)
- Aids to Navigation
- Oil Spill Monitoring
- Ocean Currents Estimates
- Ocean Ambient Noise Mapping

Future Scope

In this section we highlight some possible areas of advancement in the study of radiated noise generation.

- **Optimized models taking into account particular vessel types in the Indian Ocean Region**- Several ship dependent parameters, which contribute to radiated noise levels, weren't included in the model devised by Wittekind. These include draft of the ship (small or full), positioning of the propeller, sinkage, trim, and height of stern wave etc.[18] The Lloyd Mirror effect (interference of oncoming and reflected signals) also has a strong influence on received levels and would need to be considered when deriving a source level [7]. A study can be done on the types of ships present in the Indian Ocean Region (which is a tropical littoral region), and the Wittekind model can be tuned accordingly to give the most accurate results possible for ships in the IOR.

- **Obtaining parameters for the Wittekind Model from AIS data** – All the parameters required for the Wittekind model are not easily available (or not directly a part of the AIS data of the ship). The knowledge of naval architecture can be used to derive these unavailable parameters from the available AIS data [7].

- **Devising more accurate models for radiated noise generation –** All the current estimation models only use a handful of ship parameters (mostly related to its operating conditions) as inputs. McKenna et.al. recommend that the number of ship parameters (relating to both design and operating conditions) be increased and oceanographic conditions be considered while devising noise models [19].

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