A STUDY ON THE ACOUSTIC TRANSMISSION CHARACTERISTICS OF INSHORE FISHING VESSELS FROM NEWFOUNDLAND AND LABRADOR

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This paper presents part of an ongoing research which aims to assess the risk of noise exposure of fish harvesters involved in the inshore fishing fleet from Newfoundland and Labrador (less than 24 m), and provide short-term (adoption of hearing protection devices, best practice, gear modification) and long-term solutions (vessel design procedures and noise control) to reduce noise exposure and levels. In order to identify long-term solutions, the authors used data on sound pressure levels of spaces during regular fishing trips from an in-situ noise survey program on board a representative sample of fishing vessels. They used these measurements to identify the airborne 1/3 octave band transmission losses (TL) between spaces in order to identify critical acoustic hot-spots on the visited fishing vessels. The authors used such data to suggest possible noise control solutions that can effectively abate noise levels on board fishing vessels, in order to increase the comfort on board and reduce exposure to high noise levels due to stationary continuous noise sources. The data and the interpretation of the TL curves presented in this paper can be useful to fishing vessels designer in order to have practical information on how to control noise on fishing vessels.

Keywords: transmission loss, fishing vessel, noise levels control, acoustic design of fishing vessels, safety on fishing vessels

1. Introduction

On-board noise and vibration control can be an important task in the design of marine structures, due to possible detrimental effects on crew and passengers if not properly considered. The presence of high on-board noise levels affect both comfort and health & safety (HS) of crew and passengers. Prolonged exposure to high noise levels is generally considered as the main risk factor for the onset of occupational noise-induced hearing loss (NIHL) [1]. Furthermore, high noise levels are concurring with other environmental stressors in increasing fatigue of seafarers and hence the risk of injuries or psycho-physical stress [2]. Designs that are particularly affected by this are, among others, cruise ships [3,4], super-yachts [5], and offshore structures [6], due to the required high standards of comfort and health safety. Noise control is also becoming important in the management of underwater noise signature of vessels, and can affect underwater acoustic pollution that impacts marine life (see e.g. [7]). Noise control and management on vessels from the small-scale, inshore fishing fleet has received little attention from designers and the fishing industry worldwide. Inshore fisheries are known for catching 45%
of the global catch [8], and the inshore fleet (less than 24 m) accounts for the 98% of the total fishing vessels [9], thus employing a tremendous amount of harvesters. HS and low habitability (i.e., minimum comfort requirements) as a result of elevated noise levels can potentially involve a large amount of people worldwide. Noise control on small fishing vessel is often not considered in design phase, as reflected by the absence of a consistent regulatory framework. The reference regulation from IMO on noise levels and control does not include fishing vessels [10]. The regulations on the matter for small fishing vessels safety are fragmented and often voluntary [11]: for inshore vessels having lengths overall (LOA) less than 24 m the ILO [12], IMO and FAO [13] produced a set of voluntary guidelines for owner/operators which provide guidance for the safety on the vessel design and during fishing operations [12, 13]. These guidelines do not provide though design procedures for noise control for fishing vessel designers.

The literature on the topic is scarce. Noise levels on fishing vessels of different spaces and at various speed were reported in studies where the main goal was the characterization of noise exposures [14, 15, 16]. Studies that provided a more thorough description of the noise control issue, through the identification of noise sources, levels, transmission and noise mitigation packages, are even scarcer and covers vessels equal to 16.99 m LOA or longer, neglecting smaller vessels [17, 18]. The cited studies found rather high noise levels and a potential for hazardous noise exposures of the crew. From these research activities, it was concluded that noise control was an issue for these vessels.

This study is part of an ongoing research for the development of a multi-pronged strategy to reduce the risk of hazardous noise exposure of fish harvesters from the Newfoundland and Labrador (NL) inshore fishing fleet (LOA less than 24 m). This can be accomplished by providing: a) short-term solutions, via the adoption of hearing protection devices, best practice, minimal vessel and gear modification; b) long-term solutions, via the development of vessel design procedures for noise control for designer of small fishing vessels. This paper deals with the development of long-term solutions and is part of an orderly procedure to assess critical noise levels [19], to study the transmission on board, and to propose noise mitigation packages to abate levels to acceptable levels. In this research, the authors used sound pressure levels measured onboard to study the acoustic transmission characteristics of 7 decked fishing vessels ranging from LOA 10.66 m to 19.81 m, based on the relevant standards [20, 21]. These data are then used to identify possible critical features in the airborne noise transmission from the main noise sources (the engine and auxiliary machinery in the engine room) to the relevant spaces on board, and to suggest possible intervention on noise control features to reduce noise levels. Such data increase the available literature on the acoustic characterization of small-scale fishing vessels and provide guidance on how to address preliminary noise control in these cases.

2. Methods

2.1 Survey trips and sound pressure levels measurements

Table 1 presents the sample of surveyed vessels. The selection of the vessels sample was conducted in [19], based on a study of the NL inshore fishing fleet composition. Owners of vessels with representative characteristics were contacted through personal contacts provided by the Newfoundland and Labrador Fish Harvesting Safety Association (NL-FHSA). Once they consented to participate to the research, arrangements were made for the authors to travel on board during regular fishing trips. The measuring trips were scheduled according to the vessel and researcher availability, so that some details like the weather could not be controlled.

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1 International Maritime Organization
2 International Labour Organization
3 Food and Agriculture Organization
Table 1: Characteristics of the surveyed vessels. GRP stands for fiberglass made vessels. OB stands for Outboard, IB stands for Inboard, 4s stands for 4 strokes.

<table>
<thead>
<tr>
<th>Vessel ID</th>
<th>Vessel type</th>
<th>Length (m)</th>
<th>Vessel material</th>
<th>Engine Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel 1</td>
<td>1 Deck aft wheelhouse</td>
<td>10.7</td>
<td>Wood</td>
<td>150 IB, 4s</td>
</tr>
<tr>
<td>Vessel 2</td>
<td>11.9</td>
<td></td>
<td>Wood</td>
<td>306 IB, 4s</td>
</tr>
<tr>
<td>Vessel 3</td>
<td>1 Deck front wheelhouse</td>
<td>10.7</td>
<td>GRP</td>
<td>205 IB, 4s</td>
</tr>
<tr>
<td>Vessel 4</td>
<td>10.7</td>
<td></td>
<td>Wood</td>
<td>217 IB, 4s</td>
</tr>
<tr>
<td>Vessel 5</td>
<td>1.5 Decks</td>
<td>15.5</td>
<td>GRP</td>
<td>624 IB, 4s</td>
</tr>
<tr>
<td>Vessel 6</td>
<td>18.3</td>
<td></td>
<td>GRP</td>
<td>624 IB, 4s</td>
</tr>
<tr>
<td>Vessel 7</td>
<td>2 Decks</td>
<td>19.8</td>
<td>GRP</td>
<td>624 IB, 4s</td>
</tr>
</tbody>
</table>

During the fishing trips, the authors measured stationary steady-state continuous noise levels on spaces inside the vessels while the engine, auxiliaries and generators were running. The measures were taken at maximum sailing speed when the vessels travel to, from and in between fishing grounds. Stationary noise was acquired using a setup composed by a Class 1 PCB Piezotronic® mod. 378B02 ICP free field microphone connected to a National Instrument® mod. 9234 BNC input card, that was connected via USB to a Toshiba® Toughbook laptop computer. The sound pressure level was acquired continuously at 52.6 kHz. Care was taken so that the microphones were placed on the center of the space away from surfaces. The software end of the acquisition system was coded using LABView®.

### 2.2 Study of acoustic insulation characteristics

The standardized level differences $D_n$ were computed using the procedure from [20, 21] in order to characterize the acoustic insulation from source to receiver spaces. Time-domain sound pressure measures were postprocessed using LABView®. Signals were filtered by third octave bands, and the mean sound pressure levels $L$ for each band obtained:

$$L = 10 \log_{10} \left( \frac{1}{T} \int_0^T \left( \frac{p(t)}{p_0} \right)^2 \, dt \right)$$  \hspace{1cm} (1)

In Eq. (1), $T$ is the length of the time domain record of the sound pressure, $p(t)_{1/3\text{oct}}$ the filtered third octave band sound pressure and $p_0 = 20 \mu\text{Pa}$ is the reference sound pressure.

The standardized level difference $D_n$ used to compute the airborne transmission loss (TL) was assessed according to Eq. (2), as reported in [21]:

$$D_n = L_1 - L_2 + k + 10 \log_{10} \left( \frac{A_0 T_0}{0.16 V} \right)$$  \hspace{1cm} (2)

where $A_0 = 10 \text{m}^2$ is a reference absorption area, $T_0 = 0.5 \text{s}$ is a reference reverberation time, $L_1$ is the third octave band level in the source space, $L_2$ is the third octave band level in the receiver space, $k$ is the third octave band reverberation index, and $V$ is the volume of receiver room in $\text{m}^3$. Since no measure of reverberation time was possible, $k$ is obtained from the standard values table presented in [21]. No background noise correction was applied. This measure was not possible due the inability to stop the engines and generators at sea.
3. Results and discussion

Figures 1 to 4 show the airborne transmission paths considered from the measures of sound pressure levels. The spaces considered were enclosed spaces that are manned by crew during sailing phases. Transmission to the decks exposed to the weather was not considered due to the presence of the exhaust muffler: free-field acoustic power transmission of this source could be more dominant than the transmission from the machinery in the engine room. Generally the layout of the dividing surfaces is similar for vessels of the same material construction: on wooden vessels, they will be mainly composed of wooden planks that might be covered with layers of GRP and mounted on a wooden beam frame; on GRP vessels, they are made of plywood covered with layers of GRP and mounted on wooden beam frame. Generally no acoustic trim is applied on these surfaces. Values for the volume \( V \) of receiving spaces ranged from 4.0 \( \text{m}^3 \) to 29.7 \( \text{m}^3 \) for wheelhouse, 14.7 \( \text{m}^3 \) to 46.0 \( \text{m}^3 \) for messrooms, 4.0 \( \text{m}^3 \) to 11.5 \( \text{m}^3 \) for crew spaces. Figures 5 and 8 show \( D_n \) for groups of similar vessels. \( D_n \) was chosen as the TL measure because it is required in [20] when source and receiver spaces are not adjacent, as in some of the visited vessels (see crew spaces of the vessel in Fig. 2 or the wheelhouse in Figs. 3 and 4).

The obtained \( D_n \) curves follow similar trends for all the vessels. At lower frequencies (up to almost 1000 Hz) the curves slowly rise and at higher frequencies the curves are almost flat. It is important to state that TL is affected by flanking and structure-borne sound transmission because the sources are not purely airborne sources and are mounted in all cases rigidly to the vessel’s structures (except for the generators that are mounted on resilient).

Among all the presented cases, the acoustic insulation of vessels such as Vessels 1, 2, 3, 4, and 5 was found in line with [18] where at low frequency the values is as low as 5\,dB to increase to 30\,dB–40\,dB. This is seen in particular for the case of spaces adjacent to the source engine room, as in the transmission to Wheelhouse (all vessels) and to Crew Spaces (Vessels 3, 4, and 5). In the latter case, Vessels 3 performs better than 4 in Fig. 6, probably due to the different layout of the separating bulkhead. The presence of gaps between the planks that compose the bulkhead of Vessel 4 might reduce the airborne
acoustic insulation provided by the surface. Higher TLs are identified for Vessels 5 and 6. In this case, the effect of a smaller dividing surface between adjacent spaces is demonstrated by the higher $D_n$ values for Vessel 6 compared to 5 in the case of Crew Spaces. There seems to be an increase of TL when the receiver space is separated by other spaces from the source space, as in the case of Wheelhouse in Vessels 6 and 7, compared for instance with Vessel 5 (Figs. 7 and 8). The TL to Messroom in Vessel 7 (Fig. 8) is affected by the proximity to the engine room access door. The TL curve associated to the corridor entrance is the one closest to such door, and is sensibly lower than the one of the same space but away from the door, represented by the Messroom TL curve. The same behaviour is seen in the Wheelhouse TL from Fig. 8 where the starboard side is the closest to the stairway to the lower deck, and the cabin is a divided space withing the Wheelhouse.

From the analysis of the TL curves, acoustic insulation could be an poor when the space are adjacent and shares a dividing surface. In these cases, the insulation could be so low to induce high noise levels

$^4$ Surface area of 7.66 m$^2$ for Vessel 5 as opposed to 4.25 m$^2$ for Vessel 6
in the receiver spaces. Often these spaces are living quarters and continuously manned spaces, where levels has to be contained to acceptable levels. For instance, levels can be as high as 83 dB(A) in the crew spaces at max speed \[19\], which is 23 dB(A) higher than the requested criteria for commercial ships \[10\]. It is then advisable to increase the TL of such separating surfaces in order to cut the airborne transmission of sound directly at the source and hence insulating the sources in the engine room as much and as conveniently as possible. Such solutions should involve the use of resilient mounts for the engine and auxiliaries and a proper design of the engine foundation, that is known to effectively cut off the structure-borne sound \[22, 23\], the adoption of an optimized acoustic trim for the surfaces of the engine room and the acoustic insulation of doorways to the engine room.

4. Conclusions

This paper presented a study on the acoustic insulation characteristics of 7 fishing vessels from the Newfoundland and Labrador (NL) inshore fleet. The acoustic TL from sources (engine room) to receiver spaces (relevant manned spaces inside the vessels) were calculated in terms of standardized level difference $D_n$ using the measurements of sound pressure levels from an in-situ survey program conducted.
during regular fishing trips. The authors conducted this research as part of an orderly procedure to assess and mitigate noise levels on fishing vessels to acceptable levels. This procedure includes: 1) measurement of noise levels and identification of the noise sources; 2) characterization of the acoustic insulation on the existing vessels; 3) assessment of the acoustic power transmission by means of numerical methods; 4) identification of critical hot-spots in the acoustic design and proposal of noise mitigating solutions. This procedure can be the basis for a guideline for designers to include noise control on fishing vessels design. The acoustic insulation performance of surfaces of the visited fishing vessels due to airborne and structure-borne transmitted acoustic power was presented in terms of standardized level difference $D_n$. Even though the insulation performance of spaces away from the sources is satisfactory, improvements in TL is advised between spaces adjacent to the main source, the engine room. This is important since usually the adjacent receiver spaces are living and continuously manned working quarters. The presented TL data for fishing vessels and interpretation can be useful for fishing vessels designers who need to address noise control on fishing vessels.

Further research will involve the acoustic modelling of a case study vessel using Statistical Energy Analysis (SEA) in order to identify critical sound transmission paths and to propose and evaluate the effect of noise mitigation packages.

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REFERENCES