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A SOURCE MODEL FOR AIRBORNE NOISE FROM SHIP TRAFFIC IN FAIRWAYS

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ABSTRACT

Noise from transportation is a major global health problem, and exposure is mainly dominated by road traffic noise, followed by railway noise and aircraft noise. Noise from shipping has mostly been investigated in relation to ships at berth, and is most often due to ships running their auxillary engines to provide power for necessary systems. To what extent noise from ships underway between ports may be a cause for annoyance or otherwise have a negative health impact is very poorly investigated. In a recent project airborne noise from ships underway in the fairway leading in to the Port of Gothenburg, Sweden, was recorded for a relatively large number of ships. The measurements indicated that for some low frewquency one-third octave bands, levels are high enough to exceed Swedish indoor low frequency noise regulation levels even at relatively large distances. In the current project the aim is to use detailed AIS data together with ship register database information in an attempt to create a source model for airborne noise from ship traffic in fairways, similar to what is available for other modes of transport. Such a source model could then be used to predict noise levels around ports and fairways.

Keywords: airborne ship noise low-frequency

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1. INTRODUCTION

Airborne noise from ships is mainly considered as a noise source when ships are moored, and is thus part of the general noise emission from in-port activities. Several research projects and other efforts to quantify noise from port activities exist and for an excellent and comprehensive overview of methods and regulatory efforts regarding airborne noise from shipping, see Biot et. al. [1]. The overview mentions voluntary efforts from Classification Societies such as DNV-GL or Lloyd's Register to include noise emission levels in their classifications. One of these, Lloyd's Register, specifically mentions airborne noise from "free sailing" ships, i.e. ships underway in fairways, canals or close to ports. The overview also presents methods for measuring and modeling noise from ships at berth. These methods adopt advanced multi-point measurements to make an inventory of all sources contributing to the radiated noise, and allow for detailed comparisons like the effect on noise propagations from removing objects on certain deck levels. Such measurements are very useful for classification purposes as the total noise emission from a specific vessel is described in detail, but it is not as well suited for noise mapping purposes since those rely on the yearly average traffic situation where keeping track of individual vessels that does not enter a certain port regularly is not very pratical. Also, the suggested noise classification relies on A-weighted noise levels which severely underestimates the low frequency content which is a major part of the noise emission from ships underway. The Swedish Maritime Administration have investigated potential airborne noise exposure from planned establishment of new or altered fairways in a few cases. One investigation presents a noise map using A-weighted levels and concludes the exposure is very low.

The source data for passing ships is not presented but is described as "sound power for a ship of 8000 DWT travelling at 7 knots has been assumed. The sound power is Lw = 98 dBA or 56 dBA at a distance of 30 m från the ship. Sound power and frequency has been obtained from earlier measurements by Ramboll and has been frequency adjusted to ships of 8000 DWT through analysis of available data from relevant technical literature." [2] No further explanation is given for how the adjustments are done. An earlier municipal investigation about potential noise exposure from passing ships in planned dwellings along the Södertälje Canal presents thorough measurements of noise from a few passing ships, and an exhaustive analysis of A-weighted versus C-weighted levels to evaluate the low frequency content [3]. These measurements have since been referred to in most cases of potential noise exposure for new dwellings close to shipping lanes in Sweden. The current paper presents initial efforts in the ongoing project "SEAS - Samhällsekonomiska analyser för sjötransporter" (Socio-economic analyses for sea transportation) to develop a method for measuring and calculating noise source terms for noise mapping of ships underway in fairways close to dwellings.

2. MEASURING AIRBORNE NOISE FROM SHIPS

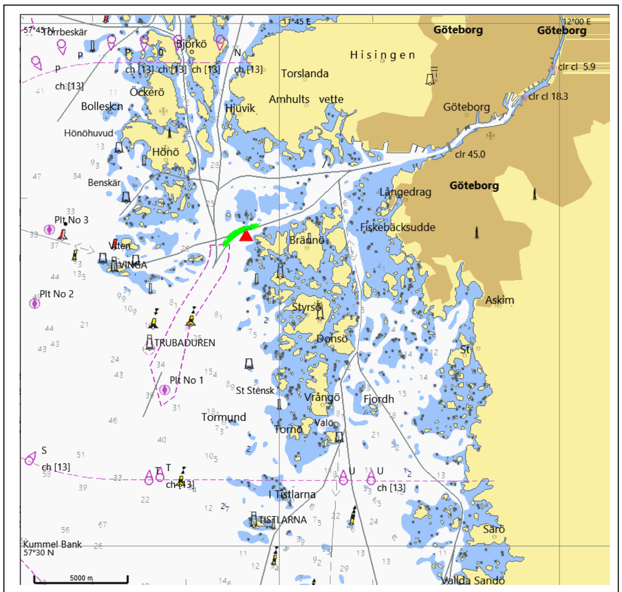


Figure 1: Position of measurement station (red triangle) in the inlet to Port of Gothenburg.

In the recent project "Silent@Sea" a sound mesurement station was positioned on a small islet next to the fairway leading in to the Port of Gothenburg, Sweden [4]. The aim was to record sound from a few specific ships that were planned to pass by the station, but as part of the method developement, sound from regularly passing ro-ro ferries was also recorded. The measurement station was equipped with an AIS receiver collecting position and speed data from all ships in the area. Fig. 1 shows the position of the measurement station in the inlet to the Port of Gothenburg. The measurement station was programmed to trigger on proximity of any of a specified list of ships identified via their unique MMSI number broadcasted by their AIS transponder and then record sound for about 10 minutes in order to catch the entire ships passage.

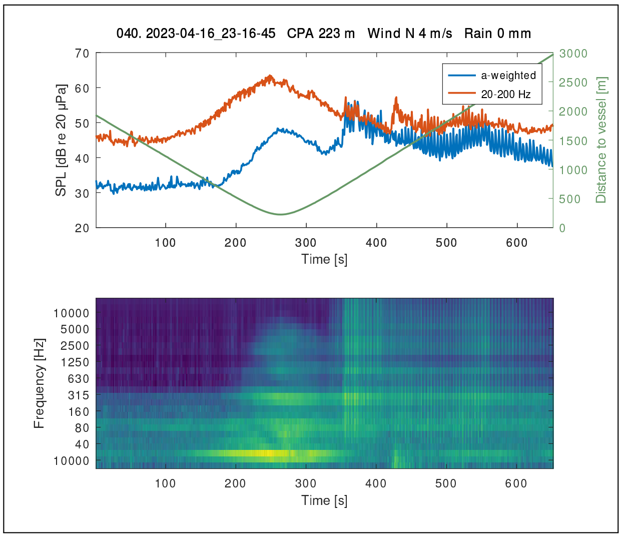


Figure 2: Momentary levels (A-weighted in blue, low-frequency in red) and spectrogram for a single ships passage at the measurement site as well as distance between vessel and receiver (in green).

One of the ro-ro ferries was chosen to investigate the potential to use these pass-by noise measurements as basis for a simplified noise source model. 243 passages of the ro-ro ferry was registered in total, but many of them were passges in the northern fairway that was too far from the measurement station to be useful. Visual inspection of signal to noise ratio for the remaining passages resulted in discarding a large amount of recordings due to dominating wind noise at wind speed above 5 m/s. Finally there were 18 passages remaining that were useful for further analysis. Of these, the single best passage from a signal to noise viewpoint was chosen to test a method for determining source terms for airnorne noise from ships underway, in a similar manner to road and rail traffic.

Fig. 2 shows momentary A-weighted sound pressure levels at the measurement station as well as a time-frequency spectrogram. Since the large main engines of a ro-ro ferry produces high levels of low frequency noise at the funnel, the A-weighted momentary sound pressure level calculations were supplemented with the momentary sound pressure levels for the frequency range between 20 Hz and 200 Hz, representing a single value low frequency level that can be juxtaposed to the A-weighted values.

Fig. 2 also shows the distance from the measurement station to the ro-ro ferry during the passage. As can be seen, the recording starts at a distance of about 2000 m and the ferry eventuelly reaches it's closest point of approach (CPA) at a distance of 223 m and then recedes until the recording stops at a distance of about 3000 m. It can also be seen that after about 320 s there is a sharp increase in sound pressure level over most of the frequency range. This is due to the wake of the ship reaching the islet where the measurement station was positioned causing waves to crash on to the rocks, and care was taken not to include that in the noise attributed to the passage of the ship.

3. DETERMINING SOUND POWER LEVELS

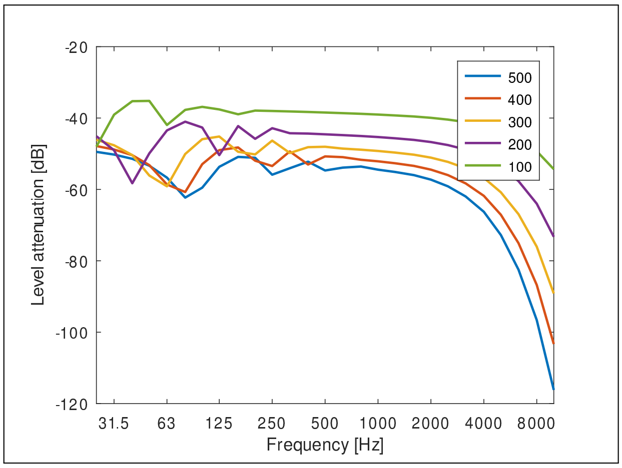


Figure 3: Distance attenuation as a function of frequency for a few distances between 100 and 500 m calculated using Nord2000.

In order to determine sound power levels of the passing ro-ro ferry the effect of the propagation from the passing ferry to the measurement microphone needs to be inversed. Inspired by a method for determining source terms for road traffic noise from road side measurements, NT ACOU 116 [5], the sound propagation was calculated using the Nord2000 noise prediction method. Setting source height to 40 m corresponds reasonably well with the ro-ro ferries that need to pass under a bridge at the mouth of the river that has a maximum clearence of 45 m. The receiver height was measured to be 10.5 m above sea level. Fig. 3 shows the effect of sound propagation calculated using Nord2000 using the given source and receiver heights and five different distances between 100 m and 500 m. As the source is moving, the effect of the sound propagation needs to be calculated in steps for each updated distance between source and receiver. In order to do so, the distance attenuation was calculated for each 1/3 octave band between 25 Hz and 10000 Hz, which are the limits of the Nord2000 method, for each of the distance values obtained from the recorded AIS data (Fig. 4).

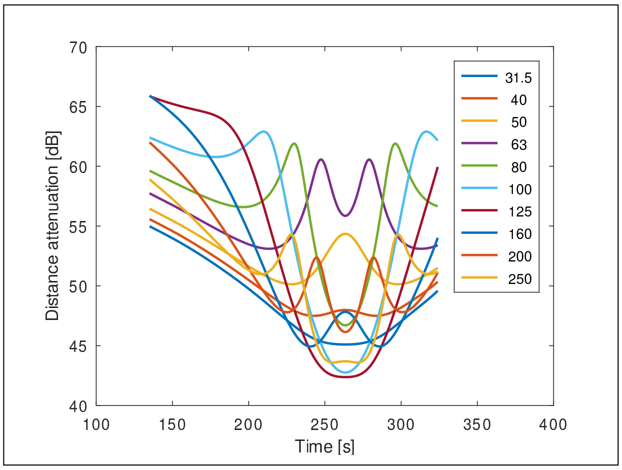


Figure 4: Distance attenuation as a function of time for a few different 1/3 octave bands calculated using Nord2000.

Finally the part of the recorded time signal that contained sound of the ship passage above the background noise level was filtered into 1/3 octave band time signals, the time dependent gain calculated for each 1/3 octave band was applied and the sound power levels were the calculated by summing the energy within each frequency band (Fig. 5).

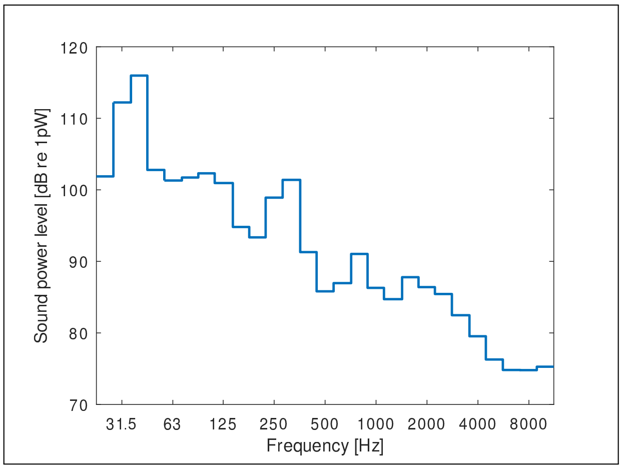


Figure 5: Source sound power levels for each 1/3 octave band calculated from ro-ro ship pass-by recording.

For clarity the source terms are also presented in Tab. 1.

4. PRELIMINARY NOISE MAPPING

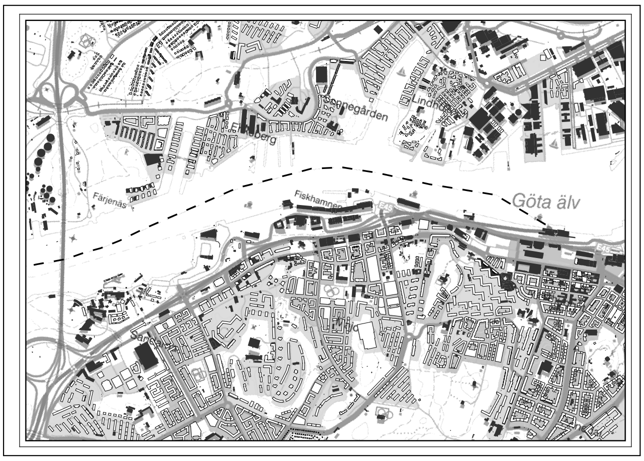


Figure 6: The modeled area for airborne ship noise contour calculations.

In order to test these new sound power levels representing a ro-ro ferry underway a noise map was created using only the ro-ro ferry as source, i.e. ignoring other sources such as nearby road or rail traffic. The area chosen for the noise mapping can be seen in Fig. 6 and represents the innermost part of the port of Gothenburg at the mouth of the river Göta Älv. The ro-ro ferries berth at the south river shore a few kilometers up river (following the dashed line in Fig. 6) so the model for the noise map contains buildings along the river where the ferries pass.

Table 1: Ro-ro ferry noise source sound power levels per 1/3 octave frequency band.

Freq.	Lw
25	101.7
31.5	112
40	115.9
50	102.7
63	101.2
80	101.6
100	102.2
125	100.9
160	94.7
200	93.3
250	99.1
315	101.2
400	90.7
500	84.7
630	85.4
800	89.1
1000	86.4
1250	83.2
1600	87.2
2000	85.9
2500	85.1
3150	82.8
4000	80.8
5000	77.9
6300	75.7
8000	75.3
10000	75.6

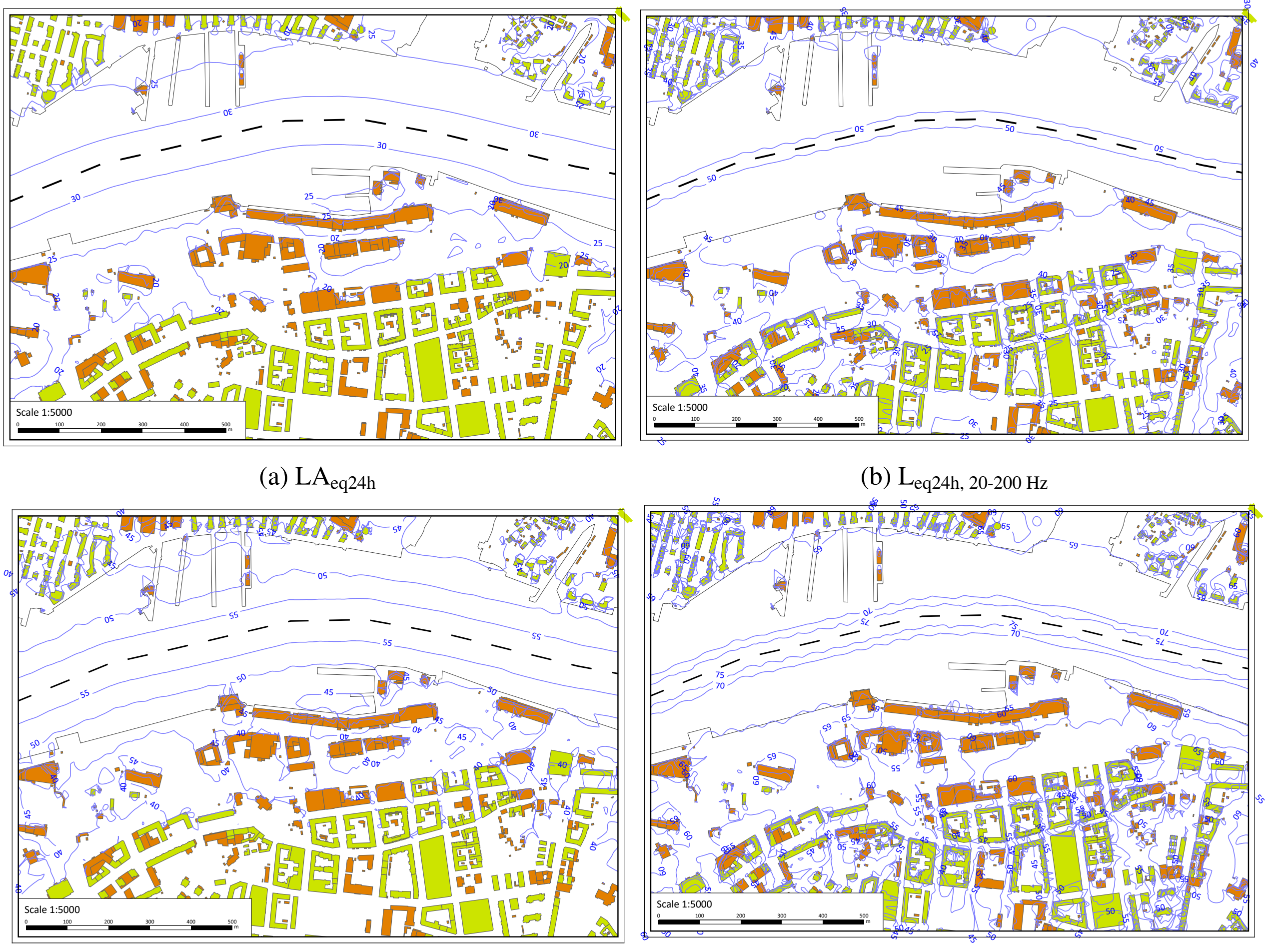
According to the time table there are four departures a day, and the speed is restricted to 5 knots or about 10 km/h, which together makes a basis for calculations of equivalent noise levels. Fig. 7 presents some preliminary noise contours for a part of the area around the Göta Älv river where the ro-ro ferries pass. As expected, A-weighted levels are below any noise policy limit levels. As there are only four ship passages per day, the 24h equivalent levels are also generally low. Thus, the A-weighted 24h equivalent levels are as low as 30 dB(A) close to the ship and only 20 dB(A) at the closest buildings. The A-weighted maximum levels reach about 40 dB(A) for the closest buildings which is also well below regulated levels for dwellings. When looking at just the low frequency content the levels are naturally higher. 24h equivalent level for frequencies between 25 Hz and 200 Hz reaches 40 dB - similar to the A-weighted maximum level. For maximum level in the 25 Hz to 200 Hz range the closest buildings are exposed to about 60 dB. There are no regulated limit values in Sweden for low frequencies outside dwellings, but considering the low efficiency most window constructions exhibit for sound reduction at low frequencies it is likely that the low frequency indoor levels are relatively high depending on the noise reduction properties of the façade and the interior room dimensions. The Swedish Public Health Agency has recommendations for maximum indoor low frequency levels Tab. 2. These recommended indoor low frequency limit levels are mainly developed for continuous, stationary noise sources and are not used for noise from traffic. The limit values are presented as equivalent levels but without a specification of a time period such as 24h, so it is unclear if the noise contours in the map represent levels comparable to those indoor noise limits.

Table 2: Swedish Public Health Agency recommended indoor low frequency noise limit values.

Freq.	Lp
31.5	56
40	49
50	43
63	42
80	40
100	38
125	36
160	34
200	32

5. DISCUSSION

This paper presents an initial effort to develop a method for determining source terms for airborne ship noise mapping. The work will continue by analyzing hundreds of additional available pass-be recordings in order to create source terms for a few vessel classes based on e.g. DWT. The classes need to include average noise source terms as well as average source height. In the preliminary noise mapping presented here the source height was set to 40 m for the ro-ro ferry, but that is in reality only valid for the lower frequency bands where the main engine firing rate determines the fundamental frequency of the sound from the funnel. Informal listening to the pass-by noise suggests that much of the broadband sound in the higher frequency range comes from the bulbous bow pushing water in front of the vessel. That type of sound source has a source height of perhaps 0 - 2 m, which would both affect the source term calculations as well as the noise propagation calculations and will therefore be part of the coming work within the project. Other common sources are different types of ventilation fans, but as these can be placed almost anywhere around the ship, it is hard to describe them as a source valid for an entire class of ships. Another important aspect is the calculation of maximum noise levels. Two main properties influence calculated maximum noise levels. First is the variation in the source sound power levels in different frequency bands between individual ships within each class. For road traffic noise this is handled by calculating a standard deviation for each vehicle class which is used to determine the probability that a particularly loud vehicle will pass by regularly depending on the average number of passing vehicles. Something similar could be calculated for classes of ships provided a large enough number of ship pass-by measurements within each class. The second property affecting the maximum levels is the distance between source and receiver. Ships follow the fairways available, but have some freedom in lateral position within the fairway depending on the width within which required under keel clearance is available. Using available AIS data providing positions for each passing ship a statistical measure of the lateral spread can be calculated and thus the corresponding variation in maximum noise level at the receiver. The existing indoor low frequency noise level limits recommended by the Swedish Public Health Agency are not well suited for intermittent noise like that from ships or from other modes of traffic with high levels of low frequency noise such as air traffic. It would be very beneficial to develop measures similar to



(a) LA_{eq24h} (b) $L_{eq24h,\ 20\text{-}200\ Hz}$

(c) LA_{max} (d) $L_{max,\ 20\text{-}200\ Hz}$

Figure 7: Calculated noise contours along a section of the river where to ro-ro ferries pass four times a day. Contours are presented for both a-weigted levels (left) and for low frequency levels (right). Residential buildings are green and other buildings are orange.

the L_{eq24h} and L_{Fmax} measures used for road, rail and air traffic, but it falls outside the scope of the SEAS project. The main focus of the project in the continuing work is on the low frequency part of the airborne noise representative for a few classes of ships, underway in fairways close to dwellings.

6. ACKNOWLEDGMENTS

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