Setting of on board noise sources in numerical simulation of airborne outdoor ship noise

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ABSTRACT. Nowadays, noise pollution is more and more increasing owing to the growth of industrial production and road and rail traffic. Harbours are certainly ones of the most sensitive areas as, in the last decades, they have become sites for development of industrial activities and goods trades, with a following unavoidable increase in noise pollution. Ship is one of the noise source that most contributes to the overall noise pollution in harbour areas.
A recent European research project called BESST is aiming to improve knowledge about ship noise in order to propose proper actions to reduce noise pollution and new uniform criteria and limits for noise radiated to European harbours. Among the various aspects that the scientific community should examine, determination of a proper computational tool to predict outdoor noise generated by ships right in ship's design phase is one of the main things.
In the present study, carried out at the University of Trieste, an operative procedure for predicting ship's outdoor noise in harbour is proposed. Procedure is outlined in all its steps from the pre to the post processing phase giving more emphasis to the noise sources setting within the numerical simulation. Effectiveness of the method has been proved by application to a case study.

INTRODUCTION

A procedure for estimation of outdoor ship noise has defined to predict noise generated in harbour by ships. The aim is to give to designer a tool for checking the level of noise pollution around a ship and for comparing it with the rule limits which are coming into force for European harbours.
The procedure has conceived to be effectively applied just in ship's design once type, power and arrangement of ship's plants had defined. On board we can find different noise sources, the main ones are the conditioning plants and especially all machinery in engine rooms. The main part of the outdoor noise comes from the outer openings of engine rooms for air supply to diesel engines and auxiliary machinery and for extractor fans of exhaust gas system. Also HVAC (Heating, Ventilation and Air-Conditioning) system radiates noise from outer openings. The typical positions of the noise sources on board a cruise ship are shown in Fig. 1. Most noise sources are located near the funnel: in this area are placed openings for both the engine rooms and auxiliary rooms ventilation systems and for the combustion air supply of the main engines and auxiliaries. At the level of the funnel foundations engine rooms exhaust air fans are also sited. Other important noise sources are the air conditioning openings usually located along the ship's side for about the whole ship's length.
To properly apply the noise prediction procedure, noise sources need to be characterized in terms of sound power level L_W, directivity index and emission angle. Noise sources setting is a necessary step to obtain an accurate and reliable numerical simulation. Setting is based on field measurements taken in the near field on board ship. Further measurements taken at a reference point where noise pollution has to be checked may help in validating the whole procedure. All

checking comparison are made in terms of sound pressure level (SPL) values. In the present study, analysis of the acoustic field is carried by making use of the Raynoise software, which is based on the Beam Method, that is a hybrid method which merges the best features of the Mirror Image Source Method and the Ray-Tracing Method.

Figure 1: Position of the main noise sources on board a cruise ship.

THE OPERATIVE PROCEDURE FOR SHIP'S OUTDOOR NOISE PREDICTION

The operative procedure for ship's outdoor noise prediction proceeds from the identification of the main onboard noise sources in terms of their nature and location. At the same time, the main characteristics of the ship's outer geometry (ship's side layout, upper deck arrangement and, in case, funnel geometry) along with the layout of the harbour (i.e., buildings, different obstacles, other ships, etc.) need to be defined. In a second step, all noise sources data have to be derived basing on board measurements.

Then, the geometry 3D model may be created including all the bodies which lie in the acoustic field. For each body, that part of the outer surface which interacts with sound radiation field needs to be generated with suitable accuracy. The materials characteristics are to be defined for each surface. In particular, it is necessary to define the absorption coefficients and, in case, the transmission coefficients. Furthermore, environmental characteristics such as temperature and relative humidity of the air are to be chosen.

Finally, each ship's noise source may be characterized by a sound power level octave-band spectrum and by information about directivity and emission angle and diffraction may be simulated by assigning to any selected geometrical edge the quality of "diffraction edge". Before to start simulation, the ray-tracing parameters are to be set, that are the number of rays and the reflection orders.

In the mapping phase, a field points plane need to be defined by generation, within the acoustic field, of a surface where collecting the simulation results in terms of pressure or sound pressure level. In the post processing phase, also consistency between the actual acoustic field and the numerical model is to be checked. If results are judged not to be accurate enough, a best setting of the procedure is then required. Iteration is developed by changing some acoustic parameters, noise sources characteristics included.

DETERMINATION OF NOISE SOURCES' CHARACTERISTICS

In order to obtain an effective simulation and good results, particular attention should be paid to the determination of noise sources' characteristics.

Sources are characterized by several factors. The first step is determining the sound power level for each octave band L_{Wf}. To do that, sound pressure level or sound intensity on board measurements of each source are required. Actions to determine the sound power level may be taken according to ISO 3744 (Sound power level is determined by means of sound pressure level measures), or by resorting to ISO 9614 (Sound power level is determined by means of sound intensity measures). In both cases, background noise level should be measured and it should be checked that the difference between the background sound pressure level and sound pressure level of each source is at least 10 dB(A).

In accordance with ISO 3744, to calculate sound power level, first of all, a hypothetical reference box has be defined as envelope of the source; a second hypothetical box containing the first one has to be identified by a proper procedure. As stated by the standard, sound pressure levels are measured on the surface of the outer box (measurement surface) and the sound power level L_{Wf} of the noise source is calculated as:

$$L_{\mathrm{Wf}} = L_{\mathrm{pf}} + 10 \log \frac{S}{S_0} + E$$

where L_{pf} is the A-weighted sound pressure level measured on the measurement surface for any octave band, S is the measurement surface in square metres, S_0 is a reference surface area of one square metre and E is near field correction.
Sound power level may also be derived from sound intensity measures taken on a proper measurement surface in accordance with ISO 9614. In case study discussed in the following, sound power levels have been calculated from sound pressure level measures.
To completely characterize any noise source the source emission angle and the directivity index should also be determined. The former parameter may be simply estimated by a visual survey, the latter one is defined by the spatial distribution of the parameters D_i, given by $D_i = L_{pi} – L_{pi}$, where L_{pi} is the sound pressure level measured at the i-th position and L_p is the sound pressure level averaged over the measurement surface.

NOISE SOURCE SETTING

The procedure for noise source setting is shown with reference to a case, study hereunder described in the main features, aimed to noise pollution assessments. A large passenger ship, a 290 meters long, 110,000 DWT cruise ship, has been considered as the only noise source in the whole acoustic field; the typical onboard noise sources have been accounted. The ship is considered to be moored along the a quay of an Italian harbour. Around the ship, for an extent of about a ship's length measured in all directions, the quay is free from obstacles except for a small built-up area – more specifically, a cluster of small houses is within a distance of about 0.5 to 1.5 ship's length. A 3D geometry model of the harbour configuration and of the ship is shown in Fig. 2.
The noise sources which take part in the overall ship noise have been identified and a screening of the sources has been made, disregarding those that, because of their low sound pressure levels, negligibly contribute to the overall sound pressure level. Three main sources have been recognized: the diesel engines exhaust gas, which carries to the upper outlets the noise generated by engines, the outdoor openings at the end of ducts serving the engine rooms exhaust air fans and the outdoor openings of the air conditioning system. To set the sources, data available to the shipbuilder are used together with data collected by author within the BESST project and aimed at supplement the shipbuilder data. The sound power level of each source has been calculated in accordance to the ISO 3744 standard.
To check the sources data, the Raynoise software has been used. Checking is considered necessary on data not specifically taken for harbour noise prediction, such as those taken by the shipbuilder to the purpose of comfort estimation on open decks. To verify accuracy of the sound power level calculations, a comparison has been performed between measured and calculated SPL values.

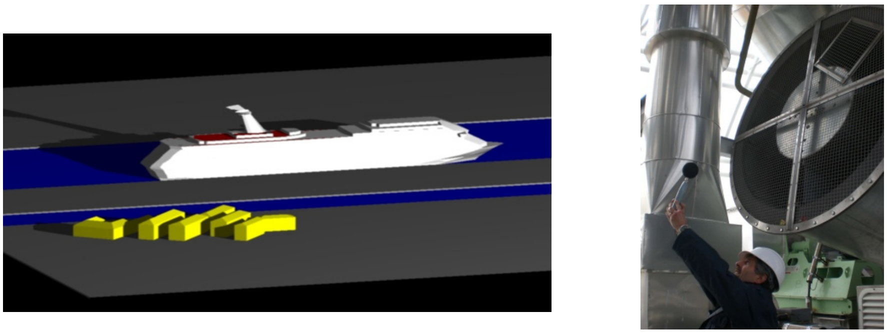

Figure 2: 3D geometry model of ship and harbour (left) and a phase of SPL measurements (right).

The source data checking procedure is here outlined with reference to the noise generated by the engine rooms exhaust air fans. Shipbuilder data made available to author are SPL values taken on the upper deck in different positions, at variable distance r, around and abaft the funnel. An initial estimate of the sound power level has been carried out assuming the noise source to be punctiform. So, sound power level may be calculated as follows:

$$L_{Wf} = L_{pf} + 20 \log r + 11$$

In the simulation model, sound pressure levels have been calculated on the field points planes placed at the position where the SPL measurements were carried out. Fig. 3 shows the field points plane placed 32 metres abaft the funnel and used for checking. Obviously, in that simulation the far field model is ineffective and only the noise source under checking is turned on.

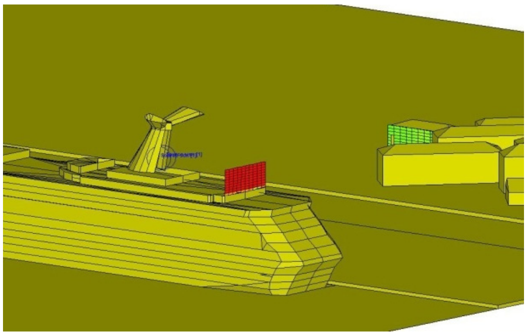

Figure 3: Field points plane used to set the source.

On the basis of the comparison between calculated and measured SPL values, the noise source sound power level estimation has been accomplished. In Fig. 4 the comparison between measured and calculated SPL values is shown. The high difference between calculated and measured SPL values at low frequencies is noticeable from the plot on the left. Need of a setting is clear, as the main part of the far field noise pollution is due to the low frequency components of the radiated noise. Adjustment of SPL spectrum is obtained by modifying the octave band L_W values of the source power spectrum in order to minimize the mean square error especially in the lower band of the reference spectrum. In the right hand plot of the same figure, the reference noise SPL spectrum obtained according with a refined noise source spectrum is shown. The same comparison has been repeated on different planes with the same result. Further refinements may be implemented on the same criterion.

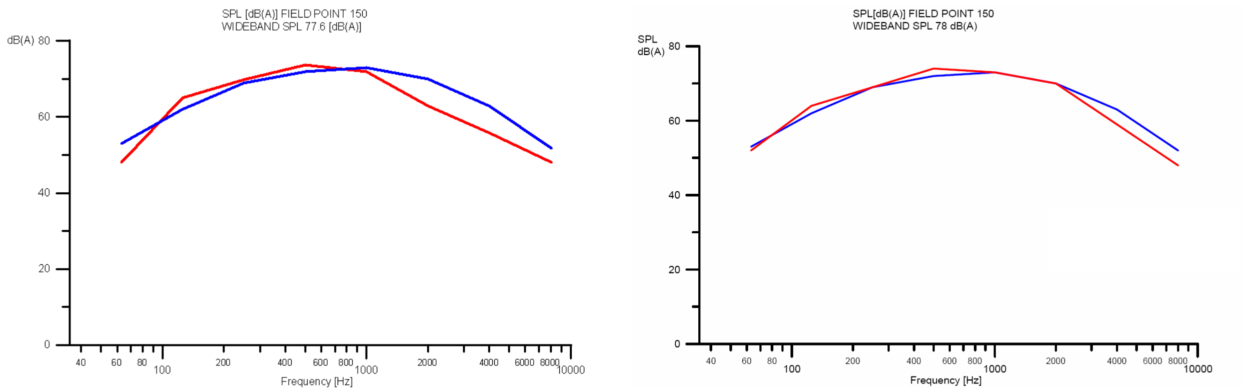

Figure 4: Comparison between the octave band SPL spectrum measured at 32 metres aft the funnel (blue line) and that calculated by Raynoise at the same point (red line).

Once a good agreement has been obtained on the reference points between calculated and measured SPL spectra, the outdoor source under consideration may be regarded as properly tuned for numerical simulation. Author's suggestion is to perform source setting on several reference points placed all around the source. That is required for directivity index evaluation. The sound power level spectrum of the tuned engine rooms exhaust air fans source is shown in Fig. 5. Once the sound power level of each source has been determined according to the above, it is possible to carry on with the procedure.

Conclusion

In last decades harbours have evolved as complex industrial areas and noise pollution from these areas were being increased according to growing of industrial activities and goods movement. Moreover, in the last years, several harbours were being expanded, becoming closer to residential areas. This is causing a constant increase in noise pollution for residents in those areas. Ships certainly contribute to the noise pollution because of the increasing installed power and number of plants. In that frame, the European Union is funding the BESST project to better the knowledge about the ship noise in order to define new uniform criteria and limits for noise radiated to European harbours. The

Department of Naval Architecture, Ocean and Environmental Engineering of the University of Trieste takes part in this European project with the determination of a proper computational tool to predict outdoor noise generated by ships.
In this paper a procedure to predict airborne ship noise in harbour is presented and a technique to properly tune sound power level of any onboard noise source is discussed. In the case study the sound power level is determined according to the ISO 3744 standard. To check the sound power level calculated by measures not specifically taken for ship noise prediction, an iterative procedure is discussed. This latter is based on the comparison of the sound pressure level measured on board and the sound pressure level calculated by the Raynoise software on a reference point within the near field. Results of the case study show the effectiveness of the entire proposed procedure. A valuable step in the procedure is the setting method proposed for determination of the most appropriate sound power level for each noise source.

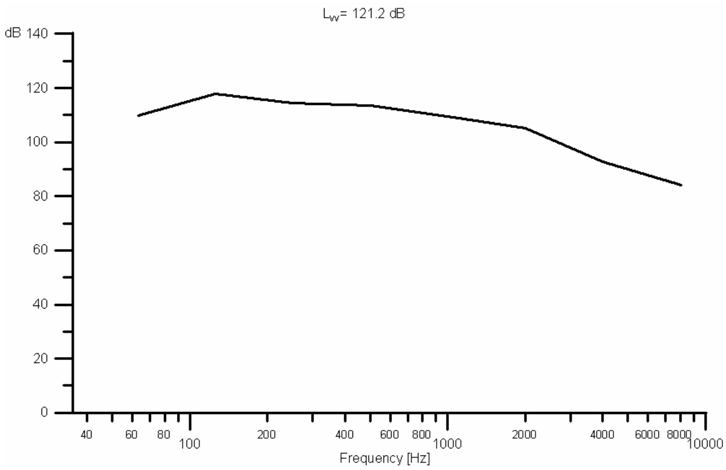

Figure 5: Engine rooms exhaust air fans octave-band LW spectrum.

Reference

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