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NUMERICAL MODELS FOR THE PREDICTION OF SHIP AIR-BORNE NOISE EMISSIONS

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The airborne noise emitted by ships represents a pollution source affecting the surrounding environment and third parties. Nowadays, in addition to numerous other kinds of environmental impacts due to shipping activities, ship airborne radiated noise in the latest years has captured the attention of universities, industries, and Regulatory Bodies. Even though this problem can be quite annoying and has raised serious complaints from the citizens of areas close to ports, shipping routes along the coast, or inland waters, the acoustic impact of ships to date has not been subjected to systematic control. The problem is primarily driven by the presence of powerful sound sources on ships and the fact that inhabited areas are often in close proximity to areas where ships operate. In response to the need to regulate the noise emitted by ships, Lloyd's Register introduced a class notation in 2019 specifically for airborne noise emissions from ships. This notation also includes a procedure for granting the notation. Within this context, the development of mathematical models to predict the propagation of noise in the air can serve as a valuable tool for anticipating and controlling the impact of ship-related airborne noise. This paper, reports problems and methods on the practical implementation of the required classification checks, in particular as regards the simulation and validation problems. As an application example, a small part of the results obtained during an industrial research activity aimed at assessing the noise radiated into the air by a passenger ship is reported.

Keywords: ray-tracing, simulation, noise emission, ship

1. Introduction

Ships are among the greenest transportation means for moving goods and people but are responsible for a considerable share of environmental impact, occurring in different mode and scales [1]. Focussing on the acoustic impact, the airborne noise related to shipping activities affects the population living near ports or navigation channels [2]. This is particularly true in the Mediterranean Sea, where ports are often close to the water city’s historical centers.

As it is commonly understood, the International Maritime Organization (IMO) has jurisdiction over almost all aspects of the environmental impact caused by ships at sea. However, when it comes to ports within cities and under local authorities, they have the ability to legislate and impose even stricter limits and regulations. In the case of noise emissions from ships while at port, it falls under the influence of various National and Local Authorities such as the Coast Guard, Port Authority, Health Care Agency, and Municipality.

The maritime industry has been addressing the issue of ship-generated noise for over three decades. Recently, there has been a growing recognition of the external acoustic impact of ships on third parties, including the propagation of underwater noise and the transmission of airborne noise. These impacts can have adverse effects on both marine and terrestrial fauna. Airborne noise related to commercial or passenger ships has generally been regulated in recent decades to protect hoteling and working spaces on board to the benefit of passengers and the crew (generally referred to as Comfort Classes) [2],[3], [4].

In recent years, something has been done through European-level projects that address airborne noise from berthed ships [5], [6].

From the outlook of experimental research, several research groups have tried to characterize the noise emitted in ports by ships. Coppola et al. (2018) conducted on-board measurements on a ferry boat docked in the port of Naples to gather data on the primary sources of noise. They also created a 3D geometric model that encompassed all the objects present in the acoustic field of the surrounding area. [2]. Bernardini et al. (2019) conducted an acoustic analysis of various small vessels at different speeds while in port, utilizing both short- and long-term measurements to gather data. [7]. In Vukic et al. (2022), the authors pursued three objectives: identifying noise sources in the port area, providing an overview of strategic noise maps, simulating noise propagation from ships at berth, and calculating the external costs associated with noise pollution. [8]. Schiavoni et al. (2022) summarized recent research findings on port noise sources, aiming to create a comprehensive database that can be easily utilized, including during the noise mapping phase. [9].

Engine funnels, ventilation inlets and outlets, air conditioning inlets and outlets, and external sources immediately radiating outside (such as winches and other handling equipment for cables, anchors, and chains) are generally the primary kinds of external noise sources. The Lloyd's Register additional class notation contains standards for evaluation and a process for granting the notation. [10].

2. Additional class notation

Two major operating conditions are recognized:

- Ship moored at the pier (when the main propulsion system is turned off and all equipment normally operating at the harbor is activated);
- Free sailing with the ship moving ad low speed in the port area or along the coast in channels with main and auxiliary engines, and ventilation systems in operation to a standard sailing speed of 5 kn.

At least 1/1-octave bands in the frequency range of 31.5-8000 Hz must be used for the assessment. The classification of a vessel requires the correct evaluation of two different quantities: the energy-based sum of all single-source sound power levels, $L_{WA,ship}$, and the sound pressure level ($L_{Aeq,T}$ as the *Equivalent Continuous A-Weighted Sound Pressure Level* and $L_{pAS,max}$ *as the maximum A-Weighted root-mean-square sound pressure level*) measured with SLOW acquisition constant during the the ship pass-by or during the defined operating condition and at definite distances from the ship. The standard and specifications that must be followed are ISO 3744 or ISO 9614 to calculate the single source power levels of each source onboard. The limit values for obtaining the class are listed in Table 1. The ship must achieve all four conditions at the same level to get the notation, which may only be issued if the measured airborne noise levels are below the appropriate limit.

Table 1: Assessment criteria

Sound power	Harbour moored		Free sailing		Distance to the side in the horizontal direction
Class	$L_{WA,ship}$	$L_{Aeq,T}$	$L_{WA,ship}$	$L_{pAS,max}$	d (m)
Super Quiet	82		92		
Quiet	88	40	98	50	50
Standard	96		106		
Inland waterways	101	65	111	75	75
Commercial	108	40	-	-	1000

For new constructions, to identify the specific SPL (and directivity index if relevant) values at given target points, the class recommends realizing a 3D model of the ship, according to ISO 9613-2 [11], [12] that shall include the main geometry and noise sources on board, screening, reflection, and absorption by the ship structure, see Fig.1.

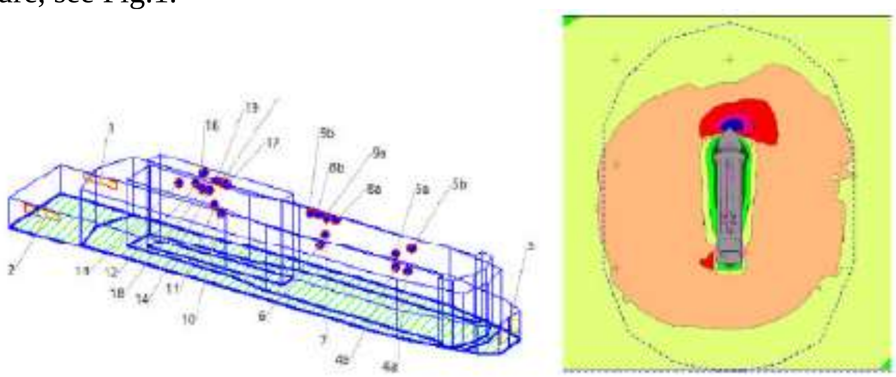

Figure 1: Illustration of 3D calculation model and noise contour map [10].

In the predictive model main sources considered are: exhaust stacks and funnels (main and auxiliary engines and if present silencers, scrubbers, and filter), ventilation (intakes and exhaust), fans, special equipment, and, the hull radiated noise (if relevant); in general, small ventilation openings and exhaust stack openings can be represented as point sources in modeling, while larger ventilation grilles are better represented as surface sources [11], [12]. As regards the on-site measurement, for both of the two operating conditions, the notation mentions prescribe to follow preferably a *near-field* method with weather conditions that should not exceed 3 on the Beaufort scale and a sea state 2. To determine the sound pressure levels $L_{Aeq,T}$ and the $L_{pAS,max}$ it is necessary to update the 3D calculation model by incorporating the single-source sound power levels. The model should then be verified at a significant distance from the sound source, considering at least two heights: 3.5 meters and at the ship's height above sea level. The purpose of this verification is to ensure compliance with the assessment criteria. By comparing the calculated sound pressure levels to the applicable criteria, one can assess whether the levels meet the required standards [10].

3. Simulation model

3.1 Data collection and input

The external airborne noise produced by running machinery is dependent on various factors such as operating conditions, sound levels at the source, and the transmission paths connecting the source to the surrounding space and the external atmosphere [13]. The most effective transmission paths are those along which a fluid continuity occurs between the source and the atmosphere outside the ship. The first and fundamental step for an accurate simulation numerical model is the set-up of a global acoustic source's database: complex of different external sources (in/outlet grids for ventilation and air conditioning systems, and funnels above all); for a large cruise vessel, this database generally include hundreds of items.

The description of external emissions from the source can be achieved through predictive or experimental methods. Predictive methods involve evaluating the machinery's noise emission at the source and considering the effect of transmission loss along the ducts.As regards the funnels, the noise levels are generally supplied by the manufacturer, and may include sound power levels after the turbocharger, information about the silencer, and the attenuations. An alternative approach would involve conducting an experimental study by directly measuring the sound power levels at the inlet/outlet grids on the ship's surface. Each measurement would be performed near each noise source at a specified distance and angle, while the equipment connected to the source operates under monitored conditions. At present, the measuring instruments that seem most suitable are classical sound level meters and the p-p or the more innovative p-v type intensity probes.

To clarify possible differences between near-field measurements (line with triangle points in Fig. 2 and Fig.3 respectively) and forecasted data obtainable from manufacturer's datasheets, two examples are given here comparing predicted data with on-board measurements for two different noise sources: air-conditioning (ID in Fig. 2) and ventilation system respectively (IDV) (refer Fig.2). For reasons of industrial secrecy, the x-axis shows the frequencies on a logarithmic scale and the y-axis shows the dBs without the numerical values; it should be noted that the delta of the y-axis grid is 20dB. As can be seen from Fig. 2 and Fig. 3, the airborne noise measured at 1m from the source are very different from those obtained by attenuating, for the same distance, the spectrum supplied for a specific grid, whether input or output, by the manufacturer of the 'plant. These results are due, for example, to the particular arrangement on board, the plant's operating conditions, and the presence of other sources in the proximity that certainly influence the measured noise. As can be seen for both types of sources, the measured noise is higher than expected.

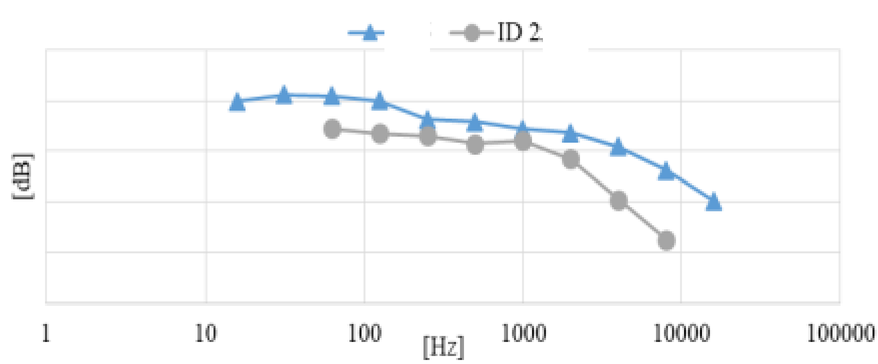

Figure 2: Example of comparison between provisional and experimental data for air conditioning systems.

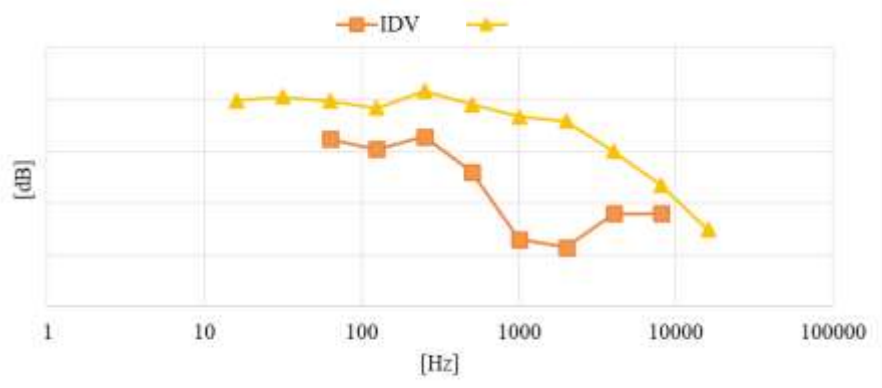

Figure 3: Example of comparison between provisional and experimental data for ventilation systems.

3.2 Model generation and propagation software

For the simulation model, being the analysis focussed on the acoustic field radiated outside the ship, only the outer surfaces of the ship are used to define the model and, as a part of the external environment, also the sea surface needs to be explicitly represented; it could be accomplished by creating a horizontal plane extending from the hull to the farthest receivers used to measure the noise emissions. Starting from the ship’s general arrangements and/or a 3D of the ship must be necessary to realize a simplified shell of the entire ship.

The ISO 9613-2 method is a commonly used empirical approach for calculating the outdoor propagation of sound from a point source to a receiver. This method is implemented in various ray-tracing software packages, making it a convenient tool for analyzing sound propagation in outdoor environments. Among the different available software, using these algorithms, also for a benchmark procedure, in our research activity three different software have been used: SoundPLAN, OTL-Terrain, and MithraSIG.

The first software mentioned is specifically designed for noise modeling and is utilized for predicting, assessing, and mapping environmental and indoor noise levels. The second software focuses on simulating and forecasting the propagation of noise from a sound source to a receiver, utilizing wave-based geometrical acoustics principles. The third software, MithraSIG, employs advanced algorithms based on asymptotic methods like ray propagation and adaptive beam propagation.

4. Sample application

In this work, the noise source is represented by a great number of standalone sources located on a complex ship’s surface. The input information available is the main geometric data of the vessels, and the main acoustical characteristics of datasheets of the main systems on board (engine, ventilation, and air conditioning systems) obtained from the manufacturer datasheet. The transmission path is made of air (half-space of a homogeneous medium), bounded from below by the sea (flat and reflective surface). By the prescriptions of the notation, the acoustic maps of sound pressure obtained on the surfaces at a distance of 50,100 and 250 m from the hull obtained through Sound Plan software are reported in Fig. 4 (perspective view) and Fig. 5 (one for each of the three distances). Fig. 4 and Fig. 5 show that, even at a distance of 50 metres, the ship's emissions do not show the effects of individual sources, except for the funnel, which exhibits a high degree of directivity. Therefore, it may be argued that various noise sources on a ship's side and smaller obstructions like lifeboats have little effect on how sound travels farther than 50 metres.

In addition, an analysis of the effect of the presence on the board of the lifeboats has been carried out; in this analysis for simplicity, in the far field, the lifeboats were modelled as simple parallelepipeds and positioned according to the CAD file. As results in this paper, a map, obtained by SoundPlan software shows the differences between the simulation with and without a lifeboat (without-with). For each of the maps, a calculation grid was used made up of points spaced 4 m from each other. The value of the equivalent pressure level in each of these points was calculated directly by the software while an automatic interpolation was performed in the remaining points. The comparisons were carried out on four longitudinal vertical planes with an area of 440 x 70 m^2 at distances of 30, 80, 180, and 280 m from the ship's side.

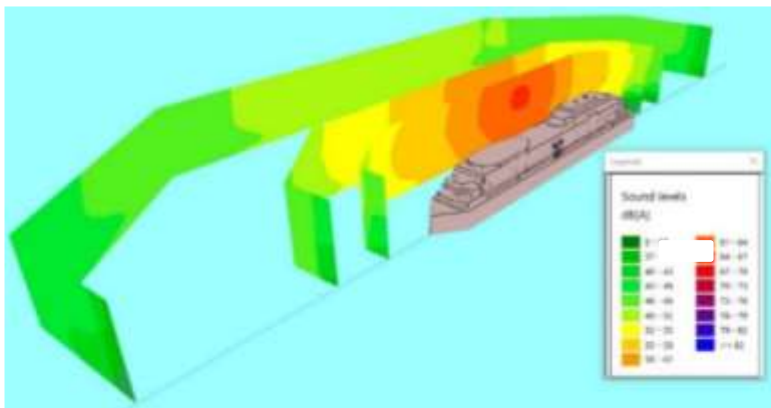

Figure 4: 3D view of the acoustic field at distances of 50, 100, and 250 m from the shipside (perspective)

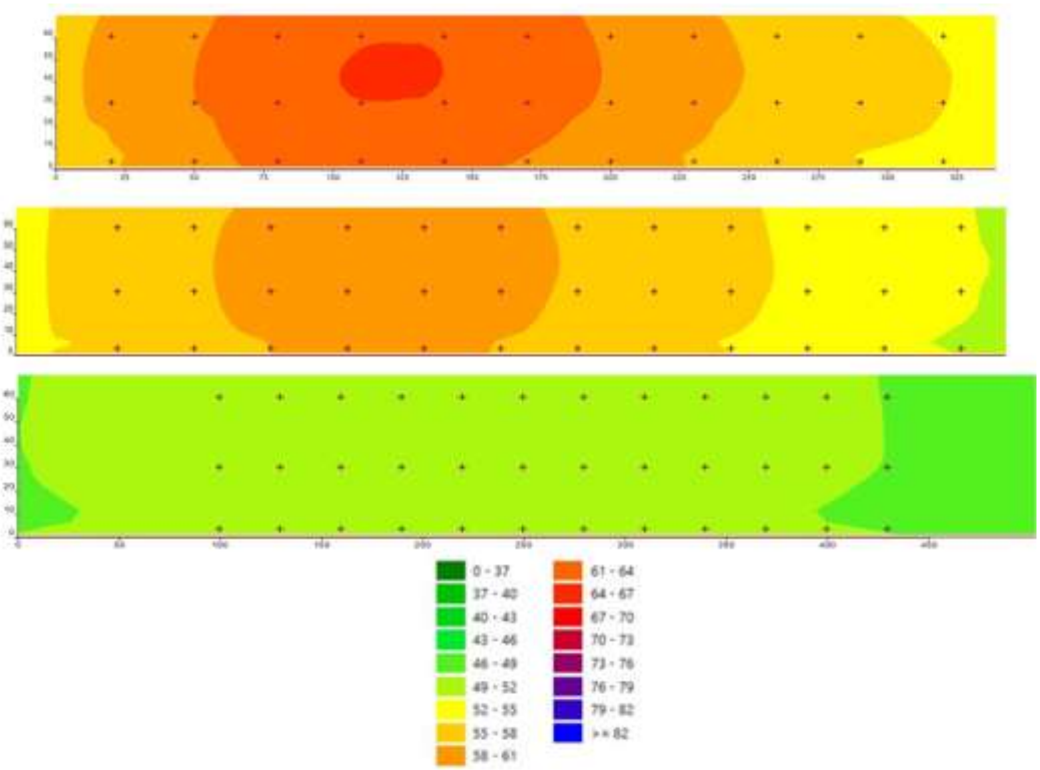

Figure 5: Vertical maps at a height of 70m of the acoustic field at 50, 100, and 250 m from the side of the ship

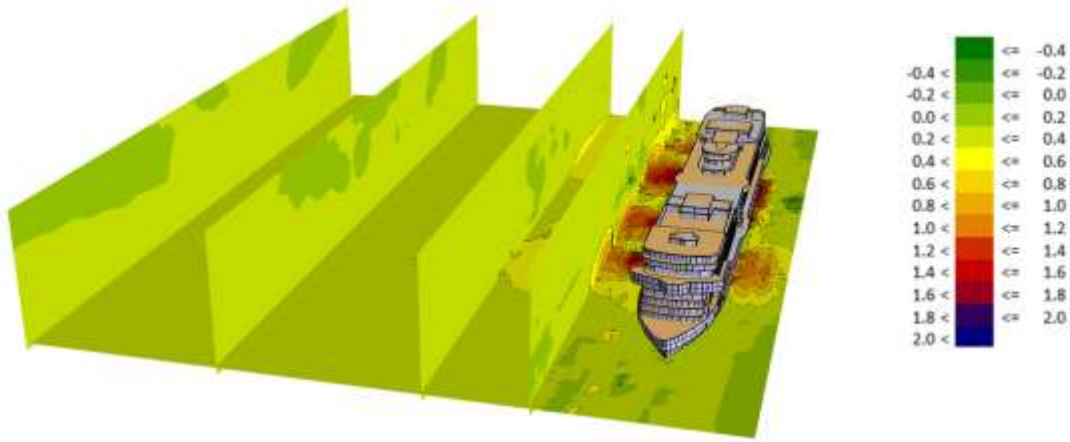

Figure 6: Perspective view of the difference between the radiated acoustic field values with and without lifeboats (vertical planes at various distances and horizontal plane placed 5 m from the sea surface)

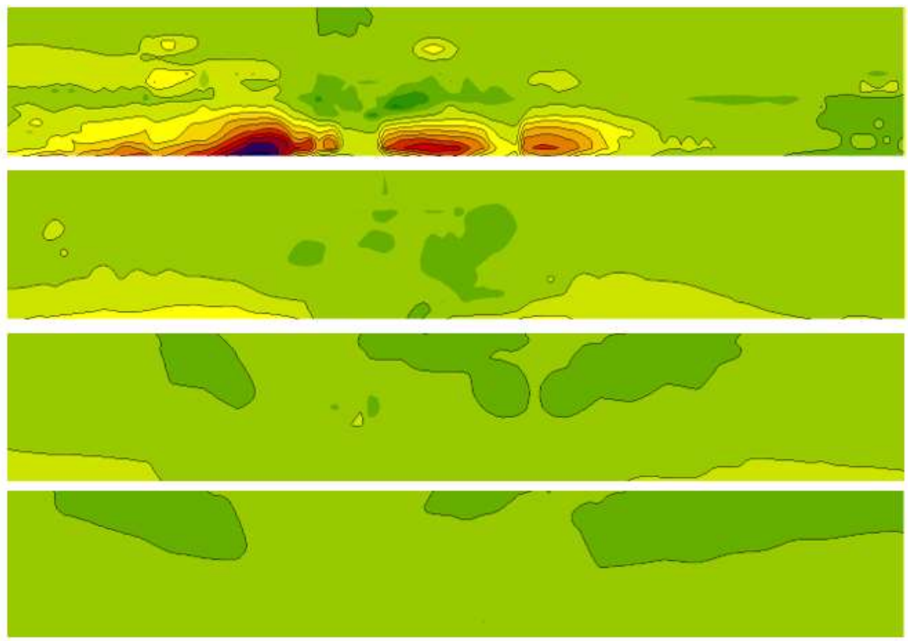

Figure 7: Vertical planes placed at 30, 80, 180, and 280 m from the side of the ship

5. Conclusions

The research aimed to verify the possibility of using commercial software to effectively study and predict airborne noise radiation at a distance from the ship (modeled as a complex acoustic source); the interest is born, from an academic and industrial point of view, after the publication of the notation of additional class from Lloyd's Register on the noise emission of ships.

A preliminary application of the procedure hypothesized by the LR document was therefore carried out, to be used as a tool for evaluating the performance of an existing ship, but also as a control tool during the design and construction phases of the ship. For the moment, the acoustic performance of the ship is not part of the design specifications, but this could change soon.

However, to be reliable, as far as the characterization of the sources is concerned, it should be based on solid predictions, effectively supported by reliable specification data but also by a robust database of experimental measurements systematically developed on board similar constructions. It is necessary to verify and survey the applicability of the class notations that Lloyd Register just introduced. The main argument is on how difficult it is to geometrically model ship hulls and surfaces; from this first experience, a set of guidelines has formed that is judged useful for academics and shipowners. Numerous challenges must be overcome by the scientific community and the maritime sector, including implementing field tests of the suggested methodologies, evaluating the precision of current measurement techniques, confirming the reproducibility of the findings, and ensuring consistency between numerical modelling and empirical tests.

REFERENCES

1. Mocerino, L., Quaranta, F., & Rizzuto, E. (2018). Climate changes and maritime transportation: A state of the art. In *NAV International Conference on Ship and Shipping Research*, (221499). https://doi.org/10.3233/978-1-61499-870-9-1005.
2. Coppola, T., Mocerino, L., Rizzuto, E., Viscardi, M., & Siano, D. (2018, June). Airborne Noise Prediction of a Ro/Ro Pax Ferry in the Port of Naples. In *Technology and Science for the Ships of the Future: Proceedings of NAV 2018: 19th International Conference on Ship & Maritime Research* (p. 157). IOS Press.
3. Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., & Schenone, C. (2016). Airborne noise emissions from ships: Experimental characterization of the source and propagation over land. *Applied Acoustics*, **104**, 158-171.
4. Badino, A., Borelli, D., Gaggero, T., Rizzuto, E., & Schenone, C. (2012, November). Modelling the outdoor noise propagation for different ship types. In *NAV 2012 17th International Conference on Ships and Shipping Research.*
5. Neptunes Project. Available online: https://www.nep tunes.pro/.
6. SILENV (2012). Ships oriented Innovative soLutions to rEduce Noise and Vibrations, FP7. http://www.silenv.eu/
7. Bernardini, M., Fredianelli, L., Fidecaro, F., Gagliardi, P., Nastasi, M., & Licitra, G. (2019). Noise assessment of small vessels for action planning in canal cities. *Environments*, **6**(3), 31.
8. Vukić, L., Peronja, I., & Glavinović, R. (2022). Multi-Faceted Analysis of Airborne Noise Impact in the Port of Split (I). *Journal of Marine Science and Engineering*, **10**(10), 1564.
9. Schiavoni, S., D'Alessandro, F., Borelli, D., Fredianelli, L., Gaggero, T., Schenone, C., & Baldinelli, G. (2022). Airborne Sound Power Levels and Spectra of Noise Sources in Port Areas. *International Journal of Environmental Research and Public Health*, **19**(17), 10996.
10. Lloyd's Register, 2019, *Design and Construction Additional Design and Construction, Procedure for the Determina-tion of Airborne Noise Emissions from Marine Vessels*, Lloyd's Register Group Limited 2019 Published by Lloyd's Register Group Limited.
11. ISO 9613-2:1996. Acoustics - Attenuation of sound during propagation outdoors - Part 2: General method of calculation, International Standard ISO 9613-2:1996.
12. Acoustics – Attenuation of sound during propagation outdoors - Part 1: Calculation of the absorption of sound by the atmosphere, International Standard ISO 9613-1:1993.
13. Fredianelli, L., Nastasi, M., Bernardini, M., Fidecaro, F., Licitra, G. Pass-by characterization of noise emitted by different categories of seagoing ships in ports. *Sustainability* 2020, **12**, 1740.