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REDUCTION OF SHIP UNDERWATER NOISE BY LIMITING SPEED: IS IT RELEVANT IN THE BALTIC SEA?

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Abstract. The underwater noise radiated by commercial ships has an impact on the underwater soundscape across oceans and inland seas. It is predicted that by 2050, the maritime transportation in the European Union will have grown dramatically. The EU legislation, as well as HELCOM and OSPAR commissions, lay backgrounds to the minimization of undesirable noise in the underwater environment. In 2014, the International Maritime Organization (IMO) of the United Nations Organisation proposed non-mandatory guidelines for the reduction of underwater noise of ships. IMO proposes noise reduction measures that include technological, operational and maintenance means such as the reduction the speed of ships or re-routing them to avoid sensitive marine areas. The scientific research urges to find trade-offs between the sizes of ships and their speed. This research focuses on the possible compromise between the IMO regulated Energy Efficiency Design Index (EEDI) of ships and the reduction of the underwater noise radiated by them by limiting their speed.

Keywords: Baltic Sea, ship, underwater noise mitigation, ship energy efficiency.

Introduction

The shipping activities are responsible for a considerable amount of the noise energy radiated into the underwater ambient soundscape (MMC, 2017), with no exclusion of the Lithuanian Baltic Sea area (Bagočius & Narščius, 2018). The shipping contribution to the ambient soundscape depends on the situation and can differ. When ships are widely scattered in a large oceanic area, the sound propagation losses per unit of the distance are small. The sound propagation losses are high in the coastal shallow areas when a great number of ships is concentrated in comparatively small areas. Provided the contributors to the traffic noise are analysed more closely, the spectral characteristics they generate reveal that the resulting noise spectra are characterized by the temporary appearance of narrow-band components at frequencies below 1000 Hz and broad-band cavitation noise extending to above kilohertz region, often with low-frequency modulation patterns (Wenz, 1962).

It is expected that maritime transportation in the EU countries will grow dramatically. The contributions from extra European and Intra European trades will make a high contribution to maritime transportation. The modal shift of transport from road to sea will take place in Europe. It is also predicted that the size of vessels will increase to enable more efficient and cost-saving freight transport in the EU (Balticlines, 2016).

The Maritime Environmental Protection Committee (MEPC) of the International Maritime Organization proposed non-mandatory guidelines on the measures to reduce the ship-caused noise (IMO, 2014). They describe the operational, organizational and technical measures for reducing shipping noise. One of the proposed operational considerations is the reduction of the speed of ships or re-routing them to avoid sensitive marine areas. The scientific literature indicates that partial reduction of the speed of ships will minimize the underwater noise, and a trade-off between the speed of ships and their size exists (Merchant, 2019).

This research emphasizes that the trade-offs between limiting the speed of ships and the energy efficiency regulated by IMO do exist. It compares the speed of ships required to be achieved by the International Maritime Organization regulations that aim at promoting the usage of less polluting engines and other equipment radiating underwater noise and operating at the same speeds.

Analysis

Methods

The ship reference speeds governed by the Energy Efficiency Design Index (EEDI) that have to be achieved by bulker ships while fulfilling their minimum required propulsion power were adopted from the minimum EEDI power lines (IMO, 2018). To define the inception speeds of the vessels having different tonnage, the equations freely available in the scientific data have been used. The vessel propeller cavitation inception speeds were defined using the equation (Jalkanen, et al., 2018)

$$\mathbf{V_{cis}} = \min\{\max[(\mathbf{1.42} - \mathbf{1.2} * \mathbf{C_B}) * \mathbf{V_D}; \mathbf{9}]; \mathbf{14}\} \quad [1]$$

where the V_{cis} is the ship propeller cavitation inception speed (in knots), V_D is the ships design speed (in knots).

The ship block coefficients have been obtained using the equation (Ventura, 2011)

$$C_B = 0.7 + 0.125 * tg^{-1}[25 * (0.23 - F_n)] \quad [2]$$

where C_B is the ship block coefficient (dimensionless unit), Fn is the Fraude number (speed-length ratio).

The relation between the length and displacement tonnage of ships was equated using the relation (Kastenmarine, 2019)

$$LOA = \sqrt[3]{\frac{\Delta_{disp}}{0.01}} \quad [3]$$

where LOA is the overall length of the ship (in meters), $\Delta disp$ is the displacement tonnage of the ship (for convenience, units in long tons assumed to be equal to metric tons).

The relation between the displacement tonnage and the merchant vessels deadweight tonnage is assumed to be DWT*1.138, and the relation between gross tonnage and the deadweight is assumed to be equal to DWT*0.5285 (Takahashi et al., 2006).

The maximum ship design speeds were defined using the equation (BoatsGroup, 2019)

$$V_{max} = 1.34 * \sqrt{LOA} \quad [4]$$

where V_{max} is the maximum ship design speed, LOA is the length of the ships; the length of the large ships is assumed to be equal to waterline length (units in meters).

The merchant ship noise sources in frequencies above 100 Hz have been equated using the formula by Ross, which is a function of the ship speed and displacement tonnage (Hallett, 2004)

$$SL = 112 + 50Log_{10}\left(\frac{U_a}{10kn}\right) + 15Log_{10}(DT) \quad [5]$$

where SL is a source level in dB re 1µPa^2, U_a is the speed of the ship, DT is a displacement tonnage of the ship.

The data of the automatic ship identification system (AIS) for the year of 2015 were provided by the Lithuanian Maritime Administration. The local AIS receiver stations are installed in the locations of Nida, Klaipėda, and Šventoji. The AIS data were continuously stored on a server, where the actual data were only available for 12 months. The necessary vessel data were retrieved from available web-based marine databases, where the gross tonnage (GT) and vessel types were of particular interest (Bagočius & Narščius 2018).

All graphs and statistical properties have been acquired using the MATLAB® software.

Results

The obtained values of the ship propeller cavitation inception speeds V_{cis} for small ships of ~12000 – 20000 DWT varied within 8-9 knots, and the bigger ships up to 175 000 DWT had the cavitation inception speeds above 12.8 knots. The obtained values are plotted as curves and shown in Figure 1.

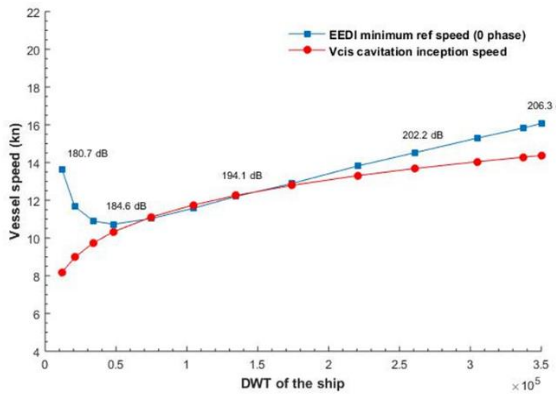

Figure 1. The blue squares represent the EEDI reference speed to be achieved by bulker (merchant) ships to fulfil the required EEDI, the minimum required propulsion power (according to minimum power lines) for the period up to 2015 (0 phase, existing ships). The red circles represent the cavitation inception speeds (V_{cis}) for the same ship sizes. The values in decibel (ref 1µPa^2) indicate the levels of the noise radiated by a ship for the required EEDI ship speed.

The resulting lines of cavitation inception speed V_{cis} and the EEDI 0 phase reference speed for the ships built in the period up to 2015 intercepts for the ships of the deadweight of approximately 75000-175000 tons. The EEDI speed of smaller ships has a negative slope of ~3 knots for the DWT of ~12000-50000 tons in contrast to the positive inclination of the inception speed curves for the same ships. This feature reveals that propellers of smaller ships will start to cavitate much earlier before they reach the EEDI speed. The same characteristic is observed for bigger vessels >175000 DWT.

The ship source noise levels in Figure 1 were plotted for different EEDI reference speeds, using Ross's formula (Eq.5). The equated ship noise source levels reveal that even small ships (<75 000DWT) at recommended EEDI speed (0 phase) will radiate noise levels above ~185 dB re 1µPa^2 (note the limited draft of the vessels cruising in the Baltic Sea (IMO, 2007)).

The AIS data of the ships acquired at the Lithuanian marine area have been analysed. The analysis revealed that ships of different types visited the Lithuanian area, the most frequent being merchant ships. The total number of 2413 ships of a different type that visited this area in 2015 was registered. The analysed data has been summarized in Table 1.

Table 1. Summary of the AIS data registered in the Lithuanian marine area in 2015 (Bagočius & Narščius 2018).

Ship type	Number of ships	Mean tonnage (GT), t±SD	Mean speed (SOG), kn±SD
Merchant	1621	12057.1±12850.0 m	6.4±4.8
Tanker	457	26195.5±23892.0 m	5.6±4.8
Fishery	83	257.9±328.7 m	3.4±2.7
Other	97	1379.0±2339.8 m	5.1±5.2
Tug	60	688.8±2258.3 m	2.5±3.1
Ro-Ro	41	20689.6±9973.4 m	14.2±5.7
Passenger	34	12251.0±32158.0 m	11.8±4.5
Dredger	20	3180.0±4063.94 m	4.1±4.2

*SD – standard deviation, SOG – speed over ground.

The highest average ship speed was registered for Ro-Ro type vessels reaching 14.2 knots, and the biggest group of the merchant vessels was sailing at an average speed of 6.4 knots in this area. Further analysed AIS data revealed the statistical properties of the speed of different ships registered in the Lithuanian marine area with resulting cumulative distribution function depicted in Figure 2.

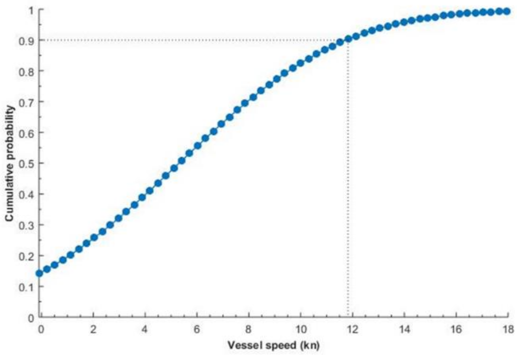

Figure 2. CDF of the ship speed registered in the Lithuanian marine area in 2015 (all ship types).

The statistical analysis of the vessel speed data revealed that the 90th percentile of the data sets equalled to 11.8-knot speed, meaning that most of the ships were sailing at the speed up to or equal to 11.8-knot speed.

The different type vessel gross tonnage (GT) data have also been analysed. The resulting cumulative distribution function (CDF) is depicted in Figure 3.

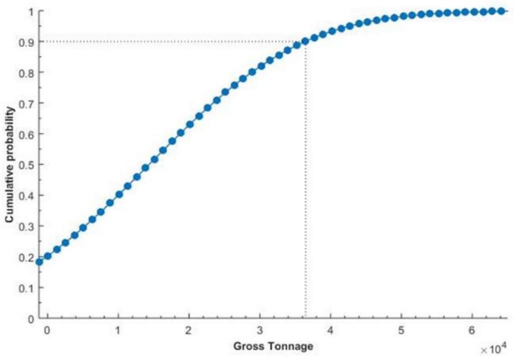

Figure 3. CDF of the ship gross tonnage (GT) registered in the Lithuanian marine area in 2015 (all types of ships).

The statistical analysis of the gross tonnage (GT) data revealed that the 90th percentile of the data sets equalled to 36450 GT, meaning that most of the ships that visited the Lithuanian marine area were of the size up to or equal to the gross tonnage defined. Assuming that merchant ships that visited the Lithuanian marine area constituted ~70 per cent of all ship types (*see* Table 1), the gross tonnage of 36450 GT is assumed to be equal to 68968.8 DWT (for conversion see the Method section).

Discussion

IMO has developed the Energy Efficiency Design Index (EEDI) for newly built ships to reduce greenhouse gas (GHG) emissions from ships. A part of the strategy to reduce the GHG from ships is to consider and analyse the use of ship speed optimization and speed reductions as a measure to reduce GHG (Leaper, 2019). IMO Marine Environmental Protection Committee (MEPC) has also issued non-mandatory guidance for ship quieting measures (IMO, 2014).

The ship radiated noise levels are directly dependent on the size and speed of the ship (Hallett, 2004). However, the scientific literature has already identified the trade-offs between the sailing time and speed of ships, as slower vessels take longer to transit, leading to a trade-off between the duration and the radiated noise. The trade-offs between the size and carrying capacities of a ship and the potential of noise reduction have been identified, as larger vessels tend to generate more noise; however, greater carrying capacities will offset the higher noise output by slowing down the growth in overall numbers of large vessels (Merchant, 2019). This research emphasizes that the trade-offs between the energy efficiency of the ship (EEDI) and ship noise reduction exist as well.

The IMO MEPC ship noise reduction guidelines (IMO, 2014) propose operational and maintenance considerations, i.e. the speed reductions of ships or re-routing decisions to avoid sensitive marine areas. The scientific literature also indicates that partial ship speed reductions will lead to underwater noise reductions

(Merchant, 2019). Our primary estimates reveal (*see* Figure 1) that the speed of energy-efficient vessels (minimum EDDI reference speed) draws the limit for the ship speed reductions related to underwater noise reduction, which is size-dependent for the ships built according to EEDI Phase 0 requirements (0 phase implemented in 2013-2015, existing ships), especially for the smaller ship sizes <75000 DWT. The later EEDI phases (1^{st}, 2^{nd} and 3^{rd} phases) will raise the minimum reference speed resulting in even higher ship noise emissions, provided the efficient technical solutions of noise reductions will be implemented (Jalkanen et al., 2018).

The analysis of the AIS data registered in the Lithuanian marine area reveal that a total number of 2413 ships of different types that visited this area in 2015 was registered. The biggest group of the ship types were cargo (merchant) ships that constitute almost 70 per cent of all of the ships in the period of interest. The statistical analysis of the ship speed data revealed that the 90^{th} percentile equals to 11.8-knot vessel speed and the data analysis of the vessel size revealed that the 90^{th} percentile of the ship sizes equals to 36450 GT, which approximately equals to a deadweight of 68968.8 tons. According to our estimates, the radiated underwater noise levels of the ships of this size and the minimum reference EEDI speed will exceed the ~185 dB re 1μPa^2 level, while some aquatic animals such as wild harbour porpoises exhibit the profound and sustained avoidance behaviour if the continuous underwater noise levels exceed the 140 dB re 1μPa^2 level (Southall et al., 2007). It is also noteworthy that the vessels of the sizes less than ~75000DWT will start to cavitate earlier before reaching the energy efficient speed (*see* Figure 1).

The data acquired in the Lithuanian Baltic Sea area allows to make an assumption that the speed of an existing vessel (assuming that it was built in the period of 2013-2015 or older and has undergone a major conversion) can be reduced by up to the 7.7 per cent without falling below the minimum energy-efficient speed of EEDI Phase 0 in this area. As the reduction of the ship speed as a measure has a limited capacity, the other operational and technical means seem to be more easily achievable. For example, as noted earlier, larger vessels tend to generate more noise but their greater carrying capacities will offset their higher noise output (Merchant, 2019). Besides, the management and planning of the speed of larger vessels with the aim of noise reduction seem to be harmonizable with the energy efficiency design and planning of ships.

Conclusions

- The speed reduction of ships with the aim of noise reduction is limited by the existing IMO energy efficiency regulations, especially for smaller ships of the size of <75000DWT.
- Later energy efficiency index (EEDI) phases (1^{st}, 2^{nd} and 3^{rd} phases) will limit the speed reductions even more, provided effective ship quieting techniques will be implemented.
- The statistical analysis of the data acquired in the Lithuanian marine area reveals that most of the ships in this area are of the sizes of equal or less than 68969 DWT and their speed is equal or less than 11.8 knots. The resulting underwater noise levels will exceed the 185 dB re 1μPa^2, which exceeds greatly the threshold of disturbance of some aquatic animal species. The smaller ships will start to cavitate much earlier before reaching energy-efficient ship speed. Consequently, the speed of a ship can be reduced up to ~7 per cent in the area of interest.
- Other operational and technical measures seem to be more appropriate to achieve noise reduction (such as the choice of bigger vessels) and comply with the IMO guidelines.

References

1. Bagočius, D., & Narščius, A. (2018). Simplistic underwater ambient noise modelling for shallow coastal areas: Lithuanian area of the Baltic Sea. Ocean Engineering, 164, 521-528.
2. Balticlines, (2016). Shipping in the Baltic Sea – Past, present and future developments relevant for Maritime Spatial Planning. Project Report I. 35 pp.
3. BoatsGgroup (2019). Crunching Numbers: Hull Speed & Boat Length. Web source: https://www.boats.com/reviews/crunching-numbers-hull-speed-boat-length/
4. Hallett, M. A., (2004). Characteristics of merchant ship acoustic signatures during port entry/exit. Proceeding of ACOUSTICS, 577 – 580.
5. Jalkanen, J. P., Johansson, L., Liefvendahl, M., Bensow, R., Sigray, P., Östberg, M., & Pajala, J., Karasalo I., Östberg M., Andersson M., Peltonen H., Pajala J., (2018). Modelling of ships as a source of underwater noise. Ocean Science, 14(6), 1373-1383.
6. Kastenmarine (2019). General Hull form equations. 5 pp. Web source: http://www.kastenmarine.com/
7. Leaper, R. C. (2019). The role of slower vessel speeds in reducing greenhouse gas emissions, underwater noise and collision risk to whales. Frontiers in Marine Science, 6, 505, 1 – 8.
8. Merchant, N. D. (2019). Underwater noise abatement: Economic factors and policy options. Environmental science & policy, 92, 116-123.
9. Marine mammal commission (MMC), (2007). Marine Mammals and Noise– A Sound Approach to Research and Management; a Report to Congress from the Marine Mammal Commission. 370 pp.

10. Southall B.L., Bowles A.E., Ellison W.T., Finneran J.J., Gentry R.L., Greene Jr.C.R., Kastak D., Ketten D.R., Miller J.H., Nachtigall P.E., Richardson W.J., Thomas J.A., & Tyack P.L., (2007). Overview. Aquatic mammals, 33(4), 411, 1 – 121.
11. IMO SN, (2007). Routeing measures other than traffic separation schemes, IMO SN.1/Circ.263, 14 pp.
12. IMO MEPC, (2014). International Maritime Organization Marine Environmental Protection Committee. Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life, IMO MEPC.1/Circ.833, 10 pp.
13. IMO MEPC, (2018). International Maritime Organization Marine Environmental Protection Committee. Air pollution and energy efficiency, IMO MEPC 72/INF.12, 297 pp.
14. Takahashi, H., Goto, A., & Abe, M. (2006). Study on standards for main dimensions of the design ship. TECHNICAL NOTE of National Institute for Land and Infrastructure Management, (309), 80 pp.
15. Ventura, M., (2011). Estimation methods for basic ship design. Instituto Superior Tecnico, Technical University of Lisbon, Portugal. 61 pp.
16. Wenz, G. M., (1962). Acoustic ambient noise in the ocean: Spectra and sources. The Journal of the Acoustical Society of America, 34(12), 1936-1956.

LAIVŲ SPINDULIUOJAMO POVANDENINIO TRIUKŠMO MAŽINIMAS RIBOJANT LAIVŲ GREITĮ: AR TAI PRASMINGA BALTIJOS JŪROJE?

Anotacija

Povandeninis triukšmas, kurį išspinduliuoja komerciniai laivai, prisideda prie bendrojo „garsovaizdžio“ jūrose ir vandenynuose. Atliktos prognozės teigia, kad Europos sąjungoje iki 2050 metų transportavimas jūromis augs dideliais tempais. Europos sąjungos teisė, taip pat Baltijos jūros aplinkos apsaugos komisija (Helsinkio komisija) bei Šiaurės ir rytų Atlanto vandenyno aplinkos apsaugos komisija (Oslo-Paryžiaus komisija) žengia pirmuosius žingsnius nepageidaujamo povandeninio triukšmo sumažinimui jūrose. 2014 metais Jungtinių tautų Tarptautinė jūrų organizacija pasiūlė neprivalomas laivų spinduliuojamo povandeninio triukšmo mažinimo gaires. Jose numatytos technologinės, operacinės bei laivų atnaujinimo priemonės, kurios apima laivų greičių ribojimą arba laivų maršrutų keitimą siekiant sumažinti biologiškai svarbių buveinių trikdymą jūrose. Moksliniai tyrimai jau pabrėžia būtinybę rasti kompromisus tarp laivų dydžių ir jų greičių bei faktorių, kurie įtakoja išspinduliuojamos triukšmo energijos kiekį į jūros aplinką. Šiame moksliniame darbe aptariami galimi kompromisai tarp laivų energetinio efektyvumo (EEDI) reguliavimo bei jų išspinduliuoto triukšmo mažinimo mažinant laivų greitį.

Reikšminiai žodžiai: Baltijos jūra, laivyba, povandeninio triukšmo mažinimas, laivų energetinis efektyvumas.

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