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The Effect of Speed on Bow Thruster Tunnel Acoustics Using Computational Fluid Dynamics Methods

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Abstract

The increasing global emphasis on sustainability and environmental conservation has driven the maritime industry to adopt technologies aimed at minimizing ecological impacts, particularly underwater noise pollution. As a significant environmental issue, underwater noise affects marine ecosystems, altering the behavior, physiology, and survival of marine fauna, while contributing to broader ecological shifts. This research investigates the acoustic properties of a vessel's bow thruster tunnel, focusing on noise generation at varying operational speeds. The study utilizes Computational Fluid Dynamics (CFD) simulations with ANSYS Fluent to analyze the relationship between fluid flow and acoustic behavior within the tunnel. Simulations conducted using CFD ANSYS Fluent reveal that high acoustic concentrations occur at the tunnel due to significant pressure differences between the interior and exterior. Results show that acoustic levels increase with ship velocity, ranging from 81.39 dB at 10 knots to 108.86 dB at 28 knots. To mitigate noise, a cone ring inlet design is proposed to reduce pressure differences and the ship's acoustic signature. These findings underscore the importance of vessel speed in influencing underwater noise levels, which can affect operational efficiency, marine ecosystems, and ship performance. The study highlights the need for a multi-faceted approach, incorporating hull design, propulsion systems, and operational strategies, to minimize acoustic impacts and promote sustainable maritime practices.

1. Introduction

The increasing global focus on sustainability and environmental conservation has driven the maritime industry to adopt technologies that minimize ecological impacts. One of the critical aspects of achieving environmental friendliness in maritime operations is reducing underwater noise pollution. Noise pollution is considered a major environmental issue, significantly impacting the marine environment. Noise pollution has become a globally growing problem caused by various natural and anthropogenic activities in marine areas [1]. However, over the past two decades, marine pollution has been the subject of several studies worldwide [2]. This can have detrimental effects on the health and survival of marine fauna by altering signals produced by animals [3], [4], [5], affecting their calling behavior [6], physiological status [7], and causing ecological shifts within natural communities and entire ecosystems [8], [9]. This situation draws attention to the integrity of natural ecosystems and stakeholders in science-related fields, such as animal welfare, conservation, legislation, and human health [10]. One of the largest contributors to noise in the ocean is shipping activity by vessel [11], [12], [13]

The main sources of noise on a ship include the main engine [14], propeller [15], [16], auxiliary engine, HVAC systems and also tunnel thruster [17]. The main engine is a significant contributor, producing noise and vibrations due to fuel combustion and mechanical movement [14]. The propeller generates noise through *cavitation* – the formation and collapse of bubbles in the water caused by the propeller's motion [15], [16]. Additionally, the auxiliary engines used for power generation and support systems add to the overall noise through their mechanical operation. HVAC systems (Heating, Ventilation, and Air Conditioning) produce noise from air circulation, fans, and compressors. Another important contributor is the tunnel thruster, which generates noise during maneuvering operations due to the movement of water [17]. These sources together impact the ship's acoustic signature, especially in underwater environments.

Research related to noise generated by the main engine has been conducted by Cui [18]. This study investigates the effects of marine engine noise on seafarer fatigue, with a specific focus on a case study conducted in China. The research aims to analyze how exposure to engine noise during sailing and berthing periods influences sleep quality and levels of fatigue. In the topic of propeller noise, research has been conducted by Dunstorm [15]. The study focuses on reducing underwater noise generated by the propulsion system of naval vessels, specifically the Carrier Seal by James Fisher Defense. A new custom-designed propeller was developed using *OpenProp* software for MATLAB, adjusting parameters such as the number of blades, blade area ratio, pitch, and skew angle. The prediction of underwater noise has been explored by Daniel [19]. This paper explores how ship design and operation affect underwater noise. It presents a noise prediction model based on Wittekind's framework and AIS data. The model includes noise from two-stroke engines, analyzed using FEM. This tool helps estimate underwater noise from ship traffic and create noise maps to understand noise sources and their impact.

The researcher identified an apparent knowledge gap in prior research concerning the impact of vessel speed on the acoustic performance of bow thruster tunnels. In addition, the prior research did not address the subject of the interaction between hydrodynamic factors and acoustic emissions under varying operational conditions. This encompasses several unexplored dimensions that have lately attracted research attention in other disciplines, such as environmental acoustics and computational modeling for noise reduction [15], [18], [19]. The hydrodynamic-acoustic relationship should be explored further to provide an understanding as to why such detailed investigations are not the case with maritime thruster systems. This could lead to innovative strategies for mitigating underwater noise pollution and fostering environmentally sustainable maritime operations.

2. Method and Object

The object of research is the bow thruster tunnel of a vessel, specifically focusing on the acoustic properties (noise) generated during different operational speeds. The bow thruster tunnel is analyzed under various speed conditions to observe changes in noise levels and acoustic characteristics. Simulations are run to see how different speeds affect noise generation within the tunnel. The study uses CFD ANSYS Fluent methods to simulate fluid flow and acoustic behavior in the bow thruster tunnel. The procedures typically include Geometry modeling of the bow thruster and tunnel. Meshing of the model to prepare it for simulation. Defining boundary conditions such as speed. Running CFD simulations to analyze fluid flow and acoustic output. Using post-processing techniques to interpret acoustic data, such as sound pressure levels.

3. CFD for acoustics assessment

To assess acoustics, CFD (Computational Fluid Dynamics) can be utilized to model sound propagation and transmission through a hull and surrounding water. The modeling process requires simulating the simulation by importing or creating the geometry. The geometry can be modified as required to ensure accurate and efficient simulation. The fluid properties and water models, including density, must be specified. And boundary conditions for the fluid domain, such as inlet and outlet conditions, must be defined.

Finally, the simulation can be run, and the results can be analyzed to assess the acoustic performance. The results may include measures of acoustic performance, such as pressure levels. These results can be utilized to optimize the design, minimize noise emissions, and evaluate compliance with requirements.

4. Results and Discussion

4.1. Simulation Method

The simulation used the SST K-Omega model. The simulation was conducted using a simple method and hybrid initialization. The simulation model used can be seen in Table 1.

Table 1. Setting up simulation

Parameter	Properties
System	Steady State
Model	SST K-Omega
Method	Simple
Initialization	Hybrid
Velocity Inlet (knot)	10, 15, 20, 22, 28

The SST k-omega model is a widely used turbulence model in Computational Fluid Dynamics simulations. It combines k-omega and k-epsilon models, making it suitable for attached and separated flows. The model accounts for the anisotropic effects of the Reynolds stress, which makes it more effective in adverse pressure gradient flows. Turbulence models like SST k-omega are essential in CFD simulations to simulate turbulent flows that are too complex to solve directly. These models provide a way to predict turbulence behavior and its impact on other physical phenomena.

The Simple algorithm is a pressure-based solver used in CFD that is appropriate for solving a broad range of flow problems, from laminar to turbulent. The name "Simple" comes from its simple pressure-velocity coupling method that links the pressure and velocity fields using the continuity equation. This solver is known for its computational efficiency and ability to converge in fewer iterations than other algorithms. However, it may not be suitable for highly transient or unsteady flows and may require some additional tweaking to achieve convergence in some cases. Despite this, the Simple algorithm is widely used and considered a dependable solver in CFD for a wide range of flow simulations.

Hybrid initialization is a technique available in CFD that combines two methods, zero-gradient and user-defined, to improve initialization accuracy and convergence speed. This approach starts with the zero-gradient method to set variables to zero at the boundaries and then switches to the user-defined method to refine the initial values. Hybrid initialization can provide better results and faster convergence than using only one of the initialization methods. It is beneficial in simulations with complex geometries or multiphase flows where initial conditions are crucial for achieving accurate results. The simulation using CFD produces a graph called a residual scale. By looking at this graph, researchers can determine whether the simulation model has converged at a particular iteration. The results of the residual scale can be seen in Figure 1.

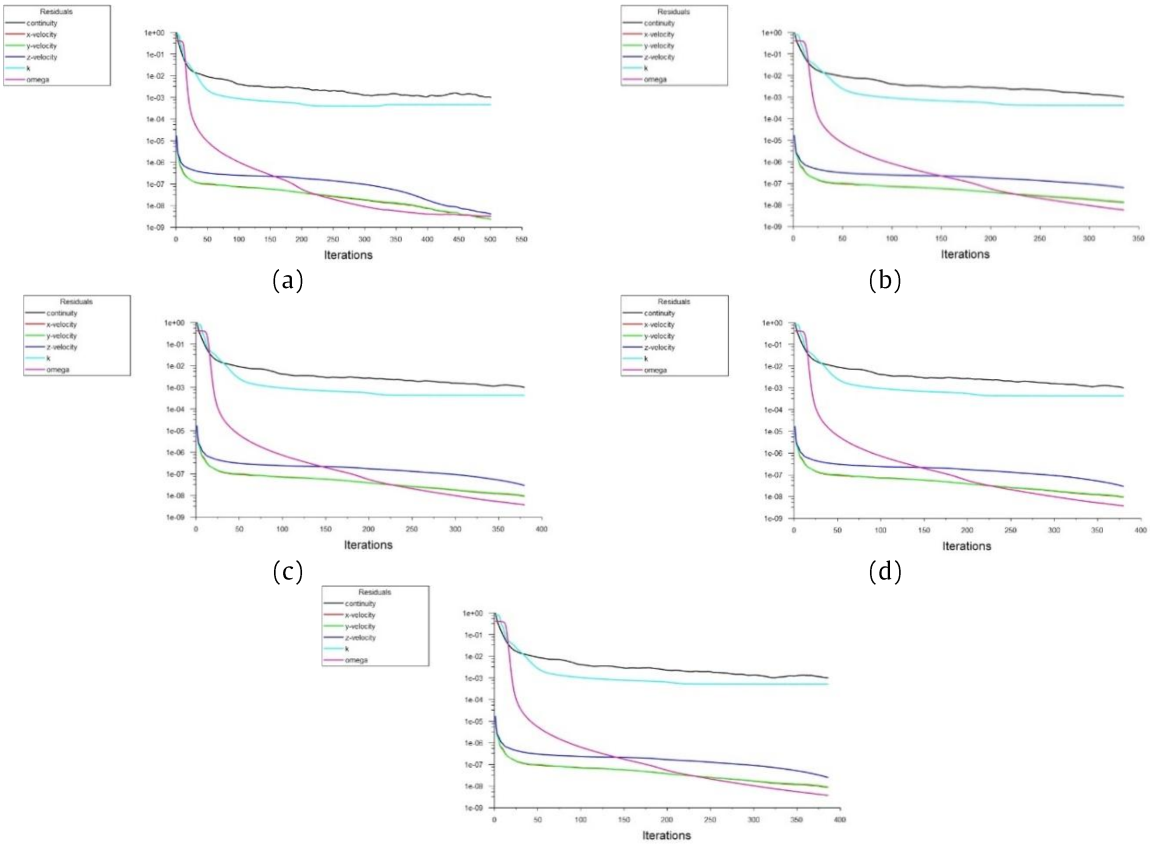


Figure 1 Scale Residual of Models (a) 10 kn (b) 15 kn (c) 20 kn (d) 22 kn (e) 28 kn

Figure 1 shows the scaled residual of the models. The scaled residual is a numerical technique used in Computational Fluid Dynamics simulations to evaluate the precision of the obtained solution. It involves computing the residuals, which are the differences between the predicted and actual values and then scaling them based on the characteristics of the solution. By comparing the scaled residuals with a predefined tolerance level, the method can determine the accuracy of the numerical solution. Scaled Residual CFD is particularly useful for assessing the stability and convergence of the solution in complex fluid flow simulations, where the non-linear and time-dependent nature of the flow can make it challenging to determine the accuracy of the solution.

Overall, the Scaled Residual CFD method is an essential tool in Computational Fluid Dynamics simulations, as it verifies the numerical solution's accuracy and dependability. It helps to identify areas where the simulation may need improvement to enhance the accuracy of the results. In CFD, the default convergence criterion is adequate for most problems. This criterion requires that the scaled residuals, defined by a continuity equation, decrease to 10^{-3} for all equations except for the energy and P-1 equations, for which the criterion is 10^{-6}. The scaled residual results for the model at each velocity can be seen in Table 2.

Table 2. Convergence Analysis

Velocity (knot)	Number of Iteration
10	500
15	335
20	380
22	383
28	386

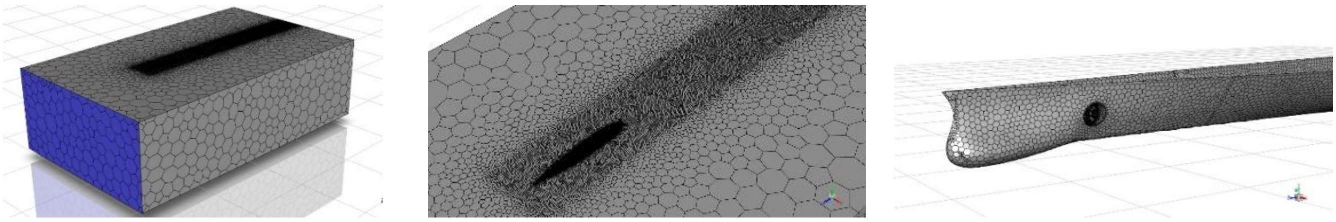
Table 2 displays the outcomes of a simulation of that specific model. The simulation was executed at different velocities spanning 10 to 28 knots, and the corresponding number of iterations and residual values are listed for each velocity. The residual values indicate the simulation convergence quality, whereas lower values suggest better convergence. It is observed that the number of iterations necessary for achieving convergence differs marginally for each velocity and varies from 335 to 500 iterations. The residual values attained for each velocity are all 10^{-3}, which was the defined convergence criterion for this simulation. This indicates that the simulation has converged to an acceptable solution for all tested velocities.

The table shows the relationship between ship velocity (in knots) and the corresponding number of iterations required for a computational process, likely related to simulating or optimizing ship performance or acoustic behavior. As the ship's velocity increases, the number of iterations generally decreases at first and then stabilizes. At 10 knots, the number of iterations is highest at 500, indicating that the computational process requires more steps to converge at lower speeds. As the velocity increases to 15 knots, the number of iterations drops significantly to 335, suggesting that the solution converges more efficiently at moderate speeds. However, beyond 15 knots, the number of iterations increases slightly, rising to 380 at 20 knots and then leveling off at 383 and 386 for 22 knots and 28 knots, respectively.

This pattern may reflect changes in the complexity of the fluid dynamics and propulsion behavior at different speeds. The initial drop could indicate that the system stabilizes at moderate speeds, leading to faster convergence. The increase and stabilization at higher speeds might be due to more complex flow patterns and increased turbulence, which require more computational effort to resolve but not as much as at very low speeds.

4.2. Meshing and Boundary Condition

In CFD, meshing is partitioning a computational domain into a finite number of interconnected cells or elements. The objective is to solve fluid flow problems numerically using the Finite Volume Method (FVM) the mesh functions as a discretized representation of the domain, which is crucial for simulations. The meshing process includes selecting the type and size of elements, determining their connectivity and boundary conditions, and considering the domain's geometry and the flow physics under investigation. A well-constructed mesh is essential for producing precise and dependable outcomes in Fluent simulations. The meshing process can be seen in Figure 2.



(a) (b) (c)

Figure 2 Meshing Process (a) domain (b) detail object (c) ship

CFD uses boundary conditions to describe fluid flow behavior at a computational domain's boundaries. The purpose of these conditions is to model the interaction between fluid flow and solid boundaries and to specify the flow properties at inlet and outlet boundaries. Velocity inlet is used to specify the velocity of the fluid at the inlet boundary, while pressure outlet sets the pressure value at the outlet boundary. The wall boundary condition models solid boundaries with the no-slip condition, where fluid velocity is zero.

4.3. Pressure

In fluid mechanics, pressure is the amount of force per unit area a fluid exerts on its surroundings. A scalar quantity indicates the strength of the perpendicular force that a fluid applies to a surface in contact with it per unit area. Pressure is a significant parameter in the study of fluid dynamics and significantly influences the behavior of fluids in motion.

Table 3. Pressure Maximum

Velocity (knot)	**Pressure in Hull (Pa)**	**Pressure in Bow Thruster Hole (Pa)**	**Contribution to Pressure Max**
10	11604	8006	69.0 %
15	26103	18028	69.1 %
20	46396	32065	69.1 %
22	56136	38025	67.7 %
28	90912	62891	69.2 %

Table 3 The table shows the pressure in a ship′ s hull and bow thruster hole at different velocities and the contribution to the maximum pressure. The ship is assumed to travel at velocities of 10, 15, 20, 22, and 28 knots. At a velocity of 10 knots, the pressure in the hull is 11604 Pa, and the pressure in the bow thruster hole is 8006 Pa, contributing to 69.0% of the maximum pressure. Similarly, at a velocity of 15 knots, the pressure in the hull and bow thruster hole is 26103 Pa and 18028 Pa, respectively, contributing to 69.1% of the maximum pressure. The pressure in both the hull and bow thruster hole increases as the velocity increases. At a velocity of 20 knots, the pressure in the hull and bow thruster hole is 46396 Pa and 32065 Pa, respectively, and they still contribute to 69.1% of the maximum pressure. However, at a velocity of 22 knots, the contribution to the maximum pressure drops to 67.7%. This is because the pressure in the bow thruster hole 38025 Pa is slightly lower compared to the other velocities, while the pressure in the hull 56136 Pa is still high. At the highest velocity of 28 knots, the pressure in the hull and bow thruster hole is 90912 Pa and 62891 Pa, respectively, contributing to 69.2% of the maximum pressure.

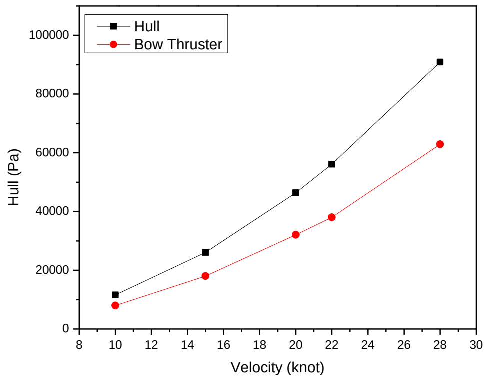


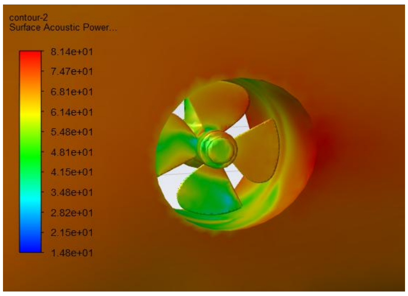
Figure 3 Relation between Velocity to Hull and Bow Thruster Pressure Maximum

Based on the provided data, it can be concluded that as the ship's velocity increases, the pressure in the hull and bow thruster hole also increases. Additionally, the contribution to pressure max remains relatively constant at around 69%, except for the velocity of 22 knots, which decreases slightly to 67.7%. It can be inferred that the ship is designed to withstand higher pressures at higher velocities, as evidenced by the significant increase in pressure from 10 to 28 knots.

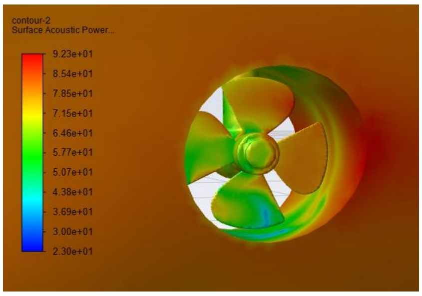
Overall, the results demonstrate that as the velocity increases, the pressure values in both the hull and bow thruster hole also increase, resulting in higher contributions to the maximum pressure value during the simulation. This information can be used to optimize the design to reduce the pressure and noise levels, which are essential factors for the mission.

4.4. Acoustic

Acoustics related to the bow thruster holes of a ship is the study of sound generation, propagation, and reception in and around the openings where water enters and exits to enable the operation of the bow thruster. The flow of water through these holes can produce noise and vibration, which can be a source of noise.



(a)



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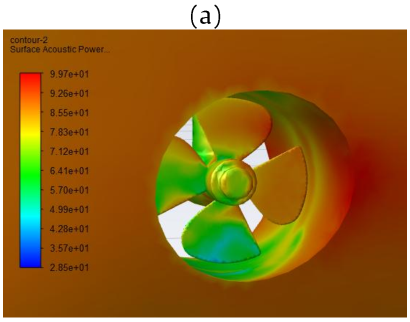

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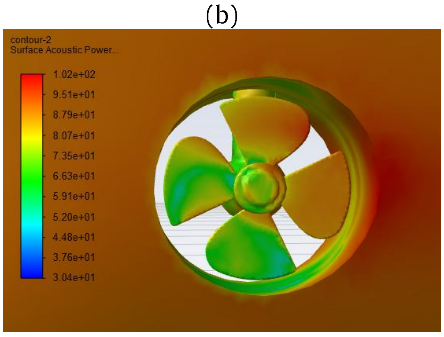

(d)

(e)

Figure 4 Surface Acoustic Power Contour (a) 10 kn (b) 15 kn (c) 20 kn (d) 22 kn (e) 28 kn

The simulations revealed that high acoustic concentrations occur at the tunnel of the bow thruster. This is due to a significant pressure difference between the interior and exterior of the bow thruster tunnel. This finding is significant because a acoustic signature can significantly impact its performance. To address this issue, one potential solution is to modify the design of the bow thruster inlet. In particular, using a cone ring inlet design can help to reduce the pressure difference between the interior and exterior of the tunnel. This can, in turn, reduce the acoustic signature of the ship.

However, it's important to note that many other factors, such as hull design, propulsion system, and overall operational strategy, can contribute to an acoustic signature. Therefore, reducing the acoustic signature is a complex problem that requires a multi-faceted approach. Nevertheless, the findings of the simulations discussed in the passage provide valuable insights into one potential solution for reducing the acoustic signature of a ship.

Table 4. Acoustics Maximum

Velocity (knot)	Acoustic Max (db)
10	81.39
15	92.31
20	99.69
22	102.31
28	108.86

Table 4 shows the maximum acoustic levels measured in decibels (dB) at different ship velocities. As the velocity of the ship increases, the acoustic levels also increase. At 10 knots, the maximum acoustic level is 81.39 dB, while at 28 knots, the maximum level reaches 108.86 dB. This suggests that the ship's speed significantly impacts the acoustic signature it produces, with higher speeds leading to louder noise levels. The table shows the relationship between ship velocity (in knots) and the corresponding maximum acoustic signature (in decibels). As the ship's velocity increases, the acoustic signature also rises, indicating that higher speeds generate more noise. At lower speeds, such as from 10 to 20 knots, the increase in noise is relatively moderate, with the acoustic signature rising from 81.39 dB at 10 knots to 99.69 dB at 20 knots – an increase of about 18.3 dB. However, at higher speeds, the noise increases more sharply. For instance, between 22 and 28 knots, the acoustic signature increases significantly from 102.31 dB to 108.86 dB, a rise of approximately 6.55 dB. This trend reflects the typical behavior of ship noise, where increased velocity leads to greater propeller cavitation, hull friction, and hydrodynamic flow noise, resulting in a steeper increase in acoustic output at higher speeds.

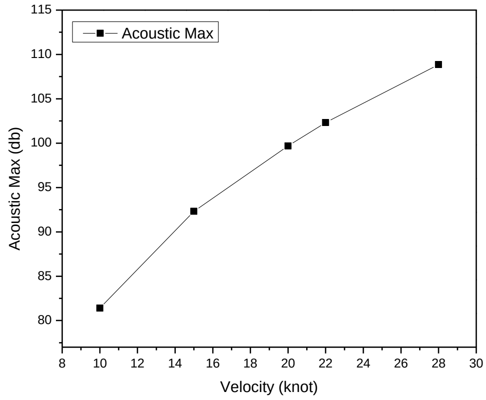

Figure 5 Relation between Velocity to Acoustic Maximum

This data relates to the ship because it highlights the significant impact of a ship's speed on its acoustic signature, which can be crucial for its performance. As the velocity of the ship increases, so does the acoustic max, indicating that the noise generated by the ship also increases. This noise can negatively impact operations, the environment, security, and the crew. Operationally, noise can reduce energy efficiency, accelerate component wear, and increase maintenance costs. Environmentally, underwater noise disrupts marine ecosystems, especially affecting animals like whales and dolphins.

This study examines how ship speed affects the noise generated by the bow thruster tunnel. The analysis likely uses CFD to simulate water flow and pressure changes within the tunnel at different speeds, helping to understand how these factors influence noise levels. However, there are some limitations to consider. The study may use simplified ship geometry and boundary conditions, which can reduce accuracy. The choice of turbulence model might not fully capture complex flow patterns, and a limited speed range could overlook important changes at very low or high speeds. Additionally, the analysis might not account for interactions with other ship components or how sound propagates through water. For future research, expanding the speed range, using more advanced turbulence models, and including acoustic propagation analysis could improve accuracy. Studying structural vibrations and validating results with real-world data would also make the findings more reliable and useful for noise reduction strategies.

5. Conclusion

The simulation results showed that a high acoustic signature occurs at the inlet of the bow thruster due to a significant pressure difference between the interior and exterior of the bow thruster tunnel. To reduce the acoustic signature and increase performance of a ship, modifying the design of the bow thruster inlet using a cone ring inlet design could be a potential solution. However, reducing the acoustic signature is a complex problem that requires a multi-faceted approach, considering other factors such as hull design, propulsion system, and operational strategy. Overall, the simulation findings provide valuable insights for developing effective strategies for reducing the acoustic signature of a ship.

References

[1] J. A. Hildebrand, "Anthropogenic and natural sources of ambient noise in the ocean," *Marine Ecology Progress Series*, vol. 395, pp. 5–20, 2009. https://doi.org/10.3354/MEPS08353

[2] M. A. McDonald, J. A. Hildebrand, and S. M. Wiggins, "Increases in deep ocean ambient noise in the Northeast Pacific west of San Nicolas Island, California," *The Journal of the Acoustical Society of America*, vol. 120, no. 2, pp. 711–718, Aug. 2006. https://doi.org/10.1121/1.2216565

[3] R. Bruintjes and A. N. Radford, "Context-dependent impacts of anthropogenic noise on individual andsocial behaviour in a cooperatively breeding fish," *Animal Behaviour*, vol. 85, no. 6, pp. 1343–1349, Jun. 2013. https://doi.org/10.1016/J.ANBEHAV.2013.03.025

[4] A. A. Y. H. Chan and D. T. Blumstein, "Attention, noise, and implications for wildlife conservation and management," *Applied Animal Behaviour Science*, vol. 131, no. 1–2, pp. 1–7, Apr. 2011. https://doi.org/10.1016/J.APPLANIM.2011.01.007

[5] C. R. Kight and J. P. Swaddle, "How and why environmental noise impacts animals: An integrative, mechanistic review," *Ecology Letters*, vol. 14, no. 10, pp. 1052–1061, Oct. 2011. https://doi.org/10.1111/J.1461-0248.2011.01664.X

[6] K. C. Buckstaff, R. S. Wells, J. G. Gannon, and D. P. Nowacek, "Responses of bottlenose dolphins (tursiops truncatus) to construction and demolition of coastal marine structures," *Aquatic Mammals*, vol. 39, no. 2, pp. 174–186, 2013. https://doi.org/10.1578/AM.39.2.2013.174

[7] R. Williams, C. Erbe, E. Ashe, and C. W. Clark, "Quiet(er) marine protected areas," *Marine Pollution Bulletin*, vol. 100, no. 1, pp. 154–161, Nov. 2015. https://doi.org/10.1016/J.MARPOLBUL.2015.09.012

[8] R. T. Buxton, R. Galvan, M. F. McKenna, C. L. White, and V. Seher, "Visitor noise at a nesting colony alters the behavior of a coastal seabird," *Marine Ecology Progress Series*, vol. 570, pp. 233–246, Apr. 2017. https://doi.org/10.3354/MEPS12073

[9] C. D. Francis, N. J. Kleist, C. P. Ortega, and A. Cruz, "Noise pollution alters ecological services: Enhanced pollination and disrupted seed dispersal," *Proceedings of the Royal Society B: Biological Sciences*, vol. 279, no. 1739, pp. 2727–2735, Jul. 2012. https://doi.org/10.1098/RSPB.2012.0230

[10] H. P. Kunc, K. E. McLaughlin, and R. Schmidt, "Aquatic noise pollution: Implications for individuals, populations, and ecosystems," *Proceedings of the Royal Society B: Biological Sciences*, vol. 283, no. 1836, Aug. 2016. https://doi.org/10.1098/RSPB.2016.0839

[11] J. P. Jalkanen, L. Johansson, M. H. Andersson, E. Majamäki, and P. Sigray, "Underwater noise emissions from ships during 2014–2020," *Environmental Pollution*, vol. 311, Oct. 2022. https://doi.org/10.1016/J.ENVPOL.2022.119766

[12] M. F. McKenna, D. Ross, S. M. Wiggins, and J. A. Hildebrand, "Underwater radiated noise from modern commercial ships," *The Journal of the Acoustical Society of America*, vol. 131, no. 1, pp. 92–103, Jan. 2012. https://doi.org/10.1121/1.3664100

[13] J. M. Jones, K. H. Westdal, A. J. Ootoowak, S. M. Wiggins, and J. A. Hildebrand, "Impact of ship noise on the underwater soundscape of Eclipse Sound in the northeastern Canadian Arctic," *Marine Pollution Bulletin*, vol. 195, p. 115534, Oct. 2023. https://doi.org/10.1016/J.MARPOLBUL.2023.115534

[14] S. A. Patil and R. R. Arakerimath, "Parametric Optimization of Biodiesel Fuelled Engine Noise using the Taguchi Method," *Engineering, Technology & Applied Science Research*, vol. 10, no. 4, pp. 6076–6079, 2020. https://doi.org/10.48084/etasr.3595

[15] A. Dunstrom and F. Skjernov, "Development and study of noise generation from propellers," KTH Royal Institute of Technology, 2022.

[16] S. Ekinci, "A Practical Noise Prediction Method for Cavitating Marine Propellers," *Brodogradnja*, vol. 61, no. 4, pp. 359–366, 2010, [Online]. Available: http://hrcak.srce.hr/file/94695

[17] M. H. Park, S. Yeo, J. H. Choi, and W. J. Lee, "Review of noise and vibration reduction technologies in marine machinery: Operational insights and engineering experience," *Applied Ocean Research*, vol. 152, p. 104195, Nov. 2024. https://doi.org/10.1016/J.APOR.2024.104195

[18] R. Cui, Z. Liu, X. Wang, Z. Yang, S. Fan, and Y. Shu, "The impact of marine engine noise exposure on seafarer fatigue: A China case," *Ocean Engineering*, vol. 266, p. 112943, Dec. 2022. https://doi.org/10.1016/J.OCEANENG.2022.112943

[19] J. M. Daniel, M. G. Schuster, G. Andresen-Paulsen, F. Holz, K. Wittekind, and S. Ehlers, "An Advanced Prediction Model for Underwater Noise Emissions of Ships," *Journal of Ship Production and Design*, vol. 38, no. 04, pp. 220–238, Nov. 2022. https://doi.org/10.5957/JSPD.06210017