MEng Project Report

Global Response of Ship Models under the Influence of Surface Waves

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1 Abstract

2 Introduction

This work is a branch of study in Near-Field Noise from Hull and Propeller (HARP). The HARP project focuses on the identification, characterization, and propagation of sound sources, which involve highly nonlinear multiphysics and multiscale physics. This research encompasses both near-field and far-field effects, with a particular emphasis on the following areas:

- **Generation:** Investigation of near-field hull and propeller fluid-structure interaction physics, including bubble wake flows and bubble-wall interactions.
- **Radiation:** Analysis of the far-field effects of the complex dynamical ocean environment, considering factors such as turbulence, waves, currents, temperature, and salinity.

Additionally, the project aims to enhance the physical understanding and mitigation of underwater noise through:

- Evaluating frequency, volume, duration, and the time to reach maximum noise levels.
- Developing monitoring and mitigation techniques, technologies, and methods, such as optimizing ship speed and propeller pitch, and designing bio-inspired propeller blades and hulls.

This comprehensive approach aims to contribute to quieter and more efficient ship designs, balancing environmental performance with operational efficacy.

Underwater radiated noise (URN) sources comes from:

1. vortex created by hull forms and appendages
2. structure vibration creating pressure waves
3. gear mesh
4. propeller crating pressure waves

Thus, as a branch of the HARP project, this work investigated into the global response/vibration of ship models under the influence of surface waves.

3 Methodology

The primary workflow of this project involves a two-step process. The initial step is to reproduce the results from Section 9.2 of Vaibhav Joshi's Ph.D. thesis[1]. This section focuses on the analysis of the DTMB5415 ship model. The subsequent step is to replace the DTMB5415 ship model with the BURNSi ship model and conduct a similar model analysis.

The main target of this analysis is to study the heave motion of the BURNSi ship model under the same inlet wave conditions as those described in Section 9.2 of [1]. By maintaining consistent wave conditions, we aim to directly compare the performance and characteristics of the BURNSi ship model against the baseline results obtained from the DTMB5415 ship model.

1. **Reproduce Section 9.2 Results:**
   - Follow the methodology outlined in Vaibhav Joshi's thesis to recreate the results using the DTMB5415 ship model.
   - Validate the accuracy and consistency of the reproduced results with the original findings.
2. **Model Analysis with BURNSi Ship Model:**
   - Replace the DTMB5415 ship model with the BURNSi ship model in the simulation framework.
   - Conduct a detailed analysis focusing on the heave motion of the BURNSi ship model.
   - Utilize the same inlet wave conditions as specified in Section 9.2 of [1] to ensure comparability.

This approach allows for a systematic evaluation of the BURNSi ship model's performance in terms of its heave motion response, providing valuable insights for further improvements and applications.

3.1 DTMB5415

The ship model used for the first part of this project is David Taylor Model Basin (DTMB5415) as shwon in figure 1, which was conceived as a preliminary design for a Navy surface combatant around 1980. The hull geometry of Model 5415 includes both a sonar dome and a transom stern. Propulsion is provided through twin open-water propellers driven by shafts supported by struts.

It is important to note that no full-scale ship exists for this model. The hull geometry and relevant loading conditions and speeds are detailed below and in the Appendix section.

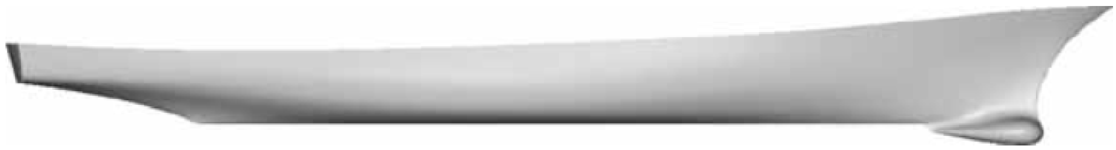

Figure 1: DTMB5415

Description		**Ship**	**Model**
Scale factor	λ	-	24.824
Length between perpendiculars	L_{PP} (m)	142.0	5.720
Length at water level	L_{WL} (m)	142.0	5.720
Overall length	L_{OS} (m)		
Breadth	B (m)	18.9	0.76
Draft	T (m)	6.16	0.248
Trim angle	(deg)	0.0	0.0
Displacement	Δ (t)	8636.0	0.549
Volume	∇ (m^3)	8425.4	0.549
Wetted surface	S_W (m^2)	2949.5	4.786

Hull coefficients

L_{PP} /B	7.530	CB	$\nabla/(L_{PP}BT)$	0.506
B/T	3.091	CP	$\nabla/(L_{PP}A_X)$	0.613
L_E/L_{PP}	0.550	CPF	$2\nabla_F/(L_{PP}A_X)$	0.594
L_R/L_{PP}	0.450	CPA	$2\nabla_A/(L_{PP}A_X)$	0.646
L_P/L_{PP}	0.0	CX	A_X/BT	0.825
$L_{PP}/\nabla^{1/3}$	6.978	CW	$A_W/(L_{PP}B)$	0.778
$S_W/\nabla^{2/3}$	7.123	CWF	$2A_{WF}/(L_{PP}B)$	0.676
X_{FB}/L_{PP}	0.505	CWA	$2A_{WA}/(L_{PP}B)$	0.881

Figure 2: DTMB5415 Specifications[2]

3.2 Domain & Boundary Conditions

The computational domain of this work is the reduced version of the Vaibhav's domain which was described in section 9.2.1 in [1] as shown in figure 3. The boundaries Γ_{in} and Γ_{out} shown in

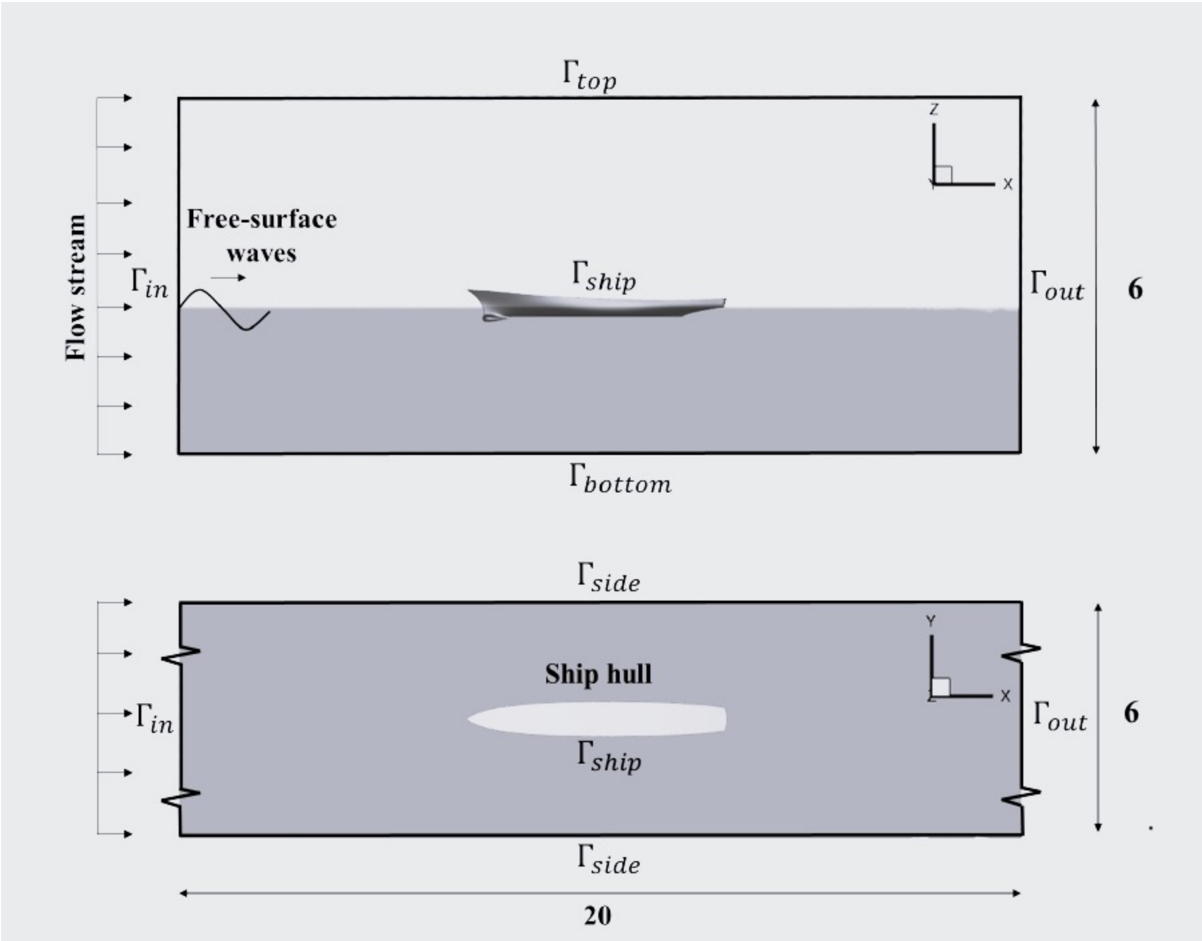

Figure 3: DTMB5415 Specifications

figure 3 denote the inlet and outlet. The inlet boundary is exposed to an incoming free-surface wave. No condition is applied at the outlet boundary, the reason will be explained in section 3.5. Slip and no-slip boundary conditions are satisfied at the sides Γ_{side} and the ship hull surface Γ_{ship}, respectively. An atmospheric condition is satisfied at Γ_{top} with a no-slip condition at Γ_{bottom}.

3.3 Mesh

The mesh for the computational domain discussed in the previous section is constructed in Gmsh. Note that for better view, only 2D mesh is presented below. A 3D view is provided in the Appendix section.

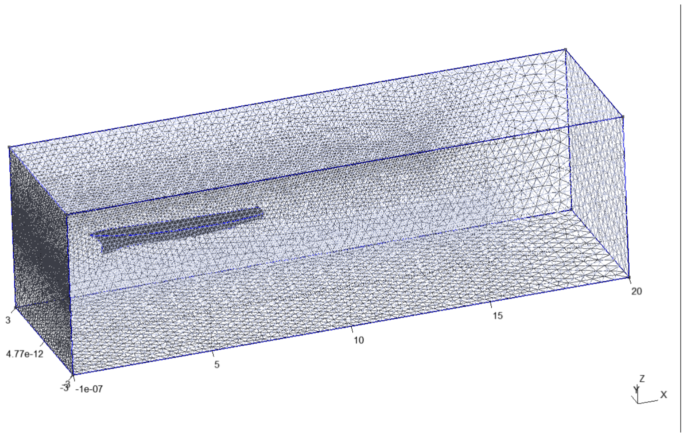

Figure 4: Mesh of the Domain

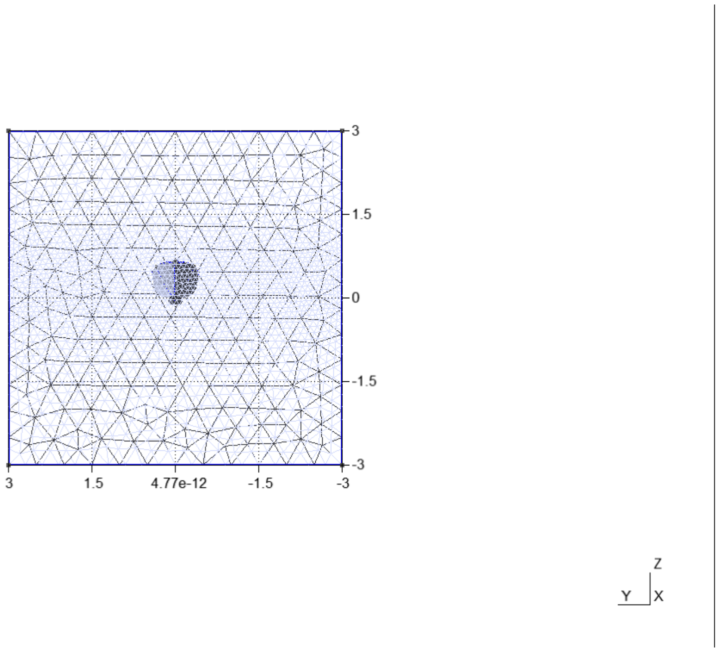

Figure 5: Front View of the Mesh

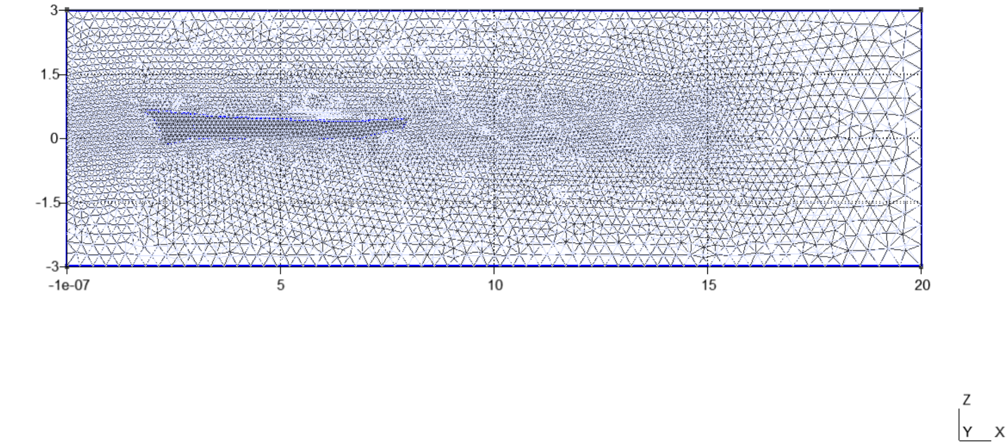

Figure 6: Side View of the Mesh

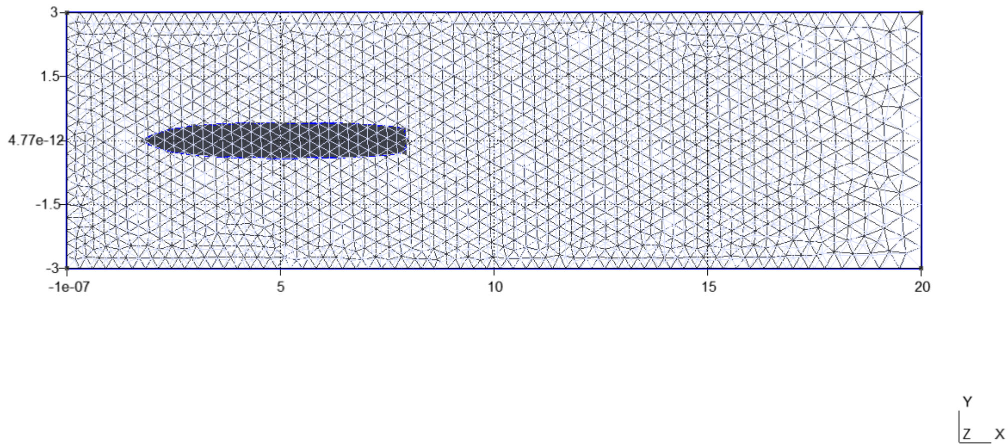

Figure 7: Top View of the Mesh

3.4 Mesh Statistics

Mesh details are shown in figure 8.

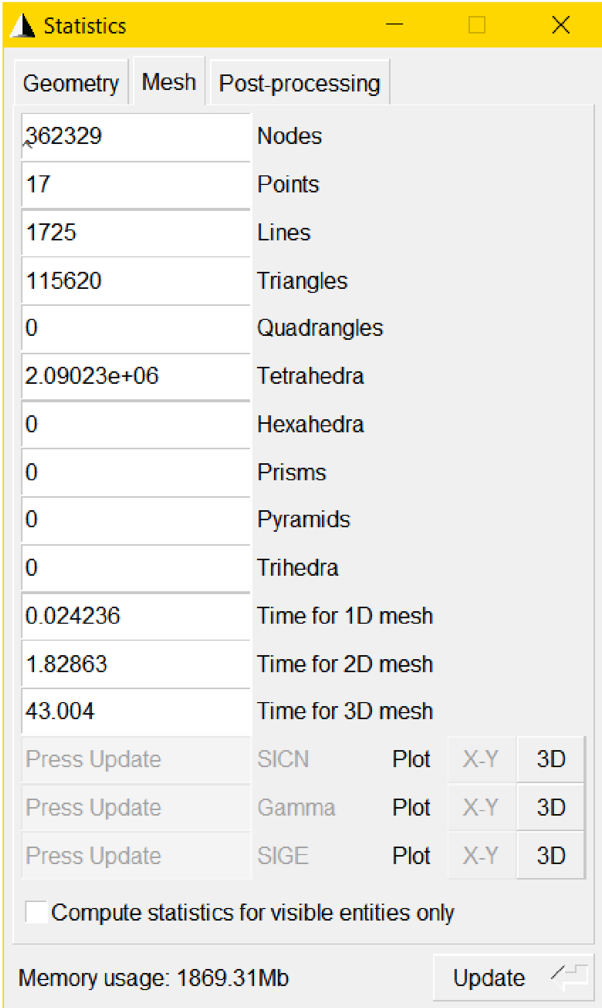

Figure 8: Mesh Statistics

3.5 SIMFLOW Simulation Configuration

The side boundaries are modeled with slip boundary conditions, while no-slip conditions are satisfied at the bottom and on the ship's surface. An atmospheric condition of $p = 0$ is satisfied at the top boundary. The physical properties of water and air are used for the two fluid phases, i.e., $\rho_f^1 = 1000$, $\nu_f^1 = 1.002 \times 10^{-3}$, $\rho_f^2 = 1.225$, and $\nu_f^2 = 1.983 \times 10^{-5}$. The acceleration due to gravity is $g = (0, 0, -9.81)$.

Based on the given data of the DTMB 5415 ship model in section 3.1, the following non-dimensional numbers are employed, where V_{disp} is the volume of the displaced fluid at equilibrium. All variables are non-dimensionalized using the reference length L_{pp} and the freestream velocity U_1:

$$Re = \frac{\rho_f^1 U_1 L_{pp}}{\nu_f^1} = 1.069 \times 10^7$$
$$\rho^* = \frac{\rho_f^1}{\rho_f^2} = 816$$
$$m^* = \frac{m_s}{\rho_f^1 V_{disp}} = 1$$
$$\nu^* = \frac{\nu_f^1}{\nu_f^2} = 50$$
$$Fr = \frac{U_1}{\sqrt{g L_{pp}}} = 0.25$$

At the inlet, a wave is generated with such parameters shown in table 1. $\mathbf{u}_f = (u, v, w)$ represents the fluid velocity components. $U_{u\infty}$ is the freestream current velocity. H_w, T_w, and k_w denote the height, time period, and wavenumber of the incoming wave.

Table 1: Wave Conditions

Parameters	Non-dimensional Value	Value	Unit
H_w	$\frac{H_w}{L_{pp}} = 0.056$	0.32032	m
k_w	$k_w = \frac{2\pi}{L_{pp}}$	1.0845	m
T_w	$\frac{T_w U_1}{L_{pp}} = 0.629$	1.929	m

Moreover, the simualtion is configured by non-dimensional time step size of $\Delta t \frac{U_1}{L_{pp}} = 3.27 \times 10^{-3}$ and a total of 2,400 time steps.

4 Result

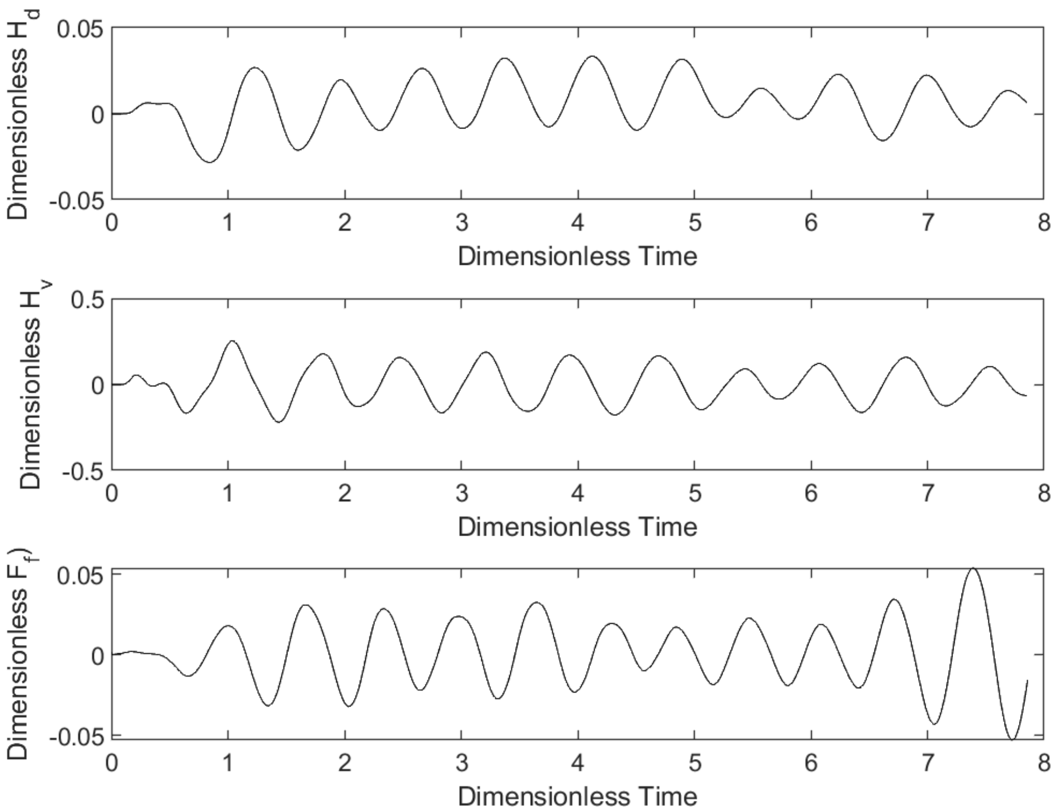

Figure 9: Heave displacement response $\left(\frac{\eta_s z}{L_{pp}}\right)$, heaving velocity $\left(\frac{\dot{\eta}_s z}{U_1}\right)$, and the vertical fluid force $\left(\frac{F_z}{\rho_f^1 U_1^2 L_{pp}^2}\right)$ on the DTMB 5415 ship model subjected to free-surface waves

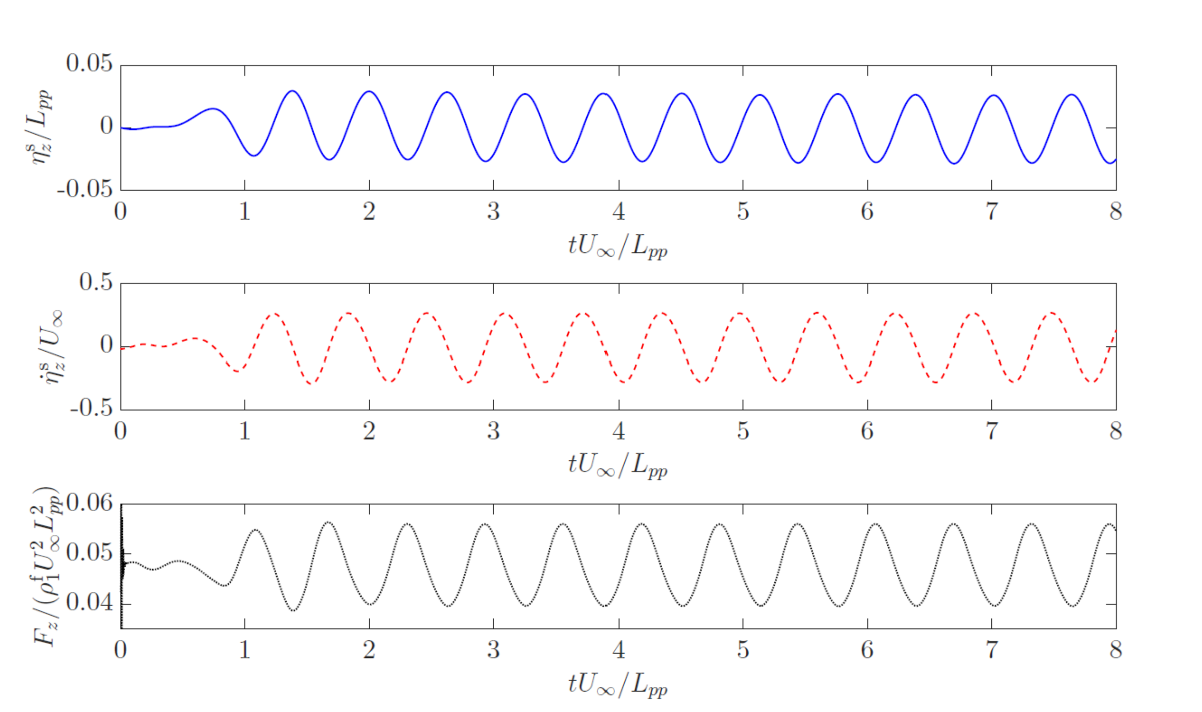

Figure 10: Vaibhav's Results

5 Discussion

As a seciton of the HARP project, this work facilitates developing innovative tools for predicting underwater vessel noise during the design phase. It will identify potential noise sources, such as on-board machinery and propeller noise. Enhanced design models are anticipated to assist the industry in adopting ‘quiet’ technologies for the next generation of ships, ensuring they maintain safety, productivity, and environmental performance.

6 Future Work

This work has only completed the first step of the scope stated in the methodology section. The future work is to replace the DTMB ship model with BURNSi model and conduct test using the set-up mentioned above.

7 Conclusion

8 Reference

References

[1] Vaibhav Joshi, *Variational Methods and Applications for Turbulent Single and Two-Phase Fluid-Structure Interaction*, ScholarBank@NUS Repository, 2018.

[2] A. Olivieri, F. Pistani, A. Avanzini, F. Stern, and R. Penna, *Towing tank experiments of resistance, sinkage and trim, boundary layer, wake, and free surface flow around a naval combatant INSEAN 2340 model*, IIHR Technical Report No. 421, 2001.

[3] A. Kendrick and R. Terweij, *Ship Underwater Radiated Noise*, Report 368-000-01, Rev 5, Vard Marine Inc., 08 July 2019.

9 Appendix

9.1 DTMB 5415 Specifications

9.2 3D Mesh

	Full-Scale	MARIN	INSEAN	IIHR	
Lpp (m)	142.00	4.002	4.002	5.719	3.048
Lwl (m)	142.18	4.007	4.008	5.726	3.052
Bwl (m)	19.06	0.537	0.538	0.768	0.409
T (m)	6.15	0.173	0.172	0.248	0.132
Displacement (m^3)	8424.4	0.189	0.188	0.554	0.0826
S w/o rudder (m^2)	2972.6	2.361	2.424	TBD	TBD
CB	0.507	0.507	0.507	0.506	TBD
CM	0.821	0.821	0.821	0.821	0.821
LCB (%Lpp), fwd+	-0.683	-0.683	-0.652	-0.652	TBD

Table 2: Main particulars of the ship model

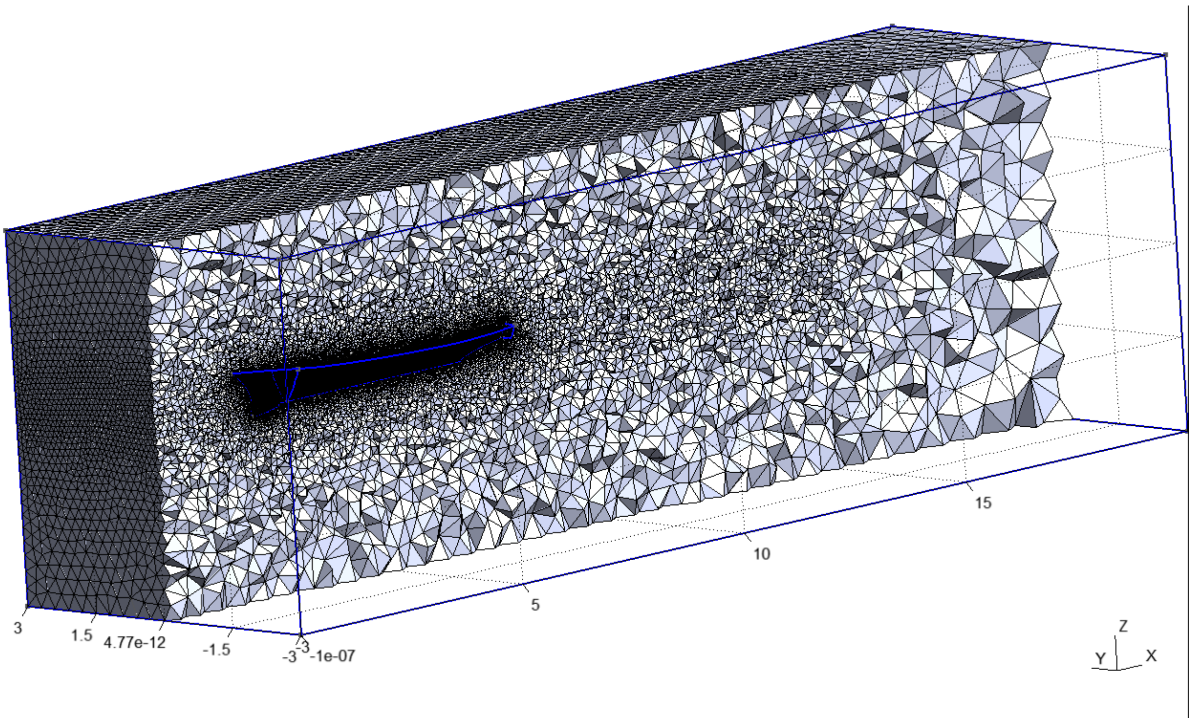

Figure 11: 3D Mesh