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Protecting Intellectual Capital at Sea

Selçuk Nas

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Keywords

Keywords: Officer, Intellectual capital, at sea

Dear Readers,

In this article, I want to talk about the importance of intellectual capital generated at sea and the strategies taken to protect it. There have been many campaigns over the past 20 years to recruit officers who have lost their motivation to return to the ships. While some of these campaigns have been successful, others were only able to provide getting back on board. Initially, some operators believed high wages, which are included in hygiene factors, to be sufficient as a motivating factor.

Although the high wage strategy initially motivated the officers, their motivation disappeared due to neglect of hygiene factors. However, the officers waited for working conditions to improve. They continued to keep 6+6 watches on the ships. While on paper, every precaution and care was taken to provide rest periods, in some fleets, the sailors could not even meet their physiological needs.

I compiled data on this subject from feedback we received from our students and graduates studying at maritime schools. While the earnings from the campaigns are lost daily, it is understood that we will have difficulty in motivating new job candidates to work at sea. By fostering crew companionship and prioritizing hygiene factors such as adequate rest periods, health and safety, career advancement, and work–life balance, organizations can create an environment that supports seafarers' well-being and promotes a motivated and committed workforce. Ultimately, by recognizing and fulfilling the unique needs of seafarers, maritime companies can elevate their operations and strengthen their competitive edge in the industry.

As a result, there is a need for new studies that can reveal the factors motivating officers to work at sea and the obstacles they face. I would like to put out a call to researchers on this subject.

We are pleased to introduce JEMS 11 (2) to our esteemed readership. We are very excited that this is the first issue of our second decade of publication and hope to complete many more decades. This issue presents valuable and intriguing studies that will without a doubt contribute to the maritime industry. Therefore, I would like to express our gratitude to the authors, who sent their valuable studies for publication, our reviewers, editorial board, section editors, and publisher, who provided quality publications by diligently following our publication policies.

Yours Sincerely,

Prof. Dr. Selçuk NAS

Editor in Chief

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Comments on the Use of 3D Printing Technology in the Design of an AUV Destined for the Identification and Destruction of Underwater Mines

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Abstract

The International Maritime Organization and the North Atlantic Treaty Organization are today, enforcing increasingly stringent rules for maritime safety and security on a national and international scale. The need for security in the Black Sea has increased, the degree of danger has risen, and the risk of loss of life and destruction of ships or other surface or submersible marine vehicles cannot be overlooked. Autonomous underwater vehicles (AUVs) have various civil applications (targeting economic, industrial, and commercial interests), but military applications have recently gained prominence (needs for information, surveillance, and inspection, for the identification and destruction of risk obstacles). Given the high risk of destruction during the operation, solutions are being sought to enable the rapid and cost-free construction of AUVs without compromising their performance and efficiency. The paper's novelty is provided by the mention of 3D printing technologies as a possible solution, taking into account the successes in other essential fields of science and technology. The contribution of the paper was related to the AUV's body extremities (bow and stern), and the following factors were considered: geometric design using computer-aided design methods; hydrodynamic analysis of forms using computational fluid dynamics methods; and prototype manufacturing using 3D printing.

Keywords: 3D printing technology, Autonomous underwater vehicles, Mine counter measure, Computer-aided design, Computational fluid dynamics

1. Introduction

Autonomous underwater vehicles (AUVs), which are part of the major group of submersibles (see Figure 1), are becoming more popular due to their ability to perform a significant variety of both civilian and military missions, including scientific research, industrial and commercial interests, information, safety, and security objectives.

Due to their advantages, they have undergone an extremely diverse architectural evolution, and the very wide range of applicability has dictated the accentuated dynamics of the construction of these types of vehicles. AUVs, with remotely operated vehicles (ROVs), are members of the complex group of unmanned underwater vehicles (UVs). Their design and construction involve interdisciplinary studies, which include computerized architecture design, computational dynamics of fluids, modeling, and control of systems, robotics, image processing, and so on. With the emergence and development of informatics-cybernetics-computerization and robotization over the last decade, the use of calculation and analysis methods of computational fluid dynamic (CFD) type has established itself as a fast, reliable, and cost-quality-efficient tool in the design and evaluation of hydrodynamic performances of submersible vehicles.

The design and construction of an AUV prototype intended for the detection and destruction of underwater mines were approved as part of the Sectoral Plan for Research and Development of the Romanian Ministry of National Defense. The approved project will be carried out in three stages (see Figure 2), as follows: in 2022, the hydrodynamic

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design of the AUV's body will be completed; in 2023, the hydrodynamic design and construction of the propulsion and governance system are targeted; and in 2024, the project will be completed with the final execution of the AUV and testing under real operating conditions.

Figure 1. *Constructive types of AUV's and ROV's [1]*

AUV: Autonomous underwater vehicle, ROV: Remotely operated vehicle

This study highlights the project's first-year results (Figure 2). The bow and stern domes of the body were the ones that received CAD hydrodynamic design and CFD simulation. In the second year of the project, after the CAD hydrodynamic design of the propulsion and governance system, the CFD simulation will be resumed and the results of model testing in the wind tunnel will be compared. Early and partial results from the second year of the project were also revealed.

2. Literature Review

The subject of UVs has sparked widespread (in terms of time) and intense (in terms of the number of published documents) interest in the world scientific community, civil and military, engineering, and other fields. If there is a single consecrated in this complex field of study, then it would undoubtedly be Thor Fossen, which has consistently addressed the issue of UVs in its publications [2-4], representing a significant bibliographic reference for any researcher interested in this topic.

The following summative results obtained by researchers interested in the field will be presented, with the selection made based on the subjects that have been approached in this study: architecture (dimensions, shape) of an AUV, ensuring nautical qualities; advanced methods of calculation, modeling, and CFD hydrodynamic simulation; equipping with on-board systems and equipment; use of 3D printing technology.

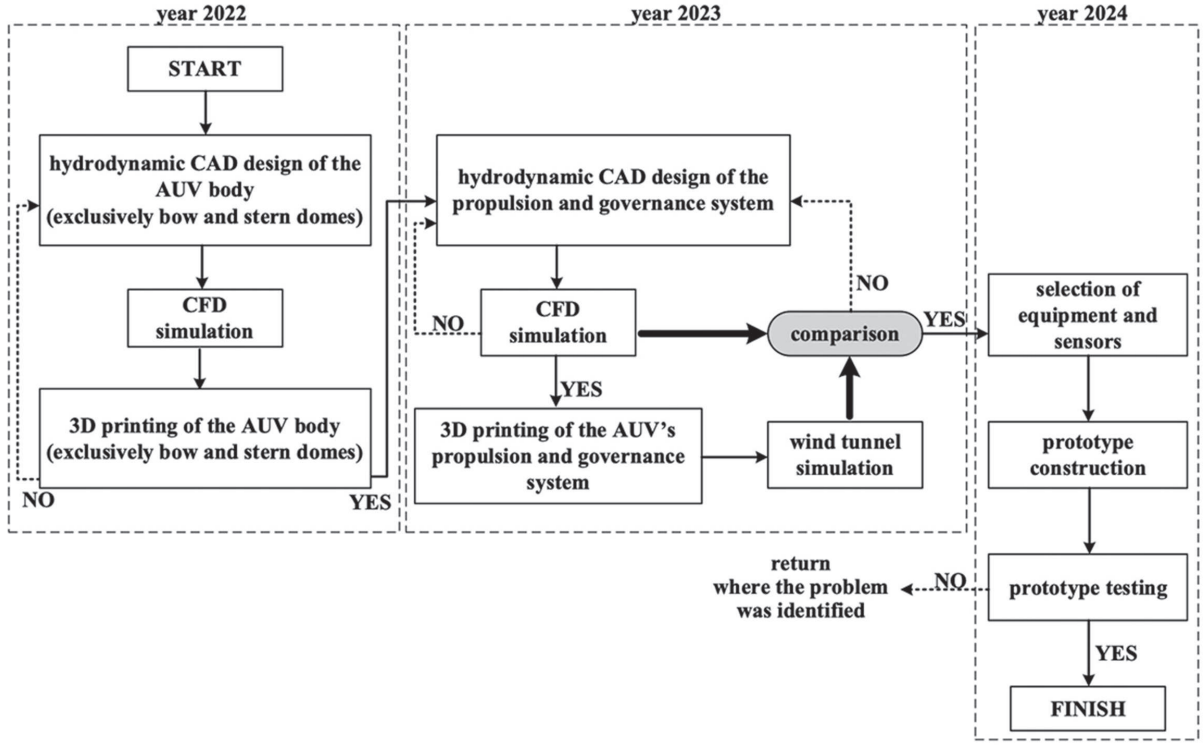

Figure 2. *Flow chart of the project*

CFD: Computational fluid dynamic

To develop the design of an AUV [5], the perspective of correlating the dimensions (of available space and equipment transport capacity) with the speed of movement was imposed (energy consumption). The parameters of an efficient design proved to be the dimensions and profile of the forward (nose) and aft (tail) structures and the dimensions of their reinforcers [6]. The optimization of the shape of an AUV is usually a multi-objective decision-making problem and is essential for determining its nautical qualities. The authors of this paper [7] recognize that the shape of an AUV is dictated by its functionality and has evolved from classical torpedo forms to special, unconventional forms.

UVs with hybrid propulsion, designed to develop an ultra-wide range of speeds, are presented in the literature [8], as is a conventional autonomous underwater glider with a propeller. A spheric amphibian vehicle is a spherical robot that is capable of operating in two different environments: terrestrial and underwater. Controlling the movement of a spherical robot is a difficult task, hence, it is designed with only two degrees of freedom: can move forward/backward and left/right [9].

More cutting-edge research proposes a bio-inspired architecture, with the shape optimized using the response surface method to obtain body sampling points [10]. The design of modular and reconfigurable AUVs aimed at improving their usability by extending their versatility and adaptability to new situations and missions is of great interest. This is achievable with a modular system design of hardware and reconfigurable software [11].

To reasonably design an AUV, the problem of stability during diving on a spiral trajectory was studied and the static, kinematic, and dynamic characteristics of diving were analyzed using MATLAB/Simulink software [12]. The relationship between net buoyancy, longitudinal center of gravity movement, metacentric height, and trajectory diving stabilization parameters was analyzed. The hydrodynamic performance of an AUV, particularly forward resistance (which is conditioned by the body's architecture), is an important factor in determining the power requirements and body shape of an AUV. The hydrodynamic performances of an AUV as well as the distribution of velocities and pressure of water particles around the body were studied [13] using CFD methods and various geometric shapes. According to Bono and Buttaro [14], the performance of an UV is conditioned by its forward resistance (drag), which is a crucial factor in the preliminary design phases to determine the hydrodynamic shape of the vehicle leading to the achievement of the operational requirements.

Maneuverability is an important dynamic nautical quality of an UV, and its prediction is essential for preliminary design. The purpose of this study [15] is to examine the maneuvering capacity of a UV during diving, lifting, or space spiraling movements. The paper [16] proposes the design of a hydrodynamic profile (using the "Myring" equations) for unmanned submersible devices, by numerical simulation, to achieve a highly maneuverable vehicle, capable of moving horizontally and vertically.

The main performances (such as the speed of movement correlated with the drift phenomenon, dynamic stability, gyration diameter, maneuverability, spiral immersion trajectories, etc.) become easily and efficiently predictable with the help of CFD modeling and simulation methods, [17]. These numerical methods must be validated by comparing them to the results obtained in the towing tanks on the models and after real-sea trials on the prototypes.

Small UVs have unique advantages in ocean exploration. Hou et al. [18], and the other members of the research team believe that the vehicle's strength and volume are key factors affecting its underwater operating time. The hydrodynamic performance of a small UV is numerically analyzed using CFD methods by which the value range of the design variables related to the body is determined. A fully detailed methodology to identify the hydrodynamic parameters of an autonomous underwater mini-vehicle and evaluate its performance using different controllers (based on the theory of handling arms in robotics) is presented in the bibliographic reference [19]. The authors investigated the effects of the head shape (nose) on the hydrodynamic performance of an AUV-type vehicle in their conducted study [20]. The essential features of vehicle nose architecture are presented and discussed, considering pressure distribution and complex friction phenomena. The results obtained by the authors can be used as a guide to improving the design of architectural forms for AUV models.

The design of AUVs is very complex due to the high demands of the marine environment, such as the range of working depths, forward resistance, and energy efficiency. Amory and Maehle [21] present a hydrodynamic analysis and simulation of fluid flow on the surface of the body of a micro AUV using CFD methods to establish a three-dimensional (3D) model and the ANSYS Fluent software for hydrodynamic properties analysis. To maximize the operation time, the AUV body must be so designed and equipped to withstand harsh environmental conditions while minimizing hydrodynamic resistance. According to [22], the main factors influencing AUV design are the pressure distribution on the body and hydrodynamic resistance. With the results obtained based on CFD simulations but also with empirical estimates, it was possible to obtain optimum parameters relating to vehicle buoyancy and drag, to reach optimal energy consumption.

The influence of the angle of attack (tilt) on the robot's trajectories in the entrance and exit phases of immersion,

was studied [23], as well as the speed, pressure distribution on the body's surface, and the suction coefficient. Honaryar and Ghiasi [24], in their paper present the hydrodynamic characteristics of an AUV designed for inspecting submarine pipelines and cables. The authors were interested in the stability of this bioinspired AUV (the shape of a sea cat), whereas this nautical quality could be affected by various disturbances, such as marine currents, during the inspection process. The findings show that, when compared to other submersible bodies with the same axis of symmetry, the proposed model is about 99 more stable; thus, it is ideal for inspecting submarine pipelines and cables. In the study of [25], the effects of the free surface on the hydrodynamics of submersibles operating at various depths are investigated. It has been concluded that the diving depth has a significant role in the resistance components for a Froude number greater than 0.7, and the various appendixes arranged on the body have little effect on the deformations of the body surface.

This paper [26] describes the hydrodynamic modeling of a multi-body UV. This special construction (a set of heterogeneous bodies with known dynamic parameters that are rigidly connected) can be used when configuring the robot controllers or intervening to fix (possibly multiple) failures. It was discovered [27] as early as 1987 that any component failure must be corrected by an automatic system for an UV to operate fully autonomously. Thus, the software architecture was conceived, and this sets out the performance requirements for command-and-control hardware.

Finally, the use of 3D printing techniques in this field should be given a suggestive reference. This paper [28] describes the design and construction of two AUV models. The 3D printing technique was used to fully achieve the sections and annexes of the models, with each necessary step for design and construction being presented in the paper. The technology of 3D printing has also piqued the interest of researchers in the maritime military field, who have discussed publicly [29] about "3D printing capsules" housed in shipping containers and which create portable 3D printing facilities, usable for a wide range of military needs, such as rapid production of spare parts or destroyed military components. Problems that arise during crises can be solved quickly and cheaply by creating such on-site 3D printing facilities.

Paragraph 23 of the "NATO 2022 Strategic Concept" [30] stipulates: "Maritime security is key to our peace and prosperity. We will strengthen our posture and situational awareness to deter and defend against all maritime threats, maintain the freedom of navigation, secure maritime trade routes, and protect our main lines of communications."

Furthermore, the European Union (EU) created the European Defense Agency (EDA). This was established on July 12, 2004, by a joint action of the Council of Ministers "to support the Member States and the Council in their effort to improve European defense capabilities in the field of crisis management and to sustain the European Security and Defense Policy as it stands now and develops in the future" [31]. EDA currently has three initiatives: coordinated annual review on defense; permanent structured cooperation (PESCO); and the European defense fund.

The project maritime (semi-) autonomous systems for mine countermeasures (MAS MCM), which includes 10 European countries, was proposed and approved under PESCO initiatives. The MAS MCM will deliver a world-class mix of (semi-) autonomous underwater, surface, and aerial technologies for maritime mine countermeasures. The project will enable Member States to protect maritime vessels, harbors, and offshore installations while also ensuring freedom of navigation on maritime trading routes. The development of autonomous vehicles, using cutting-edge technology and an open architecture in a modular configuration, will contribute significantly to the EU's maritime security by helping to counter the threat of sea mines [32].

Therefore, the initiative to develop a prototype of an AUV destinated for the identification and destruction of underwater mines using 3D printing techniques to achieve the body is justified.

3. Materials and Methods

3.1. Body Design

The vehicle was designed using AUTODESK FUSION 360 [33] and SOLIDWORKS [34] software licenses. The design was engineered with two hydrodynamic domes, with several working variants considered (Figure 3 illustrates three of them). The variants of CAD models for the AUV's body bow and stern structures were also subjected to CFD analysis, and a final choice was made, namely a modified version of variant no. 2 shown in Figure 3. In this stage of the research, the focus was on a proper modeling of the geometric shapes of the extremities of the AUV's body and ensuring the optimal flow of fluid around the theme. The next steps will bring significant changes, following the addition of other components parts of the AUV (propulsion and governance system, floaters, sensors, specific equipment et al.).

The first utility software, AUTODESK FUSION 360, was used to develop the original architecture for checking tolerances and for the detailed design of the components, while the second, SOLIDWORKS, was used to generate the work file required for ANSYS [35] software to simulate (via CFD methods) the flow of fluid around the vehicle, which ultimately allowed the choice of hydrodynamic shape (Figure 4).

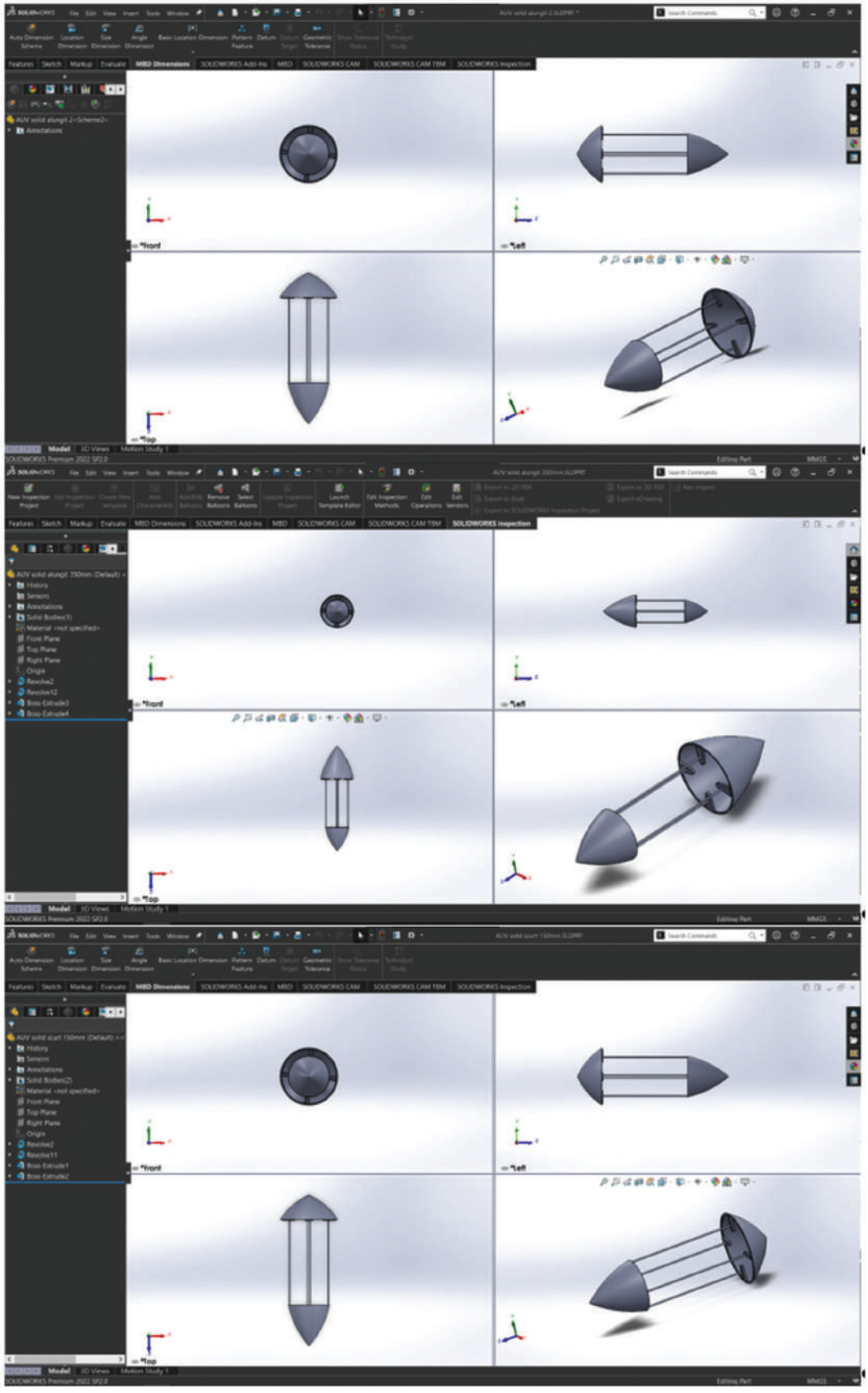

Figure 3. *Shape variants for AUV*

AUV: Autonomous underwater vehicle

We anticipate that the propulsion will be provided by two "brushless" engines located on the sides of the assembly, attached to the threaded bars through sleeves/collars and hydrodynamic profiles. Figure 5 shows the CAD design of those engines, which will be necessary for further CFD simulation (see Figure 2). The engines have more power in comparison to the gauge of the AUV, can operate underwater without problems, and only require short-term maintenance at the end of the mission.

The possibility of manually changing the position of the engines in the longitudinal plane has been ensured using M8 nuts before the operation, which determines the AUV's good maneuverability. Furthermore, by varying the engine rotative speed, a curvilinear trajectory of the vehicle can be ordered, thereby eliminating the need for a governing body (rudder). The engines included protective hulls with a NACA hydrodynamic profile, which improves efficiency, reduces propeller noise in the water, and ensures the safety of the crew or diver operating nearby.

The trajectory of the AUV during immersion (depth and angle of inclination) is controlled by two other engines (Figure 6), of the same functional type (brushless,) located in the vertical plane (one in the bow area and one in the stern area).

All components of the autonomous UV (domes, bars, engines, sleeves, and oil/air floaters) will be dimensioned in such a way that the buoyancy of the robot is positive. As a peculiarity, (immersion is ensured using vertically located motors; if a malfunction occurs or control of the robot is lost, for any reason, all engines will stop and the vehicle will slowly rise to the surface due to the buoyancy with which it was provided). The robot will be modular, allowing it to have different configurations depending on the tactical situation, resulting in different weights. The buoyancy will be maintained by adding or removing oil/air floaters.

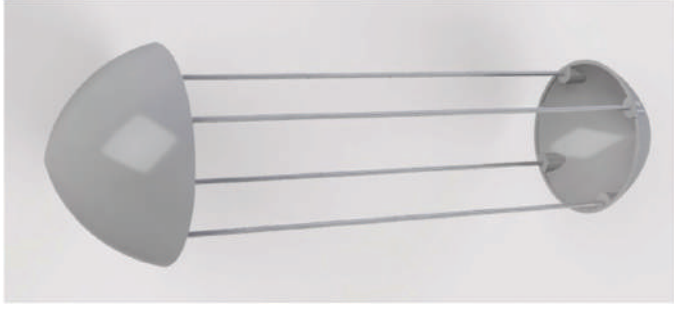

Figure 4. *View from the bow semi-profile of AUV*

AUV: Autonomous underwater vehicle

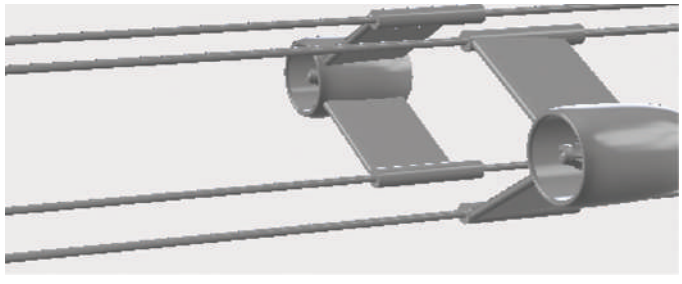

Figure 5. *View from the bow semi-profile of AUV with the propulsive system*

3.2. Hydrodynamic Analysis

Fluid dynamics are used in a wide range of fields where the behavior of gases and liquids must be studied. CFD modeling generates 3D, time-accurate data about fluid movement in general, as well as particle trajectories or surface dynamics. Simply put, if there is a geometric model (3D CAD model) of the system to be studied and information on fluid properties can be used, then various aspects, such as velocities, flow rates, trajectories of current lines, the pressure distributions of certain contours, and so on, can be successfully studied. The study of fluid-structure interaction focuses on the flow of the fluid as well as its encounter with a solid structure. Modeling with ANSYS involves, in principle, going through clear stages of work, but it should be noted that detailing the process is practically impossible. The essential steps of the way of working with ANSYS have been completed for the hydrodynamic analysis of the designed vehicle (the shape was defined with the command "Geometry"; the surface was processed with the command "Mesh" and boundary conditions have been set; the variables were determined, and the solution was processed by launching the command "Execution calculation"). "Results" is a CFD post-processor that visualizes how the analyzed object will behave in various real-world scenarios through simulated demonstrations.

It should be emphasized from the start that in the previously mentioned project, CFD simulations will be carried out in two stages (see Figure 2): for the bow and stern extremities of the AUV's body in the first year of the project (and these elements are illustrated briefly below); for the AUV equipped with the propulsion and governance system in the second year of the project (and which are not completed at this time), although some elements of propulsion and governance system design are presented in the paper (see Figures 5 and 6). The CFD simulations performed will be compared to the wind tunnel tests.

Therefore, the CFD analyses presented in this study are affected by the fact that they are made for the two domes (bow and stern) that are currently modeled in an open architecture. The purpose of including these results in this work serves to broaden the subsequent stages.

Three studies were completed, for which an underwater ambient temperature of 25° and a working depth of about 10 m below sea level (hydrostatic pressure of 1 atm.).

In the first case analyzed, the AUV moves in a horizontal plane on a linear trajectory (forward/backward, left/right) at a speed of 2 m/s.

In the second, the AUV moves horizontally on a curved trajectory (the vehicle turns right at an angle of 45°), with a resultant of speed 1.41 m/s for this compound horizontal movement.

In the third study, AUV performs a compound spatial motion (exit from the immersion at a speed of 2 m/s while performing a right turn with an angle of 45°), with the resultant speed of 1.16 m/s used in the simulation.

Only the most recent case analyzed, considered the most complex, is presented for rational sizing in this work. Some general comments are required, without entering the details of the simulation.

The computational domain around the experimental hull body is represented by a sphere (Figure 7) with a radius of 4 m, filled with water at a temperature of 25 °C, and modeled as an incompressible fluid.

The physics of the computational domain is presented in Table 1.

The vehicle body was rigid and completely submerged in water (without wave and current disturbance). Before performing the CFD, the mesh size and the shape of the boundary must be defined properly. It is recommended that the mesh size be small enough to capture the geometry of the AUV. In this case, the mesh information consisted of 167578 elements and 29474 nodes. The body vehicle has a smooth wall roughness and no-slip wall. The domain has a boundary-type opening, subsonic flow regime, and medium-intensity turbulence.

The main boundary physics is presented in Table 2.

The figures below show the graphic results of the simulations for: the variation of the velocity of the streamlines (Figure 8); the variation and the values of the drag force (Figure 9); and the pressure gradient (at the bottom of Figure 10).

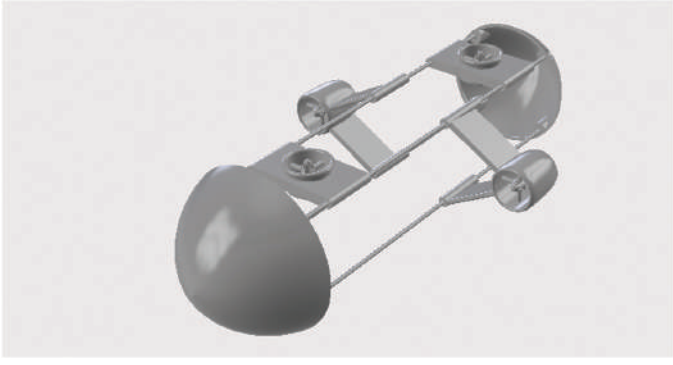

Figure 6. *View from the bow semi-profile with the entire propulsion system mounted*

3.3. 3D Printing of An Autonomous Underwater Vehicle

In Figure 11, several stages of printing of the forward dome of the AUV are illustrated.

A 3D printer (Snapmaker model) was used to create a prototype of an AUV, which can print objects in spaces ranging from (230 x 250 x 235) mm to (320 x 350 x 330) mm, with a layer resolution of 50 to 300 microns. The printer is a part of a modular group that can do everything from 3D printing to laser engraving and numerical control command

Table 1. *Computational domain physics*

Domain - Default domain	
Type	Fluid
Location	B121
Materials	
Water	
Fluid Definition	Material Library
Morphology	Continuous Fluid
Settings	
Buoyancy Model	Non-Buoyant
Domain Motion	Stationary
Reference Pressure	1.0000e+00 [atm]
Heat Transfer Model	Isothermal
Fluid Temperature	2.5000e+01 [C]
Turbulence Model	Shear Stress Transport - SST
Turbulent Wall Functions	Automatic

Table 2. *Boundary physics for CFX 2*

Domain	**Boundaries**	
Default domain	Boundary - sphere	
	Type	OPENING
	Location	F122.121
	Settings	
	Flow Regime	Subsonic
	Mass and Momentum	Cartesian Velocity Components
	U	1.1600e+00 [m s^−1]
	V	1.1600e+00 [m s^−1]
	W	1.1600e+00 [m s^−1]
	Turbulence	Medium Intensity and Eddy Viscosity Ratio
	Boundary - AUV	
	Type	WALL
	Settings	
	Mass and Momentum	No Slip Wall
	Wall Roughness	Smooth Wall

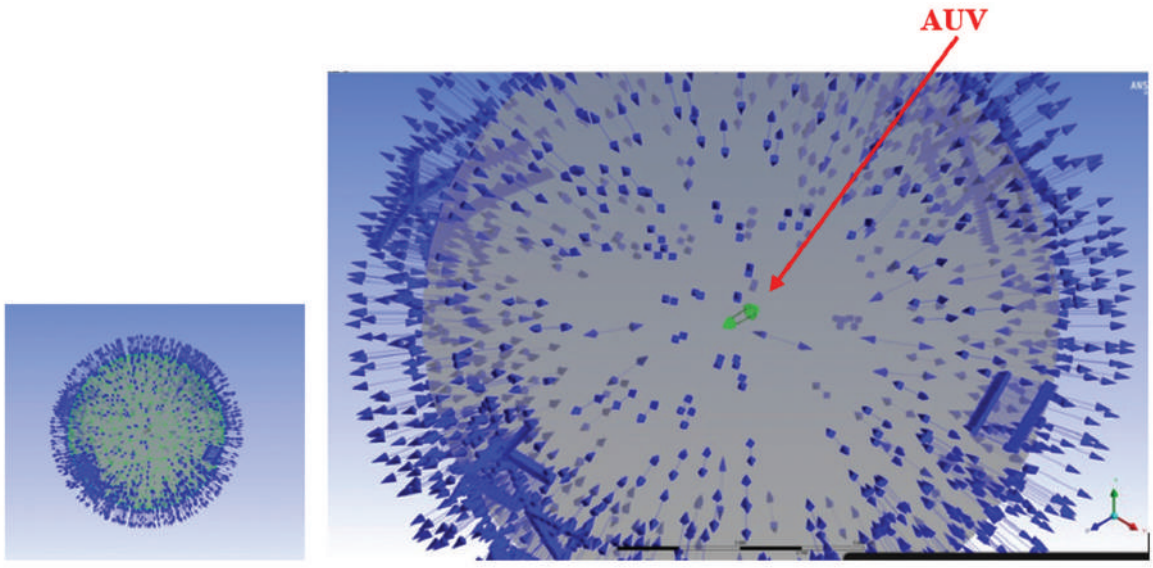

Figure 7. *Computational domain*

AUV: Autonomous underwater vehicle

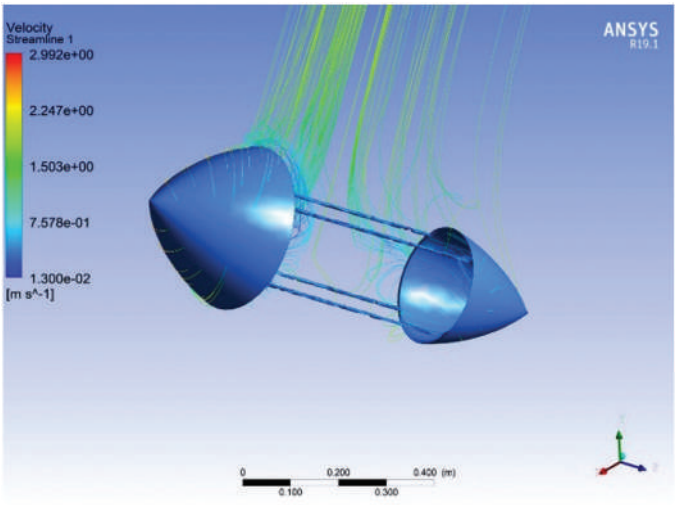

Figure 8. *Velocity variation*

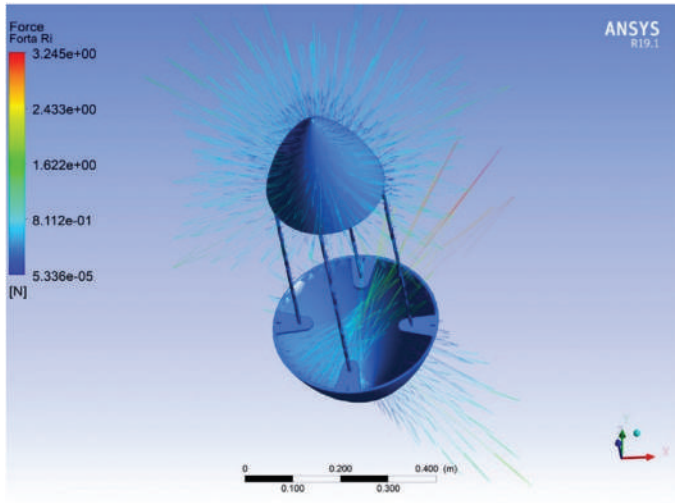

Figure 9. *Drag force variation*

cutting. The proximity sensor probes and obtains data for multiple points on the work platform, and the software calculates and compensates for microscopic irregularities in real-time, ensuring a consistent, correctly applied base layer, for 3D printing as performant as possible.

The 3D printing and installation of brushless propulsion engines, sleeves, and hydrodynamic profiles are suggestively shown in Figure 12.

4. Conclusions and Perspectives

3D printing is a technology that superimposes successive layers of material under the control of the computer (which reads a CAD file), resulting in a 3D object. As 3D printing processes have evolved and new solutions and technologies have emerged, the advantages of this technology have become more clear, as also have the disadvantages or, better said, the possible limits. The advantages are related to design freedom, rapid prototyping, personalized printing, waste minimization, and environmentally friendly processing, all of which involve efficiency, which is translated into time and cost. Technology allows for the development of design ideas, as well as a faster production process, and a higher final product quality. The disadvantages (for the moment, because 3D printing technology is advancing and the present limits will be exceeded) concerns, in particular, the high production costs for serial production, the limitations of the material s that can be used (plastic, although many metals are suitable for technology), and printer performance (which conditions the resistance of the product or the accuracy of the product).

This prototype will contribute to efforts to strengthen national and European defense and it may be used to defend and secure territorial waters, as well as joint missions to defend and secure the international EU's waters of the NATO Allied Forces. The AUV-type system can also be used for civilian purposes, such as inspection and protection of all maritime and port infrastructure.

A solution consisting of two hydrodynamic bodies joined together with threaded bars was chosen for the general architecture of an AUV, which has advantages in terms of modularity and simplicity in construction and access to components.

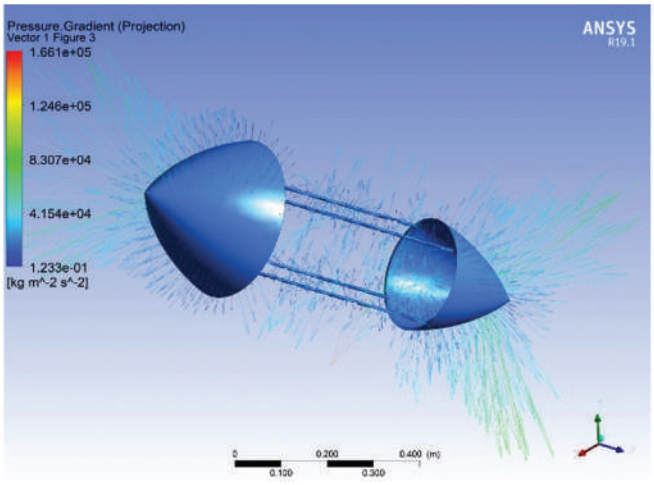

Figure 10. *Pressure gradient*

As previously stated, several architectural variants were considered, for which hydrodynamic analyses of fluid flow on the body's surface (bow and stern) were also performed. The average size, with a forward dome height of 150 mm and the height of the aft dome of 125 mm, produces the desired performance at a vehicle movement speed of 2 m/s, according to simulations.

Figure 13 shows the completed prototype, with printing at 1:2 scale. The forward dome (right side in Figure 13) has a diameter of 300 mm and is intended to form a low-pressure zone around the components behind it, to reduce friction. The aft dome (shown on the left side of Figure 13) has a diameter of 250 mm and is intended to close the pressure lines while also reducing friction. The 4 bars are 1 m long and are threaded for an M8-type assembly.

The main difference between the prototype proposed within the project accepted by the Romanian Ministry of National Defense and that made at the level of the consortium of European countries is that of the reduced consumption of resources (human, financial, production time, and so on.). The idea of the achievements of an underwater robot

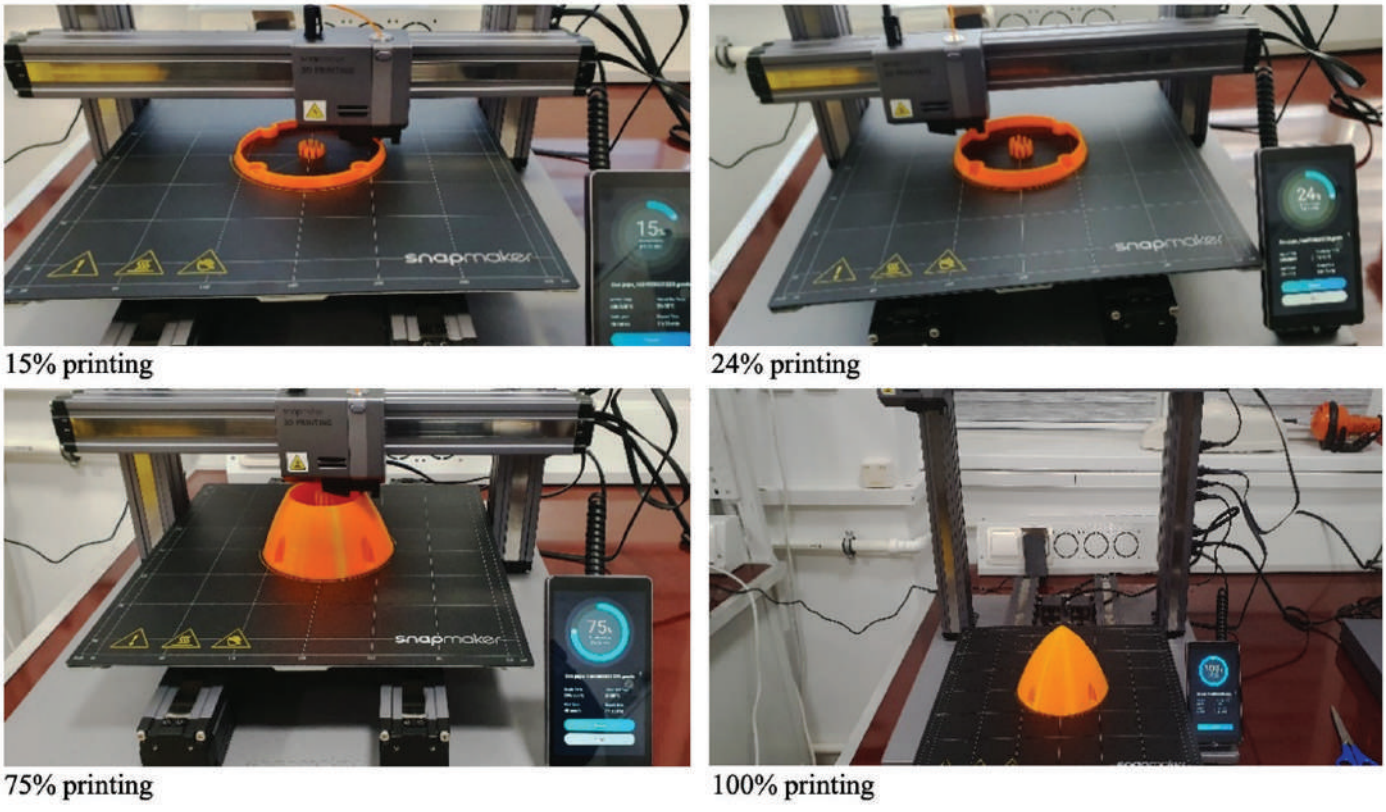

Figure 11*. Printing stages of the AUV's forward dome*

AUV: Autonomous underwater vehicle

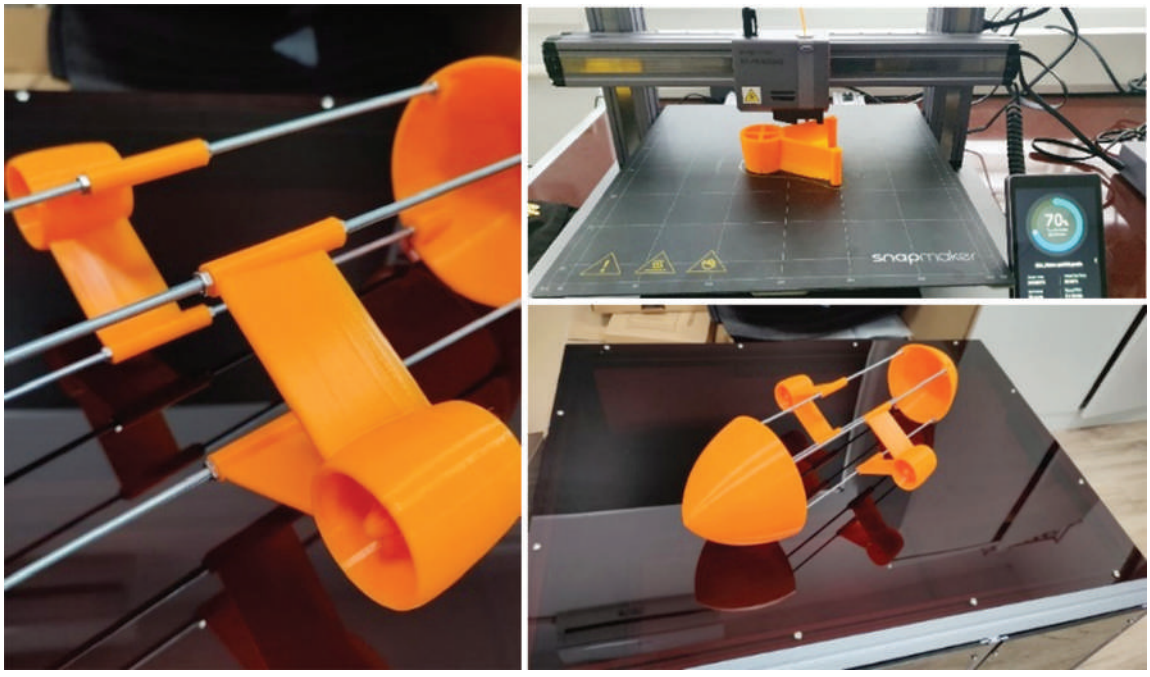

Figure 12. *Stages of printing and installation of AUV propulsion engines*

AUV: Autonomous underwater vehicle

Figure 13. *Autonomous underwater vehicle-3D printed prototype*

produced quickly and with free market equipment resulted in the context of the presence of sea mines in areas of national responsibility in the Black Sea (in the context of the armed conflict between Russia and Ukraine) and the lack of the expected final result from the MAS-MCM project. Under these conditions, the Romanian National Naval Forces were forced to intervene in the discovery and destruction of sea mines using non-compliant resources (ships from the military fleet), thus exposing both ships and personnel to very high risks.

The greatest advantage of this AUV (which is, in fact, a multifunctional underwater platform) is its modularity and architecture, which allows for the rapid installation of a robotic arm, cameras, projectors, and various sensors, among other things.

Of course, there are still steps to be taken between the prototype and the final product. This study present the results of the architectural design of the AUV body (the goal was to obtain a new underwater robot open-case (form) with optimal length and form for good hydrodynamic) as well as the advantages of using the 3D printing technology in this phase prior to the actual construction of such a vehicle.

Following that are the steps depicted in Figure 2: design and construction of the propulsion and steering system, equipping appropriate to the mission undertaken, completion of the final concept, and testing the prototype under real-world operating conditions.

The authors are convinced that they will return in a future paper with new results.

Peer-review: Externally peer-reviewed.

Authorship Contributions

Concept design: M.G. Manea, O. Cristea, Data Collection or Processing: C.-P. Clinci, O. Cristea, Analysis or Interpretation: M.G. Manea, C.-P. Clinci, O. Cristea, Literature Review: M.G. Manea, Writing, Reviewing and Editing: M.G. Manea, C.-P. Clinci, O. Cristea.

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Simulation of Shockwave Effects on a Ship-like Structure due to Underwater Explosions

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Abstract

Underwater explosions that threaten the hull integrity and proper operation of navy ships' systems and subsystems are considered from the viewpoint of damage estimation. The commercial code LS-DYNA with the Arbitrary Lagrangian-Eulerian numerical technique is used to analyze the shock effects on structural components of a ship-like form for three different scenarios. Computed maximum permanent deformations are matched with the corresponding keel shock factor (KSF) values for searching a functional relationship of a linear form. Although observed for limited simulations and therefore should be viewed with caution, the linear dependency of the maximum permanent deformations on the KSF values implies that the KSF may be a simple indicator for estimating the extent of damage due to underwater blasts.

Keywords: Underwater explosion, High-pressure shock waves, Ship-hull damage simulations, Keel shock factor

1. Introduction

An underwater explosion (UNDEX) creates a greatly compressed gas bubble, which in turn generates a shock wave [1]. Such a shock wave travels considerably faster than the speed of sound in water with a steep front and causes a very high peak pressure value that decays nearly exponentially. The expansion of the gas bubble decreases the pressure and reverses the pattern to a contraction with a pressure increase. The cycles of expansion and contraction repeat a few times, diminishing the pulse pressure values further each time. Meanwhile, the bubble rises toward the surface due to the hydrostatic lifting force. In explosions occurring at relatively close quarters of a surface ship or a submarine, the peak pressure value of the shock wave is the crucial parameter determining the safety of personnel and equipment.

Powerful underwater blasts that endanger the combat survivability of the navy ships or submarines are a major security concern. The impact of a shock wave on a sea vessel can result in severe structural and equipment damage besides personnel injuries and casualties. Therefore, naval ships must be shock-hardened as possible to ensure combat survivability for both personnel and equipment. The most reliable way of testing a ship for survivability is to conduct shock trials; however, with extensive planning and coordination, such a trial may take a year or more. Furthermore, environmental lawsuits can cause delay or even cancelation of the trials, and an actual trial involving an UNDEX can destroy the tested military vessel completely. For all these reasons, realistic combat testing of military vessels is quite difficult. On the other hand, predicting the structural response of a submerged or surface vessel to underwater shock waves is a research topic whose outcome is much sought by naval engineers. To this end, numerical simulations provide an alternative for studying structural responses and assessing the effects of underwater blasts.

Within the last few decades, commensurate with advancing computational facilities, quite several numerical studies

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for analyzing the dynamic response of structures exposed to UNDEX shock wave loadings have been conducted. Shin [2] used the doubly asymptotic approximation coupled with finite-element modeling of the structure to perform numerical ship shock analyses, which were compared with test data. Using the energy method, the ultimate capacity of a warship's bulkhead to a UNDEX was investigated by Peng et al. [3] who derived a formula for the total deflections. Quite in line with the present study, Gan et al. [4] used a box-like floating model to experimentally and numerically investigate the damage due to a spherical charge. Zhao et al. [5] performed a numerical study for simulating TNT explosions by adopting the ghost fluid method. Li et al. [6] recently presented an extensive review of the measurements of UNDEX loads, highlighting the advantages and disadvantages of different methods and emphasizing the need for measurements with large equivalent-weight charges.

The current studies use the commercial code LS-DYNA with Arbitrary Lagrangian-Eulerian (ALE) numerical technique for structural deformation simulations of a ship-like surface vessel with dimensions adopted from a real navy ship for three different scenarios of explosive configurations. Structural deformations observed from the hydrocode simulations are correlated with the corresponding KSF values for formulating a simple expression to estimate the extent of damage quantitatively.

2. Simulation Technique, Relevant Parameters, and Details for a Ship-like Structure Subject to Underwater Blasts

Conducting actual ship shock tests is the most reliable way for evaluating the structural response to an underwater blast. Nevertheless, besides the high-cost demands of shock trials, which may easily exceed $50 million per trial, the legal procedures and significant time spent in all these make numerical simulations a very affordable and valuable alternative for studying structural responses and assessing the effects of weapons under simulated combat test conditions. While all these advantages of numerical simulations are undeniable, it must be remarked that experts suggest the use of both approaches in combination as a better choice [7].

2.1. Arbitrary Lagrangian-Eulerian Technique

Besides high-pressure shock waves, UNDEXs generate liquid and gas bursts. Since the surrounding fluid medium elements around the explosive charge deform severely, the Lagrangian-based finite-element meshes in an explosive charge region are not always feasible. To account for the high-deformation rate, an extremely small time step per iteration is required, which in turn results in longer computational times. Also, numerical approximation inaccuracies increase because of large mesh distortions [8]. On the other hand, the Eulerian-based finite-element modeling advances the solution in time on a fixed mesh system using Navier-Stokes equations. Thus, unlike the Lagrangian approach, the Eulerian codes with fixed mesh arrangement avoid mesh distortions. Codes with various techniques such as Lagrangian, Eulerian, Coupled Eulerian-Lagrangian (CEL), and ALE are available. Mair et al. [9] present a thorough review of these different methods in modeling UNDEXs and related structural behavior and concludes that the CEL and Multi-Material ALE are the most versatile among all. The current simulations were performed using LS-DYNA software based on the ALE formulation technique for predicting the structural behavior of a box structure in the vicinity of an UNDEX in three different cases. The effects of shock wave propagation were modeled by the explosive charge modeling of the code in a fluid medium, while the structural response was modeled by the finite-element method.

2.2. Simulation Components

Numerical simulations using the LS-DYNA software require the specifications of definite components. There are four main components of the present simulations, which are briefly described below. Figure 1 shows the fluid and structural domains used in the simulations. The air domain, which surrounds the fluid and structural domains, extends 10 m above the fluid domain but could not be drawn due to overlapping meshing. All the boundaries are specified as open boundaries to avoid the undesirable effects of reflections.

• Explosive model: An UNDEX scenario begins with the selection of an explosive. In this work, a TNT-type spherical explosive is used in the simulations. Since high explosives react quickly and produce gases at high temperatures and pressure from an initial volume, the explosive is determined according to a given initial charge density ρ_C and mass W, which is taken in grams in the simulations. Judging by trial and error, the meshing of the explosive charge is refined to an adequate degree.

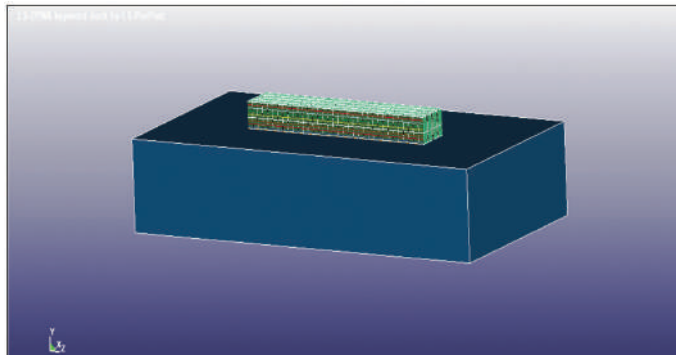

Figure 1. *Fluid and structural domains as numerically analyzed*

• Fluid model: Once the explosive model is decided, meshing for the fluid region is designed. The meshing of the fluid in the vicinity of the explosive must be performed judiciously. To model the fluid, the null material definition NULL-MAT of LS-DYNA is used. The Gruneisen equation of state is used for the water, which defines the pressure for a compressed material in terms of the density, intercept constant of the shock wave velocity curve, etc. [10]. For the fluid domain, the saltwater mass density is ρ_f=1025 kg/m^3 and the average mesh dimensions are in the range of 50 cm with a total of 404271 nodes for the present simulations.

• Air model: Following the specifications concerning the fluid model, the meshing of the air domain is constructed using NULL-MAT like the fluid material specification. For the air domain, the air mass density is ρ_f = 1025 kg/m^3 and the average mesh dimensions are in the range of 50 cm with a total of 156492 nodes for the present simulations.

• Structural model: The ship-like geometry is modeled as a barge in the shape of a rectangular prism of length L=42 m and width B=8.75 m with appropriate longitudinal and transverse structural components and two bulkheads. The total weight of the structure is represented by three lumped masses evenly placed along the keel line, ensuring that the center of gravity corresponded to the amidships. Shell plating is specified as 0.2% C-hardened steel of h=7 mm thickness, ρ_s=7870 kg/m^3 mass density, E=210 GPa Young's modulus, v=0.3 Poisson's ratio, and σ_y=315 MPa yielding stress for higher tensile steel. The structural steel parameters used in the simulations correspond to the steel commercially called DH-36. Mechanical and thermo-mechanical tests were performed on DH-36 with true strains exceeding 60% over a wide range of strain rates 0.001-000 s^{-1} and temperatures 77°K-1000°K. It has been reported that DH-36 has good ductility and plasticity even at low temperatures and high strain rates without observable micro-cracks [11]. Table 1 gives all the main parameters of the barge and its shell plating.

2.3. Preliminary Arrangements

The barge's main dimensions of are based on an actual military ship with L = 42 m, B = 8.75 m, T = 5.75 m, Δ = 480 tons (loaded). Figure 2 shows a simulation layout sketch, showing the barge and the explosive with relevant distances.

The most important part of the simulation is determining the distance between the barge and the explosive, R, and the amount of explosive, W, because the extent of damage to the barge depends on these parameters. At this stage, we use a simple empirical relationship, the hull shock factor HSF = $W^{1/2}/R$ or its slightly different form the keel shock factor (KSF), which includes the shock wave's angle of incidence [1]. The KSF is a simple but reliable formula for a quantitative estimate of the relative severity of an UNDEX as experienced by a ship at a given standoff from the explosive:

$$KSF = \frac{W^{1/2}}{R}\left(\frac{1+\sin\theta}{2}\right) \quad (1)$$

where W is the mass of charge, R the distance between the charge and the keel of the ship, and θ the angle between a horizontal reference line parallel to the sea surface and the line connecting the keel to the charge, as shown in Figure 2. Typically, a keel shock factor equal to or greater than unity, KSF ≥ 1 indicates a severe or damaging explosion to the ship.

Table 1. *Barge dimension and shell plating parameters*

Barge dimensions	L=42 m B=8.75 m T=5.75 m Δ=480 tons
Shell plating	H=7 mm ρ_s=7870 kg/m^3 E=210 GPa σ_y=315 MPa ν=0.3

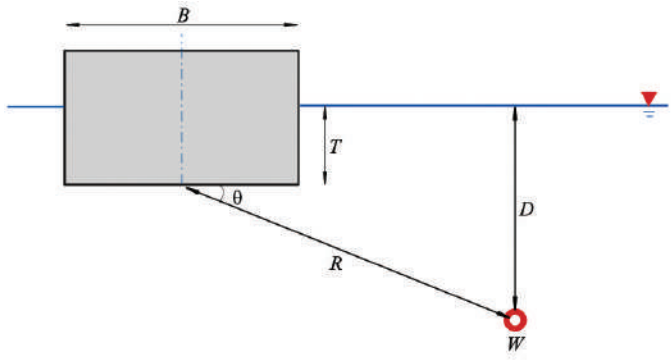

Figure 2. *Sketch of the simulation layout*

Three different simulations were carried out using the set of parameters listed in Table 2. The charge mass W and angle θ were varied so that the charge mass was doubled first, increasing KSF from 0.71 to 1.00; subsequently, sin θ was made unity by placing the explosive directly under the ship, thus making KSF = HSF = 1.37.

Meshing for the simulations was prepared using the commercial TrueGrid software. TrueGrid translates the generated finite-element model into the LS-DYNA keyword format for numerical simulation. Figure 3 shows the meshing of the barge-like structure considered; the actual mesh resolution was higher than that shown here.

Eight specific nodes on the bottom of the model were selected to observe certain locations on the hull. The node

Table 2. *Charges and distances used in numerical simulations*

Simulation number	Charge mass W (kg)	Standoff R (m)	Depth D (m)	Angle sin θ	KSF
1	500	23.1	16.50	0.465	0.71
2	1000	23.1	16.50	0.465	1.00
3	1000	23.1	28.85	1.000	1.37
KSF: Keel shock factor					

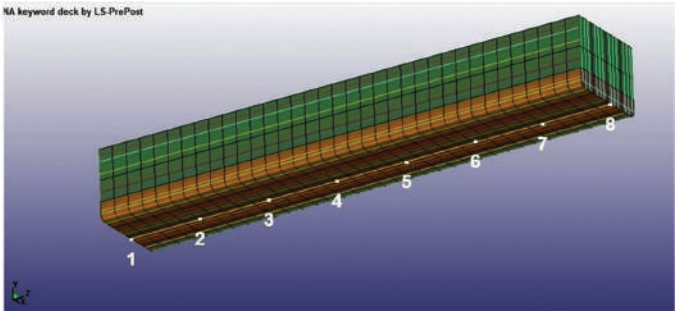

Figure 3. *The meshing of ship-like (barge) structure with control nodes 1-8*

numbers are 8042545, 8042704, 8043382, 8043589, 8044020, 8044076, 8044218, and 8044290, which are marked as 1-8 in the given order, as shown in Figure 3. At these eight nodes, the simulation data were recorded using the DATABASE-HISTORY-NODE command. This particular feature is crucial in obtaining the structural displacements, velocities, and accelerations at selected locations.

Five different types of beam elements were used. Three different sizes of stiffeners, 40×4 T, 50×5 T, and 60×6 T, were placed in the middle deck, upper and lower boards, and bottom. Plates of size 60×6 T were used as transverse elements and size 80×8 T as longitudinal elements. Finally, steel plates of 5 mm (deck) and 7 mm (all the rest) thickness were used as shell elements covering the box-like form. Figure 4 shows a perspective view showing the longitudinal cross-section of the structure with longitudinal and transverse beam elements.

3. Structural Response Results of Ship-like Form Exposed to Underwater Explosions

Since the amount of explosive specified was relatively large [12], the finite-element model was run for 30 ms with a time step scale factor of 0.67. Initially, several trial computations with different mesh sizes and time steps were performed for Simulation 1 and the differences in results were examined until it was ensured that the finally used time and mesh resolutions were reliable. For every 200 μs, the binary data file recorded the finite-element response information of the model. Thus, a single simulation run of 104 μs time interval produced 50 subsequent states of computation.

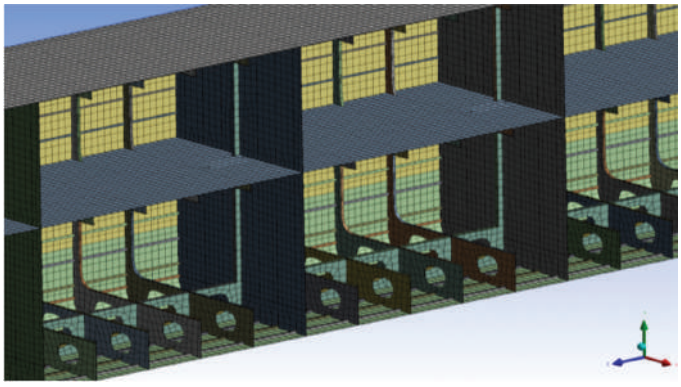

Figure 4. *Longitudinal cross-section of ship-like (barge) structure*

Three-dimensional response visualization was accomplished by LS-POST of LS-DYNA [13]. LS-POST rendered the displacement, velocity, acceleration, and pressure data display as well as allowing the user to observe the shock wave propagation through the fluid medium. LS-POST also has the capability of extracting ASCII solution data and saving it to a separate ASCII file for later evaluation.

Simulation 1: The first simulation was performed with W = 500 kg TNT-equivalent explosives and R = 23.1 m standoff as measured between the charge and the keel of the barge. The angle was selected as θ = 27.7° which gave $\sin\theta = 0.465$ and KSF ≈ 0.71. The maximum displacement value averaged for all control nodes for Simulation 1 was computed as approximately 37.8 cm. Figure 5 shows the time histories of displacements (left) and velocities (right) for Simulation 1 for all the selected nodes. Unlike the time histories of displacements, velocities fluctuate about a mean for all nodes. This is probably in accord with the propagation of the shock wave over different nodes. Acceleration graphs, though not included here, show that initially all the nodes are greatly accelerated in the burst-like fashion of the shock, but these large accelerations die out within fractions of a second. An important detail concerns the continuing increase observed in displacements at the time (0.3 s) the simulations stopped. The displacements measured are absolute displacements, which include both the plastic shell deformations and the bodily motion of the barge. To estimate the structural plastic displacements, the simulation must be terminated at a time before the bodily motion takes place. This time was judged by monitoring the velocity and more importantly acceleration fluctuations, and when these fluctuations visibly settled the simulation was terminated. This is a subjective method relying on an accurate estimate of the time lag of bodily motion, but the lack of a better option necessarily forced this approach. Therefore, the displacements given contain some uncertainties and must be viewed with caution.

Simulation 2: The second simulation was carried out for W = 1000 kg TNT-equivalent explosives and R = 23.1 m standoff as measured between the charge and the keel of the ship. The angle θ = 27.7° hence $\sin\theta = 0.465$ so that KSF ≈ 1.00, which was aimed purposely as this particular simulation corresponded to an actual physical test at sea. The computed maximum permanent deflection for Simulation 2 was approximately 56.6 cm, which agreed reasonably well with the measured maximum displacement in a physical test done under similar conditions, but open comparisons were impossible as details and the measured values of these

trials are withheld due to confidentiality issues. Despite this observed agreement, it is emphasized once more that the computed values may be regarded as only estimates due to the estimated termination time of simulations.

Simulation 3: The third simulation was carried out for W = 1000 kg TNT-equivalent explosive and R = 23.1 m standoff as measured between the charge and the keel of the barge. The angle was taken as θ = 90.0° θ = 1.0 so that KSF ≈ 1.37, which, the charge is placed directly underneath the vessel, corresponded to KSF = HSF. All the conditions being equal with Simulation 2, the present one differs only in one aspect, that is, θ. Specifically, this simulation was planned to observe the effect of angle θ on the extent of permanent damage to a vessel. Figure 6 shows the time histories of displacements (left) and velocities (right) for Simulation 3 for all the nodes. The maximum displacement values averaged for the eight control nodes for Simulations 1, 2, and 3 were found to be approximately 37.8 cm, 56.6 cm, and 90.8 cm, respectively. The computed deformations for Simulation 3 are obviously quite large, as can be visually observed from Figure 7, which depicts the structure before (upper) and after (lower) the explosion.

In Table 3, the KSF values are given against the corresponding maximum deformations computed from the simulations. The least-square approach is used to establish a linear relationship between the KSF values and the computed deflections for this structure to assess the reliability of KSF as a measure of potential damage level. Accordingly, a proportionality factor of 3/5 was obtained so that

$$\delta = \frac{3}{5}\frac{W^{1/2}}{R}\left(\frac{1+\sin\theta}{2}\right) \quad (2)$$

where δ is in meters, W the charge mass in kg, R the standoff in meters, and θ the angle as shown in Figure 2.

Figure 8 shows KSF values versus corresponding maximum deformations and the plot of equation (2). It should be emphasized that equation (2) with the given constant is valid strictly for the structural form used here, and more simulations are required to establish the linear relationship

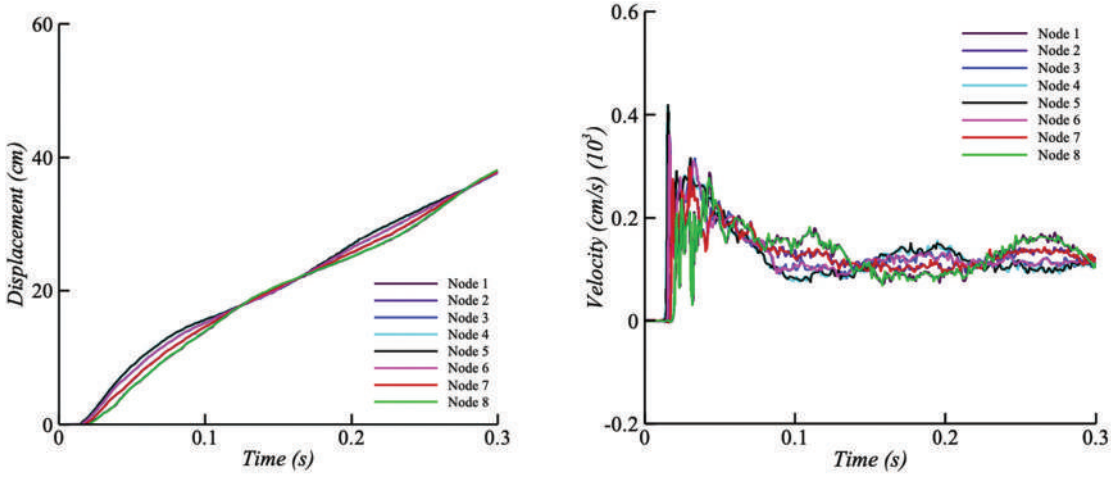

Figure 5. *Simulation 1: Time variations of displacements (left), and velocities (right)*

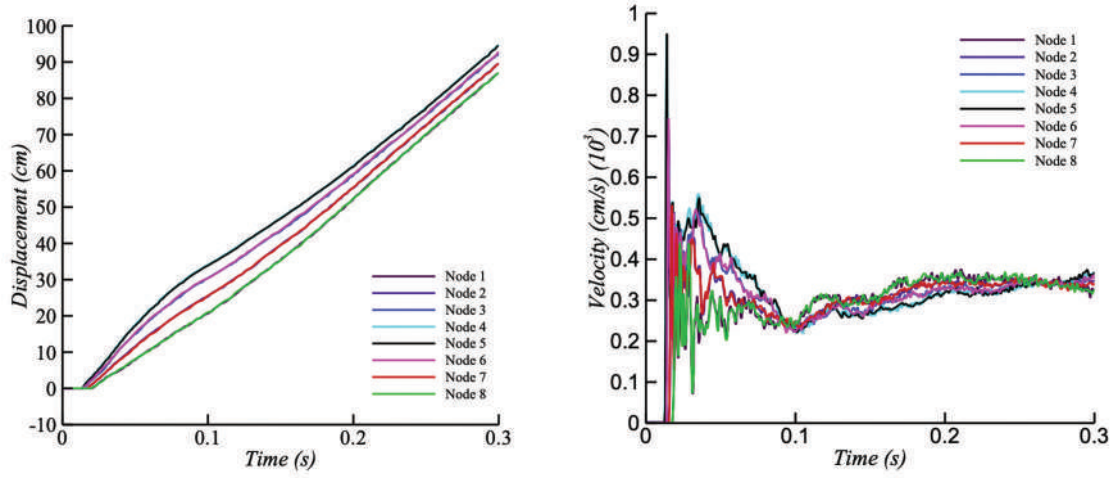

Figure 6. *Simulation 3: Time variations of displacements (left), and velocities (right)*

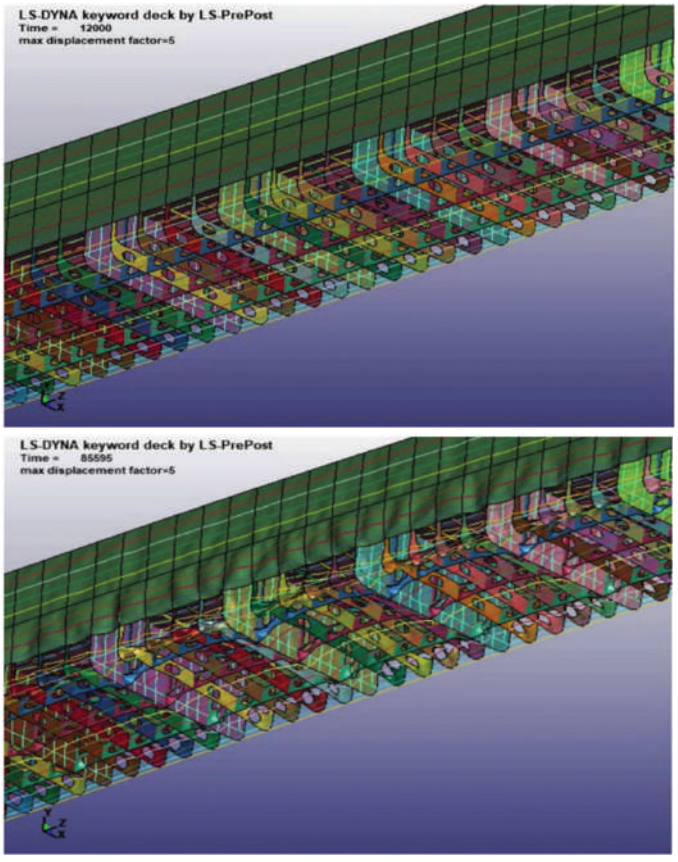

Figure 7. *Intact (upper) and deformed (lower) structures before and after the explosion for Simulation 3*

Table 3. *KSF values and corresponding maximum permanent deformations, velocities, and accelerations*

Simulation number	KSF	Max. Def. (cm)	Max. Vel. (cm/s)	Max. Acc. (cm/s²)
1	0.71	37.8	0.42	0.44
2	1.00	56.6	0.57	0.59
3	1.37	90.8	0.94	1.15

KSF: Keel shock factor

with confidence. Furthermore, the multiplying factor, 3/5 for the present case, must depend on the effective plate thickness of the structure and material yielding stress values. Therefore, Figure 8 or equation (2) should only be considered as a speculative indication of a possible relationship between maximum displacement and KSF. Equation (2) then serves just as a hint to connect KSF to the extent of damage, hence, attempts in this direction may be expected to yield a simple and useful practical formula for estimating probable damage. A separate project for establishing such a sound relationship is in progress.

4. Conclusion

The effects of a three-dimensional UNDEX on a ship-like structure modeled as a barge, which represents a ship

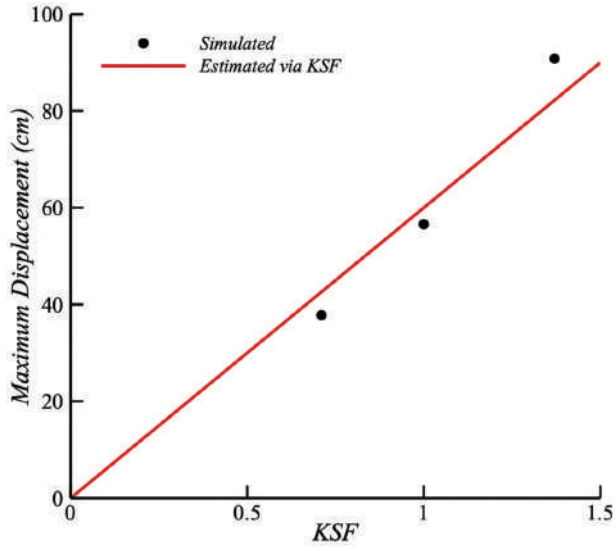

Figure 8. *Keel shock factor values versus corresponding simulated maximum displacements and equation (2)*

KSF: Keel shock factor

beam are investigated through numerical simulations by using the LS-DYNA software with the ALE approach. Three different simulations were performed to examine the effects of different KSF values. The second simulation designed for KSF ≈ 1 represents a case similar to the one for which the field measurements were available though not open to the general use. Although the computed maximum permanent deformation for the second case is found to be quite close to the measured value, the computed values should be viewed only as estimates obtained by judging a suitable simulation time to exclude the bodily motion of the barge. This is an unavoidable but significant drawback of this study. Furthermore, with the use of limited simulation data, a linear relation between the maximum deformations and the corresponding KSF values is sought for the specific structure considered here. This simple relationship, which provides a good first estimate of permanent deformations, is only an indicator that maximum permanent deformations and KSF may in some way be related though not necessarily linearly. Therefore, it may be expected that future work can produce a better established and more general formula for ship structures with different structural properties. Research project in this direction is in progress. Finally, in view of the calculated kick-off velocities, for KSF ≈ 1 serious and for KSF > 1 fatal damage to ship structures appears certain.

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Maritime Students' Assessment of Distance Education During the COVID-19 Pandemic

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Abstract

The coronavirus diseases-2019 (COVID-19) outbreak emerged in late 2019 and rapidly spread worldwide, resulting in a pandemic. The pandemic has had negative impacts on various aspects of life, particularly health and the economy. Education sector has been severely affected, as well. In Türkiye, as in many countries, face-to-face classes were replaced with distance education as a safety measure against the pandemic. Maritime education places significant emphasis on providing practical, hands-on training to its students. However, due to the COVID-19 pandemic, a shift to distance education was required, including the teaching of applied courses in this field of study. In this regard, revealing the evaluations of maritime students on distance education is an important issue that needs to be studied. Therefore, this study aims to evaluate the opinions of maritime faculty students in Türkiye regarding the technical aspects and learning process of the distance education that they received during the pandemic. To this end, the "Distance Education Evaluation Scale" was administered to students via an online platform, and the resulting data were analyzed using SPSS Statistics 25. The results show that male students have a more positive evaluation of distance education than female students. Those who participate in distance education by using mobile phones have a more negative evaluation of distance education, while successful students have a more positive evaluation of distance education. Finally, there was no significant difference according to universities and classes.

Keywords: Distance education, COVID-19, Maritime education, Maritime students

1. Introduction

When the virus outbreak occurred all over the world, many measures were taken against the coronavirus diseases-2019 (COVID-19) pandemic. One of the sectors in which strict measures were taken was the education sector. At the beginning of February 2020, only schools in China and some other affected countries were closed due to the rapidly increasing number of cases. However, by mid-March 2020, about 75 countries implemented or announced the closure of educational institutions [1]. In the fight against the COVID-19 pandemic, countries replaced traditional face-to-face education with distance education as a defense tool. In the months that followed, the distance education approach was adopted by many countries as the most applicable solution in terms of ensuring the continuity of education [2,3]. This approach has also been used in other disaster situations apart from the pandemic. For example, after the earthquake disaster in Türkiye in 2023, all universities switched from face-to-face education to distance education. Yet, although many countries were exposed to natural and man-made disasters before, distance education was not used as a solution to these crises in the way that it was applied during the COVID-19 crisis [2].

"Distance education" is defined as the carrying out of learning and teaching activities by means of various technological tools in situations wherein students and teachers are not interacting face-to-face [4]. When the first COVID-19 case in Türkiye was recorded in March 2020, distance education was immediately implemented at all educational levels. Although the first instance of distance education in our country started in the 1980s [5], its implementation in 2020 was considered a novelty not only by university students who were not educated in the distance education system, but also by the academics who

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had to use this approach. Apart from requiring a sudden change and adoption of technology among the users, it also became necessary for universities to have an infrastructure that can conduct courses with such a system or to develop their existing infrastructure quickly. Teaching staff, who have been teaching for years in the formal education system using their own methods, tried to adapt, use, and develop the emergency distance education system, which became compulsory due to the COVID-19 pandemic [6].

The transition to distance education during the COVID-19 pandemic affected all students, including those studying at maritime faculties. Applied courses have an important place in the departments of "Maritime Transportation and Management Engineering (Deck)" and "Marine Engineering (Engine)" in maritime faculties. Students studying in these departments had to take all their courses through distance education due to the pandemic. In this regard, how students in maritime faculties experienced the distance education process is an important research subject. Therefore, this study aims to evaluate the views of Turkish students studying at maritime faculties regarding the required distance education mode of learning during the COVID-19 pandemic.

In the following section, a literature review is presented. Section 3 describes the theoretical framework of the study. In Section 4, the sample of the study, data collection tool, and data analysis are presented. Section 5 includes the findings of the study, including descriptive statistics, normality results, reliability test and factor analysis, and hypothesis tests. Section 6 presents the discussion of the findings, while Section 7 concludes the paper and provides a general evaluation.

2. Literature Review

We conducted a literature review of related studies on the experiences, opinions or perceptions of university students (undergraduate or postgraduate students) regarding distance education during the COVID-19 period. The obtained and examined studies are summarized in Table 1. It was observed that numerous studies were carried out in Türkiye, Saudi Arabia, Jordan, India, China, Vietnam, the United Kingdom, Sweden, Indonesia, and Romania. In terms of data collection methods, it was seen that questionnaires were used in the majority of the studies, while the interview method was used in some of them.

Distance education during the COVID-19 pandemic has had various effects on students. In the study of Aksoğan [7], participants indicated that distance education negatively affected their socialization. The results also showed that males had more positive opinions of distance education compared with females. According to Chakraborty et al. [8], most of the participants stated that they learned better in physical classes than in online classes. Additionally, they stated that online education was more stressful and negatively affected their health and social lives. Dinu et al. [9] revealed the direct effects of the transition to distance education and the indirect effects arising from the COVID-19-related lockdowns. Savaş [10] found that the majority of students had difficulties focusing on distance education and this situation was related to gender, frequency of exercising at home, and type of university in which they were enrolled. Kartallıoğlu [11] observed a decline in the Turkish language levels of students learning Turkish as a foreign language, due to technological and educational problems they faced during the distance education process.

As reported in the reviewed studies, there have been some difficulties in distance education during the COVID-19 pandemic. According to Slamet et al. [12], the supervision of students' theses could not be carried out by distance education as it required interactive communication. Baykal and Tutuncu [13] concluded that students were unable to take advantage of applied courses during distance education and that they had problems arising from the system, themselves, and other factors. Nordqvist [14] reported that one of the biggest challenges students faced during the COVID-19 pandemic related to their ability to improve the English language. According to Karaaslan et al. [15], factors such as economic conditions, asynchronous learning, proficiency levels related to the use of technological software and devices, and provision of preliminary information affected the success of distance education. The results in the study of Alasmari [16] revealed that an efficient and supportive infrastructure played an important role in implementing emergency distance education during the COVID-19 pandemic.

Students' satisfaction with the distance education they received during the pandemic were revealed in some studies. For example, Dinh and Nguyen [17] found that, among social work students, their levels of satisfaction with face-to-face teaching were notably greater than their satisfaction with online teaching across all criteria. In the study of Bataineh et al. [18], the majority of the university students they investigated revealed that face-to-face education was a better approach than the distance learning method. Şeker [6] determined that students were more than moderately satisfied with the distance education system in general, while Çırakoğlu and Özbay [19] reported that dental students showed a negative attitude and low level of satisfaction with distance education.

In some studies, the factors affecting student satisfaction with distance education were stated. For example, according to Zaharia et al. [20], the functionality of the online platform

Table 1. *Literature review*

Author/Year	Subject	Data collection method	Sample	Country
Aksoğan (2020) [7]	Opinions of students on distance education in the COVID-19 pandemic	Questionnaire	508 university students	Türkiye
Alasmari (2021) [16]	Experiences of university students and instructors regarding distance education during the COVID-19 pandemic	Questionnaire	916 instructors 4623 university students	Saudi Arabia
Bataineh et al. (2021) [18]	Jordanian university students' evaluations of distance education during the COVID-19 pandemic	Questionnaire	871 undergraduate students 129 postgraduate students	Jordan
Baykal and Tutuncu (2022) [13]	Experiences of students studying in health care departments about distance education during the COVID-19 pandemic	Interview	40 university students (in health care departments)	Türkiye
Chakraborty et al. (2021) [8]	Opinions of undergraduate students about online education during the COVID-19 pandemic	Questionnaire	358 undergraduate students	India
Chen et al. (2020) [21]	User satisfaction with online education platforms during the COVID-19 pandemic	Questionnaire	712 students (primary school, middle school, high school, university, and postgraduate students)	China
Çırakoğlu and Özbay (2022) [19]	Evaluations of dental students on distance education during the COVID-19 pandemic	Questionnaire	1375 undergraduate dental students	Türkiye
Dinh and Nguyen (2020) [17]	Satisfaction of social work students with online education during the COVID-19 pandemic	Questionnaire	186 undergraduate social work students	Vietnam
Dinu et al. (2022) [9]	Perceptions of students about online education during the COVID-19 pandemic	Qualitative surveys and interview	417 students (undergraduate and postgraduate students)	United Kingdom
İnce et al. (2020) [22]	Views of students on distance education in the COVID-19 pandemic process	Questionnaire	1011 university students	Türkiye
Karaaslan et al. (2022) [15]	Experiences of nursing students with distance education during the COVID-19 pandemic	Questionnaire	454 undergraduate nursing students	Türkiye
Kartallıoğlu (2022) [11]	Opinions of the university students about distance education during the COVID-19 pandemic	Interview	31 university students (learning Turkish as a foreign language)	Türkiye
Nordqvist (2022) [14]	Evaluations of Swedish university students about distance education during the COVID-19 pandemic	Questionnaire and interview	61 undergraduate students	Sweden
Savaş (2021) [10]	University students' perceptions of their distance education experiences during the COVID-19 pandemic	Questionnaire	3861 university students (undergraduate and postgraduate students)	Türkiye
Slamet et al. (2021) [12]	Experiences of lecturers and students on distance education in Indonesia	Questionnaire	123 lecturers 404 university students	Indonesia
Şeker (2021) [6]	Opinions of students on distance accounting education during the COVID-19 pandemic	Questionnaire	124 undergraduate students	Türkiye
Zaharia et al. (2022) [20]	Student satisfaction with distance education during the COVID-19 pandemic	Questionnaire	446 undergraduate and postgraduate students	Romania

and attendance in online classes significantly impacted student satisfaction with online education in Romania. Chen et al. [21] determined that the personal factors of online education users did not directly affect user satisfaction and that platform usability had the highest effect on satisfaction. İnce et al. [22] found that students' opportunities to have a personal computer and Internet connection affected their opinions about distance education.

Overall, considering the relevant literature, it has been observed that some studies have examined the opinions and experiences of students enrolled in departments where applied courses play an important role. Among them were dental, nursing, and health care students.

It is also important to examine the views of maritime students about distance education. Maritime education places great emphasis on practical, hands-on training, because many of the skills required to work in the industry, such as navigating a ship, operating machinery, and handling cargo, can only be learned through practical experience. During the COVID-19 pandemic, maritime students had to take all their courses online, including the important applied courses. In this regard, there is a need for a study to investigate maritime students' experiences with distance education during the COVID-19 pandemic.

3. Research Hypotheses

With the onset of the pandemic, traditional educational services were replaced by distance education, wherein online platforms became the primary mode of instruction and the only means of delivering educational services [20]. To participate in distance education, it is crucial that both instructors and students possess the ability to use technology effectively [15]. However, given the technical problems that emerged with the use of online education platforms, it is important to investigate whether online education platforms are capable of fulfilling the requirements of both students and instructors [21]. At the same time, the quality of Internet access, which can lead to poor connection and audio quality, can create several challenges for students participating in online courses [17]. In cases wherein students cannot access the Internet, the desired results of distance education cannot be achieved [23]. For these reasons, the technical dimension of distance education was considered while determining the research hypotheses in this study.

The process of distance education is a complex and demanding practice that requires considerable effort to effectively involve students in online classes and accomplish the desired educational outcomes. This unexpected mode of teaching and learning presents several challenging responsibilities for both instructors and students [18]. Effective communication and interaction between instructors and their students play a crucial role in facilitating the learning process (LP). However, the learning experience in distance education is limited due to the difficulty in facilitating communication and interaction compared with a face-to-face classroom environment. This is exacerbated by the considerable physical distance between instructors and students. Besides, building an emotional connection between instructors and students is challenging in distance education because of the lack of interaction in this mode of learning [24]. As a result, it is crucial to examine the LP experienced by students in distance education. In this respect, as a second dimension, the LP dimension of distance education was considered while determining the research hypotheses.

According to the demographic variables of the maritime faculty students, the research hypotheses were formed in relation to the technical dimension and the LP dimension of distance education, as well as to distance education in general. These hypotheses and the tests applied are presented in Table 2.

4. Methodology

4.1. Sample of the Study

The study was conducted on a population of students studying in the Maritime Transportation and Management Engineering (Deck) and Marine Engineering (Engine) departments of 10 public universities in Türkiye. The total number of students in this population was 4517, with 3133 enrolled in the deck department and 1384 in the engine department [25]. Among these universities, Ordu University (ODU), Recep Tayyip Erdoğan University (RTEU), and Dokuz Eylül University (DEU) were preferred in terms of accessibility, and questionnaires were sent to the maritime faculty students via Google Forms. The stratified random sampling method was used by randomly selecting students from three maritime faculties, which were stratified on a university basis.

The survey was conducted between August and October 2021, and 296 responses were collected. However, upon examining the responses, it was found that 62 students had given the same answer to all questions on the scale; therefore, these responses were excluded from the sample. After the eliminations, the number of data to be used for the analysis was determined as 234. Bartlett et al. [26] suggested that the sampling error for continuous data should be around 3%, and the number of samples required to represent the population with 95% confidence interval should be at 119. Based on these criteria, it can be concluded that the sample size of 234 was considered adequate for representing the population. Table 3 shows the demographic characteristics of the students after data cleaning.

Table 2. *Research hypotheses in this study*

Variable	Hypotheses	Test
Gender	H_{1-1}: There is a significant difference between the technical dimension averages according to students' gender.	T-test
	H_{1-2}: There is a significant difference between the learning process dimension averages according to students' gender.	
	H_{1-3}: There is a significant difference between the distance education evaluation averages according to students' gender.	
Ownership	H_{2-1}: There is a significant difference in the technical dimension averages according to the ownership of the device used by students.	T-test
	H_{2-2}: There is a significant difference in the learning process dimension averages according to the ownership of the device used by students.	
	H_{2-3}: There is a significant difference in the distance education evaluation averages according to the ownership of the device used by students.	
University	H_{3-1}: There is a significant difference in students' technical dimension averages according to their universities.	One-Way ANOVA
	H_{3-2}: There is a significant difference in students' learning process dimension averages according to their universities.	
	H_{3-3}: There is a significant difference in students' distance education evaluation averages according to their universities.	
Device	H_{4-1}: There is a significant difference in the technical dimension averages according to the type of device used by students during distance education.	One-Way ANOVA
	H_{4-2}: There is a significant difference in the learning process dimension averages according to the type of device used by students during distance education.	
	H_{4-3}: There is a significant difference in the distance education evaluation averages according to the type of device used by students during distance education.	
Region	H_{5-1}: There is a significant difference between the technical dimension averages according to the regions students live in during distance education.	One-Way ANOVA
	H_{5-2}: There is a significant difference between the learning process dimension averages according to the regions students live in during distance education.	
	H_{5-3}: There is a significant difference between the distance education evaluation averages according to the regions students live in during distance education.	
Class	H_{6-1}: There is a significant difference in the technical dimension averages according to students' classes.	One-Way ANOVA
	H_{6-2}: There is a significant difference in the learning process dimension averages according to students' classes.	
	H_{6-3}: There is a significant difference in the distance education evaluation averages according to students' classes.	
Grade	H_{7-1}: There is a significant relationship between students' technical dimension evaluations and their grade point averages.	Pearson correlation
	H_{7-2}: There is a significant relationship between students' learning process dimension evaluations and their grade point averages.	
	H_{7-3}: There is a significant relationship between students' distance education evaluations and their grade point averages.	
Technical - Learning process	H_{8-1}: There is a significant relationship between students' technical and learning process dimensions evaluations.	Pearson correlation

In the study sample, there were 118 (50.4%), 67 (28.6%), and 49 (20.9%) students from DEU, ODU, and RTEU, respectively. Out of a total of 234 students, 205 (87.6%) were male and 29 (12.4%) were female. In addition, 195 (83.3%) students were enrolled in the deck department, while 39 (16.7%) students were in the engine department. There was no engine student in the sample, except from DEU.

4.2. Data Collection Tool

The Distance Education Evaluation Scale (UEDO), developed by Özkul et al. [27], was used as the data collection tool. This scale consists of 2 dimensions, technical (6 items) and LP (9 items), and a total of 15 items. The items in the scale were presented using a five-point Likert type scale. The scoring of the answers given by the students was determined in the range of "1= totally disagree" and "5= totally agree" [27].

Table 3. *Demographic characteristics of the sample*

University		Gender		Department		Class				Total
		Male	Female	Deck	Engine	1st	2nd	3rd	4th	
DEU	N	96	22	79	39	58	31	10	19	118
	%	41.03%	9.40%	33.76%	16.67%	24.79%	13.25%	4.27%	8.12%	50.43%
RTEU	N	47	2	49	0	28	8	8	5	49
	%	20.09%	0.85%	20.94%	0.00%	11.97%	3.42%	3.42%	2.14%	20.94%
ODU	N	62	5	67	0	18	24	13	12	67
	%	26.50%	2.14%	28.63%	0.00%	7.69%	10.26%	5.56%	5.13%	28.63%
Total	N	205	29	195	39	104	63	31	36	234
	%	87.61%	12.39%	83.33%	16.67%	44.44%	26.92%	13.25%	15.38%	100.00%

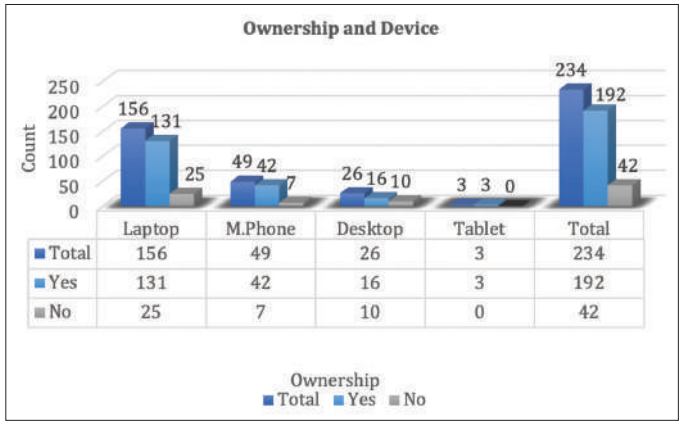

Figure 1. *Ownership and device statistics*

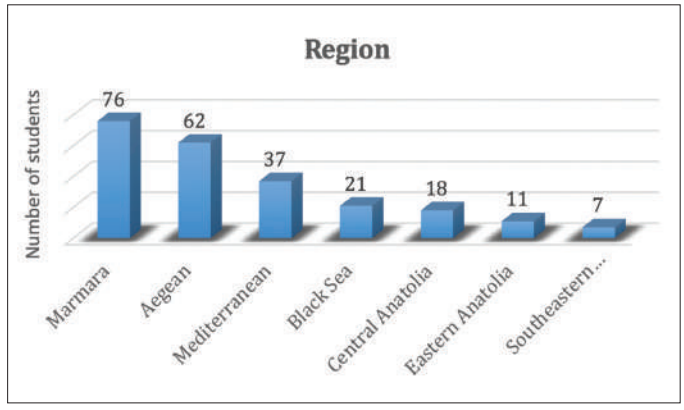

Figure 2. *Regions from which students participated in distance education*

UEDO was originally in Turkish and applied to students in Turkish. The Cronbach's alpha coefficients were 0.89, 0.96, and 0.96 for the technical (T) dimension, the LP dimension, and the total UEDO, respectively.

The other variables used in the first part of the questionnaire form were gender, department, university, class, grade point average (GPA), from which city they attended distance education, with which device they participated in distance education, and whether this device belonged only to them.

4.3. Data analysis

The SPSS 25 program was used for analyzing the collected data. Reliability test, exploratory factor analysis, independent samples t-test, One-Way ANOVA, and correlation tests were conducted for hypothesis testing.

5. Findings

5.1. Descriptive Statistics

Information about the devices used by the students to access the distance education classes is given in Figure 1. As can be seen, the most commonly used device was the laptop (156), followed by mobile phone (49), desktop computer (26), and tablet (3). While 192 students stated that these devices belonged only to them, 42 stated that they connected to distance education using a common device.

Figure 2 shows the number of students who participated in distance education from seven geographical regions in Türkiye. While the highest participation was recorded in the Marmara Region (76), the least participation was in the Southeastern Anatolia Region (7).

Marmara is the most populous region in Türkiye. This is followed by Central Anatolia (12.896.255), Mediterranean (10.584.506), Aegean (10.477.153), Southeastern Anatolia (8.576.391), Black Sea (7.696.132), and Eastern Anatolia (6.513.106) [28]. Looking at Figure 2, it can be seen that the population density of the regions and the number of students did not increase proportionally, which may be due to the fact that the students living in coastal areas preferred maritime faculty (Aegean: 62; Mediterranean: 37; Black Sea: 21).

5.2. Normality Results

Before proceeding to the hypothesis tests, whether the scale and its subdimensions were normally distributed was tested using skewness and kurtosis values. As shown in Table 4, the normality condition was met as all values were within ±2 limits [29].

Table 4. *Normality results of each dimension and total UEDO by variables*

Variable		Technical		Learning process		Total UEDO	
		Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis
Gender	Male	-0.834	0.078	0.292	-1.238	0.056	-0.902
	Female	-0.203	-0.634	1.162	0.336	0.772	-0.184
University	DEU	-0.832	0.005	0.581	-0.965	0.220	-0.738
	RTEU	-0.964	1.299	0.103	-1.290	0.006	-0.908
	ODU	-0.455	-0.647	0.230	-1.315	0.107	-1.121
Ownership	Yes	-0.804	0.007	0.308	-1.258	0.155	-1.000
	No	-0.391	-0.553	0.700	-0.614	0.147	-0.924
Device	Laptop	-0.982	0.723	0.371	-1.230	0.125	-0.886
	Desktop	-0.501	0.599	0.410	-1.063	0.331	-0.805
	Mobile Phone	-0.173	-1.095	0.468	-1.169	0.328	-1.065
Region	Marmara	-0.853	0.082	0.444	-1.038	0.142	-0.725
	Aegean	-0.866	0.863	0.309	-1.291	0.056	-0.986
	Mediterranean	-0.483	-0.971	0.459	-1.251	0.205	-1.114
	Others	-0.560	-0.125	0.365	-1.161	0.262	-0.805
Class	1st	-0.718	-0.164	0.474	-1.059	0.168	-0.709
	2nd	-0.539	-0.377	0.489	-1.175	0.320	-0.935
	3rd	-1.323	1.691	0.261	-1.166	0.238	-1.184
	4th	-0.975	0.872	0.121	-1.403	-0.111	-1.133
	Skewness			**Kurtosis**			
Grade	-0.782			1.775			
Technical	-0.757			-0.050			
Learning Process	0.372			-1.189			
Total UEDO	0.132			-0.912			

5.3. Reliability Test and Factor Analysis

Reliability analysis was performed to measure whether the scale was reliable on the applied sample. Looking at the Cronbach's alpha coefficients shown in Table 5, it can be seen that the scale is reliable (0.896, 0.974, 0.950>0.60) and suitable for exploratory factor analysis (EFA) (KMO 0.941>0.70; Bartlett's test 0.000<0.05). When the EFA results were examined, it is seen that the eigenvalues of two factors were greater than 1 (8.899, 2.676) and consisted of two dimensions as in UEDO. The technical dimension, LP dimension, and overall scale cumulatively explained 48.56%, 28.608%, and 77.168% of the variance.

5.4. Hypothesis Tests

All hypotheses and inferential tests are given in Table 2. Accordingly, a total of 22 hypotheses were established, and Independent Sample T-test, One-way ANOVA and Pearson Correlation tests were performed.

5.4.1. T-test

Table 6 shows the students' answers to UEDO according to their gender and whether the device they used belonged to them (ownership). A significant (p=0.031) difference was found when the averages of the distance education evaluation scores of the students were analyzed according to their gender. In particular, male students ($\bar{X}_{male}$=3.0872) evaluated distance education more positively than female students ($\bar{X}_{female}$=2.6483). This difference was also seen in the learning process dimension (p=0.013), in which male students scored higher than female students ($\bar{X}_{female}$=2.0077) with an average of 2.6531. However, this difference did not exist in the technical dimension (p=0.496).

When the students' answers to UEDO were examined, the results showed a significant difference (p=0.003) based on whether or not they owned the devices they used in distance education belonged. While this difference was also seen in the technical dimension (p=0.000), it was not observed in the LP dimension (p=0.168). Therefore, students who own the device they use while participating in distance education gave higher evaluation scores in terms of technical ($\bar{X}_{yes}$=3.8733, $\bar{X}_{no}$=3.0317) and total ($\bar{X}_{yes}$=3.1264, $\bar{X}_{no}$=2.6048) than students whose device does not belong to them.

Table 5. *Reliability test and factor analysis results*

N	Item	Technical	Learning process	Total UEDO
3	It is easy for me to reach the courses given by distance education.	0.886		
1	I can access the courses given by distance education whenever I want.	0.870		
2	I can access the courses given by distance education wherever I want.	0.827		
5	I use the preferred online platforms (zoom, discord, etc.) effectively in distance education	0.804		
4	I have information about the implementation schedule of the courses given by distance education.	0.780		
6	I get technical support when I have difficulties in accessing the courses given by distance education.	0.555		
12	Distance education facilitates my permanent learning.		0.935	
10	Distance education is suitable for my learning characteristics.		0.907	
15	Distance education enriches my learning process.		0.900	
11	Distance education process encourages me to learn new things.		0.895	
13	The lessons given by distance education contribute to my personal and professional development		0.885	
14	The instructional design of the lessons given by distance education is effective.		0.883	
8	Distance education process increases my learning motivation.		0.879	
7	Distance education is efficient in terms of learning processes.		0.861	
9	I evaluate my own learning process through distance education.		0.792	
	Cronbach's alpha	0.896	0.974	0.950
	Explained variance (%)	48.56	28.608	77.168
	Eigenvalue	8.899	2.676	
	KMO=0.941; Bartlett's test of Sphericity (p)=0.000			

Table 6. *T-test results of the distance education evaluations of students by gender and device ownership*

Dimension	Variable	N	$\bar{X}$	SD	t	p	Result
	Gender						
Technical	Male	205	3.738	0.957	0.691	0.496	Not Supported
	Female	29	3.609	0.934			
Learning Process	Male	205	2.653	1.305	2.512	**0.013**	Supported
	Female	29	2.008	1.227			
Total UEDO	Male	205	3.087	1.030	2.171	**0.031**	Supported
	Female	29	2.648	0.936			
	Ownership						
Technical	Yes	192	3.873	0.872	5.496	**0.000**	Supported
	No	42	3.032	1.015			
Learning Process	Yes	192	2.628	1.323	1.385	0.168	Not Supported
	No	42	2.320	1.234			
Total UEDO	Yes	192	3.126	1.008	3.034	**0.003**	Supported
	No	42	2.605	1.016			
N: Number, $\bar{X}$: Mean, SD: Standard deviation							

5.4.2. One-Way ANOVA

In Table 7, One-Way ANOVA test results of the distance education evaluations of the students according to university, device, region, and class variables are given. Accordingly, there were no significant differences between students' university and distance education evaluations

Table 7. *One-Way ANOVA test results of the distance education evaluations of students by university, device, region, and class variables*

Dimension	Variable	N	$\bar{X}$	SD	F	p	Post-hoc	Result
	UNIVERSITY							
Technical	DEU	118	3.698	0.989	1.565	0.211		Not Supported
	RTEU	49	3.925	0.832				
	ODU	67	3.617	0.964				
Learning Process	DEU	118	2.466	1.295	0.831	0.437		Not Supported
	RTEU	49	2.721	1.317				
	ODU	67	2.653	1.334				
Total UEDO	DEU	118	2.959	1.028	0.978	0.377		Not Supported
	RTEU	49	3.203	0.968				
	ODU	67	3.039	1.066				
	DEVICE							
Technical	Laptop	156	3.892	0.886	12.981	**0.000**	**Tamhane's T2**	Supported
	Desktop	26	3.737	0.762			MP-L p = 0.000	
	Mobile Phone	49	3.136	1.033			MP-D p = 0.017	
Learning Process	Laptop	156	2.614	1.330	1.004	0.368		Not Supported
	Desktop	26	2.726	1.208				
	Mobile Phone	49	2.342	1.324				
Total UEDO	Laptop	156	3.125	1.015	4.066	**0.018**	**LSD** MP-L p = 0.006	Supported
	Desktop	26	3.131	0.916				
	Mobile Phone	49	2.660	1.068				
	REGION							
Technical	Marmara	76	3.680	0.989	2.754	**0.043**	**Tamhane's T2** A-O p = 0.019	Supported
	Aegean	62	3.989	0.756				
	Mediterranean	37	3.604	1.142				
	Others	57	3.523	0.911				
Learning Process	Marmara	76	2.513	1.258	0.370	0.775		Not Supported
	Aegean	62	2.661	1.317				
	Mediterranean	37	2.393	1.288				
	Others	57	2.595	1.359				
Total UEDO	Marmara	76	2.980	1.016	0.928	0.428		Not Supported
	Aegean	62	3.192	0.951				
	Mediterranean	37	2.877	1.096				
	Others	57	2.966	1.038				
	CLASS							
Technical	1st	104	3.788	0.956	2.324	0.076		Not Supported
	2nd	63	3.479	1.004				
	3rd	31	3.978	0.811				
	4th	36	3.736	0.916				
Learning Process	1st	104	2.516	1.299	1.268	0.286		Not Supported
	2nd	63	2.402	1.347				
	3rd	31	2.875	1.266				
	4th	36	2.778	1.300				
Total UEDO	1st	104	3.025	0.979	1.790	0.150		Not Supported
	2nd	63	2.833	1.111				
	3rd	31	3.316	0.942				
	4th	36	3.161	1.045				

N: Number; $\bar{X}$: Mean; SD: Standard Deviation; L: Laptop; D: Desktop; MP: Mobile Phone; A: Aegean; O: Others

not only in total UEDO but also in both dimensions. Furthermore, students' distance education evaluations did not change according to their universities (p_{TTL}=0.377, p_{T}=0.211, p_{LP}=0.437).

In terms of the type of device used to participate in distance education, we can see that three students chose the tablet option. These cases were excluded from the sample while performing the ANOVA test, as sufficient data could not be obtained for us to make comparisons between groups. Meanwhile, we found a significant difference between at least two groups in distance education evaluations according to the type of device used by the students (p=0.018). As the test of homogeneity of variances resulted in a value of 0.430, the results of the LSD test were checked. According to test results, a significant difference was found between those who connected to distance education by mobile phone and by laptop (p_{MP-L}=0.006). Furthermore, those who used a mobile phone ($\bar{X}_{MP}$=2.6599) evaluated it more negatively than those who used a laptop ($\bar{X}_{L}$=3.1252).

While it was determined that the students' evaluations of the LP dimension did not change according to the type of device they used (p=0.368), the averages of the technical dimension evaluations showed a significant difference between at least two groups (p=0.000). In particular, significant differences were found between those who attended to distance education by mobile phone and both by laptops and desktop computers (p_{MP-L}=0.000, p_{MP-D}=0.017). According to the average scores, those who attended the lessons using laptops ($\bar{X}_{L}$=3.8921) and desktop computers ($\bar{X}_{D}$=3.7372) made more positive evaluations than those who attended using mobile phones ($\bar{X}_{MP}$=3.1361).

Before looking at the evaluation scores of the students according to the geographical regions they lived in, Black Sea, Central Anatolia, Eastern Anatolia, and Southeastern Anatolia regions with a small sample number were combined as "Others". A significant difference was found between the geographical regions from which the students participated in distance education in terms of the technical dimension (p=0.043). As the Levene test result was p=0.017, the result of Tamhane's T2 test was checked. Accordingly, the students participating in distance education from the Aegean Region made more positive evaluations than those in the geographical regions grouped as "Others" (p=0.019, $\bar{X}_{A}$=3.9892, X_{O}=3.5234). Furthermore, in the distance education evaluations according to the students' classes, no significant difference was found in the total and the both dimensions (p_{T}=0.076, p_{LP}=0.286, p_{TTL}=0.150).

5.4.3. Correlation

Table 8 shows the correlation results between students' GPAs and distance education evaluations. In addition, the relationships between the subdimensions of the scale were examined. A positive, significant, and weak relationship was found between students' distance education evaluations and their GPAs (r=0.154, p=0.019). In other words, as students' GPAs' increased, their evaluations of distance education became more positive. In addition, a positive, significant, and weak relationship was found between students' grade and technical dimension evaluations (r=0.228, p=0.001).

Furthermore, there was a positive, moderate, and significant correlation between the subdimensions of the scale (r=0.486, p=0.000). In other words, as the students made positive assessments of the technical dimension, they also made positive assessments of the LP dimension.

6. Discussion

Based on the given statistical analysis, there are several significant findings related to the evaluations of distance education made by the students. First, there was a significant difference in the evaluation scores between male and female students, with the former making more positive evaluations of distance education than the latter. In parallel with this finding, Aksoğan [7] also found that male respondents held a more positive stance toward distance education than female respondents.

Second, the students who owned the device they used for distance education gave higher evaluation scores in terms of the technical dimension and the total scale compared with those who did not own the devices they were using. If the devices used by the students belonged to them, this situation would enable them to access distance education whenever and wherever they wanted. Similar to this finding, İnce et al. [22] found that students who owned a computer

Table 8. *Correlations between students' grade point averages and distance education evaluations*

	$\bar{X}$	SD	Grade	T	LP	Total UEDO
Grade	3.036	0.461	1	**0.228****	0.090	**0.154***
T	3.722	0.953		1	**0.486****	**0.743****
LP	2.573	1.310			1	**0.946****
Total UEDO	3.033	1.027				1
**<0.01, *<0.05, T: Technical dimension, LP: Learning process dimension, $\bar{X}$: Mean, SD: Standard deviation						

were more likely to participate in all questionnaire items compared to those who did not have their own computers.

Meanwhile, there was no significant difference in the learning process dimension according to the device ownership. Thus, students' motivation to learn and their contribution to their personal and professional development did not change with the ownership of the equipment.

Regarding the university and class variables, there were no significant differences in the total and dimension evaluation scores. The universities considered in this study may have used similar educational materials and learning resources in the distance education process. In addition, students' self-study and motivation levels gained importance in the distance education process. Differences regarding the universities and classes may be insignificant depending on how the students approached this process and how motivated they were. Unlike the findings in the present study, Çırakoğlu and Özbay [19] found a significant relationship between dental students' classes and scale expressions in their study.

In terms of location, for the technical dimension, the students from the Aegean Region had more positive evaluations than those in the "Others" group. Distance education requires a computer or other devices with which students can access the Internet. In this regard, students in the Aegean Region may have more opportunities. This situation, in comparison, may lead to lower evaluation scores of students from other regions.

There were significant differences in the technical dimension evaluation scores based on the type of device used by the students. Students who used laptops or desktops evaluated distance education more positively than those who used mobile phones. Mobile phones generally have less powerful processors and smaller screens. Therefore, it may be more difficult for students to view and access distance education materials using their mobile phones. Furthermore, Internet connection problems may be more common for mobile phones, which can negatively affect students' attendance.

Finally, we found a positive correlation between students' GPAs and their evaluation scores of distance education. Students with higher GPAs may be more disciplined and have regular study habits. This situation may continue in the same way during distance education as in face-to-face education. In addition, there was a positive correlation between the technical and LP dimensions of the scale.

Overall, these findings reveal that certain factors such as students' gender, device ownership, type of device, and academic success are related to distance education evaluations.

7. Conclusion

During the COVID-19 pandemic, many countries had to urgently switch from face-to-face education to distance education. Students in all departments of many universities continued their education through distance education. Those who were enrolled in the deck and engine departments of maritime faculties, where applied courses (simulator-assisted courses, etc.) are important, also had to keep up with this situation.

The maritime industry is an essential sector for global trade and transportation, and maritime faculties play a critical role by training students as qualified personnel for this industry. Thus, any disruptions to maritime education can have far-reaching consequences for the industry and its stakeholders, given that distance education may not offer the same level of hands-on experience as face-to-face education. This could mean that students may not have the opportunity to gain practical experience in navigating a ship or working with actual maritime equipment. In this context, it is important to examine maritime students' evaluations of distance education. This study reveals the evaluations of students enrolled in three different maritime faculties in Türkiye.

Study Limitations

In terms of limitations, this study reached fewer engine students than deck students. Thus, more engine students can be included, and comparisons between deck and engine departments can be made in future studies. In addition, a more comprehensive study can be performed by including more maritime faculties. This study can also be improved by including students in the maritime faculties of private universities in the sample. Comparisons can also be made between maritime faculties in public and private universities. Apart from these, studies can also investigate how distance education affects the applied courses of maritime students.

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Analysis of Organizational Justice in Relation to Organizational Commitment in a Turkish Shipyard Organization

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Abstract

This study explored the relationships between organizational justice perception and commitment among shipyard employees in a maritime organization in Türkiye. Data were collected using two-scale and sociodemographic questionnaires that were answered via email or hand by 290 participants who were shipyard workers in Antalya, Türkiye. The questionnaire included the organizational justice scale consisting of 20 questions, the organizational commitment scale consisting of 18 questions, and 7 questions about demographic characteristics. To analyze the data, IBM SPSS 26 was used. A simple linear regression analysis technique was used to determine the effects between scales. Moreover, interviews were conducted with the employees using the semistructured interview method. It was determined that there was a positive, high-level relationship between organizational justice scale subdimension scores and total scores and this relationship was statistically significant. It was also shown that there was a positive, low-level relationship among the organizational commitment subdimensions' scores of the employees and that the relationship was statistically significant. Regression analysis identified that the organizational justice scale total scores of the employees had a statistically remarkable impact on the organizational commitment scale total scores.

Keywords: Organizational justice, Organizational commitment, Maritime management, Maritime organization, Shipyard employees

1. Introduction

The number of people employed in the transportation and warehousing industry and allied businesses (such as the automotive industry) totaled 14.9 million in 2021, an increase of 3.9% from the previous year. The level of overall transportation employment in 2021 exceeded that of 2019 and reached the highest level since 1990 [1]. In addition, the maritime industry provides services through ships in several areas such as trade, defense, transportation, shipbuilding, and tourism. With noteworthy exclusions, newly developing countries benefit from the shipbuilding industry and are optimistic in its ability to expand, but the traditional manufacturers seem to be burdened by the industry's failures and the possibility of further collapse. Perhaps, more than any other industry, shipbuilding has experienced a significant change in its regional distribution in recent years [2]. The shipbuilding industry of Türkiye has grown into a worldwide recognized trademark since the early 1990s because of the combination of traditional shipbuilding skills with contemporary technology and education. The sector also provides job opportunities for about 20,334 people directly and for a total of 63,000 people through connected industries in Türkiye [3]. Thus, the importance of shipyard employees has recently emerged to the top of the agenda.

Shipyards are engaged in the construction, maintenance, repair, and modernization of ships. With an ever-increasing competitive environment and advancing technology, shipyards are improving their ship production techniques. Thus, shipyards are responsible for delivering the orders they receive in high quality at the promised time. Top-level managers who manage this process want their employees

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to work satisfactorily and to keep qualified employees who do their job independently and are loyal to them. These organizational requests can only be met with highly committed employees. The high or low perception of justice by the employees will determine the level of commitment. Thus, the justice policies of organizations will also affect their goals. In today's wild and competent business conditions, it is seen that organizations follow employee-oriented policies to retain qualified and experienced employees. The way to achieve this is to increase the loyalty of employees to the organization through fair practices. Justice, which has grown in importance in all business and social environments today, has become a concept that cannot be ignored by organizations [4]. The concept of organizational justice is gaining increasing prominence with the increasing desire of organizations to institutionalize. Providing unity and solidarity for managers and employees is only possible as a result of providing them with fair conditions. A review of the literature proved that organizational justice and commitment have already been discussed many times over the past decades [5,6]. Affective commitment and sustained commitment, as well as job performance, are positively and strongly connected with organizational justice (procedural or interactional justice) [7]. In organizational decision-making, perceptions of organizational justice play a significant role because research links them to leadership, organizational citizenship, organizational commitment, confidence, service quality, work effectiveness, financial fraud, role breadth, isolation, and leader-member interactions [8]. Based on a study on organizational justice perceptions, which focus on the importance of equal treatment at work, attitudes of the employees, such as employee satisfaction, intention to quit, and organizational commitment, as well as workplace behavior, such as absenteeism and organizational citizenship behavior, are all significantly influenced by perceptions of organizational justice [9]. According to Kim [10], employees are more likely to retain commitment, confidence, satisfaction, and control reciprocity than when they believed they were being treated unfairly by their employer. The majority of organizational commitment definitions express the concept in terms of how much an employee identifies with and is associated with an organization [11]. Moreover, Masterson et al. [12] demonstrated that work engagement is a widespread, systemic response that individuals have to the organization they work for. Job satisfaction and organizational commitment are both strongly correlated with perceived organizational justice.

Numerous studies have been conducted on organizational justice and commitment in different sectors. However, in management science, studies on organizational behavior in the maritime industry are scarce. The maritime industry's employees undoubtedly are an integral part of the supply chain. Thus, maritime workers have recently gained a lot of importance, so field researchers have started to conduct a considerable amount of research on maritime workers' behavior patterns and work outputs. It is seen that academic studies on the perception of organizational justice and organizational commitment are included in many sectors in Türkiye and abroad. However, the limited number of studies on the maritime sector and shipyard workers is one of the strengths of this study. It is essential to study more organizational behavior issues on the employees of maritime organizations, which are indispensable parts of the logistics industry, which has gained importance in recent years. It is suggested that this study will support subsequent studies in this area. This article aims to shed light on the relationships between employees' organizational justice perceptions and organizational commitment in a shipyard in Türkiye, as well as the effects of each on the other. An important limitation of this study is that it only covers the employees of a maritime organization shipyard operating in the province of Antalya. Therefore, it is impossible to generalize the results to all maritime business organizations.

2. Organizational Justice and Organizational Commitment

In Greenberg's [13] article "A Taxonomy of Organizational Justice Theories", published in 1987, the term "justice" was used for the first time in the context of the business environment. Organizational justice is concerned with the perceptions of individuals whether they are treated fairly or not in their working lives and how the organization is affected by this situation [6]. It investigates whether managers in an organization have a positive or negative perception of fair treatment and how this perception affects the organization [14]. Organizational justice, which affects these elements, determines the opinions and thoughts of individuals about their organizations and the attitudes and behaviors they will display toward their organizations in light of these thoughts [8]. While the presence of the perception of justice in the employees ensures that positive and good behaviors are displayed, in the opposite case, the perception of injustice causes the unproductive and maladaptive behaviors of the individuals [15]. One of the crucial reasons why research on organizational justice has been included in many recent studies is its effect on the characteristics and attitudes of the employees of the organization [16]. Employees undoubtedly want to have confidence in their organization and their managers. Individuals' perceptions of organizational justice are the most important factor in establishing this trust.

While distributive justice expresses perceptions of justice that occur during profit allocation within a business, it is procedural justice that occurs about the equity of the treatments used to ascertain the quantities of these benefits [17]. Distributive justice represents employees' perceptions of individual justice in the sense of resource distribution within the organization [18]. In other words, distributive justice is the sharing of resources and gains by the organization by applying certain rules of justice considering the needs within the framework of fairness and equality for the business to succeed in its goals [19]. It is connected to the degree of equity of policies and strategies in resolutions taken regarding labor standards [20]. Employees are likely to be treated fairly in the distribution of the awards distributed by their organizations, the rules applied, and the inputs and outputs that occur within the organizational system [21]. The management of resources and rewards is a phenomenon that occurs at all levels, from small groups to a wider social environment. Procedural justice is the assessment of whether the principles followed by managers in the distribution of gains are fair to individuals [22]. Distributive justice and procedural justice are closely related, and unfair processes often produce unfair results. A study revealed that there is a powerful correlation between these two subdimensions of justice [23]. Interactional justice can be expressed as an honest and respectful explanation of the decisions on how the gains will be distributed to the employees during the implementation process [24]. This dimension of organizational justice surmounts the human dimension of justice. Interactional justice, which addresses the social component of justice, is concerned with how the organization's managers treat their employees fairly and appropriately in their decisions [25]. Two factors affect the perception of interactional justice. The first of these is whether the main arguments for the decisions made regarding the allocation of organizational resources are explained accurately, clearly, and adequately to the people affected by the decision. The second is whether the organization's officials in charge of performing the decisions taken treat the employees affected by these decisions with dignity and respect [26]. In this aspect of justice, a communication process based on honesty, courtesy, and respect should be carried out between the person applying justice and the other party [27]. Psychological disharmony, which affects perceptions of organizational justice among employees, causes damage to their behavior, energy, attitudes, sense of belonging and competence toward the organization, and burnout [28]. Because it is seen that positive attitudes and behaviors are formed with the perception of the existence of fair practices in organizations. On the contrary, it is inevitable to experience negative behaviors in the presence of an unjust situation [29].

It has been determined that organizational commitment is a crucial component in comprehending and explaining how employees behave at work in organizations [30]. Organizational commitment is the attachment of the individual to the interests that affect the individual, the assimilation of organizational goals, and interests within the organization by the employees. In other words, it is the adoption of the working individuals by creating organizational goals and internal goals, keeping the interests of the organization above their own interests, and continuing their membership, and commitment to the organization. Organizational commitment is that employees and managers remain loyal to the organization's culture and the values of the organization [31]. While the perception of justice among the employees keeps individuals together, the perception that there is injustice in the face of unfair practices not only distances the employees from each other but also negatively affects their motivation while performing their duties [32]. Organizations want to avoid high costs that may occur by reducing employee turnover, and the way to realize this desire is to increase the loyalty of their employees [33]. In addition, employees with high organizational commitment have better relations with other members of the organization, and their satisfaction levels are higher. Therefore, it is essential for organizations to be capable of ascertaining the organizational commitment of their employees [34]. Organizational commitment is expressed as the formation of a psychological bond between individuals and organizations [35]. Organizational commitment is psychologically defined as the fusion of employees and organizations, the intention of employees to continue to persist in the business in line with the organization's targets and objectives [36]. Organizational commitment also means that employees are mutually integrated with their organizations and are happy to be members of them [37]. Allen and Meyer [38] conceptualized commitment in two dimensions, namely, affective commitment, and continuance commitment. In subsequent studies, normative commitment is considered as the third dimension.

Affective commitment is the employees' intention to stay in their organization because they think that they should adopt the objectives and worth of the organization and give priority to its values without prioritizing economic conditions [39]. When people see that they are rewarded by evaluating the gains they deserve as fair, they develop an affective commitment to their organization [40]. It examines an employee's intention to stay in the organization by voluntary and self-determined decision [41]. Employees committed to the organization instinctively see themselves as part of the organization they work for. The fact that the employees have this perception, their assimilation of the

organization they work for, and the happiness they will feel from being a part of the organization, together with a strong sense of organizational commitment, brings their loyalty to the organization [42]. Affective commitment is the strongest type of organizational commitment. The desire to continue their career in the organization they are in means that they are ready to make a voluntary effort for the organization [43]. The type of commitment generally desired by organizations is affective commitment. Organizational employees who demonstrate a significant degree of commitment adopt the organization's objectives and beliefs as their own objectives and principles [44]. Employees with these characteristics develop positive attitudes toward working life. They are ready to put in more effort than necessary when necessary. As a result of these consequences, the most prized type of commitment by organizations is affective commitment [45]. The second type of commitment, continuance commitment (also known as compulsory commitment) emerges when individuals evaluate their willingness to continue working in the organization, their total investment in the organization, what they will lose when they leave the organization, and the limited availability of comparable alternatives [46]. Meyer and Allen [47] have defined the continuity of obligation as well as an understanding of the consequences of leaving the organization. Employees are aware of the risks and costs of leaving their current organization [47]. Members of organizations who see that there are few alternative job opportunities are more committed to their organizations to maintain their current situation. As a consequence, a strong continuance commitment is formed [48]. Continuance commitment generally addresses the state of commitment to needs. It is dependent on the risks and costs that employees will face if they leave their jobs [49]. Continuity is based on the valuation of the economic benefits resulting from the relationship between the organization and its workers [50]. In the development of this type of commitment, individuals' investments in an organization (such as long-term labor or friend relations) and their perception that there is no other job option play an important role [51]. Employees are motivated when they see the behaviors that they think they deserve by being appreciated and congratulated for their work. As a result of this, they will not want to leave the organization because they are more committed to the job and believe that their efforts are valuable [52]. The third dimension, normative commitment emerges as a consequence of employees' perceiving commitment to their organization as a duty and thinking that this perception is correct [53]. It reflects the employee's sense of responsibility and normative commitment. When employees leave their organizations, they think that they let their managers down, and they move away from the thought of quitting [54]. Normative commitment has been found to be related to the norms of individual belonging that employees adopt due to their family upbringing or cultural structure [55]. Employees in normative commitment do not believe that they are required to stay around work and social relations, but they believe they should. This is because the person believes that his or her thought is correct [56]. In normative commitment, managers should seek ways to create a powerful feeling of commitment to their employees by providing the necessary motivation [57].

Meanwhile, studies supporting the abovementioned cases reveal a significant connection between organizational justice and organizational commitment in a study of 300 teachers working in general, special and gifted education systems [58]. Rafei-Dehkordi et al. [58] selected 150 employees working in the Youth and Sports Department of the Directorate as a sample to evaluate the relationship between organizational justice and the organizational commitment of its employees. In line with their findings, it is seen that all components of organizational justice affect organizational commitment. There is a strong and direct link between organizational justice and its dimensions [59]. If there are no fair practices in an organization, organizational commitment should not be expected from the employees of that organization. In the opposite case, it is seen that organizational commitment increases in organizations where fair practices are used, and there is a positive relationship between the two [8,16,17,36]. A review of the literature has found limited work on the relationship between organizational justice and organizational commitment in the maritime field, especially among shipyard employees.

3. Materials and Methods

This research aims to shed light on the relationship between organizational justice perception and organizational commitment of employees of a maritime shipyard business. In this work, a questionnaire was answered by email and by the hand questionnaire method using the internet environment as a data collection tool. The population of this research included the employees of every department and status of a shipyard located in the province of Antalya, Türkiye. The organization, which is the subject of this thesis, has 302 employees. The sample size reached was 298 people, and the questionnaires from 290 people, 8 of which were deemed invalid, were evaluated. The questionnaire form consisted of 45 questions in total. The survey contained 7 questions about demographic characteristics, 20 questions about organizational justice, and 18 questions about organizational commitment. Linear regression analysis was applied to ascertain the effects between scales. Spearman correlation analysis was also used to investigate the relationship between the two scales. Data analysis for the research was performed with IBM SPSS 26. The

Institutional and National Research Ethics Committee of Ordu University approved the research (approval no: 2022-36, date: 22.03.2022).

3.1. Objective and Hypotheses of the Research

The aim of this paper was to analyze the relationships between organizational justice perceptions and the organizational commitment of shipyard workers in the maritime sector. The relationship between organizational justice and organizational commitment of shipyard workers in the maritime sector, as well as their effects on each other, has been determined based on the findings of the upcoming analysis. The subdimensions of organizational justice and organizational commitment, as well as their interactions, were examined. The study was limited to the employees of one shipyard in the maritime sector of Antalya province.

The hypotheses of the research were as follows:

H1: There is a positive relationship between the organizational justice perceptions of the shipyard employees and their organizational commitment.

H2: Organizational justice perceptions of shipyard employees positively affect their perceptions of organizational commitment.

3.2. Scales Used in the Research

The data collection tool used was survey questionnaire that included the organizational justice scale and the organizational commitment scale. The research scale comprises two main parts. In the first part, the organizational justice scale consists of 20 questions, and the organizational commitment scale consists of 18 questions and includes 38 questions in total. In the second part, demographic variables consisting of 7 questions are included. A total of 45 questions were asked to the participants. A questionnaire was used to collect data. In the questionnaires, a 5-point Likert scale was used as "1: strongly disagree", "2: disagree", "3: neutral", "4: agree", and "5: strongly agree". The validity and reliability tests of the collected data were performed using SPSS (KMO, Cronbach's alpha, and Barlett tests). For the applied scales, the organizational justice scale consisting of 20 questions improved by Niehoff and Moorman in 1993 was used. The three subdimensions of this scale are as follows: 1-5 questions measure distributive justice, 6-11 questions measure procedural justice, and 11-20 questions measure perceptions of interactional justice [52]. It was adapted to Turkish by Yıldırım [59] in 2002, validity and reliability tests were performed, and it was used in the data collection and analysis of data. The organizational commitment scale consisting of 18 questions developed by Meyer and Allen [47] in 1991 was selected. The three subdimensions of this scale are as follows: affective commitment, 1-6 questions; continued commitment, 7-12 questions; normative commitment, 13-18 questions. It was adapted to Turkish by Wasti [60] in 2000, validity and reliability tests were applied, and it was used in data collection and analysis.

3.3. Analysis

Table 1 lists the findings of frequency analysis based on the demographic features of the individuals participating in the

Table 1. *Demographic characteristics of the individuals*

Variable	n	%
Gender		
Male	270	93.1
Female	20	6.9
Age		
18-24	47	16.2
25-34	92	31.7
35-44	88	30.3
45-54	54	18.6
>55	9	3.1
Marital Status		
Single	120	41.4
Married	170	58.6
Educational Status		
Elementary education	79	27.2
High school	116	40.0
Vocational school	31	10.7
College/undergraduate	44	15.2
Postgraduate	15	5.2
Others	5	1.7
Work Experience		
0-12 months	61	21.0
1-5 years	61	21.0
6-10 years	57	19.7
11-15 years	36	12.4
>16 years	75	25.9
Department		
Technical	161	55.5
Others	70	24.1
OAMM	31	10.7
Operations	19	6.6
Logistics	9	3.1
Position		
Technical staff	156	53.8
Others	69	23.8
Manager/Deputy manager	20	6.9
Expert	18	6.2
Office staff	18	6.2
Head	9	3.1
OAMM: Operations, accounting, maritime, and management		

research. Upon examination, 93.1% of the individuals are male and 6.9% are female. The age levels of the individuals are 16.2% who are 18-24 years old, 31.7% who are 25-34 years old, 30.3% who are 35-44 years old, 18.6% who are 45-54 years old, and 3.1% who are 55 and over. According to their marital status, 58.6% of the individuals are married and 41.4% are single. The education levels of these individuals show that 27.2% of them are graduates of elementary education, 40.0% are high school, 10.7% vocational school, 15.2% college/undergraduate, 5.2% postgraduate, and 1.7% other education institutions. According to their work experience, 21.0% of individuals have 0-12 months of work experience, 21.0% have 1-5 years of work experience, 19.7% have 6-10 years of work experience, 12.4% have 11-15 years of experience, and 25.9% have 16 years or more of work experience. Of these individuals, 53.8% work as technical staff, 23.8% have other works, 6.9% work as manager/deputy manager, 6.2% work as office staff, 6.2% work as expert, and 3.1% work as head. Moreover, 55.5% of the individuals work in technical fields, 24.1% in other fields, 10.7% in OAMM, 6.6% in operations, and 3.1% in logistics. To be able to test the internal consistency of the scales, the Cronbach Alpha coefficients for the general scales and their subdimensions were calculated. The general Cronbach Alpha value of the organizational justice scale is 0.948. The reliability coefficients of the subdimensions of the organizational justice scale are 0.829 (distributive justice), 0.853 (procedural justice), and 0.942 (interactional justice). For the organizational commitment scale, the overall reliability coefficient is 0.788. The reliability coefficients of the subdimensions of the commitment justice scale are 0.616 (affective commitment), 0.760 (continuance commitment), and 0.743 (normative commitment).

Table 2 lists the descriptive statistics for the subdimension and total scores of the organizational justice and commitment scales of the research participants. In Table 2, it is found that the distributive justice subdimension mean score of the individuals is 15.72, the procedural justice subdimension mean score is 18.45, the interactional justice subdimension mean score is 30.97, and the total organizational justice scale mean score is 65.13. Moreover, the affective commitment subdimension score average of individuals is 18.55, the continuance commitment subdimension mean score is 19.43, the normative commitment subdimension mean score is 15.35, and the total organizational commitment scale mean score is 53.33.

Table 2. *Descriptive statistics on subdimension scores and total scores of individuals' organizational justice and commitment scales*

Dimensions		SS	Min.	Max.
Distributive justice	15.72	4.99	5.00	25.00
Procedural justice	18.45	5.83	6.00	30.00
Interactional justice	30.97	9.15	9.00	45.00
OJS	65.13	17.91	20.00	100.00
Affective commitment	18.55	4.52	6.00	30.00
Continuance commitment	19.43	5.17	7.00	30.00
Normative commitment	15.35	5.16	6.00	30.00
OCS	53.33	10.81	22.00	86.00

$\bar{X}$: Mean, SD: Standard deviation, Min: Minimum, Max: Maximum, OJS: Organizational justice scale, OCS: Organizational commitment scale

Table 3 examines the findings of the Spearman correlation analysis, which was applied to evaluate the relationship between the subdimension and total scores of the organizational justice and commitment scales of the individuals participating in the research. In Table 3, it is noted that there is a positive, high-level relationship between organizational justice scale subdimension and total scores and the relationship is significant ($p<0.05$). The distributive justice subdimension scores and the organizational commitment scale subdimensions and total scores are low in the positive direction ($r=0.258$, $p<0.05$), and there is a high level in the positive direction ($r=0.520$, $p<0.05$), a low level in the positive direction ($r=0.151$, $p<0.05$), and moderate relationship in the positive direction ($r=0.419$, $p<0.05$). Between individuals' procedural justice subdimension scores and organizational commitment scale subdimension and total scores, respectively, there is a low level in the positive direction ($r=0.193$, $p<0.05$), ($r=0.491$, $p<0.05$) moderately positive, ($r=0.184$, $p<0.05$) a low level in the positive direction, and ($r=0.399$, $p<0.05$) moderate correlation in the positive direction. Moreover, individuals' interactional justice subdimension scores and organizational commitment scale subdimension and total scores are positively low ($r=0.274$, $p<0.05$); ($r=0.543$, $p<0.05$) there is a high level in the positive direction, ($r=0.064$, $p>0.05$) no relationship, ($r=0.392$, $p<0.05$), and a moderate correlation in the positive direction. Individuals' organizational justice scale total scores and organizational commitment scale subdimension and total scores are ($r=0.280$, $p<0.05$) low in the positive direction; it is observed that there is a high level in the positive direction ($r=0.588$, $p<0.05$), a low-level positive correlation ($r=0.137$, $p<0.05$), and a moderate positive correlation ($r=0.454$, $p<0.05$).

Simple regression analysis is preferred for determining the relative impact of the predictor variable on a specific outcome. The goal of simple regression analysis is to determine the relative influence of a predictor variable on a specific outcome [70]. The findings of the simple linear regression analysis are presented in Table 4, in which the total scores of the organizational commitment scale of the

Table 3. *The relationship between the subdimension scores and total scores of the organizational justice and commitment scales of individuals*

	1	2	3	4	5	6	7	8
1. Distributive justice	1	0.614*	0.633*	0.810*	0.258*	0.520*	0.151*	0.419*
2. Procedural justice		1	0.727*	0.873*	0.193*	0.491*	0.184*	0.399*
3. Interactional justice			1	0.928*	0.274*	0.543*	0.064	0.392*
4. OJS				1	0.280*	0.588*	0.137*	0.454*
5. Affective commitment					1	0.271*	0.277*	0.644*
6. Continuance commitment						1	0.208*	0.697*
7. Normative commitment							1	0.728*
8. OCS								1
OJS: Organizational justice scale, OCS: Organizational commitment scale, *p<0.05								

Table 4. *Simple linear regression analysis results*

Variable	Beta	SH	t	p
Constant	33.477	2.073	16.151	<0.001
OJS	0.305	0.031	9.935	<0.001
R2=0.255				
F=98.697				
p<0.001				
OJS: Organizational justice scale, Beta: Coefficient, SD: Standard deviation				

individuals are used as the dependent variable and the total scores of the organizational justice scale are used as the independent variable. When the findings are examined, the total scores of the organizational justice scale explain approximately 25.5% of the change in the total scores of the individuals' organizational commitment scale (F=98.697, p<0.05). When the model coefficients are tested, it is observed that the organizational justice scale total scores of the individuals have a statistically remarkable effect on the organizational commitment scale total scores (p<0.05). In view of these results, when the total scores of the individuals' organizational justice scale increase by one unit, it causes an increase of approximately 0.305 on the total scores of the organizational commitment scale.

Moreover, qualitative data were gathered using the semistructured interview method, which involved asking five questions to five employees from various departments of the organization. The answers given during the interviews are given in the table below.

The answers given by the employees to questions regarding the perception of equal treatment in the distribution of earnings, the views, and opinions of the employees are considered by the managers, the protection of personal rights are examined. The use of the same service and cafeteria in the work environment by the managers and employees has created the perception of equal treatment. The concept of organizational justice; how promotions, rewards, punishments, and gains are distributed and implemented; and how managers' actions are perceived by employees [61] have been observed that receiving similar responses to this definition is supportive. The perception of organizational commitment is that it can only exist if managers and employees mutually provide it through social activities with all staff and conversations with employees during managers' work visits, giving employees the perception that they are valued. Affective commitment refers to the relationships between employees and the organization [47]. It is obvious that affective commitment is at the forefront of employee behavior. In the answers received about how employee productivity increased, employees stated that improved working conditions, fairness of labor, and wage balance, employee trainings, social activities, fair distribution of earnings, and doing this in transparent way increase productivity. The priority of managers who distribute rewards equally is not to ensure a standard of fairness, but to increase productivity in the long run [62]. Managers expect higher performance and motivation from their employees with the decisions they make about the equal distribution of wages and rewards and aim to maintain productivity [63].

4. Discussion

In this research, the relationship between organizational justice and organizational commitment was investigated. Results showed that there is a positive relationship between the organizational justice perceptions of the shipyard employees and their organizational commitment and organizational justice perceptions of shipyard employees positively affect their perceptions of organizational commitment. The distributive justice subdimension scores and the organizational commitment scale subdimensions and total scores were low in the positive direction, and it was observed that there is a high level in the positive direction, a low level in the positive direction, moderate relationship in the positive direction. Similar results have

Table 5. *Interview questions and answers*

	1. What kind of practices is carried out in your organization to create and reinforce organizational justice?	2. What kind of practices is carried out in your organization to create and reinforce organizational commitment?	3. What are the practices in your organization that make you feel that they are not treating you fairly?	4. What are the practices that create a sense of commitment toward your organization?	5. What kind of practices and gains increase efficiency in your organization?
Interviewee 1	The fair application of the gains such as the distribution of duties, authorities, wage levels, and rewards of the employees by the management creates a feeling of justice.	The formation and consolidation of commitment can be mutually ensured between management and employees. First, the sense of corporate justice by the management will increase; in turn, the commitment of the employees to their work and the sense of belonging will increase.	Valuing the work we do, the policies we implement, and the effort we spend. My feelings increase according to the respect shown to me in bilateral relations.	The desire to benefit from their knowledge and experience, the respect, and love shown are enough for me.	Positives such as physical conditions of the workplace, internal relations, knowledge, and experience of employees, harmony of labor-wage balance, effective use of technology, and success, and continuity in production increase productivity.
Interviewee 2	For the development of organizational justice, wages are evaluated according to seniority, experience, and education.	My area of authority and responsibility is quite high.	Even if there are deficiencies in matters such as career planning and education, we can say that what is necessary is done by keeping the old employees in the organization.	Working directly with the board of directors on some issues and the board of directors contacting me directly allows me to see the business of the organization as my own.	Our organization increases the wages by considering the economic conditions. Getting paid for my labor increases my productivity.
Interviewee 3	I think that the employee representative and the employee's participation in the management are taken into account by the organizational management.	Remuneration policy is being reviewed, giving priority to employees for in-house capacity needs.	Fair treatment in working hours and working conditions.	Respect and sincerity of managers and colleagues.	Appropriate equipment, equal rights, specific job descriptions, advanced standards, and management policy that support personal development and careers.
Interviewee 4	In determining the personal rights of the employees, the equal evaluation of employees at all levels without discrimination constitutes justice.	Social events organized with all employees contribute to organizational commitment, for example, barbecue parties, and dinner organizations.	It is fair for me to receive the reward for the hard work I have given to my organization.	Strong communication with the managers increases my commitment to the organization.	Social events, seeing, and rewarding my success, being thanked at the end of my work. Constantly thinking out loud and brainstorming with my managers.
Interviewee 5	Everyone eats in the same cafeteria and uses the same service vehicles, regardless of being blue or white collar.	Our managers frequently visit us and chat with us. Seeing that we are valued increases organizational commitment.	The organization's protection of the rights of each individual in the provision and protection of personal rights of the employees, and equal treatment when sharing duties.	Behaviors that make me feel that my work is valuable and being there for me in my joy and in my hard times makes me feel belonging to the organization.	In-house training programs provide increased productivity. Seeing that the levels in the hierarchical structure of the organization are transparent and accessible not only increases the sense of belonging but also increases productivity.

been found in the literature. According to Bakhshi et al. [30], distributive justice was shown to have a favorable relationship with both organizational commitment and job satisfaction. Rahman et al. [64] revealed that both distributive justice and procedural justice have significant and advantageous effects on the employees' organizational commitment, which is a dependent variable. On the other hand, the findings in another study demonstrated that while procedural justice is not significantly associated with work satisfaction, distributive justice is. In addition, it has been discovered that organizational commitment and both distributive justice and procedural justice are highly connected [30]. Based on the work by Thompson and Heron [65], the association between psychological contract violation and knowledge worker commitment was mitigated when employees simultaneously reported high levels of procedural and interactional fairness. Positive opinions of procedural justice also attenuated the connection between commitment and contract breaches. However, regardless of the degree of procedural fairness, low perceived levels of interactional justice in the context of contract fulfillment predicted lower comparative levels of commitment.

We refer to the studies performed in different fields. In a study conducted on 500 employees in 3 different higher education organizations in Pakistan, it was revealed that organizational justice has a positive effect on organizational commitment [64]. From an analysis of a survey study participated by 300 nurses working in a hospital in Korea, organizational justice is observed to have a high effect on organizational commitment [66]. Lau and Moser [67] uncovered that procedural justice has a positive relationship with organizational commitment [68]. In addition, in another study conducted on 418 South Korean police officers, when the effects of organizational justice and organizational commitment are examined, it is seen that organizational justice has a positive impact on organizational commitment [69]. In the literature, there are many similar studies in different sectors. As a result, as seen in preceding studies, organizational justice is generally strongly linked to organizational commitment and positively affects each other [66-70].

Based on the results of the regression analysis in this work, it is observed that the organizational justice scale total scores of the employees have a statistically remarkable impact on the organizational commitment scale total scores. It was shown that there is a positive relationship between the organizational justice perceptions of the shipyard employees and their organizational commitment. Therefore, Hypothesis 1 has been supported. In addition, another finding of the study has justified that organizational justice perceptions of shipyard employees positively affect their perceptions of organizational commitment. That is to say that Hypothesis 2 has been supported. In the interview with the employees of the organization, it was seen that answers were received in support of this study and literature studies. It is important in terms of guiding employers and managers to determine what kind of justice perception their employees have in the preferences and procedures made by the executives within the organization and the related level of commitment. The results of the current study will offer top managers, administrators, and decision-makers a glimpse into the relationship between organizational commitment and perceived organizational justice as well as insight into how to maintain employees using an organizational justice perspective to elicit favorable attitudinal and behavioral responses from employees. This study would give them a better understanding of how to keep valuable personnel, raise workers' commitment to and satisfaction with their work, increase workers' happiness, and enhance workers' productivity.

5. Conclusion

In this study, organizational commitment and justice are empirically analyzed for the first time in the context of a shipbuilding organization in Türkiye. The study reveals that the existence of organizational justice perceptions of the employees affects employee commitment, as well a positive relationship. The study revealed that the highest correlation between variables is interactional justice, procedural justice, distributive justice, and organizational justice: normative, continuance, and affective commitment with organizational commitment. Low and moderate relations have been observed between organizational justice and commitment. The importance of the employees is emerging not only in the maritime industry but also in others. Finding goods that benefit both the employer and the employee is becoming more and more important. Employee loyalty to their employers has been connected to various organizational outcomes such as turnover, commitment, productivity, dedication, engagement, and organizational performance. Employees that are loyal to their employers are more invested in their businesses, more productive, and less absent. Expanding the research and applying it to shipyard workers in different Turkish provinces or around the world will enable businesses to update themselves in terms of management and to go to managerial reforms. At the same time, it will be determined how much employee perceptions of justice exist in the face of decisions and practices taken by the managers in the organization. It is thought that determining the level of commitment of the employees is important in terms of guiding employers and managers. Moreover, it is considered that it would be beneficial to make subsequent comparative studies on a

sectoral or regional basis. In the future, the application of this study not only to the shipyard workers but also to the Turkish seafarers and maritime workers, which has gained importance in recent years, will also contribute to Türkiye's maritime sector. It is thought that this study would fill the gap in the literature by addressing the commitment of employees to fair practices in maritime organizations and would contribute to organizations in the maritime sector.

6. Recommendations

- There must be fair treatment between all departments.
- It is recommended to follow the policies that keep the employees in the organization, such as increasing premium wages, providing promotion opportunities, and providing social opportunities.
- Employees are encouraged to take responsibility.
- In the face of the individual's dedication to the organization, certain rewards and outputs (such as education, bonus, family support, and social support) should be given by organizations.
- Thus, individuals with organizational commitment become more harmonious, more satisfied, more productive, and work with a higher sense of loyalty and responsibility.
- It is recommended that organizational managers retain their highly qualified employees by applying fair policies.

Ethics

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Advancing Computational Hydroacoustics for Marine Propellers: Investigating the Limits of Incompressible Solvers in Far-Field Noise Prediction

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Abstract

As sound is a propagating pressure wave, it is important to obtain the hydrodynamic pressure oscillations in the fluid to calculate propeller noise. Numerical hydroacoustic simulations generally assume incompressible flow. Time delays in sound propagation are neglected due to the incompressibility assumption, leading to physically infeasible results in the far field. However, recent works have shown that incompressible solvers can comfortably be used in the near field. This work focused on the effect of distance on the accuracy of the incompressible solver and investigated the hydrodynamic and hydroacoustic properties of a model-scale Duisburg Test Case (DTC) propeller by the finite volume-based computational method. Open-water experiments on a 1/59.407 model-scale DTC propeller were carried out at the Ata Nutku Ship Model Testing Laboratory in Istanbul Technical University. Open-water numerical simulations were performed to determine the hydrodynamic and hydroacoustic properties of the propeller and validated with the hydrodynamic performance of the open-water propeller. Thrust and torque coefficients and open-water efficiency were compared with experiments. The Ffowcs-Williams and Hawkings equation was coupled with the incompressible solver using impermeable surfaces in hydroacoustic predictions of the hybrid solver. Pressure oscillations in the time domain at 21 receivers were used to calculate the sound pressure levels in the vicinity of the propeller. Results of incompressible and hybrid solvers were compared to determine the reach of incompressible solvers for hydroacoustic predictions. It was revealed that discrepancy starts after a 1.5-2D propeller.

Keywords: Ffowcs-Williams and Hawkings, Underwater acoustics, Propeller noise, Open-water propeller, Numerical hydroacoustics

1. Introduction

Noise emanating from ship propellers can be predicted by computational fluid dynamics approaches. Combined with robust turbulence modeling, finite volume-based methods have started dominating hydroacoustic predictions in the last two decades. A pioneering study in this field [1] implemented the boundary element method to solve for the flow around a marine propeller; however, recent works have used Reynolds-averaged Navier-Stokes equations (RANSEs). Resolving pressures in the flow field are mandatory to compute sound pressure levels; the RANSE is very effective in resolving the pressure field in the vicinity of propellers, but moving away from the cylinder loses its effectiveness. To solve this, the RANSE is combined with the Ffowcs-Williams and Hawkings (FWH) equation to calculate the pressure in the far field. Then, a substantial question can be raised: How far can we go from a noise source using incompressible solvers?

Sound travels through water due to the alternate compression and decompression of water molecules. Compressible flow can be solved by finite volume-based computational tools, which are very costly. When implementing incompressible solvers for noise calculation, time delays are ignored due to the travel of sound. The FWH equation emerges just at this point: it adds compressibility effects to incompressible solvers to account for time shifts. Incompressible solvers

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are sufficient for near-field noise calculation, but for far-field noise calculation, they must be coupled with the FWH equation.

Transmission losses in underwater acoustic recordings are calculated for the correct noise estimation. Measurements and calculations are generally performed for receivers in the near field, and the general practice is to adopt the ITTC distance normalization equation [2] to exclude the effect of distance. This approach may provide a general idea about noise, however; it cannot be rated as entirely correct. The ITTC distance normalization equation is based on the inverse-square law method and is valid for point noise sources in stationary flow, while a ship propeller is a moving body consisting of many surfaces [3]. Thus, the sole implementation of incompressible solvers (with the inverse-square law method to carry results to the far field) will lead to crippled results after a certain distance.

In this work, the range of applicabilities of incompressible solvers for hydroacoustic predictions of marine propellers were studied. Comparison of computational results with the hybrid solver was made, in which the FWH-RANSE equation includes the time delay effect. The hull greatly contributes to the hydrodynamic performances of propellers [4], but hydroacoustic properties are not [5]. The scattering effect due to the hull is negligible in propeller near-field sound properties [6]; hence, only open-water propellers were involved. Numerical results were first validated by the hydrodynamic performance of the propeller in open water using experiments from two different laboratories. Cavitation was not included. The advance coefficient of the propeller in numerical simulations is rather high $J = 0.8$, at which higher noise levels are expected at the propeller disk [7].

2. Open-Water Experiments on the Propeller

Open-water experiments were performed for a 1/59.407 model-scale DTC propeller with fixed-pitch five blade, a geometry very close to the Wageningen Propeller B-Series, a propeller geometry very similar to that of the KCS propeller [8]. The propeller has open-water test results at this model scale, as shown in previous work [9]. Comparisons have also been done with the KCS propeller [10]. Table 1 lists the geometric properties of the propeller.

The propeller was manufactured with a high-precision three-dimensional printer that could use PLA, ABS, and TPU filaments and has a printing volume of 200 mm × 200 mm × 200 mm. To obtain high surface sensitivity, a thin layer of paste and sanding were applied first on the propeller surface followed by painting (Figure 1) before readying for the experiments.

Table 1. *Geometric properties of the DTC propeller*

Type	Fixed-pitch
No. of blades	5
P/D $(0.7R)$	0.959
A_E/A_0	0.8
Direction of rotation	Right-handed
Hub ratio	0.176
Diameter	0.15 m

Figure 1. *DTC propeller geometry*

DTC: Duisburg Test Case

The experiments were conducted at the Ata Nutku Ship Model Testing Laboratory in İstanbul Technical University. Recommendations and procedures of the ITTC [11] on conducting open-water experiments were followed during the tests. A ship model was used to determine the open-water performance of the model propeller. The electric motor, dynamometer, shaft, and propeller, which are the experimental setup, were placed in the model. The model propeller was extended with the help of a shaft to a distance that will not be affected by the hull. The propeller was placed in front of the model so that the model velocity is equal to the flow velocity on the propeller. In this way, the inflow to the propeller is uniform and homogeneous. The propeller center was submerged to at least $1.5D$ under the free surface that it is not affected by the free water surface. The propeller's flow rate, propeller revolution rate (n), thrust (T), and torque (Q) were simultaneously stored. Open-water experiments were performed in a wide J range corresponding to constant velocity and variable revolution rate. The experiments were then repeated for the same case without the propeller, and necessary corrections were made on the raw results. The propeller was connected to

an electric motor via a shaft and submerged to at least $1.5D$ under the water. The experiments were then repeated for the same case without the propeller, and necessary corrections were made on the raw results.

The force and moment generated by the propeller were measured using a multicomponent sensor. Thrust T and torque Q read from the sensor were nondimensionalized by the following equations:

$$K_T = \frac{T}{\rho n^2 D^4} \quad (1)$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \quad (2)$$

where n, ρ, and D refer to the propeller rotation rate, fluid density, and propeller diameter to obtain the thrust and torque coefficients denoted by K_T and K_Q, respectively. The open-water propeller efficiency was calculated using

$$\eta_0 = \frac{J}{2\pi}\frac{K_T}{K_Q} \quad (3)$$

3. Details of the Numerical Simulations

Numerical simulations of the open-water propeller were conducted using a fluid domain consisting of two interbedded cylinders. The outer cylinder covers the whole fluid domain, and the inner cylinder covers the rotating domain. The whole fluid domain has a diameter of $10D/3$ and a length of $100D/3$. The propeller is surrounded by the inner cylinder that has a diameter of $4D/3$ and a length of $10D/3$. This rotating domain is given a rotation rate to represent the propeller rotation. Hydroacoustic analysis is more dependent on grid resolution than hydrodynamic analysis [12]; therefore, more elements than conventional open-water performance tests were used. There are 3.82M elements in the whole domain, including the 2.4M in the rotating domain. The boundary layer close to the propeller was discretized by 6 prism layers to introduce viscous effects. Grid refinements were applied to the hydrophone locations to obtain a better pressure field using the incompressible solver. A plane section of the grid structure at $y = 0$ is given in Figure 2. Locations of the 21 hydrophones in the domain are shown by red dots in this figure above the propeller.

Numerical hydroacoustic simulations are conducted for the $1/59.407$ model-scale propeller in open water. This model scale corresponds to a propeller diameter of $D = 15$ cm. The surfaces of the inner circle surrounding the propeller are defined as the interface between the dynamic (rotating) and static (no rotation) domains. The outer cylindrical domain has two different boundary conditions. The inlet and the side wall are defined as "velocity inlet," while the outlet is defined as "pressure outlet." The fluid is flowing in the $-x$ direction. The rotation rate applied on the inner circle (rotating domain) and the velocity defined for the velocity inlet boundary condition are given in Table 2.

The turbulent flow around the propeller is simulated using the $k-\varepsilon$ turbulence model [13]. The simulation is set to be transient to obtain the fluctuations in hydrodynamic

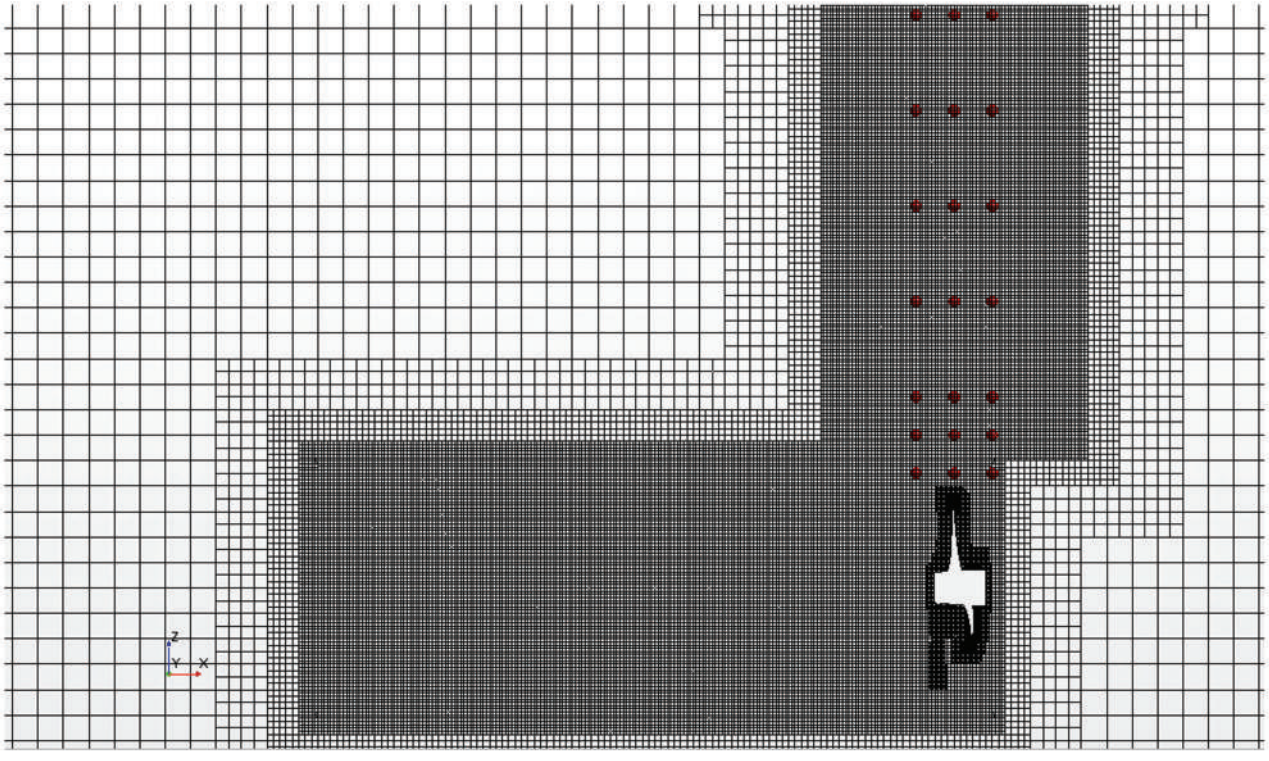

Figure 2. *View of the part of the grid structure implemented in the fluid domain. The grid was refined in hydrophone positions (red dots) to obtain sensitive pressure results with the incompressible solver*

Table 2. *Simulation parameters for the open-water propeller test*

Propeller diameter, D (m)	Propeller rotation rate, n (rps)	Flow velocity, V (m/s)	Propeller advance ratio, J (-)
0.15	13.9	1.668	0.8

pressure in the time domain. The time step size is selected using the formulation given elsewhere [3]:

$$\Delta t \leq {}_{k \cdot BPF}^{1} \quad (4)$$

The blade passage frequency of the simulation in this study is $BPF = n \cdot Z = 13.9 \cdot 5 = 69.5Hz$. The constant in the time step size formulation is taken as $k = 9$ in the reference study. In this case, the time step size should be $\Delta t \leq 0.0016s$. To obtain smooth pressure curves, the time step size was selected to be $\Delta t = 7.5 \cdot 10^{-4} s$.

In the simulations, the flow is assumed to be incompressible. Throughout the paper, "FWH" means that the FWH equation is coupled with the incompressible solver. This hybrid method uses the inner surface surrounding the propeller as an "impermeable" surface and solves the equation:

$$\bar{\mathbb{D}}^2 p' = \frac{\partial}{\partial t}[\rho_0 \vec{v}\, \delta(f)\, \Delta f] - \nabla \cdot [P\, \delta(f)\, \Delta f] + \nabla \cdot \nabla \cdot [T\, H(f)] \quad (5)$$

This equation was first put forward by previous work [14] and later solved by another study [15] without considering the quadrupole terms. Mathematically, the monopole and dipole sources are defined using the Green function:

$$4\pi p'_T(x,t) = \int_{f=0} \left[\frac{\rho_0\, v_n}{r(1-M_r)^2} + \frac{\rho_0\, v_n \dot{r_i} \dot{M_i}}{r(1-M_r)^3}\right]_{ret} dS + \int_{f=0} \left[\frac{\rho_0 c\, v_n (M_r - M^2)}{r^2(1-M_r)^3}\right]_{ret} dS \quad (6)$$

$$4\pi p'_L(x,t) = \int_{f=0} \left[\frac{\dot{P}\cos\theta}{cr(1-M_r)^2} + \frac{\dot{r_i} \dot{M_i} P \cos\theta}{cr(1-M_r)^3}\right]_{ret} dS + \int_{f=0} \left[\frac{P(\cos\theta - M_i n_i)}{r^2(1-M_r)^2} + \frac{(M_r - M^2) P \cos\theta}{r^2(1-M_r)^3}\right]_{ret} dS \quad (7)$$

For the definition of the relevant parameters in these two equations and their derivations, readers are referred to the reference report [15]. Locations of the hydrophones are generally selected on (or close to) the propeller disk for hydroacoustic calculations. This is due to the incapability of RANSE in resolving the chaotic flow in the wake of the propeller [16]. The flow was sent to the propeller rotating at a constant rate in the $-x$ direction, and pressure fluctuations were calculated at 21 points in the vicinity of the propeller disk. Figure 3 shows the locations of the hydrophones (the figure is rotated to save space).

4. Results

Numerical simulation results validated with open-water propeller experiments conducted in two different laboratories are presented followed by, after observing a good match, predictions of propeller noise at different locations in the flow.

4.1. Hydrodynamic Validation with Experiments

Despite recent efforts to improve the hydroacoustic testing capabilities of towing tanks [17], it is still not convenient to measure noise in long but narrow tanks due to possible reverberation effects from side walls [15]. Thus, in this work, the numerical approach was only validated with the hydrodynamic aspects of flow, which only considers the thrust and torque generated by the propeller. The open-water propeller tests in previous work [9] were conducted at the Ata Nutku Ship Model Testing Laboratory in İstanbul Technical University. Figure 4 illustrates the results.

This is an indirect way of validating computational hydroacoustic results, but it is indeed one of the best methods for the assessment of numerical simulations. Finite volume-based methods use the Navier-Stokes equations to solve for the pressure applied on the body to calculate the forces and moments acting on it. If the pressure on the body is accurate, then inherently forces and moments acting on the body will also be accurate. Considering that sound is a form of pressure wave and that the implemented finite volume-based method is good enough to solve for the pressure in the fluid domain, we can make an assessment that once the hydrodynamic aspects of a propeller are solved correctly, then hydroacoustic predictions are also valid. All results are in accordance with each other in Figure 4, and therefore, it is considered that the numerical simulation at $J = 0.8$ has enough accuracy to predict the noise levels of the propeller.

4.2. Hydroacoustic Predictions

Investigation of the pressure oscillations in the time domain for 21 hydrophones will reveal the effects of the incompressibility assumption in the flow, the effect of the axial distance to the noise source, and the effect of the radial distance to the noise source.

To understand the effect of the axial distance, hydrodynamic pressures in the time domain for the closest hydrophones were investigated. Figure 5 gives the pressure oscillations in the time domain and sound pressure levels in the frequency domain for HP1, HP2, and HP3.

As noted in previous sections, numerical simulations were conducted at $n = 13.9$ rps. Considering the five blades $Z = 5$ of the DTC propeller used here, the blade passage frequency becomes $BPF = n \cdot Z = 69.5$ Hz. Thus, we expect the subharmonic to be at the propeller rotation rate n, which is 13 Hz, the first harmonic to be at BPF, which is 69.5 Hz, and the second harmonic to be double the BPF, which makes 139 Hz.

The subharmonic, the first harmonic, and the second harmonic are all visible for all the hydrophones given in Figure 5. Due to being located at the propeller disk, HP2 has

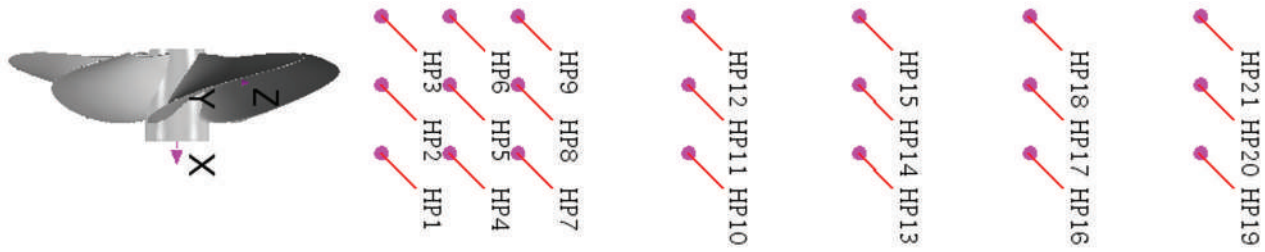

Figure 3. *Locations of the hydrophones in the fluid domain*

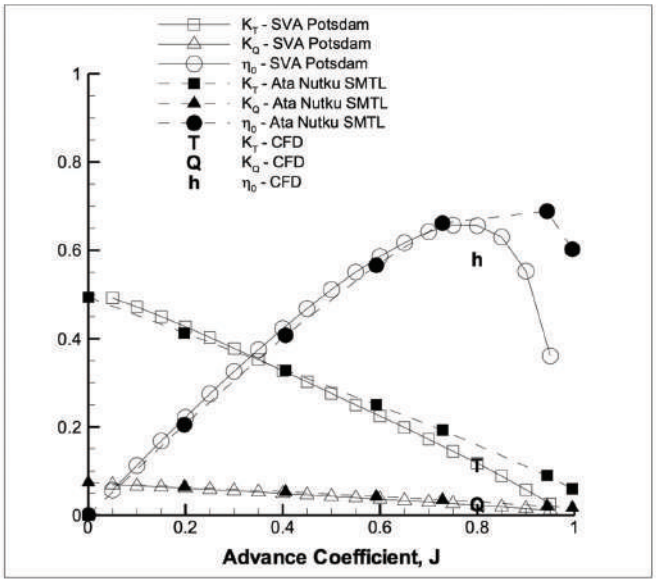

Figure 4. *Open-water experiments at two different towing tanks in comparison with the numerical simulation at J = 0.8*

the largest oscillations in pressure, leading, as a return, to higher sound pressure levels. HP1 and HP3 are equidistant to the propeller disk. As observed from the graphs, pressure oscillations (and inherently sound pressure levels) are similar for these two hydrophones. Thus, if the axial distances are similar, sound pressure levels are also similar regardless of the receiver being located upstream or downstream. These three hydrophones are located closest to the propeller, considered to be in the near field. Results obtained by the hybrid solver (FWH) are in line with the results of the incompressible solver (RANSE), which is expected. The first harmonic is dominant in the sound pressure levels, which corresponds to the blade passage frequency of the propeller. The effect of radial distance from the noise source is investigated in Figure 6 using the pressure oscillations obtained from HP5, HP11, and HP20.

All hydrophones given in Figure 6 lie on the propeller disk. We start to see deviations between the incompressible solver (RANSE) and the hybrid solver (FWH) as we move away from the propeller tip. Results are compatible in HP5 but quite different in HP2, which leads us to the conclusion that time shifts start playing a significant role in sound transmission. Pressure oscillations tend to get smaller as the distance increased from the propeller. This is also observable from the sound pressure levels in the frequency domain: noise levels are distinguishably lower. Another thing to note from this figure is that the first harmonic is dominant in the near-field, while it is subharmonic in the far-field. The effects of the first and the second harmonics nearly vanish in HP20 in FWH-based results. On the contrary, the incompressible solver (RANSE) still shows a significant level of the first harmonic in the frequency domain, but this is considered to be due to turbulence dissipation [18]. Table 3 lists the dominant frequencies and sound pressure levels obtained using FWH.

To make a better assessment of the differences in the incompressible solver (RANSE) with the hybrid solver (FWH), sound pressure levels at the subharmonic, the first harmonic, and the second harmonic are extracted from the frequency domain and graphed with respect to the distance from the propeller, as shown in Figure 7. Although the subharmonic results are in good accordance regardless of the distance to the propeller (covered in this study), incompressible solver (RANSE) results are draw apart from the hybrid solver (FWH) for the first and second harmonics after $1.5–2D$ from the propeller. It should be kept in mind that cavitation does not exist in our case. In the presence of serious cavitation, the deviation could even start from the very near field [3].

The findings in this work indicate the necessity of adding compressibility effects in the far field. FWH is a supporting equation to add this particular effect on the incompressible solver. The incompressible solver is capable of generating accurate results in the immediate vicinity but becomes inadequate as the distance over which sound travels increases. RANSE, by itself, cannot handle the first and second harmonics of the sound pressure as the results start deviating after a certain distance. The accordance of subharmonic results is considered to be within an acceptable range, but the differences in the other harmonics lead to erroneous calculations of the overall sound pressure levels generated within the fluid.

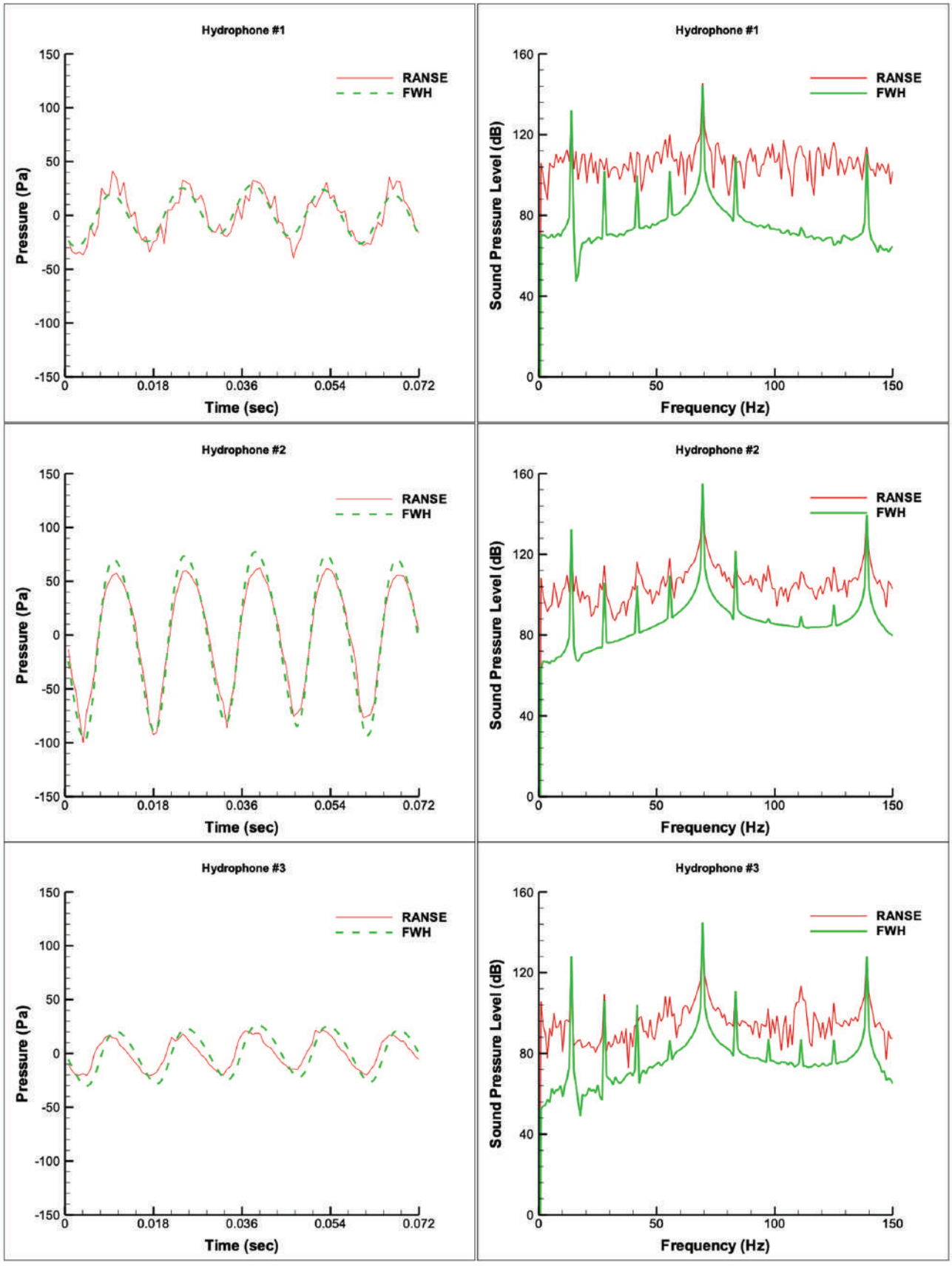

Figure 5. *Pressure oscillations in time domain for HP1, HP2 and HP3 (left). Sound pressure levels in frequency domain for the same hydrophones (right)*

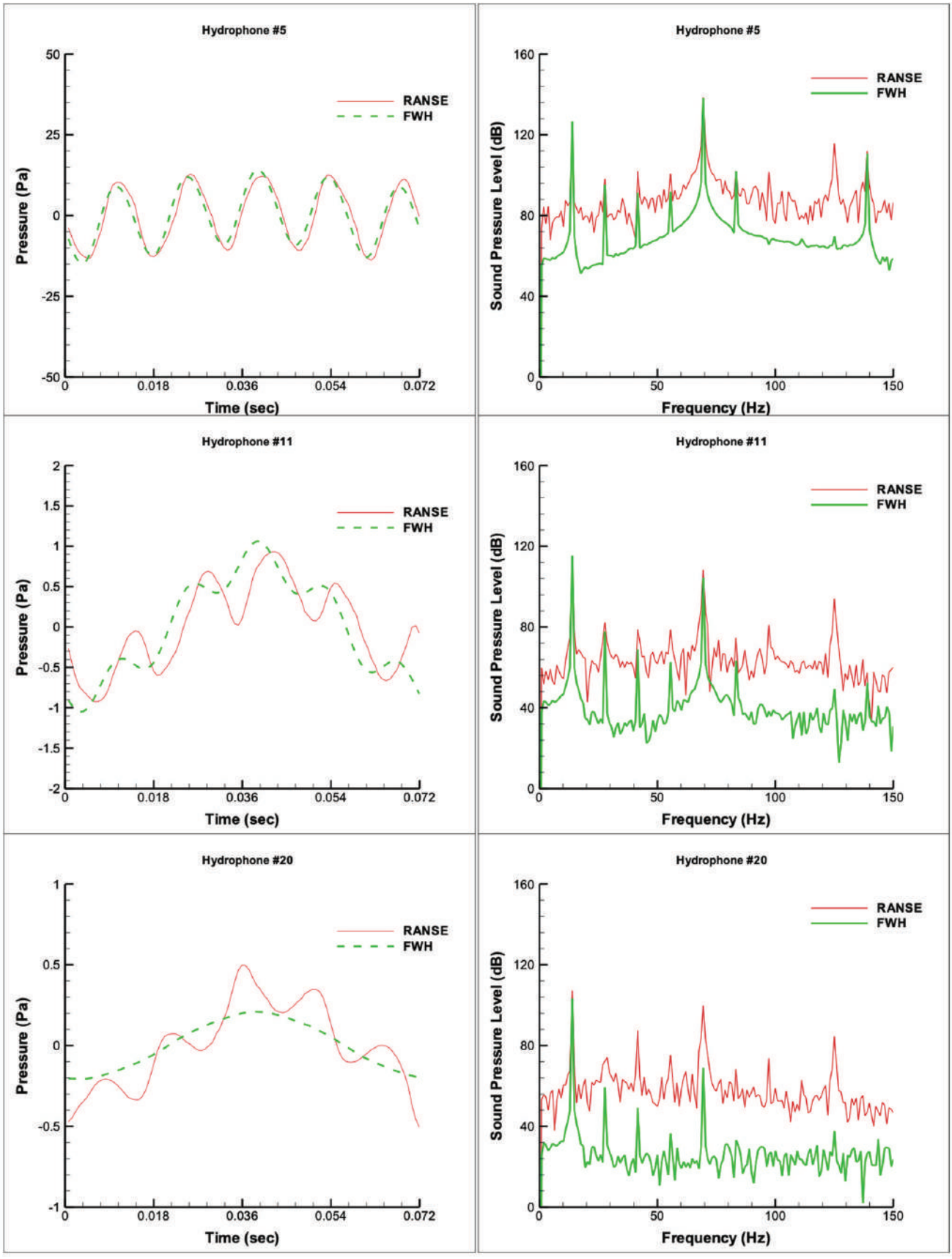

Figure 6. *Pressure oscillations in time domain for HP5, HP11 and HP20 (left). Sound pressure levels in frequency domain for the same hydrophones (right)*

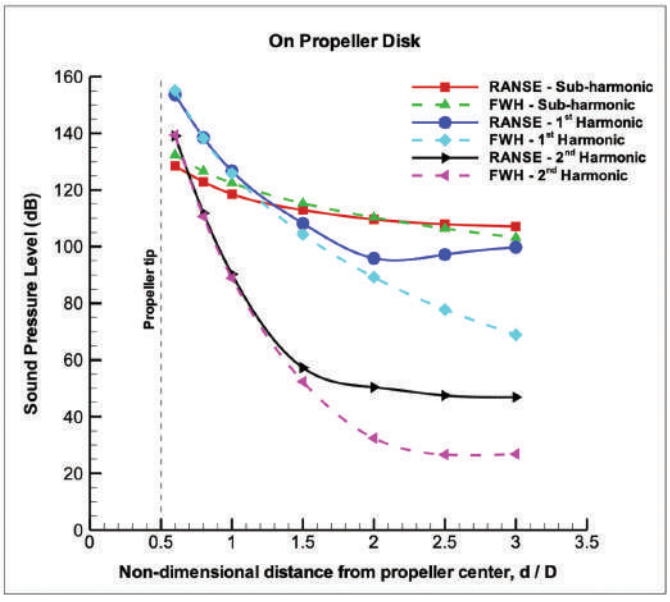

Figure 7. *Subharmonic, first harmonic, and second harmonic results obtained by RANSE and FWH with respect to the distance from the noise*

RANSE: Reynolds-averaged Navier-Stokes equations, FWH: Ffowcs-Williams and Hawkings

Table 3. *Dominant frequencies and sound pressure levels at the receivers*

Hydrophones	Dominant frequency	SPL (approximately)
HP1-HP9	First harmonic	135-150dB
HP10-HP21	Subharmonic	105-115dB

5. Conclusion

In this work, two different hydroacoustic models were tested on a model-scale DTC propeller with a finite volume-based computational method. The numerical approach was first validated by open-water experiments conducted at the Ata Nutku Ship Model Testing Laboratory and compared with the literature results. The hydrodynamic results of the open-water propeller were found to be compatible. After method validation, hydroacoustic results from the incompressible solver (RANSE) were compared with the hybrid solver (FWH). Assessments were made using pressure data from 21 hydrophones in the fluid domain.

The differences in results from the incompressible and hybrid solvers were investigated in the axial and radial directions. Both solvers generated similar results for receivers having equal axial distance to the noise source, regardless its location upstream or downstream. For hydrophones located in the propeller near-field, the incompressible and hybrid solvers are in good accordance. Numerical hydroacoustic simulations revealed that the first harmonic is dominant in sound pressure levels corresponding to the propeller's blade passage frequency but increasing radial distance from the source starts to show discrepancies.

Time delays due to compressibility start becoming a decisive factor in the results for the far field. While the incompressible and hybrid solvers generate similar results in the near field, deviations arise in the far field. Although the decrease in noise levels with increasing velocity is observable from both solvers, the incompressible solver starts generating unconceivable results in the far field. The first harmonic is dominant in the near field, which is clear in both solvers; however, the incompressible solver fails to capture the amplitudes of subharmonic frequencies after 1.5-2D from the propeller.

Future work is being done for conducting research on sound directivity (which is partially covered in this study). Moreover, sound pressure levels in the wake region of the propeller remain a concern using both solvers: more hydroacoustic simulations using advanced turbulence models such as LES, DES, or SAS are required to resolve the noise characteristics in this chaotic flow regime.

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Experimental Study of the Heave and Pitch Motions of an Inverted Bow Hull

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Abstract

In this study, the experimental heave and pitch motion responses of inverted bow hulls in regular head waves were investigated. Comparison of the pitch and heave motion responses of two modified versions of an NA8-14 British Ship Research Association reference fishing vessel with 45 and 60 degrees inverted bows was performed. The findings showed that decreasing the inversion angle of the bow to 45 degrees improves the dynamic performance of the model. Moreover, the interactions between the heave and pitch motions led to the frequent appearance of "kinks" in coupled form in response to the heave and pitch motions.

Keywords: Inverted bow hull, Towing tank, Model test, Heave and pitch RAO, Seakeeping

1. Introduction

The lower amplitude of heave and pitch motions is favorable for the crews and passengers of ships. Also, the less displacement of ship cargo is another good result of calm and proper ship motion. In the past years, three different traditional ship bow forms, namely, vertical (e.g., Titanic ship bow form), Maier, and conventional, as well as unconventional bow forms such as axe bow, plump bow and inverted bow, have been used in ship design. The inverted or reversed bow design is of keen interest when designing ships [1-3]. It is a type of bow form that is used where reforming the hull to the back instead of ahead in the forepeak part of the ship (Figure 1) and is often accompanied by a negative tumblehome or flare over the ship hull length, for example, the US Navy destroyer Zumwalt 1000. However, the destroyer's seakeeping and dynamic performances are less known.

Gelling [4] studied the seakeeping performance of some realistic hull forms and revealed that the reverse bow increases the amplitude of pitch and heave motions but reduces vertical acceleration. An optimization procedure using different software tools has been developed by Boulougouris and Papanikolaou [5] and applied to investigate possible improvements of the hydrodynamic performance of the initial RO-PAX 2000 hull form with respect to total resistance and seakeeping. They revealed that application of an optimization procedure by genetic algorithms is very encouraging for the performances of very different bulbous bow shapes.

Akbari et al. [6] described the results of several seakeeping tests on a wave-piercing trimaran. They measured the heave and pitch motions at Froude numbers of 0.2, 0.37, and 0.51 and demonstrated that for lower Froude numbers, the interval between variations in the magnitudes of the RAOs of heave or pitch motions due to the change in the wavelength, wave frequency, and wave amplitude were not so wide. It has been revealed that regarding vertical motions and accelerations, ship resistance, water spray (deck wetness), slamming criteria, and signing, by using inverted bow form, many changes in ship responses can be expected. White et al. [7] investigated the resistance and seakeeping performance of the inverted bow form by a model test in a towing tank by constructing two models of the frigate FFG-7 using two 1:80 scale models in traditional form and another inverted bow form, revealing that the inverted bow reduces the resistance of the model and improves the seakeeping performance of the ships. Shahraki et al. [8] evaluated the effect of different

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bow forms on the motions of a segmented model, equipped with two 6 degrees of freedom force/torque sensors to measure dynamic loads. The results showed a significant variation in slam loads when comparing the three center bow lengths.

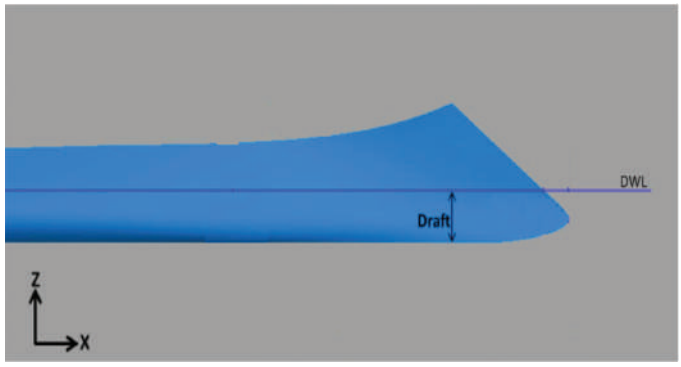

Figure 1. *Schema of ship with inverted bow shape*

Seo et al. [9] conducted model tests of a wave-piercing high-speed ship to examine the seakeeping performance at the towing tank. Their results demonstrated that vertical acceleration in the fore perpendicular region decreased by 11.3%. Mallat et al. [10] described the bubble sweep-down phenomenon on three bow designs by an experimental method and provided the performance of each bow geometry and the effect of bow shape changes in the face ON bubble sweep-down. Kim et al. [11] conducted model tests of a high-speed vessel with a modified inverted bow and showed an improved wave pattern by shifting the generation place of the forwarding divergent wave. Yuntao et al. [12] developed a multiobjective strategy to identify the parameters of pitch and heave coupled motions in ships to analyze the mathematical models for heave and pitch coupled and unknown parameters in dynamic equations.

Askarian Khoob et al. [13] conducted a series of model experiments using the National Iranian Marine Laboratory wave-piercing bow trimaran to determine the influence of outrigger symmetry on the heave and pitch motion responses. Nicolás et al. [14] selected the GNU SALOME platform as the working environment and developed a Python code to automate the shape construction of an inverted bow hull family from a series of input parameters. Shuling et al. [15] conducted a numerical comparative study using computational fluid dynamics on the seakeeping and added resistance of model ships with wave-piercing and "X-bow" monohulls in regular head waves.

In the literature, there are few technical data on the hydrodynamic performance of an inverted bow hull. Thus, this study investigates the effect of the inverted bow configuration on the dynamic performance of a reversed bow hull in regular head seas.

2. The Design of Two Experimental Models

The NA8-14 trawler of the British Ship Research Association was selected and scanned by a 3D scanner. The scanner output was imported into Rhino and SolidWorks to change it to an inverted bow with two different angles, namely, 45 and 60 degrees.

Figure 2 shows a plot of the 60 degree inverted bow form after changes in the software environment. Table 1 lists the main particulars of the prototype and its scaled models. Both models are 1/58th scale and do not have appendages. The vessel model was built with polylactic acid that has the capability of proper machining, superior resistance to water absorption, excellent impact-resistant performance, and smoothness surfaces for model construction. The midship and stern parts of the main hull were built without changes, but the forepart was changed to an inverted shape (Figure 2).

3. Experimental Testing Conditions

The objective was to assess the heave and pitch motion responses of the reverse bow design. Tests were performed at the towing tank of Nowshahr Maritime Academy, Iran. The test conditions and towing tank specifications are described. The load cell H3-C3-B3-D55 was procured from Zemek Company and can be carried up to 25 kg, and measure heave, pitch, yaw, roll, sway, and resistance data. The most important input for the test system is the speed of the model, which changes according to the type of test. The towing tank has a wavemaker maximum wavelength set at 4.85 m and towing carriage at 6 m/s maximum speed with dimensions 37 m × 3 m × 0.8 m. The model heave motion was measured using a potentiometer separately. Figure 3 shows the inverted bow model and towing tank load cell. The towing tank was outfitted with a flap and an electromechanical wavemaker with a frequency domain of 0.2 to 1.8 Hz. The water density was 1002 kg/m^3, and the temperature of the water was recorded at approximately 23 °C. With the connection of the arm to the model, at first,

Table 1. *Main particulars of the prototype and its scaled models*

Property	Ship	Model with 45° inverted bow	Model with 60° inverted bow
L_{pp}(m)	45.7	0.784 0.79	
T(m)	4.06	0.055-0.065	0.055-0.065
B(m)	8.03	0.138	0.138
$\nabla(m)^3$	839.5	0.004533	0.004538
C_w	0.775(-)		
C_b	0.564(-)		
C_p	0.627(-)		

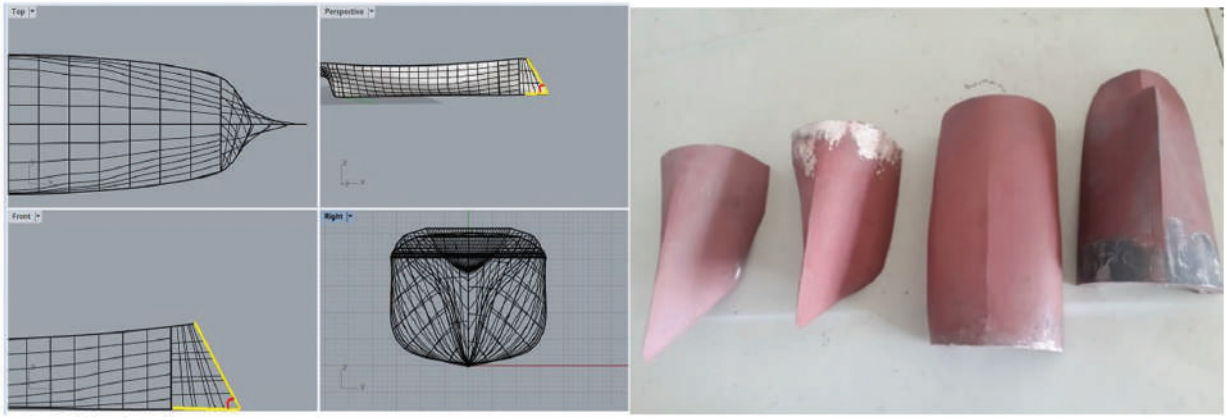

Figure 2. *Bow design and construction*

the center of gravity must be determined. Afterward, by placing the model in the towing tank, the amount of draft was checked so that it was consistent with the designed draft; then, the initial calibration was performed with great accuracy. With the wavemaker generating the proper wave, the model moves at a certain speed, and the load cell wirelessly sends the results to the computer. In Figure 3, the inverted bow model was configured into four separate parts: the aft and midship parts connected for overall tests were joined by nuts and bolts, but the fore segments in two inverted bow forms, 45 and 60 degrees, for any special test series were fixed.

Wave height H is directly related to the wavemaker stroke. Before testing the model, two parameters, namely, wavemaker stroke and frequency were entered into the wave maker to create regular waves. The calculation model velocity must be calculated according to the scale. Froude similarity can be written as;

$$\lambda = \frac{L_{ship}}{L_{model}} = 45/0.775 = 58 \quad (1)$$

$$(F_n)_{ship} = (F_n)_{model} \quad (2)$$

$$V_s/\sqrt{(L_s g)} = V_m/\sqrt{(L_m g)} \Rightarrow \quad V_s / V_m = \sqrt{(L_s/L_m)} = \sqrt{\lambda} \quad (3)$$

Assuming ship service speed to be 15 knots, the model speed can be expressed as;

$$V_{model} = V_{ship}/\sqrt{\lambda} = 15/\sqrt{58} = 1.976 \text{ knots} \quad (4)$$

$$V_{model} = (1.9760) \times (0.5144) = 1.013 \text{ m/s} \quad (5)$$

As a result, three speeds, namely, 0.6, 0.9, and 1.2 m/s, were considered for towing tank tests. The waves generated in the towing tank were of regular type, with wavelengths changing from 0.6 to 1.6 L by an increment of 0.2 L.

Two wave heights of 3 and 5 m, equal to the average wave height and the highest effective wave height of the Persian Gulf were considered for model testing. The scale wave height for the towing tank was obtained using Equation (6):

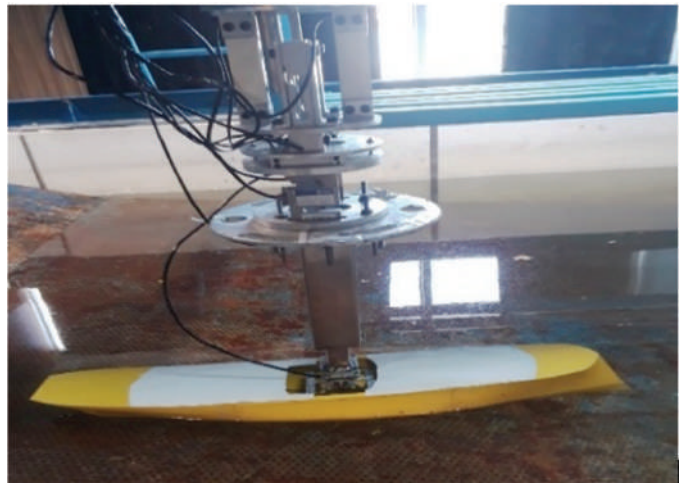

Figure 3. *The model with 60° inverted bow*

$$H_{model} = \frac{H}{\lambda} = \frac{3}{58} = 0.052m \quad (6)$$

$$H_{model} = \frac{H}{\lambda} = \frac{5}{58} = 0.086m \quad (7)$$

Thus, both values of the heave and pitch RAOs can be drawn against the encountering wave frequency (ωe) or the encountering wavelength (λ_w). To analyze the heave motion behavior in the model, a dimensionless property RAO (response amplitude operator) was calculated using

$$RAO_{Heave} = {}^{z_a}/_{\xi_a} \quad (8)$$

where heave z_a is the motion amplitude and ξ_a is the imposed wave amplitude for the model. The experimental model tests were performed at three speeds corresponding to ship speeds from 0.6 to 1.2 m/s at 0.3 increments. To avoid the occurrence and subsequent spurious measurement of results in the presence of any reflected waves and residual decaying, a waiting period between the respective tests of 20-40 min (depending on the wave amplitude and frequency) was allowed. Water surface was also visually controlled.

4. Experimental Testing Conditions

In this study, there were 36 runs of individual tests per model comprising six wave frequencies, two wave heights, and three vessel speeds performed on each of the two models.

4.1. Heave Motion

Figures 4-6 illustrate the comparison of the heave motion responses of the two models, revealing non-linear responses concerning the wave frequencies as well as plots containing the "kink." The "kink" is due to the coupling of the heave and pitch motion responses at their respective frequencies. These changes in vessel speeds affect the peak magnitude response of the models. Some of these kinks are the resonance effects on the model. The responses for the 60 degree inverted bow contain kinks with higher magnitude than those for the 45 degree inverted bow. The comparison of the heave motion responses for the two models shows significantly different trends, but their magnitudes increase with increasing model speed. There is a clear distinction between their magnitudes (Figures 4a and 6b): the 60 degree inverted bow model has higher magnitudes at the same vessel speeds, wave height, and all frequencies than the 45 degree inverted bow model. In Figures 4a and 6b, the 45 degree inverted concept performs better than the 60 degree one in terms of having lower magnitudes of motion responses. In other words, low inversion angles for the bow hull suggest proper seakeeping effects compared with high angles of the inverted bow. In Figure 5b, at a speed test of 0.9 m/s, the heave RAOs for the 60 degree inverted bow model are less at lower frequencies. Figure 6a shows a harmonic behavior of heave RAO for both 45° and 60° inverted bow in various λ_w/L. It is observed that at λ_w/L, 0.9 - 1.3 the 45 degrees inverted concept performs better than the 60 degrees inverted bow in this research.

A comparison of the heave motions concerning the three model speeds for two different wave heights shows that the responses at speed 0.9 m/s correspond to the vessel cruise speeds: the 60 degree inverted bow model has the highest responses at higher non-dimensional wavelengths. At 1.2 λ_w /L, a rise can also be identified for more plots of heave RAO. It is found that the model speed of 1.2 m/s experiences a significant high RAO for the 45 and 60 degree inverted bows. In addition, these curves show a peak region of the heave RAO. These changes may identify the resonance region. Again, in higher λ_w/L heave, RAO experiences a descending characteristic. At 1.2 m/s speed, the model experiences the highest responses at all non-dimensional wavelengths. At 0.052 m wave height, the responses are visibly high compared with the wave height of 0.086 m wave height, which has a lower response.

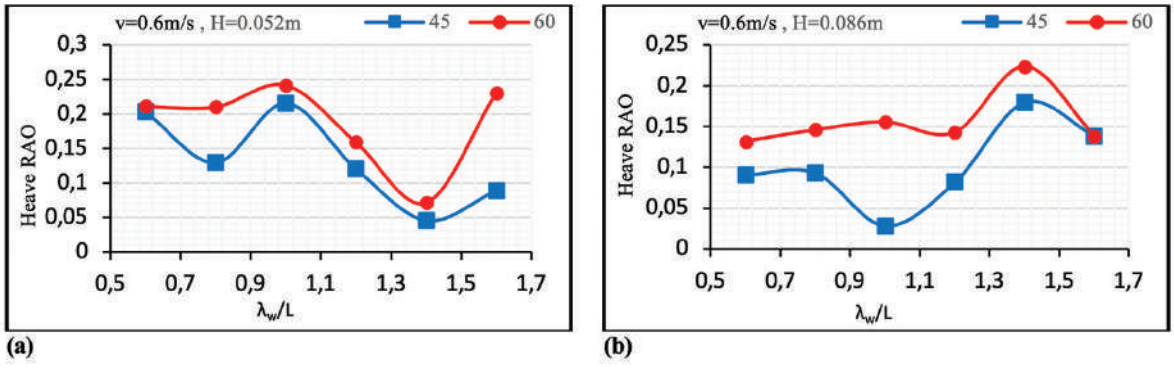

Figure 4. *Comparison of heave RAOs at v=0.6 m/s, (a): H=0.052 m and (b): H=0.086 m*

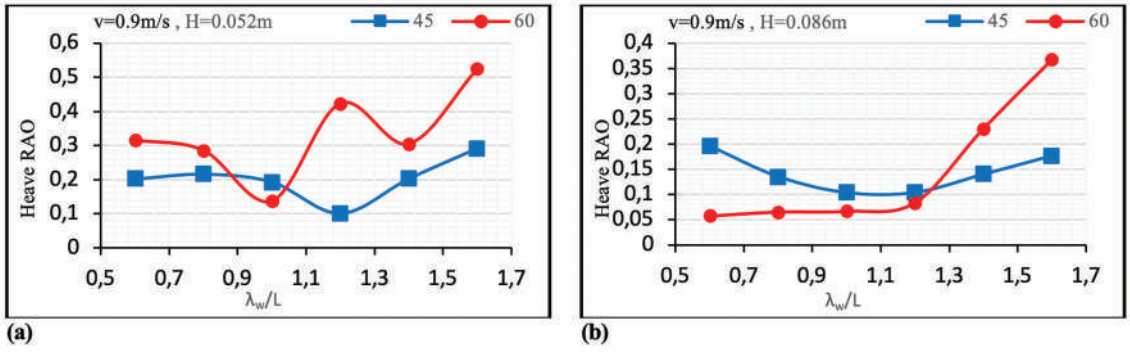

Figure 5. *Comparison of heave RAOs at v=0.9 m/s, (a): H=0.052 m and (b): H=0.086 m*

4.2. Pitch Motion

Figures 7-9 exhibit a comparison of the pitch motion responses of the two models. As observed, the responses contain "kinks" (as described above) that are more visible in the 60 degree inverted bow plots. The responses for the 60 degree inverted bow contain kinks with higher magnitude than those for the 45 degree inverted bow. Comparison of pitch motion responses for the two models shows that their trends are significantly different, but the 60 degree inverted bow model has higher magnitudes at the same vessel speeds, wave height, and most frequencies than the 45 degree inverted bow model. Each graph shows the change in pitch RAOs due to wave and speed changes. Similar to the heave motion in the pitch motion response comparisons, it has been established that the 45 degree inverted configuration performs better than the 60 degree one in terms of having lower magnitudes of pitch motion responses. Figure 8b shows the maximum pitch RAO of the 45 degree inverted bow model at 1.4 λ_w/L. It is observed that loss occurred suddenly. As predicted, Figure 9b demonstrates a larger pitch RAO for the 1.2 m/s speed; as seen in λ_w/L 1.0 to 1.6, there is a high rise of pitch RAO of the 60 degree inverted bow configuration. However, outside this two-pitch region, RAO is nearly identical.

A comparison of the heave motions concerning the model speeds at two different wave heights shows the responses at a speed of 0.9 m/s and a wave height of 0.0522 m (which corresponds to the vessel cruise and top speeds): the 60 degrees inverted bow model has the highest responses at higher non-dimensional wavelengths. The model

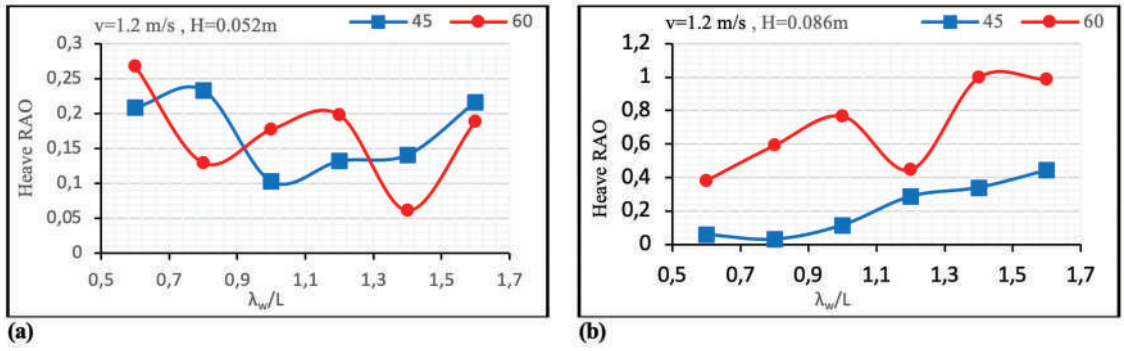

Figure 6. *Comparison of heave RAOs at v=1.2 m/s, (a): H=0.052 m and (b):H=0.086 m*

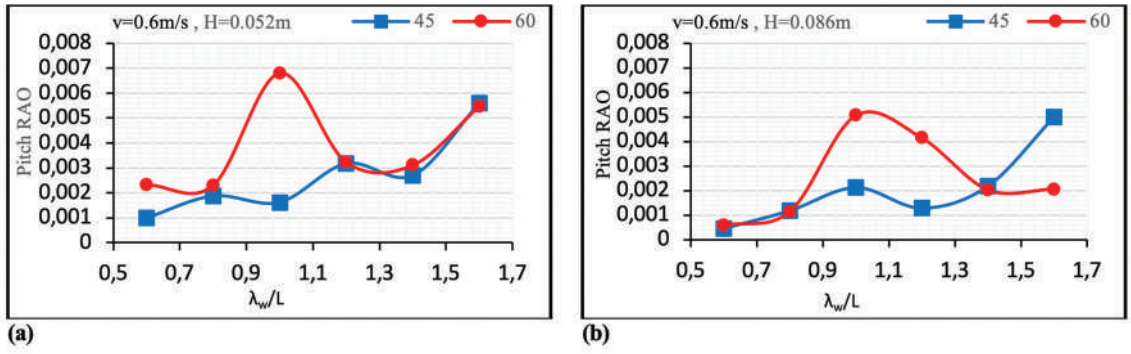

Figure 7. *Comparison of pitch RAOs at v=0.6 m/s, (a): H=0.052 m and (b): H=0.086 m*

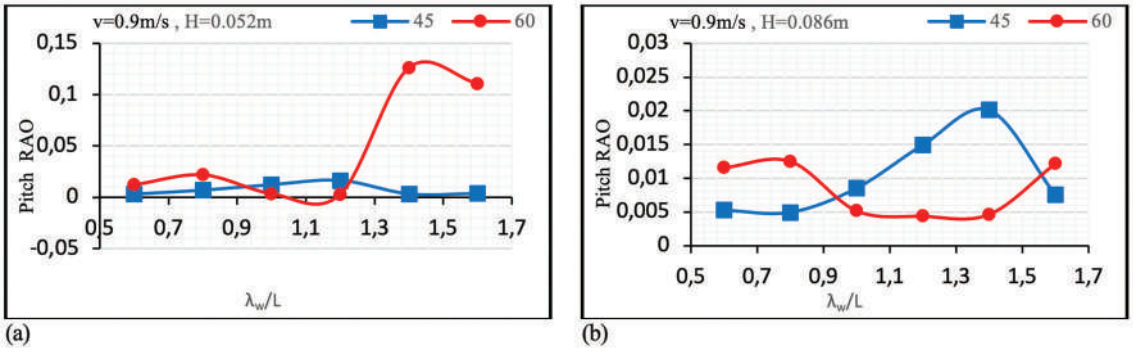

Figure 8. *Comparison of pitch RAOs at v=0.9 m/s, (a): H=0.052 m and (b): H=0.086 m*

experienced the highest magnitudes at a wave height of 0.086 m, and the responses were visibly higher than those at a wave height of 0.052 m, that have a lower response. It should be mentioned that by changing the value of λ_w/L from 0.6 to 1.6, a slight change occurs in the pitch RAO except for the case of model speed 1.2 for the 60 degree inverted bow.

Figure 10 illustrates the design of the conventional bow form in the software to compare with the results of the behavior of the inverted bow form, revealing that the RAO values are different from the conventional ship RAO values,

Figure 11 illustrates the harmonic behavior of heave RAO for the conventional bow form model and 60 degree inverted bow in various λ_w/L (at v=0.6 m/s).

A table of changes (Table 2) was obtained to compare the values of the inverted bow form with the conventional bow form.

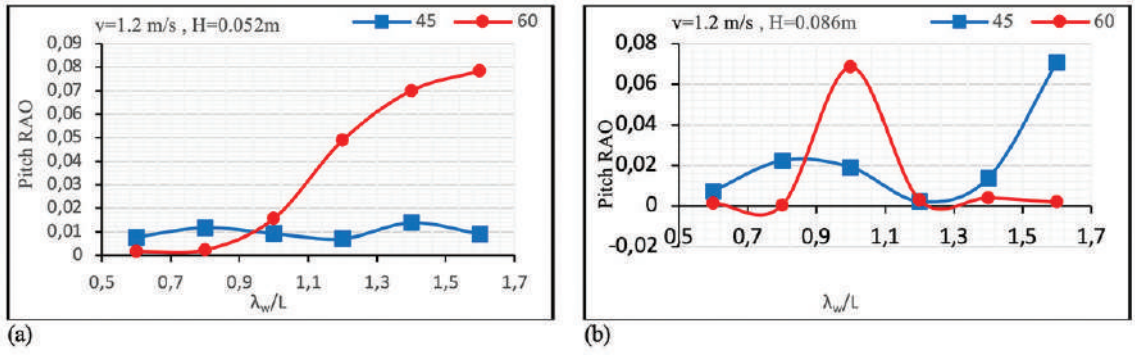

Figure 9. *Comparison of pitch RAOs at v=1.2 m/s, (a): H=0.052m and (b): H=0.086 m*

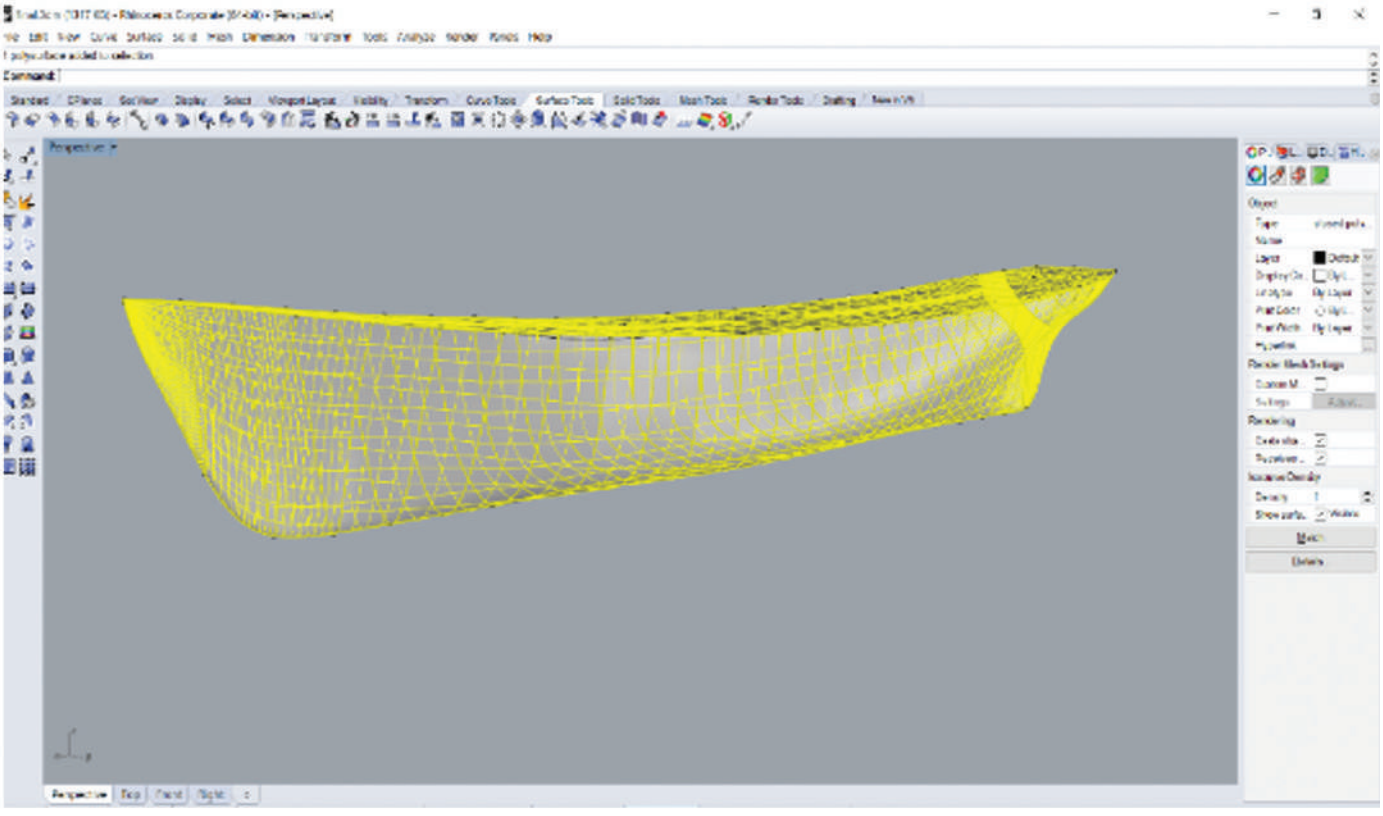

Figure 10. *Designed conventional bow form in the software*

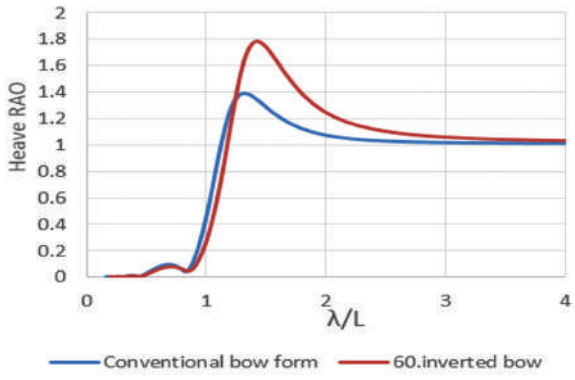

Figure 11. *Heave RAO for conventional bow form model and 60° inverted bow in various λ_w/L (at v=0.6 m/s)*

Table 2. *The average changes in the RAO movement of inverted bow form with conventional bow form*

Test speed	The average change in percentage of heave's movement ratio	
	From the beginning point until the maximum point of Rao heave (for conventional bow form)	From the maximum point of heave Rao for conventional bow until the end of the range
$u_1 = 0/6\frac{m}{s}$	-28.12%	17.7%
$u_2 = 0/9\frac{m}{s}$	-47.1%	21.2%
Overall average percentage change	37.47%	20.2%
The negative percentage of heave RAO, shows smaller amounts for inverted bow shape*		

5. Conclusion

A series of seakeeping tests to measure the heave and pitch motions of an inverted bow hull with two inversion angles, 45 and 60 degrees, were performed at the towing tank of Nowshahr Maritime Academy.

It was found that the 45 degree inverted bow (shorter inverted bow) offered better performance in waves than the 60 degree configuration. The reason for this behavior is more cutting water waves to the sides, which were observed in most experimental tests related to the 45 degree inverted bow model compared with the 60 degree inverted bow model.

The interactions between the heave and pitch motion responses led to the frequent appearance of "kinks" in the coupled form. These couplings were observed mostly at higher frequencies and hurt performance of the vessel. Such "kinks" were also attributed to the effects of vessel speed changes because their magnitudes usually increase when the vessel speed increases.

The responses for the 60 degree inverted bow contained kinks with higher magnitude than those for the 45 degree inverted bow. The comparison of the heave motion response for the two models showed significantly different trends, but their magnitudes increased with increasing model speed.

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Authorship Contributions

Concept design: Data Collection or Processing: Analysis or Interpretation: Literature Review: Writing, Reviewing and Editing: All authors have contributed equally.

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Volatility Transmission Between Container and Dry Bulk Freight Markets During the COVID-19 Pandemic

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Abstract

Shipping is a highly volatile, cyclical, and capital-intensive industry defined by extreme highs and lows. This makes information regarding volatility in this market material and relevant for decisions related to portfolio diversification, forecasting, and hedging in the maritime industry. Understanding how volatility is disseminated across the shipping market can help shipping companies to improve operational efficiency by making them more responsive to market changes. When shipping companies can anticipate market changes, they can swiftly respond and adjust their operations accordingly. In addition, volatility transmission in the shipping industry is crucial for policymakers seeking to improve the economic outlook of individuals and business entities that depend on the shipping industry. By monitoring the flow of volatility between shipping markets, they can promote effective pro-industry economic policies by more accurately estimating the effects of introducing new shocks to one freight market on another one. Therefore, understanding the volatility transmission between the container and dry bulk freight markets could provide an effective risk management mechanism that improves decision- making in shipping. This study analyzes volatility transmission between the container and dry bulk freight markets during the coronavirus disease-2019 pandemic using an asymmetric BEKK-GARCH(1,1) model that can also serve as a weak efficiency test. The results indicate that there was bidirectional volatility transmission between the container and dry bulk freight markets during the pandemic and that transmission from the container to dry bulk freight market was dominant. These findings support the price formation hypothesis of shipping, which states that dry bulk freight rates will follow container freight rates when freight rates exhibit an upward trend. Furthermore, the statistical significance of volatility transmission suggests that container and dry bulk freight rates can be used as a prediction mechanism for each other, serving as a market inefficiency indicator for both freight markets.

Keywords: Volatility transmission, Market efficiency, Freight markets, COVID-19, Lead-lag relationship

1. Introduction

Volatility transmission is defined as the transmission or spread of instability in a market, which is generated by external shocks and innovations, to another market. Transmission occurs when changes in volatility in one market have a lagged impact on changes in volatility in another market, beyond the level of fluctuation that is typical or normal. These types of interactions are especially common in financial markets [1].

When information flows are considered, volatility transmission is expected when markets are interconnected [2]. Given this interconnectedness, volatility transmission becomes material for portfolio diversification, forecasting, hedging, and asset pricing decisions [3].

Reinhart and Rogoff [4] show that during crisis time, volatility strongly increases and is transmitted to other markets. Therefore, we expect that the coronavirus disease-2019 (COVID-19) pandemic caused increased volatility and fueled volatility transmission among various markets. Before we analyze such transmission, we briefly address the nature of volatility.

The mechanisms and structures of financial asset return volatilities have been thoroughly studied since Baillie and Bollerslev [5], and Lin et al. [6] laid the foundation for

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this field of research. They observed that volatilities vary across asset classes, time periods, markets, and regions, and volatility research has been pursued in various areas of finance, such as asset pricing, portfolio structuring, and risk management, over the years.

As the amount of time between financial crises has decreased since the Asian financial crisis of 1997, the question of how those crises affect volatility transmission between markets has become more urgent. Over the last two decades, the globalization of capital markets has increased the degree of inter-dependence across these markets. First, liberalization in capital markets greatly enhanced economic ties among countries and regions through policy coordination. This promoted global economic integration through international trade and foreign direct investment. The emergence of regional trade blocks, monetary unions, and free trade zones has increased cooperation and therefore interdependency among the world's economies [7]. Second, deregulation of capital markets, numerous financial innovations, and advances in information flow and mode of communication have intensified the interdependencies among capital markets across various countries [8]. The growth in international portfolio management (especially by hedge funds), cross-listings of companies on stock exchanges in different countries, and allowing foreign investment in many financial markets have elevated the linkages between national and international financial markets [9]. Given this background information on volatility and volatility transmission concepts, we now explain the objectives of this study.

One of the objectives is to verify results in previous studies regarding the weak form of the efficient market hypothesis (EMH), using an alternative validation tool. Therefore, we briefly review the EMH and its role in freight markets. The EMH focuses on the availability of information. Under the EMH, a market can be considered efficient only if prices fully reflect information that is available to the public [10]. The "weak" form of the theory states that it is impossible to predict prices in a market using historical price information. Thus, if a market displays weak form efficiency, using technical analysis to outperform the market is ineffective. Market efficiency has deep roots in the literature; almost all markets have been analyzed using this concept, and shipping is no exception. A number of studies suggest that various segments of the shipping market are indeed inefficient such as Evans [11], Kavusannos and Alizadeh [12], Hale and Vanags [13], Veenstra [14], Adland and Cullinane [15], and Adland and Strandenes [16]. According to the EMH, this situation suggests that participants in the shipping market can profit from information asymmetries in that market.

This study contributes to the literature by providing insights about how volatility is disseminated in shipping freight markets. This can help shipping companies to improve operational efficiency by making them more aware of the effects of market changes. When a shipping company can accurately anticipate market changes, it can respond swiftly and adjust its operations accordingly. In addition, volatility transmission in the shipping freight markets can help policymakers who seek to improve economic conditions for individuals and organizations that depend on the shipping industry. Keeping the transmission of volatility between these shipping markets in mind can help to promote targeted economic policies more accurately, as they would more accurately estimate the ripple effects of introducing new shocks to a shipping freight market.

This study also differs from previous studies in the literature in two ways. First, current studies attempted to explain the volatility transmission mechanism among freight markets using variance causality and diagonal autoregressive methods (which are discussed in the next section). However, transmission effects mostly reside in off-diagonal matrices. Therefore, this study employs asymmetric full BEKK-GARCH parameterization to capture bivariate volatility transmission effects to the highest extent. Also, because a bivariate BEKK-GARCH model directly specifies the conditional variance-covariance matrix of freight returns, hedge ratios for container and dry bulk freight rates can be generated as a byproduct of our estimation as fresh observations become available [17]. Investors in the maritime industry could benefit from having such a tool at their disposal.

Second, to the author's knowledge, no study examining volatility transmission between freight markets based on financial contagion has focused on the COVID-19 pandemic period. Financial contagion refers to the spread of financial disturbances or shocks from one market or institution to another, leading to a wider systemic crisis. Understanding financial contagion is important as it can have significant adverse effects on the global financial system, economies, businesses, investors, and consumers. Thus, this study examines the systemic effects of the COVID-19 pandemic on container and dry bulk freight markets.

The remainder of this study is organized as follows. In section 2, the shipping volatility literature is discussed and prevailing hypotheses of the lead-lag relationship between container and dry bulk markets are laid out. In section 3, the modeling process and methodology of the study are explained and the data is introduced. The last section discusses the estimation results and offers conclusions.

2. Shipping Volatility

During the last decade, emerging market economies that have experienced substantial growth and increased trade volumes have increased volatility in all subsectors of shipping

freight markets. As emerging economies, most notably China, became heavily involved in global trade in a globalizing world, shipping markets that arose from international trade became one of the first markets to be affected by changes in the global economic climate. The first group of studies on this topic focuses on the dynamics of shipping market volatility. Kavussanos and Visvikis [18] discuss global freight rates and point out that enormous freight volatility and a high risk-high reward structure characterize the shipping market. As a result, high short-run volatility in freight rates has caused frequent bubbles and crashes over the years [15]. As freight revenues comprise the majority of a shipping company's revenues, freight rate volatility is a critical factor affecting maritime business profitability. Thus, during times of turmoil, volatility could threaten business survival.

It is crucial for all stakeholders in the maritime industry to understand the structure and transmission of volatility between shipping markets. Adland and Cullinane [19] point out that short-term variations in freight rates could easily result in bubbles and crashes. It would help shipping carriers and other businesses to better understand the lead–lag interaction between dry bulk transportation and container shipping freight markets, and the volatility transmission between these two markets, for hedging and managing freight rate risks. Kavussanos [20] shows the benefits of Autoregressive Conditional Heteroscedasticity (ARCH) modeling in assessing risks in spot and time charter dry bulk markets, as their variances are not constant over time. Another study examines the structure of secondhand tanker market price volatility using ARCH modeling [21]. Prices for larger tankers, such as Very/Ultra Large Crude Carriers, fluctuate more than prices in smaller market segments. Another pioneering study uses ARCH-type modeling to analyze the volatility properties of the secondhand market for different-sized dry bulk vessels [22] and reveals volatility clustering for all segments and higher volatility for prices of larger ships.

The second group of studies focuses on the drivers of shipping market volatility. Lim et al. [23] analyze the drivers of freight market volatility using several macroeconomic and shipping-related factors known to affect supply and demand for shipping, and examine their impact on the term structure of freight options' implied volatilities. They state that volatility is mainly driven by global economic policy uncertainty, although shipping-specific factors such as fleet size growth, new building orders, and scrapping activity also play a role. Homan [24] examines how the Maritime Transportation Security Act affected the stability of marine firms using a market model. His findings suggest the Act might reduce financial risks these firms face and help maritime businesses to raise financing. Chi and Cheng [25] examine how maritime trade between Australia and some of its most significant trading partners, notably China, is impacted by real income and exchange rate volatility. They conclude that the volatility of exchange rates has a considerable and long-term impact on the volume of maritime exports.

Following these studies of the volatility characteristics of shipping markets, other studies examined interactions across these markets. Studies of the interaction between container and dry bulk markets mainly focused on the lead-lag relationship among them. The three prevailing hypotheses regarding this relationship are as follows.

The Transport of Goods Hypothesis suggests that when the market it trending upward, the container market will follow the dry bulk market. The reasoning behind this hypothesis is that the demand for raw materials will react first in an upward-trending economy, and will indicate changes in demand for finished and semifinished products. In contrast, in a downward trending economy demand for finished and semifinished products will react first, leading to changes in demand for raw materials [26]. The Shipping Contract Hypothesis states that dry bulk contracts are typically short-term by nature. Therefore, dry bulk freight rates are more flexible in adapting to market trends [12]. The price formation hypothesis assumes that the market for dry bulk shipping approaches perfect competition in the absence of large participants that would have enough influence and market share to corner the market by setting the price of a homogeneous product. As the market structure of liner shipping exhibits an oligopolistic structure, it is heavily influenced by large shipping alliances that dominate the market [27] (Table 1).

Table 1. *The Lead-Lag relationships of three hypotheses*

Hypothesis	Downwards Trend	Upwards Trend
Transport of Goods	Container Leads Dry Bulk	Dry Bulk Lead Container
Shipping Contract	Dry Bulk Lead Container	Dry Bulk Lead Container
Price Formation	Dry Bulk Lead Container	Container Leads Dry Bulk
Source: Hsiao et al. [26]		

If we summarize the main characteristics of the maritime industry as capital intensity with a high risk-high reward structure, the volatility of freight rates stands out as one of the most important threats to monitor. Therefore, understanding volatility transmission between the container and dry bulk freight markets could improve risk management and aid the decision-making process in shipping [28].

As Stopford [29] indicates, the dry bulk freight market is considered a primary indicator of international trade

and demand for raw material, whereas price levels in the container freight market directly reflect international trade and demand for semifinished and finished products. Due to the direct link between freight rates and the economy activity, they are considered leading indicators of the global economic climate [30]. Thus, it is evident that freight rates are situated at the inner circle of the global money stream [31], making it crucial for decision-makers in the maritime industry, financial markets, and businesses that rely on shipping to get their products to markets and their materials from suppliers to understand volatility transmission between the container and dry bulk freight markets.

3. Methodology

As discussed in the previous sections, the existing literature analyzes volatility transmission in shipping using variance causality and diagonal autoregressive methods. However, transmission effects are mostly found in off-diagonal matrices [32]. Kroner and Ng [33], and Abdelradi and Serra [34] argue that the BEKK-GARCH (p,q) model is superior to alternative, more restrictive specifications used in previous studies and is capable of capturing asymmetric volatility patterns. Also, since a bivariate BEKK-GARCH model directly specifies the conditional variance-covariance matrix of freight returns, hedge ratios can be generated as a byproduct of updated estimations as new observations become available [17]. Therefore, this study employs an asymmetric full BEKK-GARCH parameterization to best capture bivariate volatility transmission effects.

To do so, we employ an asymmetric BEKK-GARCH(1,1) model, optimized for measuring volatility transmission effects between two markets, to model volatility transmission between the container and dry bulk freight markets during March 2020 through May 2022. The data analysis was conducted using WinRATS 9.2 Pro software, which was shown to be effective in the software benchmarking analysis for BEKK-type models conducted by Brooks et al. [35]. Figures were produced using the Eviews 12 software package due to the authors' visual preferences.

Our mean function is constructed as follows:

$$R_{i,t} = \mu_i + \Gamma_i R_{i,t-1} + \varepsilon_{i,t} \text{ where } i = BDI, SCFI \quad (1)$$

Where $R_{i,t}$ and $R_{i,t-1}$ are the freight index return variables at times t and $t-1$, μ_i is the constant coefficient, Γ_i is the correlation coefficient, and $\varepsilon_{i,t}$ is the conditional variance coefficient. And the variance function is

$$\varepsilon_{i,t} | \Omega_{t-1} \backsim N\left(0, H_{i,t}\right) \quad (2)$$

$$H_{i,t} = C_i' C_i + A_i' \varepsilon_{i,t-1} \varepsilon_{i,t-1}' A_i + B_i' H_{i,t-1} B_i + D_i' \xi_{i,t-1}' \xi_{i,t-1} D_i' \quad (3)$$

where

$$C_i = \begin{pmatrix} c_{i,11} & c_{i,12} \\ 0 & c_{i,22} \end{pmatrix}, A_i = \begin{pmatrix} a_{i,11} & a_{i,12} \\ a_{i,21} & a_{i,22} \end{pmatrix}, B_i = \begin{pmatrix} b_{i,11} & b_{i,12} \\ b_{i,21} & b_{i,22} \end{pmatrix}, D_i = \begin{pmatrix} d_{i,11} & d_{i,12} \\ d_{i,21} & d_{i,22} \end{pmatrix} \quad (4)$$

Here, $\xi_{i,t-1}$ is represented as $\varepsilon_{i,t-1}$ if $\varepsilon_{i,t-1}$ is negative, and 0 if positive, which reflects the impacts of asymmetric shocks. $H_{i,t}$ is a conditional variance matrix and C_i is a lower triangular matrix with its inverse co-efficient matrix C_i'. A_i, B_i and D_i ($a_{i,mn}$ $b_{i,mn}$ *and* $d_{i,mn}$) matrices, which represent the diagonal parameters, measure the impacts of historical shocks, volatility, and negative shocks seen in market m on the current conditional variance of market n, while A_i', B_i', and B_i' are their inversed forms. Meanwhile, Ω_{t-1} is the information set containing all information available up to time $t-1$.

3.1. Data Analysis

The data used in the analysis consists of weekly Shanghai Containerized Freight Index (SCFI) data published by the Shanghai Shipping Exchange, and weekly closing values of the Baltic Dry Index (BDI) published by the Baltic Exchange for the period from March 13, 2020 through May 27, 2022. The SCFI is the most widely used index for sea freight rates for container shipping worldwide. This index has been calculated weekly since 2009 and shows the most current freight prices for container transport from China's main ports, including Shanghai. BDI, a shipping freight-cost index for the dry bulk freight market, is a composite of the Capesize, Panamax, and Supramax time charter average indices. It is used around the world as a proxy for dry bulk shipping stocks and is a general shipping market bellwether. Both series consist of 115 observations obtained from the Bloomberg Professional Terminal. The sample starting date is March 13, 2020 because that is the date the World Health Organization deemed COVID-19 to be a global pandemic.

Reviewing the descriptive statistics in Table 2, we immediately note the large difference between the maximum and minimum index values and the enormity of the standard deviations of both indices. The standard deviation/mean ratio for SCFI (0.4931) and BDI (0.5023) reflects the high variation in the series. Also, the skewness, kurtosis, and Jarque–Bera test show that the indices have excess kurtosis, are skewed, and not normally distributed [36].

Figure 1 shows overall freight rates increased exponentially when COVID-19 was declared a global pandemic. While the dry bulk freight market is clearly more volatile, the container freight market continued to increase steadily. This can be attributed to the oligopolistic market structure of the container shipping industry, where freight rates are determined by a few powerful shipping alliances that are more inclined to increase rates than decrease them [37]. This reinforces information asymmetry in the market, which is one of the main factors of inefficiency in the shipping freight markets discussed in the previous sections.

Table 2. *Descriptive statistics of SCFI and BDI*

	SCFI	BDI
Mean	3003.095	2162.617
Median	2885.000	1977.000
Maximum	5109.600	5206.000
Minimum	818.1600	393.0000
Standard deviation	1481.077	1086.487
Skewness	-0.174789	0.641206
Kurtosis	1.508344	3.041447
Jarque-Bera	11.24721	7.888523
Probability	0.003612	0.019366

Source: Bloomberg, Authors' calculations

SCFI: Shanghai Containerized Freight Index, BDI: Baltic Dry Index, Std. Dev.: Standard deviation

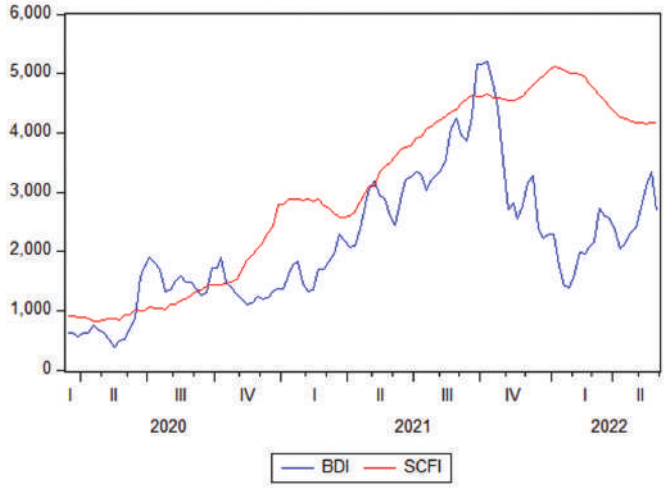

Figure 1. *Time trend of SCFI and BDI*

SCFI: Shanghai Containerized Freight Index, BDI: Baltic Dry Index

3.2. Data Preparation

To employ GARCH-type modeling, the raw data were first converted into a percentage return time series as follows:

$$R_t = Log\left(\frac{P_t}{P_{t-1}}\right)*100 \quad (5)$$

where P_t is the freight index value and R_t is the freight index return (in percentage terms). After converting the SCFI and BDI data series to percentile return values, we computed descriptive statistics as shown in Table 3. Trend graphs are shown in Figure 2.

Table 3 shows the mean returns of both RSCFI and RBDI are positive, and the standard deviations show that price fluctuations in the dry bulk freight market are more than four times the fluctuations seen in the container freight market. The skewness, kurtosis, and Jarque-Bera test statistics show that both indices are fat-tailed, positively skewed, and do not follow a normal distribution [36].

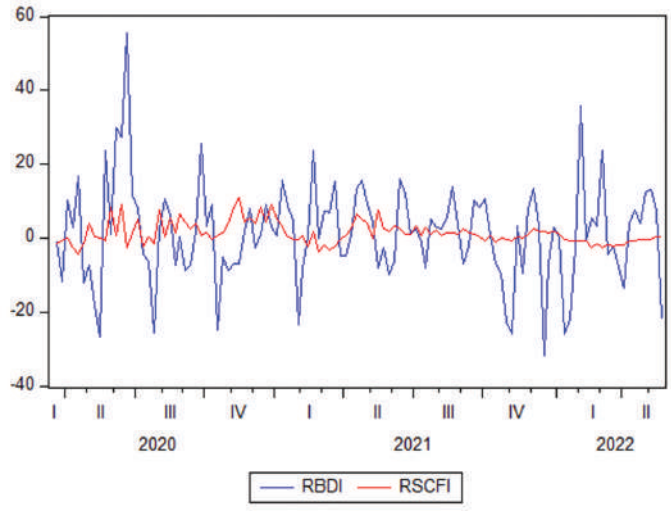

Figure 2. *Trends in SCFI and BDI percentage returns*

SCFI: Shanghai Containerized Freight Index, BDI: Baltic Dry Index

Table 3. *Descriptive statistics of RSCFI and RBDI*

	R(SCFI)	R(BDI)
Mean	1.334630	1.266206
Median	0.730591	1.899155
Maximum	10.95791	55.46442
Minimum	-4.541441	-31.87212
Standard deviation	3.006210	13.51546
Skewness	0.968335	0.365936
Kurtosis	3.771197	4.896752
Jarque-Bera	20.64081	19.63320
Probability	0.000033	0.000055

Figure 2 shows that in both series, periods of extreme volatility are followed by more extreme volatility, and mild volatility is followed by mild volatility. In other words, volatility clustering is obvious, and is more pronounced in the dry bulk freight market than in the container freight market.

To conduct a time series analysis, the series must be free of unit roots and stationary. If not, they must be made stationary by differencing them until no unit roots remain. The stationarity of both return series were tested using the Augmented Dickey-Fuller unit root test, where the null hypothesis is the existence of a unit root [38]. Table 4 shows that the null hypothesis is rejected for both series and both series are I(0); in other words, they are stationary.

4. Results

After ensuring the stationarity of the return series, an asymmetric BEKK-GARCH(1,1) model is specified to analyze volatility transmission between the container and dry bulk freight markets during the COVID-19 pandemic. The order of the GARCH(p,q) model is selected based on the Akaike

Table 4. *ADF unit root test results*

	R(SCFI)	R(BDI)
ADF test statistic	-3.589952***	-6.148515***
1% level critical value	-3.489659	-3.491345
5% level critical value	-2.887425	-2.888157
10% level critical value	-2.580651	-2.581041
***: Indicates the null hypothesis of non-stationarity is rejected at the 1% level		

Information Criterion (AIC) developed by Akaike [39], which suggests that the optimal model produces the minimum AIC statistic. The criterion graphs of the models are given in Table 5 and estimation results are given in Table 6.

The results show that for both the dry bulk and container freight markets, volatility is significantly affected by past freight returns in the short run, with values of 0.3896 [A(1,1)] and 0.4637 [A(2,2)]. The transmission effects of volatility indicate that past SCFI volatility had a large and significant impact on the volatility of BDI during the COVID-19 pandemic, with a value of 0.9880 [A(2,1)]. Although not nearly as large in magnitude, volatility transmission from BDI to SCFI is also significant with a value of -0.747 [A(1,2)].

The results also reveal the long-run self-transmission effects of prior volatilities on current period volatilities for both BDI and SCFI, with values of 0.7558 [B(1,1)] and 0.7093 [B(2,2)], respectively. Both are significant and confirm the volatility clustering observed via visual inspection. Regarding the long-run mutual transmission effects of past volatility on current volatility, the results show that SCFI's past volatility has a significant long-run transmission effect on BDI's volatility with a value of −1.7415 [B(2,1)]. Although not nearly as large, volatility transmission from BDI to SCFI over the long run is also significant with a value of 0.0801 [B(1,2)]. Therefore, we conclude there is a significant, continuous, long-run bidirectional volatility transmission between the two indices.

Table 5. *Model comparison based on AIC statistics*

Model	AIC Statistic
BEKK-GARCH(1,1)	13.090*
BEKK-GARCH(1,2)	13.135
BEKK-GARCH(2,1)	13.161
BEKK-GARCH(2,2)	13.111
*: Refers to the model with minimum AIC statistic	

The results also highlight that SCFI returns exhibit a negative leverage effect, which means they were affected more by bad news during COVID-19. We also observe a bidirectional cross-market asymmetric response between the container and dry bulk freight markets. Asymmetric transmissions were significantly stronger from SCFI to BDI with a coefficient of 1.7845 [D(2,1)], compared to a small, but still significant 0.1054 [D(1,2)] value for BDI to SCFI. Additionally, when both dry bulk and container markets experienced simultaneous negative external shocks during the pandemic, these negative shocks clearly boosted the subsequent week's asset return covariance for both markets.

To ensure the robustness of our results, the residuals of the estimation must be free of any ARCH effects, i.e., they should be homoscedastic. We conduct an ARCH-LM test proposed by Engle [40] on the residuals of our estimation. The null hypothesis, which states the residual series are homoscedastic, cannot be rejected as depicted in Table 7.

5. Conclusion

The findings in this study indicate that although the container and dry bulk freight shipping markets mutually

Table 6. *Asymmetric BEKK-GARCH(1,1) model estimation results*

Variable	Coefficient	p-value	Variable	Coefficient	p-value
Mean (RBDI)	1.3914	0.4897	B(1,1)	0.7558***	0.0000
Mean (RSCFI)	1.2169***	0.0000	B(1,2)	0.0801***	0.0000
C(1,1)	2.5261*	0.0837	B(2,1)	-1.7415***	0.0000
C(2,1)	-0.3515	0.2155	B(2,2)	0.7093***	0.0000
C(2,2)	-0.0000	0.9999	D(1,1)	-0.1702	0.4436
A(1,1)	0.3896***	0.0001	D(1,2)	0.1054***	0.0089
A(1,2)	-0.0747***	0.0024	D(2,1)	1.7845*	0.0681
A(2,1)	0.9880**	0.0264	D(2,2)	-0.4044*	0.0573
A(2,2)	0.4637***	0.0000			
Summary statistics					
Log likelihood			-729.1575		
SIC			0.0000067		
***, **, and * refer to significance at the 1%, 5%, and 10% levels, respectively					

Table 7. *ARCH-LM test results*

Lags	Statistics	Significance
2	0.267	0.76620
5	0.249	0.93926
10	1.426	0.18153

transmit volatility to each other, the transmission from the container market to the dry bulk market is much stronger. Therefore, we can conclude that both indices have significant continuous volatility transmission effects both in the short and long run. These results support the price formation hypothesis by showing a lead-lag relationship between the container and dry bulk freight markets. The results are also consistent with previous studies as they suggest dry bulk freight rates will follow container freight rates in a strengthening economy, as was seen during the pandemic when the massive increase in e-commerce volumes and international demand resulting from supply chain distortions increased freight rates and created enormous market pressures in the shipping industry. The results may indicate the existence of a leverage effect during the COVID-19 period, in which negative shocks or bad news generate more volatility for container and dry bulk freight markets than positive shocks, indicating overreaction. The explanation for this phenomenon may be the capital intensity and capital structure of shipping companies, since French et al. [41] state that bad news increases the riskiness of firms with higher debt-to-equity ratios and greatly increases the return volatility of the markets in which those firms operate This appears to explain the negative leverage effect of the container freight market, as studies by Drobetz et al. [42] and Yeo [43] on the capital structures of the top 115 and top 130 shipping firms, respectively, showed an average debt-to-equity ratio of 1.74 for the shipping industry.

The weak form of the EMH suggests there should be no volatility transmission between these markets [32,44]. However, our results show strong mutual volatility transmissions between the container and dry bulk freight markets, meaning they can be used as predictive indicators for each other. The volatilities of both are also heavily affected by their own past volatilities, which mean that historical freight values can be used to predict future freight values. This indicates inefficiencies in both the container and dry bulk freight markets.

This study contributes to the literature in two ways. First, previous studies attempted to explain the volatility transmission mechanism among freight markets using variance causality and diagonal autoregressive methods. However, transmission effects mostly reside in off-diagonal matrices, which we modeled in our research.

Second, to the best of our knowledge, no previous study has examined the disruptive effects of COVID-19 on the freight markets by considering volatility transmission, i.e., the spread of financial disturbances or shocks from one market or institution to another, which can lead to a wider systemic crisis. The results in this study shed light on the pandemic's significant adverse effects on the container and dry bulk freight markets.

Participants in the shipping markets should consider the volatility transmission effects shown here when planning and imposing shipping policies on either the container or bulk market to better anticipate the effects of those policies on the other market. From an efficient market perspective, regulators and policy makers should consider regulatory actions to support market efficiency in dry bulk and container freight markets, and future research could focus on efficiency guidelines for these markets. Future research could extend this study by including other segments of the freight market or by focusing on other aspects of the shipping markets such as the sale and purchase markets. Also, as a byproduct of our estimation process, our model can be used to generate hedge ratios between container and dry bulk freight markets as fresh observations become available.

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Authorship Contributions

Concept design: R. Memişoğlu, S. Sigalı, Data Collection or Processing: R. Memişoğlu, Analysis or Interpretation: R. Memişoğlu, Literature Review: R. Memişoğlu, S. Sigalı, Writing, Reviewing and Editing: R. Memişoğlu, S. Sigalı.

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