THE ANNALS OF “DUNAREA DE JOS” UNIVERSITY OF GALATI
FASCICLE XI – SHIPBUILDING. ISSN 1221-4620, e-ISSN 2668-3156
DOI: https://doi.org/10.35219/AnnUgalShipBuilding/2022.45.11
2022

# STUDY REGARDING THE INFLUENCE OF SHIP HULL FORMS ON THE PROPELLER DESIGN FOR A CONTAINER SHIP

**Victor-Marian Cocris**
University “Dunarea de Jos” of Galati,
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,
E-mail: cocrisvictor@gmail.com

**Mihaela Amoraritei**
University “Dunarea de Jos” of Galati,
Faculty of Naval Architecture, Galati, Domneasca Street, No. 47, 800008, Romania,
E-mail: mihaela.amoraritei@ugal.ro

## ABSTRACT

*The paper presents the results of the second stage of a study regarding the influence of ship hull forms on the propulsive performances of an imposed capacity containership. In the first stage, starting from the dimensions and the forms of a given containership, other ten ship hulls have been generated and the hydrodynamic ships' resistance has been computed. In the second stage, for two of the generated ship hull forms having the lowest resistance, the propellers have been designed, encountering problems with the placement of the optimal propeller at the end of the ship. This focused the present study on changing the dimensions and shapes of the aft for these two ships, in an attempt to ensure the installation of a propeller with an optimal diameter from a propulsive efficiency point of view, as large as possible.*

**Keywords:** containership, propulsion performances, propeller design, propeller clearance

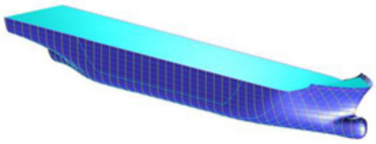
## 1. INTRODUCTION

The work done in the second stage of a study regarding the influence of the ship hull forms on the propulsive performances of an imposed capacity containership is presented in this paper. In the first step, based on the main dimensions and shapes of an imposed capacity containership, ten ships hulls have been generated with the DELFTship calculation program, the hydrodynamic ships' resistance has been computed and the results have been presented in a previous paper [1].

In the second step, two of the newly generated ship hull forms, having the lowest hydrodynamic resistance, have been selected to continue the investigations, respectively to design the propulsion system, ensuring the best performances in terms of propulsion efficiency. Different main engines have been selected and the propellers have been designed, encountering problems with the placement of the optimal propeller in the stern area. This focused the present study on changing the dimensions and shapes of the end for these two ships, in an attempt to ensure the installation of a propeller with an optimal diameter from a propulsive efficiency point of view, as large as possible.

In the future third stage, aspects regarding the influence of ship forms on the propulsive performances considering the IMO conditions for reducing greenhouse gas emissions (Energy Efficiency Design Index - EEDI) will be analysed.

All the investigations have been carried out starting from an imposed capacity containership (1805 TEU), having the main dimensions and shapes given in Figure 1 [1], [2].



- Length over all.........173,950 [m]
- Floating length.........166,000 [m]
- Beam.....................27,300 [m]
- Draught..................8,500 [m]

**Fig. 1**. Main dimensions and shapes for the initially containership [1], [2]

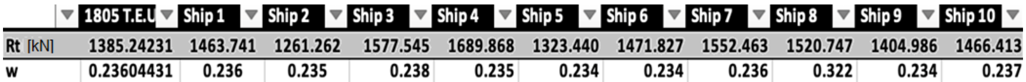
## 2. SHIP SHAPES INVESTIGATION AND SELECTION

In the first stage, based on the main dimensions and the shapes of the given containership, ten ship hulls have been generated with the DELFTship calculation program. For every case, the total hydrodynamic ships' resistance (Rt [kN]) and hull propeller interaction coefficients (w, t – wake and thrust deduction coefficients) have been computed for a ship velocity range around the owner required speed, using the Holtrop Mennen method.

In the second stage, two of the newly generated ship hull forms, having the lowest hydrodynamic resistance at 18.7 knots, have been selected to continue the study (Ship 2 and Ship 5 - Figure 2 [1]), respectively to choose and design the main components of the propulsion system, ensuring the best performances in terms of propulsion efficiency.

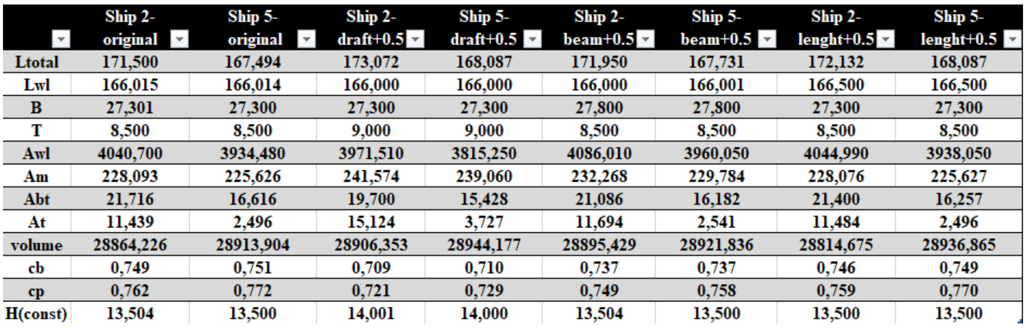
The necessary propulsive power has been calculated for the main engine selection and the propellers have been designed, encountering problems with the placement of the optimal propeller at the end of the ship. This focused the present study on changing the dimensions and shapes of the aft for these two ships, in an attempt to ensure the installation of a propeller with an optimal diameter from a propulsive efficiency point of view, as large as possible.

Thus, starting from the ship's hull forms with the best performances in terms of minimum hydrodynamic resistance (Ship 2 and Ship 5), other 6 new ship hulls have been generated, deriving by turn the main dimensions with: 0,5 m on the beam, 0,5 m on the length, 0,5 m on the draught. Due to the main dimensions' derivation, the geometrical characteristics of the new ships have been changed (Figure 3). The 2D shape lines, 3D model-lines and model-surface for the new ships are presented in Figures 4-9.



| | 1805 T.E.U | Ship 1 | Ship 2 | Ship 3 | Ship 4 | Ship 5 | Ship 6 | Ship 7 | Ship 8 | Ship 9 | Ship 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Rt [kN] | 1385.24231 | 1463.741 | 1261.262 | 1577.545 | 1689.868 | 1323.440 | 1471.827 | 1552.463 | 1520.747 | 1404.986 | 1466.413 |
| w | 0.23604431 | 0.236 | 0.235 | 0.238 | 0.235 | 0.234 | 0.234 | 0.236 | 0.322 | 0.234 | 0.237 |

**Fig.2.** Total ship resistance and w-wake coefficients for the initial generated 10 ship hulls [1]



| | Ship 2-original | Ship 5-original | Ship 2-draft+0.5 | Ship 5-draft+0.5 | Ship 2-beam+0.5 | Ship 5-beam+0.5 | Ship 2-lenght+0.5 | Ship 5-lenght+0.5 |
|---|---|---|---|---|---|---|---|---|
| Ltotal | 171,500 | 167,494 | 173,072 | 168,087 | 171,950 | 167,731 | 172,132 | 168,087 |
| Lwl | 166,015 | 166,014 | 166,000 | 166,000 | 166,000 | 166,001 | 166,500 | 166,500 |
| B | 27,301 | 27,300 | 27,300 | 27,300 | 27,800 | 27,800 | 27,300 | 27,300 |
| T | 8,500 | 8,500 | 9,000 | 9,000 | 8,500 | 8,500 | 8,500 | 8,500 |
| Awl | 4040,700 | 3934,480 | 3971,510 | 3815,250 | 4086,010 | 3960,050 | 4044,990 | 3938,050 |
| Am | 228,093 | 225,626 | 241,574 | 239,060 | 232,268 | 229,784 | 228,076 | 225,627 |
| Abt | 21,716 | 16,616 | 19,700 | 15,428 | 21,086 | 16,182 | 21,400 | 16,257 |
| At | 11,439 | 2,496 | 15,124 | 3,727 | 11,694 | 2,541 | 11,484 | 2,496 |
| volume | 28864,226 | 28913,904 | 28906,353 | 28944,177 | 28895,429 | 28921,836 | 28814,675 | 28936,865 |
| cb | 0,749 | 0,751 | 0,709 | 0,710 | 0,737 | 0,737 | 0,746 | 0,749 |
| cp | 0,762 | 0,772 | 0,721 | 0,729 | 0,749 | 0,758 | 0,759 | 0,770 |
| H(const) | 13,504 | 13,500 | 14,001 | 14,000 | 13,504 | 13,500 | 13,500 | 13,500 |

**Fig.3.** Main geometrical characteristics for the 6 new generated ship hulls

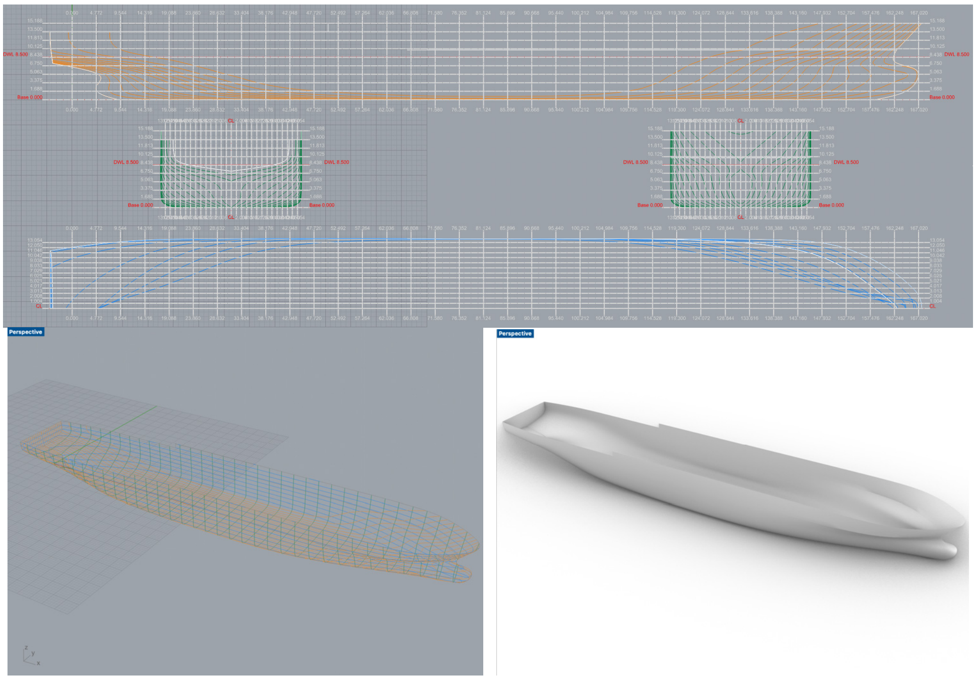


**Fig. 4.** Ship 2 beam+0.5, 2D shape lines, 3D model-lines and 3D model-surface

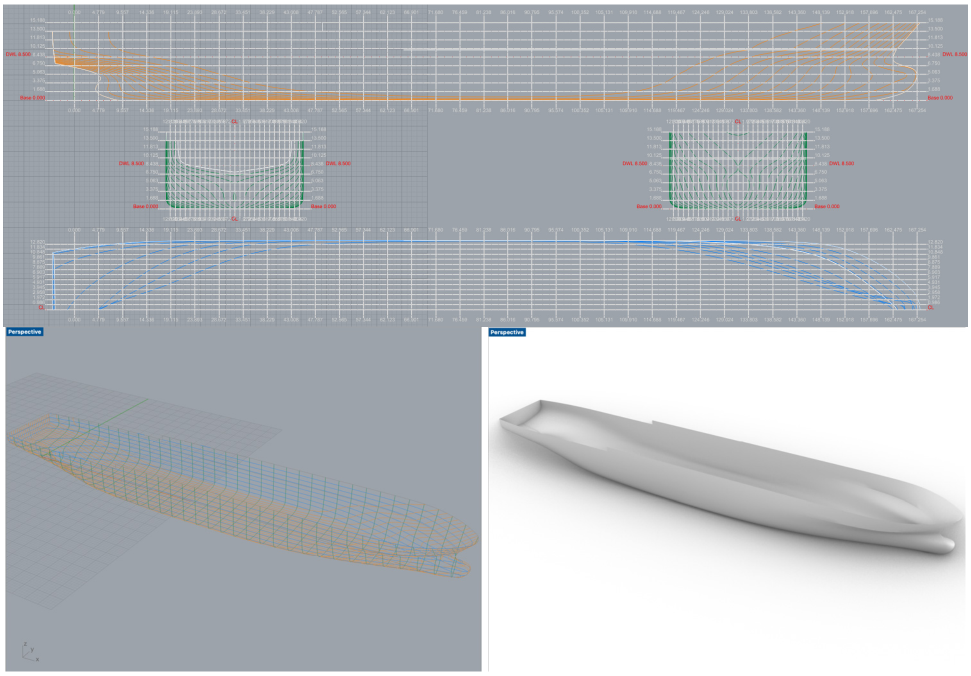


**Fig. 5.** Ship 2 length+0.5, 2D shape lines, 3D model-lines and 3D model-surface

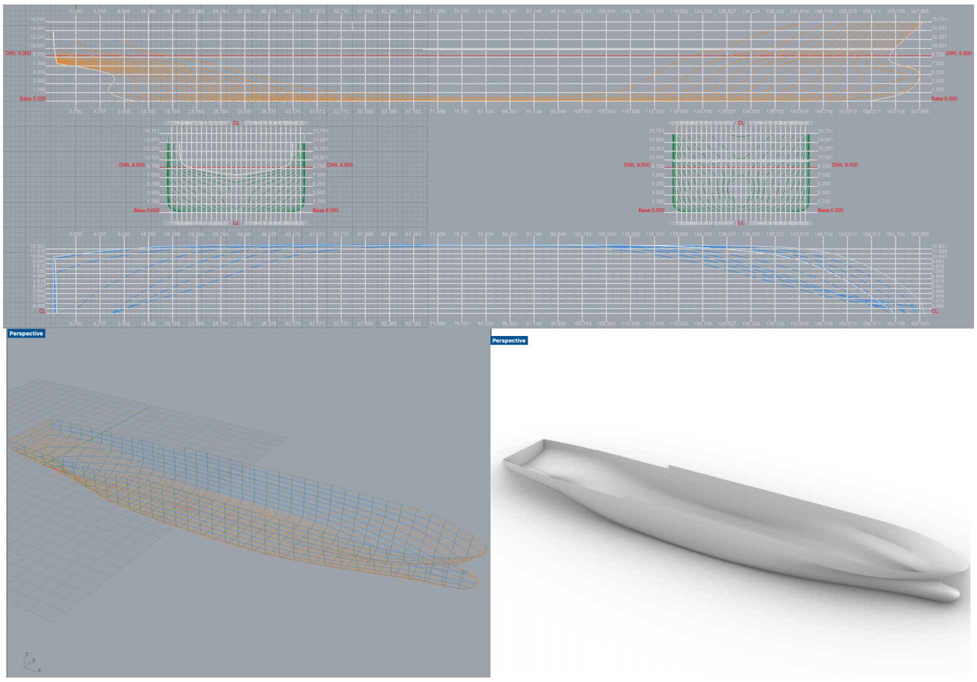


**Fig. 6.** Ship 2 draught+0.5, 2D shape lines, 3D model-lines and 3D model-surface

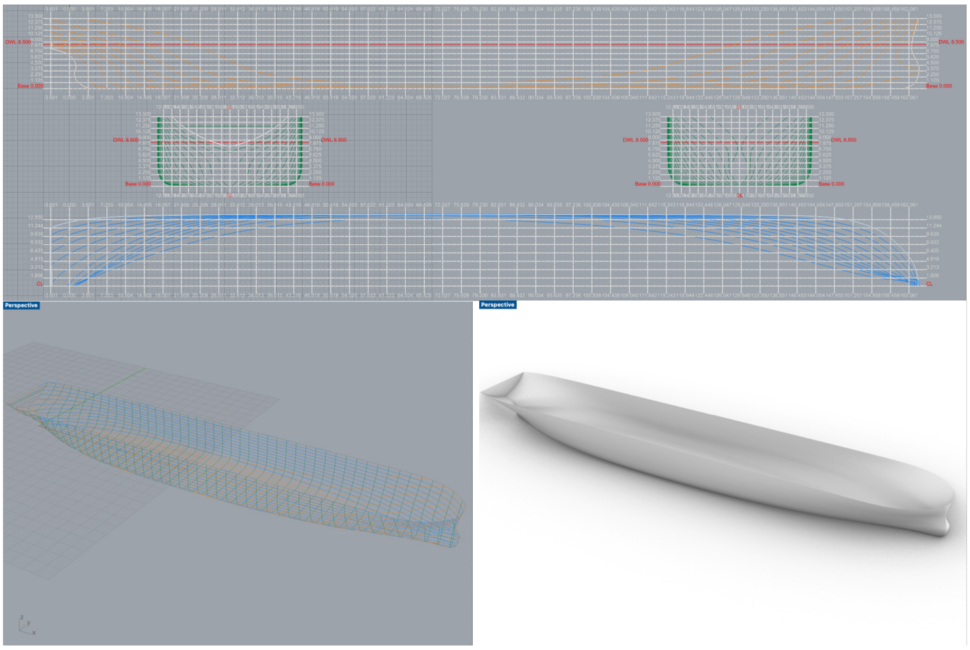


**Fig. 7.** Ship 5 beam+0.5, 2D shape lines, 3D model-lines and 3D model-surface

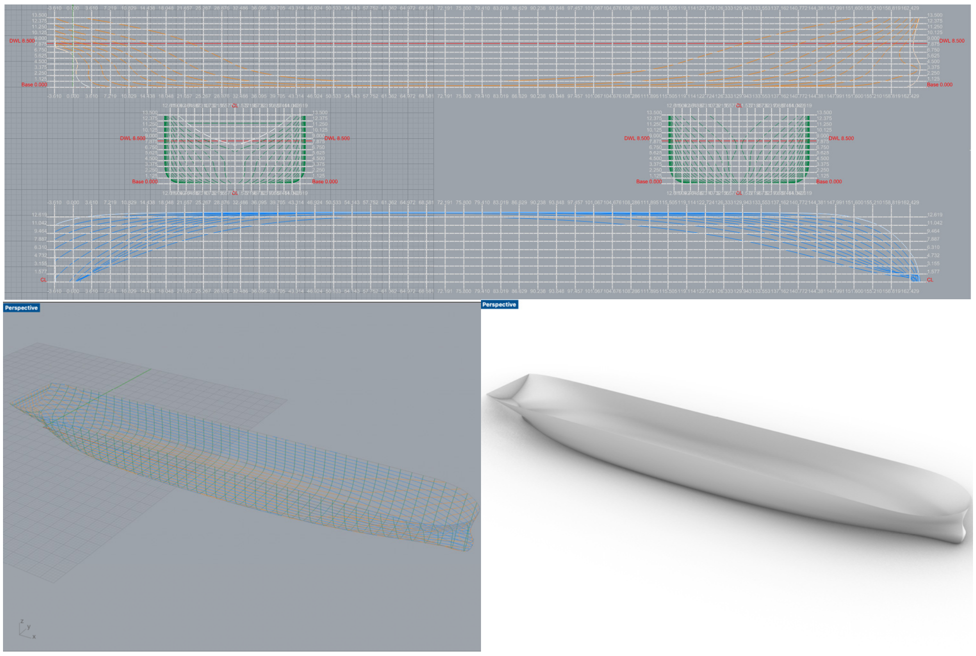


**Fig. 8.** Ship 5 length+0.5, 2D shape lines, 3D model-lines and 3D model-surface

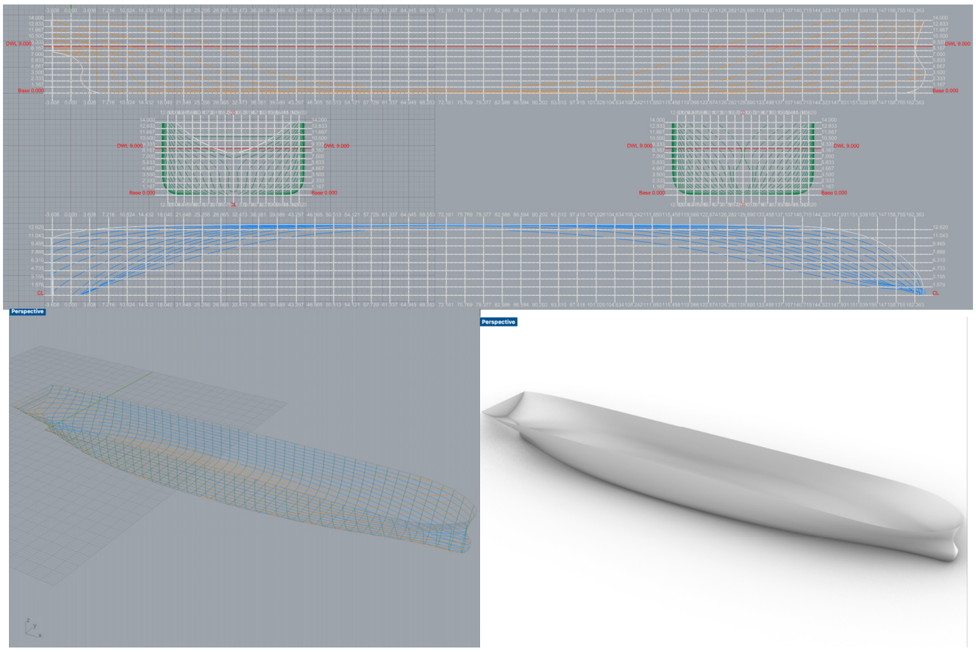
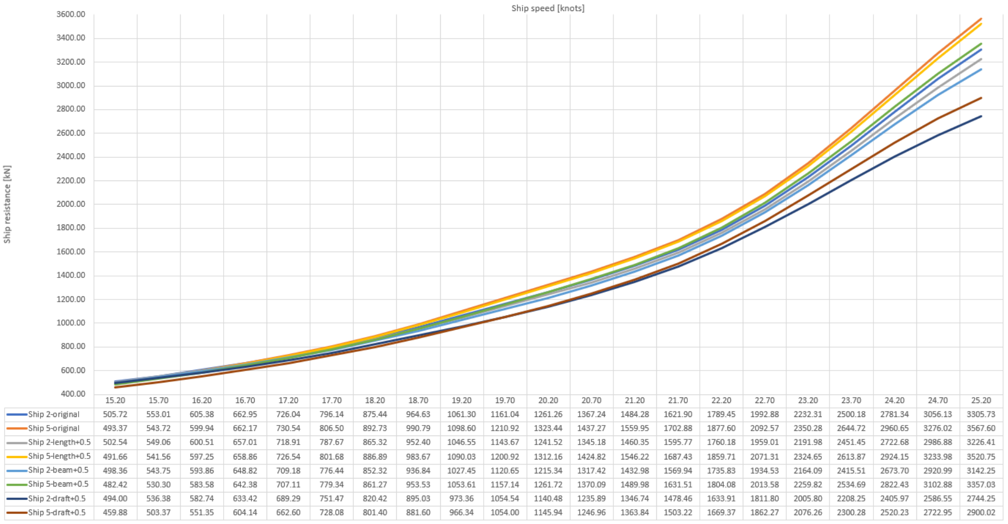


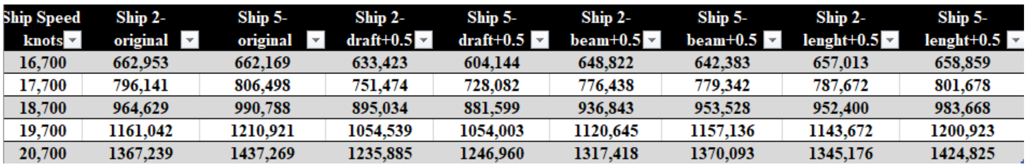
**Fig. 9.** Ship 5 draught+0.5, 2D shape lines, 3D model-lines and 3D model-surface



| | 15.20 | 15.70 | 16.20 | 16.70 | 17.20 | 17.70 | 18.20 | 18.70 | 19.20 |
|---|---|---|---|---|---|---|---|---|---|
| Ship 2-original | 505.72 | 553.01 | 605.38 | 662.95 | 726.04 | 796.14 | 875.44 | 964.63 | 1061.30 |
| Ship 5-original | 493.37 | 543.72 | 599.94 | 662.17 | 730.54 | 806.50 | 892.73 | 990.79 | 1098.60 |
| Ship 2-length+0.5 | 502.54 | 549.06 | 600.51 | 657.01 | 718.91 | 787.67 | 865.32 | 952.40 | 1046.55 |
| Ship 5-length+0.5 | 491.66 | 541.56 | 597.25 | 658.86 | 726.54 | 801.68 | 886.89 | 983.67 | 1090.03 |
| Ship 2-beam+0.5 | 498.36 | 543.75 | 593.86 | 648.82 | 709.18 | 776.44 | 852.32 | 936.84 | 1027.45 |
| Ship 5-beam+0.5 | 482.42 | 530.30 | 583.58 | 642.38 | 707.11 | 779.34 | 861.27 | 953.53 | 1053.61 |
| Ship 2-draft+0.5 | 494.00 | 536.38 | 582.74 | 633.42 | 689.29 | 751.47 | 820.42 | 895.03 | 973.36 |
| Ship 5-draft+0.5 | 459.88 | 503.37 | 551.35 | 604.14 | 662.60 | 728.08 | 801.40 | 881.60 | 966.34 |

| | 19.70 | 20.20 | 20.70 | 21.20 | 21.70 | 22.20 | 22.70 | 23.20 | 23.70 | 24.20 | 24.70 | 25.20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ship 2-original | 1161.04 | 1261.26 | 1367.24 | 1484.28 | 1621.90 | 1789.45 | 1992.88 | 2232.31 | 2500.18 | 2781.34 | 3056.13 | 3305.73 |
| Ship 5-original | 1210.92 | 1323.44 | 1437.27 | 1559.95 | 1702.88 | 1877.60 | 2092.57 | 2350.28 | 2644.72 | 2960.65 | 3276.02 | 3567.60 |
| Ship 2-length+0.5 | 1143.67 | 1241.52 | 1345.18 | 1460.35 | 1595.77 | 1760.18 | 1959.01 | 2191.98 | 2451.45 | 2722.68 | 2986.88 | 3226.41 |
| Ship 5-length+0.5 | 1200.92 | 1312.16 | 1424.82 | 1546.22 | 1687.43 | 1859.71 | 2071.31 | 2324.65 | 2613.87 | 2924.15 | 3233.98 | 3520.75 |
| Ship 2-beam+0.5 | 1120.65 | 1215.34 | 1317.42 | 1432.98 | 1569.94 | 1735.83 | 1934.53 | 2164.09 | 2415.51 | 2673.70 | 2920.99 | 3142.25 |
| Ship 5-beam+0.5 | 1157.14 | 1261.72 | 1370.09 | 1489.98 | 1631.51 | 1804.08 | 2013.58 | 2259.82 | 2534.69 | 2822.43 | 3102.88 | 3357.03 |
| Ship 2-draft+0.5 | 1054.54 | 1140.48 | 1235.89 | 1346.74 | 1478.46 | 1633.91 | 1811.80 | 2005.80 | 2208.25 | 2405.97 | 2586.55 | 2744.25 |
| Ship 5-draft+0.5 | 1054.00 | 1145.94 | 1246.96 | 1363.84 | 1503.22 | 1669.37 | 1862.27 | 2076.26 | 2300.28 | 2520.23 | 2722.95 | 2900.02 |

**Fig.10.** Ships resistance for the initial Ship 2, Ship 5 and for 6 newly derived ship hulls



| Ship Speed knots | Ship 2-original | Ship 5-original | Ship 2-draft+0.5 | Ship 5-draft+0.5 | Ship 2-beam+0.5 | Ship 5-beam+0.5 | Ship 2-lenght+0.5 | Ship 5-lenght+0.5 |
|---|---|---|---|---|---|---|---|---|
| 16,700 | 662,953 | 662,169 | 633,423 | 604,144 | 648,822 | 642,383 | 657,013 | 658,859 |
| 17,700 | 796,141 | 806,498 | 751,474 | 728,082 | 776,438 | 779,342 | 787,672 | 801,678 |
| 18,700 | 964,629 | 990,788 | 895,034 | 881,599 | 936,843 | 953,528 | 952,400 | 983,668 |
| 19,700 | 1161,042 | 1210,921 | 1054,539 | 1054,003 | 1120,645 | 1157,136 | 1143,672 | 1200,923 |
| 20,700 | 1367,239 | 1437,269 | 1235,885 | 1246,960 | 1317,418 | 1370,093 | 1345,176 | 1424,825 |

**Fig.11.** Total ship resistance for 6 newly generated ship hulls at 18.7 knots ship speed

## 3. RESULTS REGARDING PROPELLER DESIGN

The results regarding the hydrodynamic ship resistance for the 6 newly generated ship hulls, starting from Ship 2 and Ship 5 have been computed and plotted for a velocities range around the owner-required speed (Figures 10, 11).

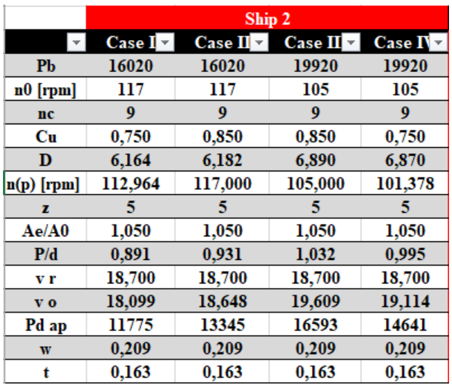
Analysing the ship resistance for the 6 newly generated ship shapes (Figures 10, 11), two ship hull forms (Ship 2 draft+0.5 and Ship 5 draft+0.5) having the lowest hydrodynamic resistance have been selected to continue the present investigation. Using the ship resistance as initial data, the necessary propulsive power has been computed for the main engine selection. The study has been performed for two slow diesel engines with the following characteristics:

- case 1. $P_b$=19920 kW, $n_o$ =105rpm,
- case 2. $P_b$=16020 kW, $n_o$=117 rpm,

where $P_b$ is the brake power and $n_o$ the engine's revolution rate.

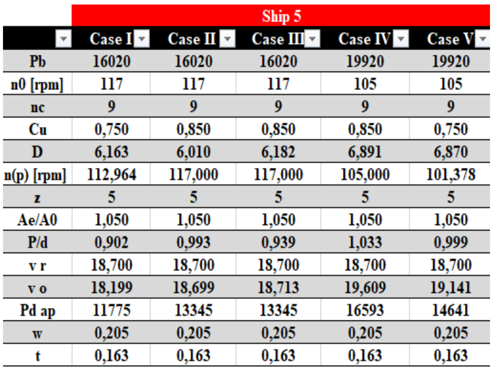
For each studied ship hull and for the chosen main engine, the optimal propeller, in terms of efficiency, has been designed to consume the delivered power and the results have been presented in Figures 12, 13. The propellers have been designed for two different design points taking into consideration the sea margin SM=15% and different values for the engine margin EM=0-10% [4] (power using coefficient cu=0.85 and cu=0.75). The results regarding propeller design for Ship 2 draught+0.5 and Ship 5 draught+0.5 for the selected engines are presented in Figures 12, 13.

There were still problems with the placement of the propeller with optimal diameter from the efficiency point of view in the stern area. It is known that a higher propeller diameter and a lower revolution rate lead to higher efficiency from an energetic point of view. But from a constructive point of view, the after-body hull lines, the draught and the clearance between the tip propeller and ship hull have to be taken into account.



| | Ship 2 | | | |
|---|---|---|---|---|
| | Case I | Case II | Case II | Case IV |
| Pb | 16020 | 16020 | 19920 | 19920 |
| n0 [rpm] | 117 | 117 | 105 | 105 |
| nc | 9 | 9 | 9 | 9 |
| Cu | 0,750 | 0,850 | 0,850 | 0,750 |
| D | 6,164 | 6,182 | 6,890 | 6,870 |
| n(p) [rpm] | 112,964 | 117,000 | 105,000 | 101,378 |
| z | 5 | 5 | 5 | 5 |
| Ae/A0 | 1,050 | 1,050 | 1,050 | 1,050 |
| P/d | 0,891 | 0,931 | 1,032 | 0,995 |
| v r | 18,700 | 18,700 | 18,700 | 18,700 |
| v o | 18,099 | 18,648 | 19,609 | 19,114 |
| Pd ap | 11775 | 13345 | 16593 | 14641 |
| w | 0,209 | 0,209 | 0,209 | 0,209 |
| t | 0,163 | 0,163 | 0,163 | 0,163 |

**Fig.12.** Results regarding propeller design Ship 2 draught+0.5.



| | Ship 5 | | | | |
|---|---|---|---|---|---|
| | Case I | Case II | Case III | Case IV | Case V |
| Pb | 16020 | 16020 | 16020 | 19920 | 19920 |
| n0 [rpm] | 117 | 117 | 117 | 105 | 105 |
| nc | 9 | 9 | 9 | 9 | 9 |
| Cu | 0,750 | 0,850 | 0,850 | 0,850 | 0,750 |
| D | 6,163 | 6,010 | 6,182 | 6,891 | 6,870 |
| n(p) [rpm] | 112,964 | 117,000 | 117,000 | 105,000 | 101,378 |
| z | 5 | 5 | 5 | 5 | 5 |
| Ae/A0 | 1,050 | 1,050 | 1,050 | 1,050 | 1,050 |
| P/d | 0,902 | 0,993 | 0,939 | 1,033 | 0,999 |
| v r | 18,700 | 18,700 | 18,700 | 18,700 | 18,700 |
| v o | 18,199 | 18,699 | 18,713 | 19,609 | 19,141 |
| Pd ap | 11775 | 13345 | 13345 | 16593 | 14641 |
| w | 0,205 | 0,205 | 0,205 | 0,205 | 0,205 |
| t | 0,163 | 0,163 | 0,163 | 0,163 | 0,163 |

**Fig.13.** Results regarding propeller design Ship 5 draught+0.5.

The maximum values of the propeller diameters that can be fitted behind the stern of the studied ship hulls are a maximum of 5.89m for ship 2 draught+0.5 and 6.01m for ship 5 draught+0.5. These values have been calculated and measured on the 2D shape lines plan, by taking into consideration the requirements related to the clearance between the propeller and hull structure [3]. The propeller diameter is limited on the one hand by the distance between the lower blade's tip and the baseline (from safety conditions to avoid damages) and on the other hand by the clearance between the propeller and the ship hull to avoid a high level of pressure pulses, noises and vibrations. Usually, these distances are given in percent of diameter.

In the case of engine 1, for both studied ships, due to the higher power and lower revolution rate, large values of diameters for the optimal propellers have been obtained. In an attempt to comply with the clearance requirements, the second engine with a lower power and a higher revolution rate has been chosen for propulsive performance investigation.

For Ship 2 draft+0.5, the most favourable case from the required speed performances point of view was case II from Figure 12, but unfortunately, it does not comply with the requirements regarding the clearance and safety of the propeller from a construction point of view.

For Ship5 draft+0.5, the most favourable case from the required speed performances point of view was case III from Figure 13, but unfortunately, it does not comply with the requirements regarding the clearance and safety of the propeller from a constructive point of view. That's why, for this variant of ship shapes and for the second case of motorisation, a compromise has been made regarding the propeller's design.

The engine with 16020 kW brake power and 117 rpm has been chosen, and the maximum constructive acceptable diameter has been imposed D=6.01 m instead of the efficiency optimal diameter D=6.182. As a result of the propeller diameter reduction, a decrease in the ship's speed has been obtained, from 18.713 knots to 18.699 knots. It results in a classic case of compromise in propeller design when a propeller with optimal diameter in terms of efficiency cannot be placed behind the stern of the ship for constructive reasons.

Another solution to solve the problem would be to search and find anoother combination for the main engine propeller, but it must be taken into account that, in general, slow diesel engines of high power have low revolution rates, which leads to large propeller diameters.

It can be seen that the stern shapes for Ship 5 lead to a slight reduction of the wake coefficient, ensuring a better uniformity of the flow in the propeller disc. A CFD analysis of the flow phenomenon around these shapes would be useful for studying the influence of ship shapes on propulsive performances.

## 4. CONCLUDING REMARKS

The paper presents the second stage of a study regarding the influence of ship hull forms on the propulsive performances of an imposed capacity containership. In the first stage, starting from a given containership, other ten ship hulls have been generated and the ship's resistance has been computed. In the second stage, for two of the newly generated ship hull forms with the lowest resistance, the propulsion systems have been designed, encountering problems with the placement of the optimal propeller at the end of the ship. This focused the present study on changing the dimensions and shapes of the aft for these two ships, in an attempt to fit the optimal propeller diameter in terms of propulsive efficiency, as large as possible.

Thus, starting from two of the ship's hull forms with lower resistance, other 6 new ship hulls have been generated, deriving by turn, the main dimensions beam, length and draught with 0.5 m. The hydrodynamic ship's resistance for the 6 newly generated ships hulls has been computed and analysed and two hulls (Ship 2 draft+0.5 and Ship 5 draft+0.5) with the lowest hydrodynamic resistance have been selected to continue the study. The necessary propulsive power has been computed, two slow diesel engines have been selected for every case, and an optimal propeller in terms of efficiency has been designed.

There were still problems to fit the optimal propeller diameter in the stern area, which finally led to the choice of shapes of Ship 5 draft+0.5, in the second case of motorisation, with the maximum propeller diameter from a constructive point of view. It resulted in a classic case of compromise in propeller design when a propeller with optimal diameter in terms of efficiency cannot be placed behind the stern of the ship for constructive reasons, but in this case, the ship's velocity with the selected propulsion system was very close to the owner's required speed.

In the future third stage, aspects regarding the influence of ship forms on the propulsive performances considering the IMO EEDI (Energy Efficiency Design Index) requirements will be analysed.

## Acknowledgements

The present research has been performed in the frame of the Naval Architecture Research Centre of the Faculty of Naval Architecture of Galati.

## REFERENCES

[1]. **Cocris, V.,M., Amoraritei, M.,** *"Ship Resistance Performances Assesment for a containership",The Annals of Dunarea de Jos University of Galati, Fascicle XI, 2021, pp 31-38 .*

[2]. **Dragomir, D.,***" Ships Shapes Album",* Dunarea de JosUniversity Foundation Publishing House, 2014

[3]. Warsilla Encyclopedia of Marine and Energy Technology

[4]. ITTC – Recommended Procedures and Guidelines - Testing and Extrapolation Methods, Propulsion, Performance, Predicting Powering Margins

***Paper received on November 18th, 2022***