Journal of
Marine Science and Engineering

MDPI

Editorial

Hydrodynamic Design of Ships

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During the last two decades, the process of designing a ship has encompassed and incorporated its hydrodynamic performance in calm water and in waves, as well as that of the propulsion units, as a major aspect of its merit in service. The computational tools developed during the second half of the 20th century, for the evaluation of a ship's resistance, propulsion and seakeeping, including added resistance in waves, are exploited in the preliminary design process. In most cases, formal optimization strategies are implemented. They are based on biomimetic methods, i.e., genetic algorithms, evolutionary strategies and artificial neural networks, which are capable of handling multi-objective problems, and are implemented on an existing (parent) hull form or generic design. A variety of techniques to accelerate the execution time of these methods, taking into account the available hardware, resources, without a significant reduction in their accuracy and robustness, are proposed in this Special Issue. In these cases, the revealed properties of the objectives under consideration are exploited to reduce randomness in the search, and to drive the procedure to reach the optimum faster, with reduced variant evaluations. Both potential and viscous flow environments, with a wide range of grid densities and fidelities, and in various mixtures, are used in the optimization process. The validity of the final outcome is evaluated by model tests.

During the last decade, international organizations, the European Union and national authorities have focused their interest on environmental protection. In this respect, the CO_2, greenhouse gases (GHG) and carbon particles emitted by transportation means, including waterborne transportation, using carbon-based fossil fuel, should be radically reduced until 2050. The issued guidelines for the shipping industry indicate a strong target towards the optimization of the operation of ships, which is mainly feasible via the optimization of their hydrodynamic performance, and improvement in the performance of their main engines and propulsion characteristics, as well as their dynamic responses and additional power requirements in actual seaways. Aiming to reduce the operating expenses, the main target is to minimize the fuel consumption in all sailing conditions. The outcome of the optimization of ship design will also be applicable in the case of alternative fuels (LNG, methanol, ammonia or hydrogen) and all electric propulsion.

The high-quality papers published in this Special Issue are directly related to most of the aforementioned aspects of the hydrodynamic performance of a ship, including novel techniques, in ship hydrodynamics, emission reduction, optimization strategies, hull form optimization, seakeeping, resistance, propulsion, maneuvering, as well as some interesting case studies. Monohulls, catamarans and SWATHs, in deep and shallow water, are considered. To be more specific, the following contributions are included in this Special Issue:

Shi et al. [1] numerically evaluated the resistance at full scale of a zero-emission, highspeed catamaran, in both deep and shallow water, for a Froude number (Fn) ranging from 0.2 to 0.8. The numerical methods are validated by the available model and a blind validation, using two different flow solvers. The total resistance is highly affected by the pressure component, which is maximized at Fn = 0.58 in deep water and at Fn = 0.30 in shallow water, when the secondary trough is created at the stern, leading to the largest trim

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Citation: Grigoropoulos, G.J. Hydrodynamic Design of Ships. *J. Mar. Sci. Eng.* **2022**, *10*, 512. https://doi.org/10.3390/jmse10040512

Received: 26 January 2022
Accepted: 31 March 2022
Published: 7 April 2022

angle. The vessel witnesses a hump near the critical speed (Fn = 0.30) in shallow water, due to the interaction between the wave systems created by the demi-hulls.

Deng et al. [2] study the principal dimensions and the hull form of a bulk carrier, to optimize its hydrodynamic performance. They considered ship resistance and seakeeping, while maneuverability was estimated by empirical methods. A new parent ship was chosen from 496 sets of hulls, after comprehensive consideration. A further hull form optimization was performed on the new parent ship, according to the minimum wave-making resistance. He concluded that optimization with respect to the principal dimensions provides a high-quality parent ship, which can be further optimized for both the principal dimensions and the hull form parameters.

Zoon and Park [3] use the component mode method to carry out vibration analyses when they design local structures on ships. The method provides natural mode functions and, eventually, reasonable natural frequencies. In their study, they use adaptive polynomials as additional flexible model functions, or a purely mathematical approach, with very good numerical results.

Xu et al. [4] used an RBF (radial basis function) neural network and NSGA-II (non-dominated sorting genetic algorithm) to optimize the hydraulic performance of the annular jet pump applied in submarine trenching and dredging. The suction angle, diffusion angle, area ratio and flow ratio were selected as the design variables. On the basis of CFD numerical simulation, an RBF neural network approximation model was established. Finally, the NSGA-II algorithm was selected to carry out multi-objective optimization and obtain the optimal design variable combination. The results show that both optimization criteria, the jet pump efficiency and the head ratio, were accurately modelled via the RBF neural network, while the optimization resulted in a 30% increase in the head ratio and a slight improvement in the efficiency.

Doctors [5] revisited the hydrodynamics supporting the design and development of the RiverCat class of catamaran ferries, which have operated in Sydney Harbor since 1991. They used more advanced software to account for the hydrodynamics of the transom demi-sterns that experience partial or full ventilation, depending on the vessel speed, which gives rise to hydrostatic drag. On the other hand, the transom creates hollowness in the water, causing effective hydrodynamic lengthening of the vessel, leading to a reduction in the wave resistance. The associated detailed analysis quite accurately predicts the phenomena and allows for the optimization of the vessel using affine transformations of the hull geometry, including the size of the transom.

Wheeler et al. [6] deal with heavily loaded hard-chine boats, which are usually intended for high-speed regimes in planing mode and relatively light displacement. They present the results for the steady-state hydrodynamic performance of these boats at nominal weight and when overloaded in calm water using the CFD solver program STAR-CCM+. The resistance and attitude values of a constant-deadrise reference hull and its modifications, with more pronounced bows of concave and convex shapes, are obtained. On average, 40% heavier hulls showed about 30% larger drag over the speed range from the displacement to planing mode. The hull with a concave bow is found to have 5–12% lower resistance than the other hulls in the semi-displacement regime and heavy loadings, and 2–10% lower drag in the displacement regime and nominal loadings, while this hull is also capable of achieving fast planning speeds at the nominal weight, with the typical available thrust. Selected near-hull wave patterns and hull pressure distributions are also presented and discussed.

Wang et al. [7] explored the bubble sweep-down phenomenon of research vessels and its effect on the position of the stern sonar of a research vessel; the use of a fairing was investigated as a defoaming appendage. The separation vortex turbulence model was selected for simulation, and the coupled Eulerian–Lagrangian method was adopted to study the characteristics of the bubble sweep-down motion, captured using a discrete element model. The interactions between the bubbles, water, air, and hull were defined via a multiphase interaction method. The bubble point position and bubble layer were calculated separately. The spatial movement characteristics of the bubbles were extracted from the bubble trajectories. It was demonstrated that the bubble sweep-down phenomenon is closely related to the distribution of the bow pressure field, and that the bubble motion characteristics are related to the speed and initial bubble position. When the initial bubble position is between the water surface and the ship bottom, the impact on the middle of the ship bottom is greater, and increases further with increasing speed. A deflector forces the bubbles to both sides through physical shielding, strengthening the local vortex structure and keeping the bubbles away from the middle of the ship bottom.

Peri [8] applied some methodologies aimed at the identification of the Pareto front of a multi-objective optimization problem. He presented the following three different approaches: local sampling, Pareto front resampling and normal boundary intersection (NBI). The first approximation of the Pareto front is obtained by regular sampling of the design space, and then the Pareto front is improved and enriched using the other two abovementioned techniques. A detailed Pareto front is obtained for an optimization problem where algebraic objective functions are applied and also compared with standard techniques. Encouraging results are obtained for two different ship design problems. The use of algebraic functions allows for a comparison with the real Pareto front, correctly detected. The variety of ship design problems allows for the applicability of the methodology to be generalized.

Papanikolaou et al. [9] focused on the hydrodynamic hull form optimization of a zero-emission, battery-driven, fast catamaran vessel. A two-stage optimization procedure was implemented to identify, in the first stage (global optimization), the optimum combination of a ship's main dimensions and, later on, in the second stage (local optimization), the optimal ship hull form, minimizing the required propulsion power for the set operational specifications and design constraints. The numerical results of the speed-power performance for a prototype catamaran, intended for operation in the Stavanger area (Norway), were verified by model experiments at Hamburgische Schiffbau Versuchsanstalt (HSVA), proving the feasibility of this innovative, zero-emission, waterborne urban transportation concept.

Nesteruk et al. [10] studied the body shapes of aquatic animals, which ensure laminar flow, without boundary layer separation, at rather high Reynolds numbers. The commercial efficiencies (drag-to-weight ratio) of similar hulls were estimated. Examples of neutrally buoyant vehicles, with high commercial efficiency, were proposed. It was shown that such hulls can be effectively used in both water and air. The authors discussed their application in SWATH (small-water-area twin hulls) vehicles, where the seakeeping characteristics of such ships can be improved, due to the use of underwater hulls. In addition, the special shape of these hulls allows the total drag to be reduced, as well as the energetic needs and pollution. The presented estimations show that a weight-to-drag ratio of 165 can be achieved for a yacht with such specially shaped underwater hulls, permitting the use of electrical engines only, and solar cells to charge the batteries.

Harries and Uharek [11] applied a flexible approach of partially parametric modelling, on the basis of radial basis functions (RBF), for the modification of an existing hull form (baseline). Contrary to other similar approaches, RBF functions allow sources that lie on the baseline and targets that define the intended new shape to be identified. Sources and targets can be corresponding sets of points, curves and surfaces, used to derive a transformation field that subsequently modifies those parts of the geometry that shall be subjected to variation, making the approach intuitive and quick to set up. Since the RBF approach may potentially introduce quite a few degrees of freedom, a principal component analysis (PCA) is utilized to reduce the dimensionality of the design space. PCA allows the deliberate sacrifice of variability, in order to define variations of interest with fewer variables, denoted as principal parameters. The aim of combining RBFs and PCA is to make simulation-driven design (SDD) easier and faster to use. Ideally, the turn-around time within which to achieve noticeable improvements should be 24 h, including the time needed to set up both the CAD model and the CFD simulation, as well as to run the first optimization campaign. The methodology was implemented on an electric catamaran, using a potential (SHIPFLOW) and a viscous (NEPTUNO) solver in the environment of CAESES, a versatile process integration and design optimization software. The combination of RBF and PCA proved quite efficient, resulting in meaningful reductions in total resistance and, hence, improvements in energy efficiency within very few simulations. For a deterministic search strategy via a one-stop steepest descent, 10 to 12 CFD runs are needed to identify better hulls, within one working day and a night for CFD runs.

Grigoropoulos et al. [12] proposed a new mixed-fidelity method to optimize the shape of ships using genetic algorithms (GA) and potential flow codes, to evaluate the hydrodynamics of variant hull forms, enhanced by a surrogate model, based on an artificial neural network (ANN), to account for viscous effects. The performance of the variant hull forms generated by the GA is evaluated for calm water resistance using potential flow methods, which are quite fast when they are run on modern computers. However, these methods do not take into account the viscous effects, which are dominant in the stern region of the ship. Solvers of the Reynolds-averaged Navier–Stokes equations (RANS) should be used in this respect, which, however, are too time consuming to be used for the evaluation of some hundreds of variants within the GA search. In this study, a RANS solver is used prior to the execution of the GA, to train the ANN to model the effect of stern design geometrical parameters only. The potential flow results, accounting for the geometrical design parameters of the rest of the hull, are combined with the aforementioned trained meta-model for evaluation of the final hull form. This work concentrates on the provision of a more reliable framework for the evaluation of hull form performance in calm water, without a significant increase in the computing time.

Enjoy reading this Special Issue on "Hydrodynamic Design of Ships".

Funding: This research received no external funding.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Shi, G.; Priftis, A.; Xing-Kaeding, Y.; Boulougouris, E.; Papanikolaou, A.D.; Wang, H.; Symonds, G. Numerical Investigation of the Resistance of a Zero-Emission Full-Scale Fast Catamaran in Shallow Water. *J. Mar. Sci. Eng.* **2021**, *9*, 563. [CrossRef]
2. Deng, R.; Wang, S.; Hu, Y.; Wang, Y.; Wu, T. The Effect of Hull Form Parameters on the Hydrodynamic Performance of a Bulk Carrier. *J. Mar. Sci. Eng.* **2021**, *9*, 373. [CrossRef]
3. Yoon, D.Y.; Park, J.H. Adaptive Polynomials for the Vibration Analysis of an L-Type Beam Structure with a Free End. *J. Mar. Sci. Eng.* **2021**, *9*, 300. [CrossRef]
4. Xu, K.; Wang, G.; Zhang, L.; Wang, L.; Yun, F.; Sun, W.; Wang, X.; Chen, X. Multi-Objective Optimization of Jet Pump Based on RBF Neural Network Model. *J. Mar. Sci. Eng.* **2021**, *9*, 236. [CrossRef]
5. Doctors, J.D. Reanalysis of the Sydney Harbor RiverCat Ferry, JMSE Special Issue Hydrodynamic Ship Design. *J. Mar. Sci. Eng.* **2021**, *9*, 215. [CrossRef]
6. Wheeler, M.P.; Matveev, K.I.; Xing, T. Numerical Study of Hydrodynamics of Heavily Loaded Hard-Chine Hulls in Calm Water. *J. Mar. Sci. Eng.* **2021**, *9*, 184. [CrossRef]
7. Wang, W.; Cai, G.; Pang, Y.; Guo, C.; Han, Y.; Zhou, G. Bubble Sweep-Down of Research Vessels Based on the Coupled Eulerian-Lagrangian Method. *J. Mar. Sci. Eng.* **2020**, *8*, 1040. [CrossRef]
8. Peri, D. Direct Tracking of the Pareto Front of a Multi-Objective Optimization Problem. *J. Mar. Sci. Eng.* **2020**, *8*, 699. [CrossRef]
9. Papanikolaou, A.D.; Xing-Kaeding, Y.; Strobe, J.; Kanellopoulou, A.; Zaraphonitis, G.; Tolo, E. Numerical and Experimental Optimization Study on a Fast, Zero Emission Catamaran. *J. Mar. Sci. Eng.* **2020**, *8*, 657. [CrossRef]
10. Nesteruk, I.; Krile, S.; Koboevic, Z. Electrical Swath Ships with Underwater Hulls Preventing the Boundary Layer Separation. *J. Mar. Sci. Eng.* **2020**, *8*, 652. [CrossRef]
11. Harries, S.; Uharek, S. Radial Basis Functions for Partially-Parametric Modeling and Principal Component Analysis for Faster Hydrodynamic Optimization of a Catamaran. *J. Mar. Sci. Eng.* **2021**, *9*, 1069. [CrossRef]
12. Grigoropoulos, G.J.; Bakirtzoglou, C.; Papadakis, G.; Ntouras, D. Mixed-Fidelity Design Optimization of Hull Form Using CFD and Potential Flow Solvers. *J. Mar. Sci. Eng.* **2021**, *9*, 1234. [CrossRef]