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Editorial

Ship Dynamics and Hydrodynamics

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1. Introduction

Ship hydrodynamics and dynamics is a rather old, traditional branch of applied mechanics and also of naval architecture. Typically, methods and theories developed in the former are applied to the latter aiming at the development of more advanced and efficient ships, and other marine vehicles and ocean structures.

The long development of ship hydrodynamics over many decades has crystallised in the following traditional scientific disciplines: resistance, propulsion, seakeeping, and manoeuvrability. However, in the earlier stages of the development of the naval architecture, the focus was on the properties of a displacement ship, such as its floatability, static stability, and unsinkability. All these properties have been analysed in ship hydrostatics and although the mentioned properties are fundamental, ship hydrostatics has lately been provided with no attention, presuming that all hydrostatic problems are solvable with relatively small efforts and that the corresponding computations are performed routinely. However, this is not true for the remaining disciplines listed above: those which are constantly and intensely developed exploiting multiple theoretical, numerical, and experimental approaches inspired by fluid mechanics, nonlinear dynamics, theory of oscillations, data analysis, control theory, and many other areas.

The present Special Issue contains 17 articles, 1 of which deals with some specific applications of ship hydrostatics to risk analysis, 3 papers belong to the area of ship resistance, 4 revolve around ship propulsion, 5 papers cover the various aspects of seakeeping, and 4 articles are rather dedicated to ship manoeuvrability. However, as can be seen from the more detailed review that follows in the next section, some papers are interdisciplinary, and the above classification is approximate. It is also worthwhile to note that 9 papers out of 17 extensively use methods and codes belonging to computational fluid dynamics (CFD).

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2. Contributions' Overview

The paper written by Braidotti et al. [1] is related to the unsinkability problem; however, their scope is far beyond the classic single-case formulations. First, a scenario of the schematised accidental lateral ramming was considered and used for the generation of a damages database. For each damage case, progressive flooding was simulated, and random forest regression was used to create a flooding time predictor. Although the paper focused on passenger vessel applications, its usefulness for naval ships is also evident.

Duman et al. [2] have performed a thorough numerical study of the resistance of a fast displacement catamaran in deep and shallow water. The CFD commercial code Star CCM+ was applied to the ship advancing with a constant speed and free in sinkage and trim. The Froude number which ranges from 0.2 to 0.67 covers both the sub-critical and supercritical speed ranges in the shallow water case. For deep water, the results for the resistance coefficients and the dynamic trim and sinkage were validated against the towing-tank data, showing a good agreement. An interesting feature of this study is that not only the total resistance was considered but also the frictional, residual, form, and wave resistance components separately. The form factor for the viscous resistance was estimated with the help of additional CFD simulations with the doubled hull.

The paper by Chang et al. [3] could be attributed to the area of ship design as it considers some issues related to the optimum design of the ship hull; although, it also deals with the inverse problem of ship resistance. Only the wave-making resistance was subject to minimisation performed with the particle swarm global optimisation algorithm. Special attention was paid to the reduction in the dimensionality of the effective design factor space performed with special methods based on the analysis of the eigenvalues of the information matrix. The wave resistance for any defined hull shape was computed using the commercial code SHIPFLOW. The method was applied to optimise the hull of the well-known benchmark destroyer DTMB-5415. Two variants of the optimisation procedure were used: without and with dimensionality reduction. In both cases, a substantial and almost identical reduction in the wave resistance was achieved, but in the second case, a substantial reduction in the required computation time was observed. The optimisation was performed under the constraints imposed on variations in the hull displacement and of the longitudinal position of the centre of buoyancy. However, the optimisation was performed for a moderate Froude number rather than corresponding to the cruising speed, which is much lower than the ship's full speed when the wave-making resistance dominates.

The study presented by Li et al. [4] also belongs to the area of ship resistance and is applied for optimizing the shape of the bow of an Arctic class vessel operating both in clean water and in ice conditions. A mathematical model embracing both the hydrodynamic and ice resistance was created based on the finite volume method used in the commercial CFD code Star CCM+ for the former and on the smooth particles hydrodynamics for the latter. The model was validated using cone ice sample tests and towing tests in a refrigerating tank performed with scaled ship models. Three bow-shape parameters were considered: the waterline entrance angle, stem inclination, and the frame deadrise angle. The parameters' variations resulted in a three-level, three-factor orthogonal fractional factorial experimental design comprising nine variants. The obtained dataset was then subject to sensitivity analysis, and a minimum of three ice-resistance configurations were selected, for which the clean-water resistance was further computed. Finally, the so-called "overall resistance index" accounting for both ice and hydrodynamic resistance was estimated, which permitted the selection of a single optimal configuration.

Tadros et al. [5] studied some of the special aspects of the optimum propeller design. In particular, the effect of cupping the propeller blades was investigated. The blade cup means the deformation of the blade near the trailing edge, mimicking to some extent deflection of an aircraft wing's flap. The optimum design was based on complexing a built-in the MatLab optimiser with the specialised NavCad code. The constraints related to the cavitation inception and to the engine's limiting characteristics were taken into account. The obtained calm-water-optimal propellers were further analysed on the quasi-stationary level for a set of weather conditions for real sea routes. According to the authors' results, the heavily cupped propellers turned out to be more efficient and less prone to cavitation.

In paper [6], Tadros et al. explored a more traditional method of improving propulsive efficiency, presuming the application of contra-rotating propellers possibly also combined with cupping. The numerical study was based on the same methodology and software as used in [5], but only the calm-water condition was considered. The effectiveness of the contra-rotating propellers was confirmed, and it was demonstrated that cupping further boosts the propulsive efficiency.

Sezen and Atlar [7] studied the influence of the roughness of a propeller hub surface on the cavitation in the axial free vortex. The modelling was performed for a rather typical four-blade propeller with the CFD code Star CCM+ validated with the experimental data obtained for a smooth hub. It was found that the hub roughness only slightly reduces the open-water efficiency of the propeller while substantially mitigating the vortex cavitation noise, which is important for reducing the environmental impact and improving the stealthiness of the ship.

The study performed by Zhang et al. [8] belongs, first of all, to the area of ship machinery, but, as long as the longitudinal vibration of the propeller shaft is considered, this study also has links with the ship propulsion and marine acoustics. The paper describes a rather detailed investigation of the dynamics of a shaft line equipped with dry or Coulomb dampers in the main thrust bearing. A physical experiment and a theoretical study have confirmed the effectiveness of such damping devices, which proved to be superior to more traditional viscous dampers. The study includes the identification of the Coulomb friction coefficient based on the particle swarm global optimisation.

Pérez-Canoza et al. [9] used a highly simplified 1DOF rolling model in an attempt to analyse the capsizing of a fishing vessel.

Mohapatra et al. [10] have studied the interaction of a solitary wave with a large floating pontoon in shallow water. The elevation of the free surface and wave loads acting upon the pontoon were computed using an analytical solution developed by the authors based on the Boussinesq theory, and also using the Navier–Stokes laminar regime equations solved with the application of the OpenFoam package and the OceanWave3D fully nonlinear potential flow code. A good agreement with results obtained with different methods was found.

The paper authored by Park and Wang [11] deals with a rather different kind of floating structure consisting of a smoothed polygonal platform floating inside a similar ring with different draughts. The actual shape was formed by low-order Fourier descriptors. The application of a cylindrical coordinate system permitted to obtain an analytical solution to the radiation-and-diffraction problem using the variables separation method. The resulting solution takes the form of Fourier series with coefficients containing the Bessel, McDonalds, and Hankel functions. The numerical results obtained with this solution were compared with those provided by the commercial finite-element code ANSYS AQWA, demonstrating a good agreement. The analytical solution was further used for a systematic investigation of the influence of various parameters defining the structure's configuration.

Gao et al. [12] have performed a RANSE modelling of a seakeeping problem using the OpenFoam package. The case of oblique regular oncoming waves in shallow water was studied. All the computations were performed for the virtual benchmark KVLCC2 ship in the model scale. The surge and sway forces and the yaw moment were computed, and their time-averaging resulted in the second-order loads. The kinematic responses in heave and pitch were also computed. The CFD results were validated against the experimental data.

The study carried out by Mai et al. [13] aimed to establish the added mass and damping coefficients associated with the roll rate and acceleration, including the cross-coupling with the sway force and yaw moment. The code Star CCM+ was used to determine hydrodynamic loads for the simulated forced isolated rolling of four benchmark ships, which included a container ship, two naval combatants, and a fast displacement catamaran. A possible dependence on the roll frequency and amplitude was neglected as the results were supposed to be used not in seakeeping but in a 4DOF manoeuvring code.

Islam et al. [14] have applied a CFD code based on the OpenFoam to the investigation of the aerodynamic characteristics of a patrol ship. The study was performed with the aim of discovering further applications for manoeuvring simulations and the all-around dependencies for the surge and sway forces and the yaw moment as functions of the inflow angle were obtained. Most of the computations were performed in the model scale, but some isolated cases were also repeated for the full-scale Reynolds number. Considerable attention was paid to convergence studies and the influence of the applied turbulence model. An additional indirect validation of the results was performed through a comparison with published wind-tunnel data obtained for similar (though not identical) above-water configurations.

The article by Sutulo and Guedes Soares [15] presents a comprehensive review of publications related to the elaboration and analysis of various manoeuvring performance criteria and standards. Alongside the review, the authors performed a preliminary analysis of possible approaches to accounting for the environmental exogenous factors in standardizing manoeuvring qualities. A hypothesis was formulated that all such factors related to hydrodynamics (sea waves, hydrodynamic interaction) can be accounted for indirectly through the appropriate augmentation of the calm-water manoeuvring standards. At the same time, the wind action can only be taken into account using some special additional criteria. The paper also contains some new developments related to standardizing wind-related manoeuvring qualities.

The study performed by Lu et al. [16] is indirectly associated with ship manoeuvrability as its results may turn out to be useful for a reliable prediction of the open-water hydrodynamic characteristics of rudders. The paper represents a significant contribution to the practice of the application of CFD codes and grid generators. The commercial ANSYS codes ICEM and Fluent were used for investigating the influence of the grid's characteristics of the 2D symmetric profiles of the NACA family. The obtained results were also validated against experimental data and the data provided by several other CFD codes. It was found that the lift could be predicted with a much lower uncertainty than the drag at least in the pre-stall regime.

The study performed by Song et al. [17] de facto belongs to the area of applied control theory, aiming, however, at the application of the manoeuvring problem of heading stabilisation and path tracking. The novelty of the study consists of the developed sophisticated algorithm for a dynamic optimisation of the parameters of a PD control law. The method was validated through computer simulations performed based on a rather common 3DOF holistic dynamics model with exogenous factors simulated as artificial high-frequency perturbations of the sway force and the yaw moment. The results obtained in the simulated tracking of straight, polyline, and circular paths using the line-of-sight method combined with the heading PD control have confirmed the better quality of the tracking provided by the new tuning algorithm.

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