Design and Optimization of a Duct for Enhanced Ducted Propeller Open-Water Performance

Negin Donyavizadeh[1], Arash Eslamdoost[1], Rickard Bensow[1]
[1]Department of Mechanics and Maritime Sciences, Chalmers University of Technology, Sweden

Ducted propellers play a crucial role in marine propulsion systems, providing improved efficiency and thrust, especially for ships navigating at low speeds or in challenging conditions. The effectiveness of these systems largely depends on the duct's design, with factors like the angle of attack and chord length significantly impacting performance.

The main objective of this study is to design and optimize a duct by utilizing a combination of parametric modeling (CAD), Computational Fluid Dynamics (CFD) simulations, and systematic analysis to achieve the best possible propulsion performance.

The duct profile is parameterized by control points that define the cross-section profile of the duct and key geometric parameters, including the angle of attack and chord length along the duct's sections.

Initially, 2D axisymmetric simulations are performed to investigate the basic hydrodynamic characteristics of the duct. Subsequently, a more comprehensive 3D analysis of the flow is carried out, using steady-state Reynolds-Averaged Navier-Stokes (RANS) and a Moving Reference Frame (MRF) approach is employed to model the propeller.

The optimization process is carried out using HEEDS Multidisciplinary Design Optimization (MDO) software, which links the parametric CAD model generated in CAESES with CFD simulations in STAR-CCM+. This integration enabled an automated and efficient optimization process, where the primary design goals are to maximize thrust and minimize torque.

The optimization process explored various combinations of the profile parameters, the angle of attack, and the chord length to identify the optimal design that delivers the best performance. To validate the optimization results, surrogate modeling is employed using a second-order Gaussian Kriging method, which is used to demonstrate the accuracy of the optimization method with an R^2 value and a low root mean square error (RMSE).

This research demonstrates the effective integration of parametric modeling, CFD, and optimization techniques in improving the design of ducted propellers. The results highlight the significant impact of geometric parameters on propulsion efficiency and provide a foundation for future work in the development of more efficient, sustainable marine propulsion systems.

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