

Improving the efficiency of marine vessels in seaways

Adjoint shape optimization of marine vessels in head waves

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In Short

- Marine vessels operate in seaways affecting their hydrodynamic performance.
- Shape optimization of the hull geometry can help reduce unwanted effects of the vessel motion due to incoming head waves.
- Reduced order modeling methods can be applied to compress primal flow data and support adjoint shape optimization under unsteady conditions at a moderate cost.

Modern ocean-going ships operate in seaways of varying characteristics and their hydrodynamic performance can be significantly affected by incoming head waves. The added resistance in comparison to calm water conditions forces ship operators to increase the power output of marine engines during operation to counteract the increase in resistance. This, in turn, increases fuel costs and carbon emissions. The seakeeping ability also determines the size of the installed engine to maintain a minimum propulsive power for safe navigation in very rough seas. The seakeeping performance thus affects the compliance with relevant energy efficiency regulations such as the EEDI. For that reason, research on the seakeeping of marine vessels is active (cf. [1]) and modern vessel designs often incorporate features to enhance relevant performance. An example of such a feature is a straight, sharp bow such as the one in figure 1.

The project aims at improving the seakeeping ability of merchant vessels using simulation-based shape optimizations of the hull geometry. It will follow the path of previous projects at the Institute for Fluid Dynamics and Ship Theory (Hamburg University of Technology) to numerically optimize the resistance of free-floating vessels exposed to turbulent two-phase flows, using gradient-based adjoint shape optimization approaches [2,3]. These were also coupled to advanced descent strategies to improve parameter-free shapes [4] and successfully validated for realistic steady state configurations at large Reynolds- and Froude-numbers [5]. An adjoint shape optimization framework has been established in the in-house RANS/LES solver FreSCo^+ , which

will be further developed and used during the current project.

Applications aim to address minimizing the added resistance of marine vessels or the rigid body motion accelerations. The rigid body motion accelerations can damage equipment or cargo onboard the vessel or make the journey uncomfortable for the crew or passengers. Therefore, it is essential to develop an adjoint framework for the rigid body motions to support a gradient-based optimization approach of vessel seaworthiness. Relevant derivations for the adjoint floatation framework will be carried out during the project and fluid-body interaction coupling strategies will be applied for the numerical coupling of the adjoint body motion with the adjoint flow field.

Efforts towards simulation-driven shape optimizations in the framework of the present project will require unsteady adjoint optimization methods, where difficulties arise from the oppositely directed information transport of the primal and adjoint procedures. In a trade-off between compute and memory expenses, check-pointing strategies were previously suggested [6,7]. However, the related overheads often question their feasibility in an industrial design process. An innovative alternative refers to order reducing singular value decomposition (SVD) methods. In the context of adjoint shape optimizations, they can be implemented as time-incrementing, spatially parallel strategies to project the primal flow field into a compact formulation. Such a method presented in [8] could achieve a high compression ratio while retaining accuracy of the reconstructed field. This method will be further tested in unsteady seakeeping simulations during the initial stages of the project and applied in a shape optimization framework during subsequent stages.



Figure 1: Example of sharp bow shape on a bulk carrier (courtesy of Japan Marine United Corporation)

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More Information

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