Improving the propulsion efficiency of marine vessels

Adjoint shape optimization of Energy-Saving-Devices under unsteady conditions

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In Short

- Energy-saving-devices (ESD) contribute to the fuel efficiency of vessels and the decarbonization of the maritime industry.
- Shape optimization of ESDs can help maximize the potential savings in cost and emissions.
- Active propulsion and propeller-hull interaction effects should be considered for the shape optimization of ESD.
- Reduced order modeling methods can be applied to compress primal flow data and support adjoint shape optimization under unsteady conditions at a moderate cost.

Merchant shipping is responsible for more than 90% of the global trade, and the 50.000 merchant vessels have a significant environmental impact as regards CO2-, SOx- and NOx emissions. The project aims at improving the environmental impact of merchant vessels using simulation-based shape optimizations of Energy-Saving-Devices (ESD). Many different types of ESD have been proposed in the past. Examples of ESD can be seen in figure 1. However, certain types of devices that favorably manipulate either the flow approaching or leaving the propeller have shown to have the greatest potential. Propulsion power reductions in the range of 5% - 8% have been measured in model tests of one of these technologies [1]. Propulsion power reductions increase the vessel's fuel efficiency, thus improving the fuel economy and help comply with the relevant energy efficiency regulations such as the EEDI.

***Figure 1:** Examples of Energy-saving-devices (courtesy of MMG and Becker Marine Systems)*

The project will follow the path of previous phase projects (GRK2583-O2) 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 $\texttt{FreSCo}^{+}$, which will be further developed and used during the current project.

Applications aim to address minimizing the power requirement for ESD-equipped vessels. ESDs are installed in areas where the propeller-hull interaction is significant, affecting the local flow characteristics and the efficiency of the device. Therefore it is important to take into account the propeller-hull-ESD interaction by considering active propulsion of the ship and resolving the rotation of the propeller. Propeller resolution methods based on rotating grids can accurately capture this interaction. However, CFD simulations of maritime two-phase flows can be challenging due to the large Reynolds number ($Re \approx 10^8$), possibly large Froude-numbers ($Fn \approx 0.4$) and the free floatation of the vessel. The required temporal and spatial discretizations to face these challenges and apply rotating grid methods result in high computational cost. Emphasis will thus be given to "smart" methods that describe the unsteady interaction of the rotating propeller, the ESD and the hull and thereby support related shape optimizations at moderate cost. To this end, fully resolved grid rotation methods will be combined with moving frame of reference approaches (MRF) and evaluated for their potential savings in computational cost of shape optimization applications.

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 propulsion simulations during the initial stages of the project and applied in a shape optimization framework during subsequent stages.

WWW

https://www.c3s.uni-hamburg.de/rtg2583.html

More Information

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Project Partners

University of Hamburg
Max-Plank-Institute for Meteorology

Funding

DFG Research Training Group, RTG 2583

DFG Subject Area

404-03 Fluid Mechanics