Coupling efficient multivariate analysis and optimization strategies with an innovative flow solver for hull hydrodynamics

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ABSTRACT

An important application of optimization for ship design is the minimization of calm-water resistance for a given displacement. Inherently coupled with the design process is design optimization, which consists of the selection of the best design out of a set of feasible solutions based on a range of design objectives and constraints. Traditional optimization methods applied to early-stage design process usually deal with a parametric geometrical model linked to an inviscid flow solver to predict flow resistance, as computational expenses required by more accurate RANSE solvers are prohibitive for a full optimization study. The drawback of using a low-fidelity model to predict merit is that a lack of accuracy may lead to the selection of an un-optimal design. In addition, the large number of design variables required to define the geometrical variation of the shape of the hull is taken into account in ship early stage design process which make the optimization problem very complex for the designer and not always feasible. The addition of design constraints imposed to characterize the design exploration phase as well as multiple objectives make the optimization process even more challenging. Consequently, in such a scenario it may occur that the optimization process does not find the optimal solution.

In this work, an innovative flow solver based on OPENFOAM® [1]technology that combines free-surface effects with a viscous solution is employed for accurate drag prediction with fast turnaround times ideally suited for an optimization study. The key elements of the solver included a polyhedral finite-volume discretization of the water phase. The steady formulation of the governing equations and boundary conditions are used to pose a problem that is efficiently solved with conventional CFD techniques. A consistent linearized free-surface boundary condition for a viscous flow is applied to the approximate free surface. This novel approach is shown to retain accuracy while reducing the computational expense that is introduced when solving for unnecessary nonlinear features of the flow.

In addition, different techniques will be examined in this paper to reduce the curse of dimensionality by applying efficient methods like design space exploration [1][2] and multivariate analysis (MVA) [3] available in modeFRONTIER to predict ship performance over a range of different speeds for a

[1] OPENFOAM® is a registered trade mark of Silicon Graphics International Corp.

given displacement. Further, MVA methods allow the designer to get a better understanding of the design space response and relationships between variables prior to formulate the optimization problem, thus making the process more efficient.

For the approach detailed here, an initial Design of Experiments (DOE) analysis is performed to sample the design space efficiently. Afterwards Clustering methods [4] are employed to detect local sensitivities between design parameters and output responses and reduce the design space complexity by grouping together multiple design samples with similar characteristics into different clusters. Finally an optimization run on the most favorable clusters of the design space is carried out until the layout of the optimal solution is found.

Using the proposed approach, the optimal solution can be retrieved with far fewer evaluations with respect to the traditional methods, thus saving considerable amount of computational time such that it is possible to use high-fidelity CFD simulations. Finally, the application of CAP method available in modeFRONTIER allows the designer to have a better insight into the design space, which becomes crucial in the decision-making phase of the design process.

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