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A Practical Hydrodynamic Optimization Tool for the Design of a Monohull Ship

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ABSTRACT

This paper presents a practical hydrodynamic optimization tool for the design of a monohull ship. The main components of this tool consists of a practical design-oriented CFD tool, a NURBS representation for the hull surface, and a gradient-based optimization procedure. The CFD tool, which is used to evaluate the steady flow about a ship, is based on a new theory, called Neumann-Michell (NM) theory. The wave drag predicted by the NM theory is in fairly good agreement with experimental measurements. The hull surface is represented by NURBS, which allows for the large variation of hull form during optimization cycles. For purposes of illustration, the classical Wigley hull is taken as an initial hull and the hydrodynamic optimization tool is used to determine the optimal hull forms for three design speeds and for a given speed range with displacement constraint.

KEY WORDS: hydrodynamic optimization, NURBS, Neumann-Michell theory, hull form design.

INTRODUCTION

Hydrodynamic optimization is an important aspect of ship design. For the development of new ships it has become increasingly important to both model hull forms accurately and evaluate hydrodynamic performance efficiently during the early stage of the design process. Today, computational methods in the fields of geometric modeling and fluid dynamics simulation are applied in determining a ship's geometry and predicting its hydrodynamic performance.

However, both Computer Aided Ship Hull Design (CASHD) and Computational Fluid Dynamics (CFD) are still mostly utilized consecutively, i.e., one after the other and without direct feedback. Usually, the hull's geometry is modeled in a highly iterative process consuming a considerable amount of resources, i.e., time and labor, to meet all design criteria. Then, the geometry is passed on to the numerical flow field analysis using CFD tool. On the basis of the numerical results, the geometry is changed, often intuitively, by interactive modification. This approach does not generate an optimum hull form automatically.

In order to compare the merit of different designs quantitatively, an objective function I is defined. This objective function depends on design parameters $\boldsymbol{\beta}$, and the changes in flow variables $\mathbf{v}(\boldsymbol{\beta})$ due to them. The aim is then to minimize (or maximize) this objective function subject to PDE (Partial Differential Equations that govern the flow) constraints, geometry constraints, and physical constraints. Examples for the objective function are drag or prescribed pressure, for PDE constraints the Euler/Navier-Stokes equations or Laplace equation, for geometric constraints the displacement or transverse moment of inertia of the waterplane, and for physical constraints a minimal pressure to prevent cavitation. Various optimization techniques can be used to minimize (or maximize) this objective function. The gradient-based optimization technique is adopted in this study.

There exist a variety of ways of computing the required gradients $I_{,\boldsymbol{\beta}}$. The easiest way is via finite differences. For each β_i, vary its value by a small amount, recompute the objective function I, and measure the gradient with respect to β_i. For central differences, this implies $O(2N)$ field solutions for each gradient evaluation. An alternative is to use a first order finite difference with complex variables. This requires $O(N)$ field solutions for each gradient evaluation, but at the cost of a flow solver with complex variables. For 'noisy' or 'rough' objective functions, gradients may be computed from so-called response surfaces. The parameter space in a region close to the present design is populated, and a low-order polynomial is fitted through these data points. The gradients are then obtained from the low-order polynomial. This type of technique also requires $O(N)$ field solutions for each gradient evaluation.

The only alternative to obtain gradients in a more expeditious manner is via adjoint solvers. The PDE constraints are used in adjoint solvers to obtain all gradients at once analytically. The