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A Family of Ship Hulls for Drag-Optimization Studies

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ABSTRACT

A mathematically-defined family of ship hulls that consist of a forebody $0 \leq x \leq \ell$ and a cylindrical region $-1 + \ell \leq x \leq 0$ aft of the forebody is considered. The cylindrical surface aft of the forebody has nearly rectangular framelines, with beam $2b$ and draft d. The forebody is determined by its length ℓ and seven other parameters that further control its shape. These eight shape parameters, plus the beam and the draft, define a relatively general and realistic mathematical family of ship hulls that can be used for optimization and related basic studies. The calm-water drag of this family of ship hulls is estimated as the sum of the friction drag and the wave drag given by the classical ITTC friction formula and the Hogner slender-ship approximation. This approach provides a particularly simple and efficient way of estimating the total drag that can be used to gain insight for concept and preliminary design. The variations of the displacement volume, the friction and wave components of the drag, and the total drag of the hull that result from variations of the parameters associated with the mathematical family of ship hulls are considered.

KEY WORDS: Mathematical family of ship hulls; Hogner slender-ship approximation; hull-form optimization

INTRODUCTION

The drag is well known to be a major element of ship design. Accordingly, naval architects require CFD tools for predicting the drag of a ship that are well suited for every design stage (concept design, preliminary design, detail design, design evaluation). These CFD tools must be practical and robust (of particular importance for early design stages) and must account for dominant flow physics. Robustness and efficiency are particularly important for hull-form optimization, increasingly used in ship design; e.g. (Kim et al., 2008; Yang et al., 2008; Kim et al., 2009b,a, 2010b,a, 2011).

Hull-form optimization involves several nontrivial issues and uncertainties associated with the choices that must be made with regard to constraints and design variables, optimization procedure, hull-surface representation, and flow solver. The latter issue is of particular interest to the CFD community. An important basic question is whether a simple CFD tool that involves simplifying approximations and only accounts for dominant flow physics may be sufficient for hull-form optimization, or a more complex but more accurate CFD tool is in fact required. This consequential basic question is nontrivial and may not have been sufficiently considered in the literature.

For the simple hull-form optimization problem of minimizing the total drag of a ship (within a set of constraints) that is of primary interest in this study, there is limited evidence that a simple CFD tool based on simplifying approximations might in fact be adequate, e.g. (Letcher and Marshall, 1987; Percival et al., 2001; Yang et al., 2002). However, more thorough studies are required to arrive at a firm conclusion about this consequential issue. A family of ship hulls that is defined mathematically provides a useful vehicle, notably because the hull geometry can be defined accurately, for performing systematic comparisons of predictions given by alternative CFD tools.

In addition, a relatively general and realistic mathematical family of ship hulls that is defined in terms of a limited number of parameters, coupled with a simple CFD tool, can be useful for concept and preliminary design because variations in a ship drag due to major hull-form changes can be easily estimated. Indeed, a simple and highly efficient CFD tool applied to a mathematically-defined family of ship hulls, as considered here, may provide 'cause and effect' relationships between parameters that define a hull form, on the 'cause' side, and corresponding hydrodynamic features (e.g. the drag) on the 'effect' side. This 'numerical' approach is similar to the 'experimental' approach based on experimental measurements for a series of ship models, e.g. the classical Series 60 series of ship models, for which the hull geometry is varied in a systematic manner. The information gained from this 'experimental' approach provides invaluable insight and benefits for hydrodynamic design. However, systematic experimental studies are expensive. CFD tools can hopefully be used for the same purpose. An illustration of the feasibility and benefits of performing systematic numerical calculations based on a simple CFD tool (thin-ship theory) is given in (Noblesse et al., 2011).

Although a mathematical family of ship hulls offers the advantage that the hull geometry can be defined easily and accurately, as already noted, this approach is not without limitations. Specifically, it is not possible to define a mathematical family of ship hulls that is sufficiently general and flexible to encompass every hull form that might be worth consideration. A similar restriction holds for the 'experimental' approach noted earlier. This study provides an initial report of ongoing research. Specifically, the study presents a mathematical family of ship hulls. The