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A Framework for Scenario-Based Hydrodynamic Design Optimization of Hard Chine Planing Craft

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Abstract

An optimization framework for the design of hard chine planing craft incorporating resistance, seakeeping and stability considerations is presented. The proposed framework consists of a surface information retrieval module, a geometry manipulation module and an optimization module backed by standard naval architectural performance estimation tools. Total resistance comprising calm water resistance and added resistance in waves is minimized subject to constraints on displacement, stability and seakeeping requirements. Three optimization algorithms are incorporated in the optimization module: Non-dominated Sorting Genetic Algorithm (NSGA-II), Evolutionary Algorithm with Spatially Distributed Surrogates (EASDS), and Infeasibility Driven Evolutionary Algorithm (IDEA). The individual performance of each algorithm is reported. The proposed framework is capable of generating the optimum hull form, which allows for a better estimate of performance compared to methods that generate only the optimum principal dimensions. The importance and effects of the vertical impact acceleration constraint on manned and unmanned missions are also discussed.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>Beam (m)</td>
</tr>
<tr>
<td>C_v</td>
<td>Speed coefficient</td>
</tr>
<tr>
<td>Disp.</td>
<td>Displacement (kg)</td>
</tr>
<tr>
<td>F_n</td>
<td>Froude number</td>
</tr>
<tr>
<td>GM</td>
<td>Metacentric height (m)</td>
</tr>
<tr>
<td>H_1/3</td>
<td>Significant wave height (m)</td>
</tr>
<tr>
<td>I_e</td>
<td>Half angle of entrance (degrees)</td>
</tr>
<tr>
<td>I_a</td>
<td>Vertical impact acceleration (g)</td>
</tr>
<tr>
<td>L</td>
<td>Length (m)</td>
</tr>
<tr>
<td>LCB</td>
<td>Longitudinal centre of buoyancy (m)</td>
</tr>
<tr>
<td>R_A</td>
<td>Added resistance (N)</td>
</tr>
<tr>
<td>R_C</td>
<td>Calm water resistance (N)</td>
</tr>
<tr>
<td>R_T</td>
<td>Total resistance (N)</td>
</tr>
<tr>
<td>T</td>
<td>Draft (m)</td>
</tr>
<tr>
<td>Vol.</td>
<td>Displaced volume (m$^3$)</td>
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</table>

1. Introduction

Ship design involves the practice of satisfying requirements based on a vessel’s intended tasks and rationalization, Schneekluth and Bertram (1998). The design of a ship should meet statutory requirements, mission requirements, economic criteria, safety requirements and so on. The choices of main dimensions of the ship affect the hydrostatic and hydrodynamic performance of the ship such as its resistance and response in the seaway. Ship design optimization allows the tradeoff between various performance requirements and is an indispensable element of modern day design processes. Consideration of seakeeping performance during the phase of design has been reported in a number of recent studies. Sarioz and Narli (2005) presented an example of seakeeping assessment under various vertical acceleration regimes outlined in ISO 2631, Mason and Thomas (2007) illustrated the use Computational Fluid Dynamics (CFD) and Genetic Algorithm (GA) for the optimization of International America’s Cup Class (IACC) yachts, Peri and Campana (2003) designed a naval surface combatant with total resistance and seakeeping considerations. Other examples involving multiple design aspects i.e. resistance, seakeeping, cost and safety optimization based on specific scenarios have been presented by Smith (1992), Ray (1995), Ganesan (1999), Neti (2005) and Berseneff et al. (2009).

Most of the above studies focused on displacement crafts and there are only a handful studies dealing with planing crafts. Minimization of calm water resistance for planing crafts appears in Almeter (1995) and Mohamad Ayob et al. (2009). Presented in this paper is a scenario based hydrodynamic
optimization of planing craft in seaway operations. An integrated approach is taken that simultaneously considers resistance and motions in a seaway. A number of efficient optimization algorithms are employed for solving the problems posed. The Non-dominated Sorting Genetic Algorithm-II (NSGA-II) by Deb et al. (2002) is incorporated in the planing craft optimization framework. In addition to NSGA-II, a surrogate assisted optimization scheme (referred here as EASDS) by Isaacs et al. (2007) and an Infeasibility Driven Evolutionary Algorithm (IDEA) Ray et al. (2009) is incorporated for increased efficiency.

In order to support design optimization of planing craft, the underlying framework should:

1. allow easy incorporation of different scenarios, design criteria etc. with alternate analysis modules providing different levels of fidelity;
2. allow shape representation and manipulation that is able to generate different variants of hull forms with the required fairness and chine definitions; and
3. include an optimization method that is capable of dealing with single and multi-objective optimization problems with constraints. Furthermore, since the performance evaluations are computationally expensive, the optimization algorithms employed should be efficient.

The proposed framework is built using a modular concept with the Microsoft® COM interface as the underlying communication platform between applications. A modular design in any optimization framework opens the possibility of conducting more complex analysis, Ray (1995), where other optimization schemes and high fidelity multidisciplinary analysis tools can be added and executed for comparative purposes. A number of researchers have discussed helpful proposals for integration of different tools within a ship design framework. Neu et al. (2000) applied Microsoft® COM interface in containership design optimization. Mohamad Ayob et al. (2009) used Maxsurf Automation, Maxsurf (2007) (a form of Microsoft® COM interface) for planing craft design optimization. Abt et al. (2009) presented a broader aspect of integration between tools, including integration of in-house and commercial codes using XML files, generic templates and Microsoft COM interface.

2. Optimization framework components

The optimization framework proposed in this paper consists of three applications namely Matlab, Microsoft® Excel and Maxsurf. Maxsurf Automation Library built upon Microsoft® COM interface is used as a medium of communication (inter-process) between applications. Presented in Fig. 1 is a generic sequence diagram to illustrate the workflow of the current optimization framework. The inter-process communication is initialized with the selection of principal dimensions \( (L, B, T) \) by the optimizer module in Matlab. Parametric transformation is invoked to generate a candidate hull followed by evaluation of the hydrostatics and calm water resistance of the candidate hull in Maxsurf using the methods of Savitsky (1964). Finally the seakeeping performance is evaluated using the Savitsky and Koelbel (1993) method. This completes one workflow loop. The detail flowchart on the optimization framework is presented in Fig. 2 with further discussion of this provided in subsequent sections.

![Fig. 1: Inter-process communication flow between applications](image-url)
2.1. Geometry tools

The geometry tools consist of a surface information retrieval module and a geometry manipulation module. Shown in Fig. 2, the surface information retrieval module is employed to generate B-spline representation of the hull while the geometry manipulation module changes the shape of the hull based on principal dimensions given by the optimizer.

The formulation of surface information module is based on the inverse B-spline method, Rogers and Adams (1990). A set of known surface (offset) data is used to determine the defining polygon net for a B-spline surface that best interpolates the data. This method is further expanded to yield a representation of a hard chine form that normally represents a planing craft, Mohamad Ayob et al. (2009). Three B-spline surfaces defined by their own respective polygon nets station-wise with the exclusion of the bow are connected to produce hard chines of the planing craft as shown in Fig. 3.