MDO of Hull Forms Using Low-Cost Evolutionary Algorithms

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ABSTRACT

This paper analyses the optimization of two modern hull forms in calm and rough water using wash waves and selected dynamic responses, respectively. Parametric hull form modelling is used to generate the candidate hull forms. For their hydrodynamic evaluation in calm water and in waves, a Rankine-source panel method and a strip theory one are used, respectively. The methodology is applied on a modern fast displacement ferry with a bulbous bow in two different ways, as a dual-level optimization method by optimizing first the bow bulb for sailing in calm water and then the rest of the hull form and as a single-level (conventional) optimization for the whole hull form including the bow bulb. Furthermore, it is implemented in the optimization of a high-speed, double-chine, semi-planing hull form. The MDO has been carried out using distributed, metamodel-assisted evolutionary algorithms. The effects of various options on the optimization algorithm are investigated, in order to reduce as much as possible the overall CPU cost.

1.0 INTRODUCTION

The performance of a vessel in calm water was always the major concern of the ship designer and the ship operator, since it is directly related to the installed horsepower as well to the maximum achievable speed. Nowadays that the cost of fuel emerged to the prevailing cost factor for waterborne transportation, the reduction of the power requirements at a given service speed is of prime importance. On the other hand, the contemporary statutory requirements for increased safety and improved passenger comfort pose high standards in the seakeeping behaviour of ships, another sector of hydrodynamic ship design and operation. Should additional goals be imposed by the owner, the classification societies, local authorities and international organizations, these can readily be included in the optimizations scheme as new objectives or constraints.

From the hydrodynamic point of view, the seakeeping performance of the vessel depends primarily on global hull form parameters, i.e. parameters affecting the overall characteristics of the ship and, thus, it should be taken into consideration during the preliminary design stage, when these properties are established. The calm water behavior on the other hand, is influenced both by the global and the local form parameters of the vessel. The incorporation of both local and global hull form parameters in an automated optimization process can only be accomplished if a powerful tool for the parametric hull modelling capable of treating a good amount of parameters is available.

In this respect the system developed by Prof. Nowacki and his successors at TU Berlin, currently available as FRIENDSHIP Modeler was used (Nowacki et al., 1995[1]). FRIENDShip Modeler incorporates a modelling technique based on a parametric curve generation approach developed by Harries and Abt (1998)[2] and Kim (2004)[3] and is capable of modelling the hull form in sufficient detail. In addition, the software allows for the generation of various hull forms with some of the form parameters modified and the rest of them kept constant. For reasonable modifications, the variants represent realistic hull forms. Harries and Abt (1998)[2] optimized a fast ferry hull form with respect to its calm water resistance using modeFRONTIER (2002)[4] as optimization tool. Furthermore, Abt et al. (2003)[5] presented an application of hull form optimization, where FRIENDShip Modeler was used in conjunction with SHIPFLOW (1999)[6] for CFD calculations. These works, however, refer to single objective optimizations.

Grigoropoulos et al (2004)[7] proposed a dual-discipline optimization scheme to optimize a hull form with respect to calm water resistance and seakeeping. They also adopted FRIENDShip Modeler for hull form modelling and modification and two commercial optimization codes to accomplish multi-objective optimization by evolutionary algorithms (EAs). In the case of seakeeping, more than one objective could be selected. The hydrodynamic evaluation of the hull forms was carried out by the Rankine source panel code SWAN1 (Sclavounos, 1996)[9] and the NTUA standard seakeeping code (SPP-86, 1994)[10] implementing the classical strip theory method (Salvesen et al, 1970)[11]. The methodology was implemented in the hull form design of two fast vessels, the parent of NTUA series of double-chine high-speed hull forms and a naval combatant.

More recently, Grigoropoulos and Chalkias (2008)[12] presented an improved MDO methodology using EAs with various options. In that paper the authors present also a state of the art review of the hull form optimization both for resistance and seakeeping. The authors proposed an optimization scheme involving FRIENDShip Modeler for hull form representation and modification, SWAN1 for the evaluation of wash waves, NTUA strip theory code to evaluate the seakeeping qualities and the EASY optimization software (Giannakoglou, 2004)[8], [22] to carry out a multi-objective optimization on the basis of a merit for wash waves and another one for seakeeping. Using the proposed methodology, the parent of the NTUA Series of double-chine, planing hull forms and a fast displacement ferry are optimized. Campana et al. (2009)[13] presented additional optimization tools in their exhaustive review of the numerical optimization methods for ship hydrodynamic design including viscous flow (Navier-Stokes equations) solvers.

In this paper, the two hull forms optimized by Grigoropoulos and Chalkias (2008)[12] are considered. Single- and Multi-Objective Optimization problems in one or more levels are solved using low-cost Evolutionary Algorithms. In the Multi-Objective cases more than one disciplines referring to the hydrodynamic performance of the hull forms are involved.

2.0 THE HULL FORM OPTIMIZATION PROBLEM

2.1 Hull Form Representation

A major concern of any optimization procedure is to associate the set of hull form parameters identifying the variants to a faired hull form. Parametric models offer the only way to establish this relation and to ensure that at each stage of the optimization a feasible model is produced. Then, state-of-the-art algorithms can evaluate its hydrodynamic performance both in calm and rough water as it will be described in the sequel. In this paper the parametric representation of hull forms is carried out using FRIENDShip Modeler. The latter, adopts the classic naval architect's technique by laying down a set of longitudinal lines (basic curves) including topological, differential and integral information to describe the hull. Examples of topological curves are the design sections' inclination angles at the waterline level, while the most characteristic integral curve is that of the sectional area. These basic curves are sufficient to describe exclusively and correctly different hull topologies, to produce all the design sections and to establish the geometry of the hull form. This is done in a three-stage process:

- Parametric design of a suitable set of basic curves such as deck, design waterline, flat-of-side, flat-of-bottom, center plane etc. The basic curves are built in agreement with a few prominent transversal curves like the main frame section, the transom, and, optionally, additional sections in the fore or aft body.

- Parametric modeling of design sections derived from the basic curves.
- Generation of a set of surfaces that either interpolate or approximate the design sections.

FRIENDShip Modeler is fully based on B-spline curves and surfaces determined by the form parameters on the basis of a variational formulation proposed by Harries and Abt (1998)[2]. Since fairness is a characteristic incorporated in the whole procedure, all surfaces are smooth and have high quality. There is no need for manual handling of any control point. Furthermore, any appendages fitted on the hull form have their individual and problem-oriented parameterizations. Efficient and effective form variations can thus be achieved and the approach is well-suited for automated optimization. In order to define the size of the initial design space, preliminary investigations on the resulting hull-forms were performed. The range of each parameter is selected so that its variation, with the rest of the parameters kept constant, leads to realistic hull forms. This does not mean that any combination of the parameters within their respective ranges produces acceptable hull forms.

The advantage of the above approach compared to traditional modeling methods is that the hulls are created and modified on a high level, so that the alteration of selected form parameters is sufficient to cause either local or global modifications.

2.2 Hydrodynamic Evaluation

As it was stated in the introduction, the optimization is carried out for two different aspects of the hydrodynamic performance of ships, the calm water and the waves. The former is traditionally evaluated on the basis of the calm water resistance. However, since potential flow codes neglect viscous phenomena, especially in the stern region, they cannot provide reliable estimations of the calm water resistance. On the contrary, they are more successful in predicting the profiles of the wash waves generated by a ship sailing in calm water, which form a reliable basis for the estimation of wave resistance. Furthermore, recently wash evolved to a major area of concern, especially for fast vessels serving short-sea shipping or operating in the vicinity of shoreline. Thus, it was decided to use the maximum wave height of the wave wash to quantify the performance of the hull form in calm sea. The maximum wave height is defined in Figure 1. In the examples considered in this paper the wave height is computed using longitudinal wave cuts at an athwartship distance of 0.25 L off the ship route, while the computational domain extends to 0.75 L.

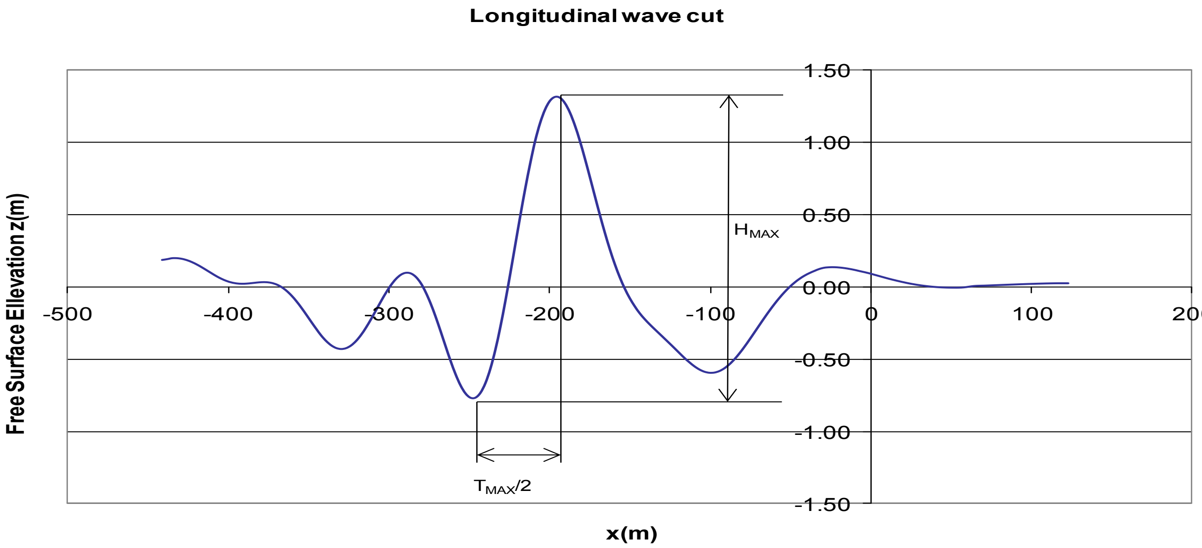

Figure 1: Longitudinal wave cut for the definition of the maximum wave height of wave wash.

The computation of the wave wash of the hull forms is based on the 3D panel SWAN1 software [15]. This is iteratively called so as to achieve convergence to the actual dynamic draft and trim of the vessel at each speed. The necessary interface that prepares (in an automatic manner) the detailed description of the hull form needed by SWAN1 has been devised.

Regarding seakeeping performance, the designer has to specify the most important dynamic response(s) to be minimized during the optimization process, and a proper merit to quantify them. The sum of the Root Mean Square (RMS) values of the responses in a set of encountered seaways, weighted according to their relative frequency of appearance along a typical ship route is a realistic measure of merit. However, the evaluation of this merit involves a lot of calculations and assumes the knowledge of operational details during the preliminary design of a ship. The problem is circumvented by exploiting the conclusion derived by Grigoropoulos (1989)[14], that it is sufficient to evaluate the peak value of the respective Response Amplitude Operator (RAO) curves. Since in [14] gradient-based optimization methods, that couldn't handle multi-objective cases, were used, the weighted sum of two seakeeping responses formed the objective function to be minimized. Within this paper only one seakeeping response, the absolute vertical acceleration either at the bridge or at the bow is used as the measure of merit for the seakeeping performance, without any reduction in the applicability of the proposed methodology. Any additional response could be included either within a weighted sum with the first one or as independent objective, to be handled by the evolutionary algorithm.

Though the same code used for the calm water performance evaluation (SWAN 1) could also perform the seakeeping calculations, the robust and reliable strip theory was preferred instead, so as to decrease the CPU time of each evaluation. Strip theory is a reliable method for seakeeping calculations and may lead to realistic forms of the RAO curve around its resonance for the vertical ship responses (Grigoropoulos and Chalkias (2008))[12], which is essential for the seakeeping optimization criterion. In particular, the SPP-86 software [10], developed by the Laboratory for Ship and Marine Hydrodynamics of the NTUA has been herein used for the strip theory calculations. SPP-86 incorporates the modified strip theory of Salvesen, Tuck and Faltinsen, S-T-F [11], disregarding the transom stern terms, coupled with the close-fit hull form representation proposed by Frank (1967)[16].

3.0 OPTIMIZATION ALGORITHM

In this paper, EAs, which are often used to solve single- or multi-objective optimization problems in engineering, undertake the design of optimal hull forms. EAs have the advantage of easily incorporating any *problem-specific evaluation software* (PSES) as a black box; for instance, in fluid mechanics, PSES may stand for a (commercial or in-house) CFD code, which is known to be computationally demanding. Despite their advantages, conventional EAs require many calls to the PSES for the evaluation of the evolving candidate solutions, before reaching the optimal one(s). For this reason, a technique that reduces the CPU cost of EAs and makes them competitive optimization methods for large-scale applications was developed. Some of them rely on the "smart" use of artificial neural networks, polynomial regression, Kriging models etc as low-cost/approximate evaluation models that displace the use of the costly PSES, as much as possible. These are usually referred to as *surrogate evaluation models* or *metamodels*. Another way to cut down the cost of an EA-based optimization is by using distributed search schemes. The combined use of the two methods is certainly possible.

There are various ways to incorporate metamodels within an EA, so there are various *metamodel-assisted EAs* (MAEAs). Many relevant papers are based on the use of *off-line trained metamodels*, i.e. metamodels which are trained separately from the evolution, Giannakoglou (2002)[17], Bull (1999)[20], Shyy et al. (2001)[21]. In its simplest variant, a single metamodel is considered for the entire search space and the whole evolution. This is trained beforehand on a series of representative training patterns. "Design of experiments" methods can be used to scan the search space and generate the necessary training patterns; this is a costly process since their evaluation is based on the PSES. The EA-based search is exclusively based on the metamodels and locates "optimal solution(s)", at very low CPU cost. However, these may deviate from the real optimal solution(s). So, they are re-evaluated on the PSES and, if necessary, more samples in the design space are generated and evaluated on the PSES. The training set is enriched, a new metamodel is trained and the EA starts anew. On the other hand, in the variant of metamodel-assisted EAs (MAEAs) with *on-line trained metamodels*, these are trained on the fly, separately for each new population member, Giannakoglou (2002)[17], Karakasis et al. (2006, 2003)[18, 19]. Each time a new population member is generated a few already evaluated neighbouring individuals are selected and used to train the corresponding metamodel. This individual is "inexactly" pre-evaluated (IPE) on the metamodel and this is how all population members are pre-evaluated too. Then, only the top few population members are re-evaluated on the PSES, before proceeding to the next generation.

In distributed EAs (DEAs), a small number of sub-populations (demes or islands) are evolving in semi-isolation, by using the same or different evolution policies and by regularly exchanging promising individuals. Different migration policies and possible variations in the exploitation/exploration features of each deme give rise to more efficient DEAs. Based on the relevant literature, Karakasis et al. (2003)[19], DEAs outperform single-population EAs. By handling sub-populations, rather than a single population per generation and allowing metamodels to be used by the EA of each deme, a distributed MAEA (DMAEA) such as the one used herein, has been created.

In this work, the design of the full forms under consideration is carried out by means of a DMAEA as implemented by the EASY optimization platform [22], developed and brought to market by the Parallel CFD & Optimization Unit of the School of Mechanical Engineering of NTUA. The core of the optimization method is a (μ,λ)-EA, where μ and λ are the parent and offspring population sizes, respectively. The use of metamodels within the distributed search decreases the number of the evaluations needed to reach the optimal solution(s) along with the computational cost of the optimization. To further reduce the wall clock time more than one candidate solutions are concurrently evaluated by assigning them to the available processors of a multi-processor system.

As said before, in the DEA, the population is divided into concurrently evolving demes. They regularly exchange promising solutions and this inter-deme communication is controlled by a number of user-defined parameters, such as:

- The migration frequency, which stands for the generation interval between successive inter-deme migrations.
- The migration rate, determining the number of individuals allowed to migrate from deme to deme.
- The emigrant selection scheme, i.e. criteria based on which emigrants are selected. A common practice is that the current-best of each deme becomes an emigrant. However, depending also on the migration rate, one or more randomly selected ones can be allowed to migrate too.
- The migration route, i.e. a directed graph connecting nodes used to determine the allowed migrations among the demes. Ring, tree-like, star, grid or hypercube connectivity types can be used.
- The replacement policy in the destination deme which determines the selection of the individual to be displaced by the immigrant. Usually, the worst individuals of each deme and/or some randomly selected ones (determined by a user-defined probability) are replaced.

In the DMAEA, the IPE technique applies separately to each deme. Note that the EA (or DEA, in this case) evolves for a small number of generations using exclusively the PSES to evaluate all population members tool. This is absolutely necessary in order to archive the minimum number of evaluated individuals into a database (DB), before training metamodels. Once this is achieved, the offspring of each generation are initially evaluated on metamodels trained on a small number of neighbouring (in the design space) DB entries and the objective(s) value(s) are approximated. In multi-objective problems, a scalar cost value is assigned to each offspring based on dominance criteria and the SPEA2 technique, Zitzler et.al (2001)[23]. The top population members, based on the objective function values predicted by the metamodels, are selected to undergo evaluation on the PSES. The population (or sub-population, in a DEA) of the next generation is formed using the evolutionary operators (selection, crossover, mutation), acting on a population or deme with most of their members being evaluated on the metamodels and only just a few of them on the PSES.

4.0 APPLICATIONS

4.1 Fast Displacement Hull Form Design

The first case is concerned with the design of a modern fast displacement ferry with bow bulb shown in Figure 2. Four optimization runs, either for calm water of for both calm and rough water performance, were carried out at a speed corresponding to Fn = 0.35. The design variables along with their lower and upper bounds are given in Table 1. The volume of displacement was allowed to vary within preset limits during the optimization.

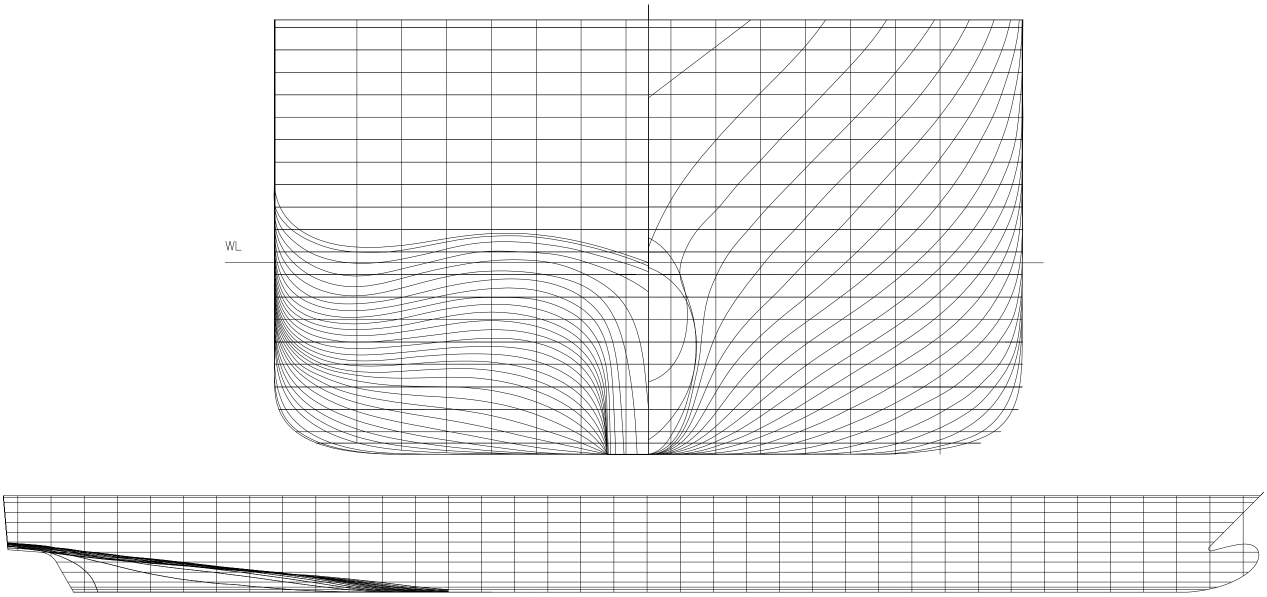

Figure 2: Body Plan and Profile of the parent of fast displacement hull form

The first two optimization runs constitute, practically, the two steps of a two-stage optimization process (C1). In the first of them, the bulb form was solely optimized for calm water performance. To this end, a MAEA was used to compute the optimal set of values for the first nine design variables among those tabulated in Table 1. The remaining were kept fixed at the values of the parent hull form, and are shown in Table 1 along with the computed set of values for the design variables corresponding to the optimal bulb; see column labeled with "*1st Stage OB Case 1 (SOO)*".

In the second run, the hull accommodating the bulb derived in the previous stage was optimized for both calm and rough water performance using the last eight design variables of Table 1. As shown in Figure 4, the two-objective optimization led to a Pareto front with four non-dominated solutions. These are marked with blue diamonds in Figure 4; note that three of these points are close enough and give the impression that they almost coincide with the blue diamond on the right. The left and one of the three almost coinciding points on the right are analyzed in the two columns of Table 1 marked with "*2nd Stage OH Case 1-opt1 (MDO)*" and "*2nd Stage OH Case 1-opt2 (MDO)*".

The third run (C2) aimed at simultaneously optimizing the hull and the bulb, in calm water (one objective: minimization of the wash wave height). So, the entire set of tabulated design variables was used. This optimization was repeated three times using an EA, a DEA and a DMAEA so as to quantify the gain in CPU cost from the use of the distributed search and/or the metamodels (according to the IPE technique). A (40, 60)-EA, a DEA with 2x(20, 30)-EA (i.e. with two demes) and a DMAEA with 2x(20, 30)-MAEAs were used. In the DMAEA both demes were assisted by RBF networks as metamodels for the IPE of the population, which was activated after the first 200 evaluations on the PSES. Once the metamodels have been activated, 8 individuals per generation and deme were exactly re-evaluated on PSES. In all cases a stopping criterion of 1000 evaluations on the PSES (often referred to as *exact evaluations*) was imposed. The convergence histories are presented in Figure 3, where it can be seen that DMAEA outperforms DEA which, in turn, outperforms the conventional EA. The optimal fast displacement ferry geometry obtained using DMAEA is given in Table 1, column marked with "*OHB Case 2-DMAEA (SOO)*".

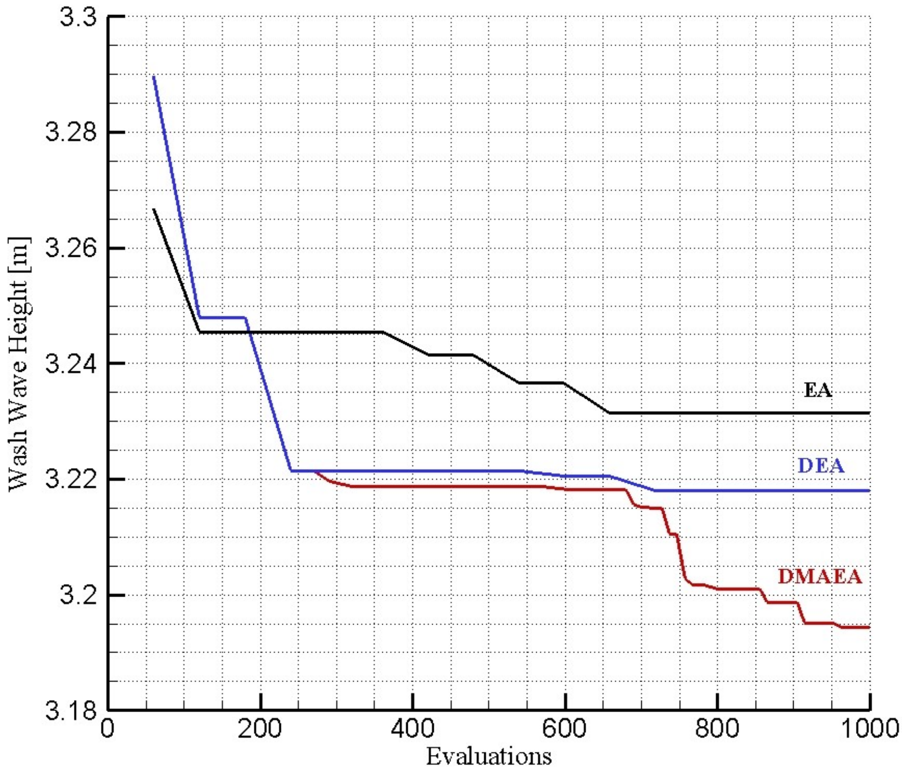

Figure 3: Fast displacement hull form design. Comparison of the EA, DEA and DMAEA for the single objective optimization (SOO) problem.

The fourth run (C3) used the same design variables (17) as before and two objectives, i.e. the performances in calm water and in waves. This was exclusively based on a DMAEA, according to the previous finding. A stopping criterion of 2000 exact evaluations was imposed. The resulting front of non-dominated solutions is also included in Figure 4 (red squares). For the sake of completeness, a (green) point that corresponds to the optimal configuration obtained by the DMAEA for the SOO run of Figure 3 (after being re-evaluated on both PSES) is also included. Based on this figure, the MDO strategy provides very competitive hull and bulb configurations.

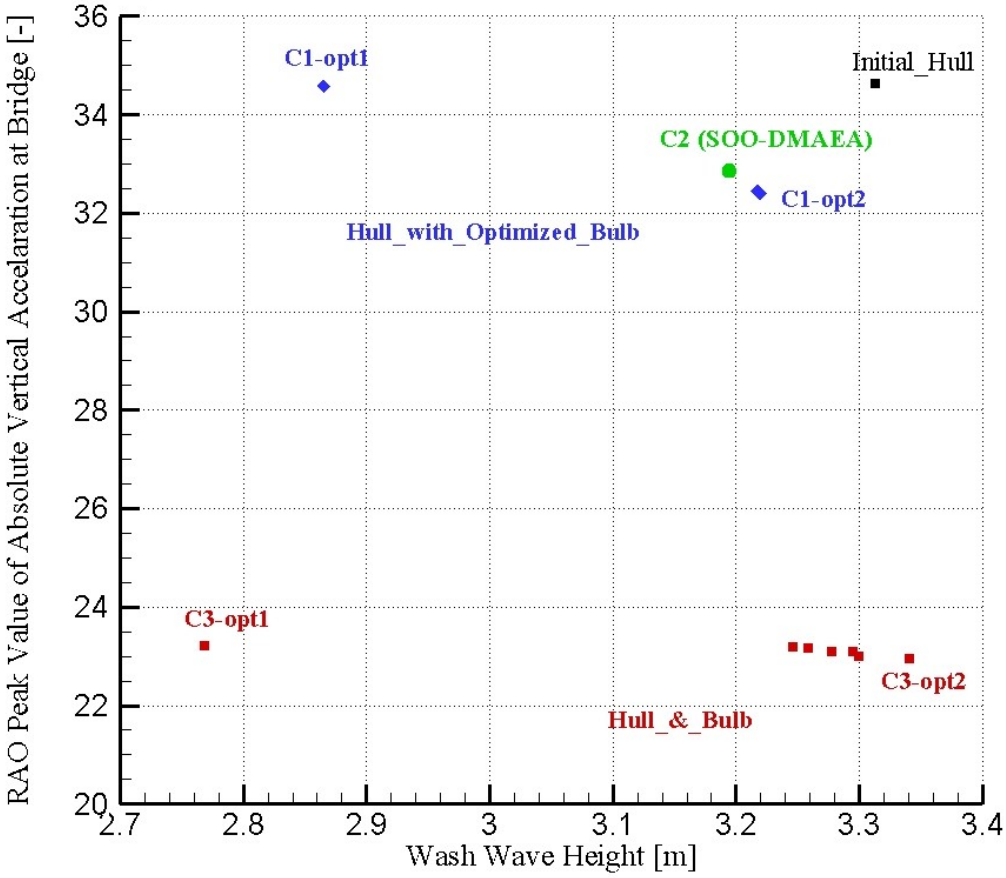

Figure 4: Fast displacement hull form design. On this figure the SOO results for the bulb only and the hull & bulb are presented. The respective MDO Pareto front is derived via DMAEA.

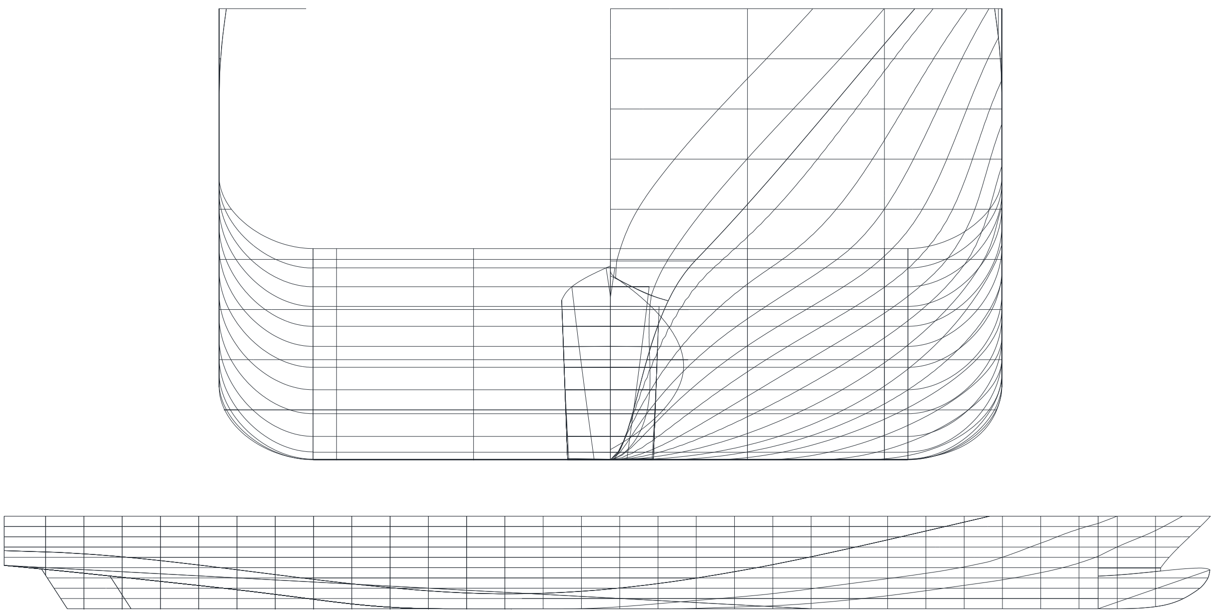

Figure 5: Body Plan and Profile of the optimized C3-opt1 fast displacement hull form (17 parameters, DMAEA).

Table 1: Design variables of the fast displacement hull form investigated and their range of variation

Var. No.	Design Variables	Units	Lower Bound	Upper Bound	Initial Value	1st Stage OB Case 1 (SOO)	2nd Stage OH Case 1-opt1 (MDO)	2nd Stage OH Case 1-opt2 (MDO)	OHB Case 2-DMAEA (SOO)	OHB Case 3-opt1 (MDO)	OHB Case 3-opt2 (MDO)
1	Distance of the fwd perpendicular (FP) to the fwd tip of the bulb	[m]	7.200	7.800	7.600	7.387	7.387	7.387	7.529	7.723	7.800
2	Vertical position of the fwd tip	[m]	-2.000	0.000	-1.000	-0.774	-0.774	-0.774	-0.323	-0.323	-0.774
3	Vertical position of the max. horizontal top position of the bulb at xTop	[m]	0.000	1.200	0.800	0.929	0.929	0.929	0.480	0.000	0.000
4	Position ahead of the FP of the max. horizontal top position (=xTop)	[m]	5.500	7.000	6.000	5.232	5.232	5.232	6.300	6.100	6.700
5	Height of the bulb at FP measured from the lower edge of the bulb	[m]	5.100	6.000	6.000	5.952	5.952	5.952	5.940	5.520	5.400
6	Area of the section at FP	[m^2]	13.0	20.0	14.3	12.0	12.0	12.0	13	18.6	20.0
7	Angle of the sectional area curve of the bulb at FP	[deg]	-10.00	25.00	-7.00	18.39	18.39	18.39	18.00	3.00	-5.00
8	Area coefficient of the fwd part of the sectional area curve of the bulb	[-]	0.700	0.900	0.750	0.650	0.650	0.650	0.860	0.793	0.887
9	Area coefficient of the aft part of the sectional area curve of the bulb	[-]	0.400	0.500	0.480	0.437	0.437	0.437	0.400	0.460	0.460
10	Centroid shift of sectional area curve (SAC)	[%]	0.000	1.500	0.000	0.000	0.097	0.000	0.000	0.194	0.484
11	Fore body prismatic coefficient	[-]	0.565	0.588	0.577	0.577	0.565	0.565	0.565	0.570	0.574
12	Sectional area coefficient of a ref. frame in the bow region	[%]	10.000	20.000	13.000	13.000	10.000	10.000	10.000	10.000	10.645
13	Tangent of SAC at FP	[deg]	0.00	20.00	0.00	0.00	18.06	16.77	9.03	10.97	17.42
14	Flare at deck of the ref. frame in the bow region	[deg]	45.00	80.00	65.00	65.00	46.13	61.94	57.42	70.97	57.42
15	Tangent at bow of the design waterline	[deg]	8.00	20.00	11.00	11.00	19.20	19.20	8.00	12.80	19.20
16	Area coefficient of the fore body design waterline	[-]	0.570	0.630	0.600	0.600	0.630	0.630	0.626	0.626	0.630
17	Flare at waterline at the ref. frame in the bow region	[deg]	30.00	55.00	43.00	43.00	31.61	33.23	34.03	33.23	47.74

Notes:

a. OH = Optimized Hull, OB = Optimized Bulb, OHB = Optimized Hull and Bulb

b. In Case 1 two additional hull forms very similar to opt2 have been derived by MDO which cannot be distinguished in Fig.4.

The configurations obtained by the C3 optimization run low resulted in hull forms possessing low wash wave characteristics and perfect seakeeping performance compared to the parent hull (black point in Figure 4). Following Figure 4, among the seven members of the front, one (C3-opt1) depicts significant improvement in both disciplines. On the other hand, C3-opt2 though performs similarly to the parent hull form in calm water, is the absolute winner with respect to seakeeping. Thus, it seems reasonable to select C3-opt1 for further analysis and to plot its body plan and its profile on Figure 5.

4.2 Double-Chine Hull Form Design

As the second case, which is concerned only with MOO, the parent hull form of the NTUA Series of double-chine, planing hull forms, Grigoropoulos and Loukakis (2002)[24] has been selected. Although this hull form has constantly increasing warp in the stern to bow direction, it is composed of relatively simple lines and curves (Figure 6). Furthermore, the immersion of the upper and lower chine is critical for the hydrodynamic performance of the hull form at high speeds.

In this case, the two-objective optimization was carried out using DMAEA with a (20, 35)-MAEA for each one of the two demes used. In each deme the IPE technique was activated after the first 120 evaluations on the PSES. During the metamodels-based generations, 6 individuals per generation and deme were exactly re-evaluated on the PSES. The stopping criterion of the optimization was set to 2000 exact evaluations.

The design variables used for the optimization along with their lower and upper bounds are summarized in Table 2. The hull form was designed to perform optimally in calm and rough water. The absolute vertical acceleration at the bow was selected as critical response to quantify seakeeping behavior. The obtained front of non-dominated solutions is presented in Figure 7. In the same figure the parent (initial) hull form is also included. The body plans of the parent and three members of Pareto front are shown in Figure 7 and their characteristics are provided in Table 2.

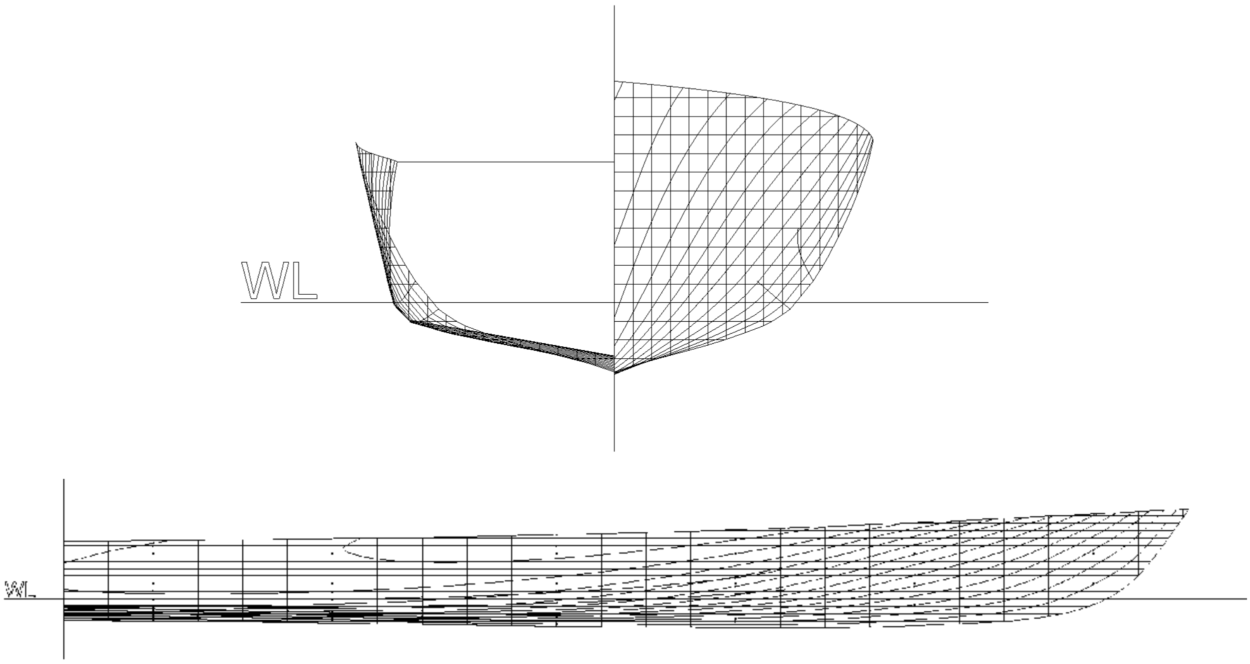

Figure 6: Body Plan and Profile of the parent of the double-chine hull form

Table 2: Design variables of the NTUA Series parent hull form investigated and their range of variation

Design Variables	Units	Lower Bound	Upper Bound	Initial Value	OH P1	OH P2	OH P3
Angle of entrance of design waterline	[deg]	0.00	20.00	10.00	18.06	20.00	20.00
Longitudinal Position of FP	[m]	34.950	37.000	34.950	35.082	36.934	36.934
BEVEL.depth at transom (distance of chines-connecting line from the hypothetical intersection of bottom and side)	[m]	0.100	0.400	0.140	0.100	0.100	0.110
Area coefficient of forebody deadrise angle distribution curve	[-]	0.800	0.900	0.800	0.803	0.800	0.800
Area coefficient of the forebody distribution curve of the flare at deck angle	[-]	0.550	1.000	0.750	0.652	0.724	0.623
Inclination of the transom with respect to the vertical in the profile view	[deg]	10.00	25.00	14.00	23.00	23.00	23.00

Note: OH = Optimized Hull

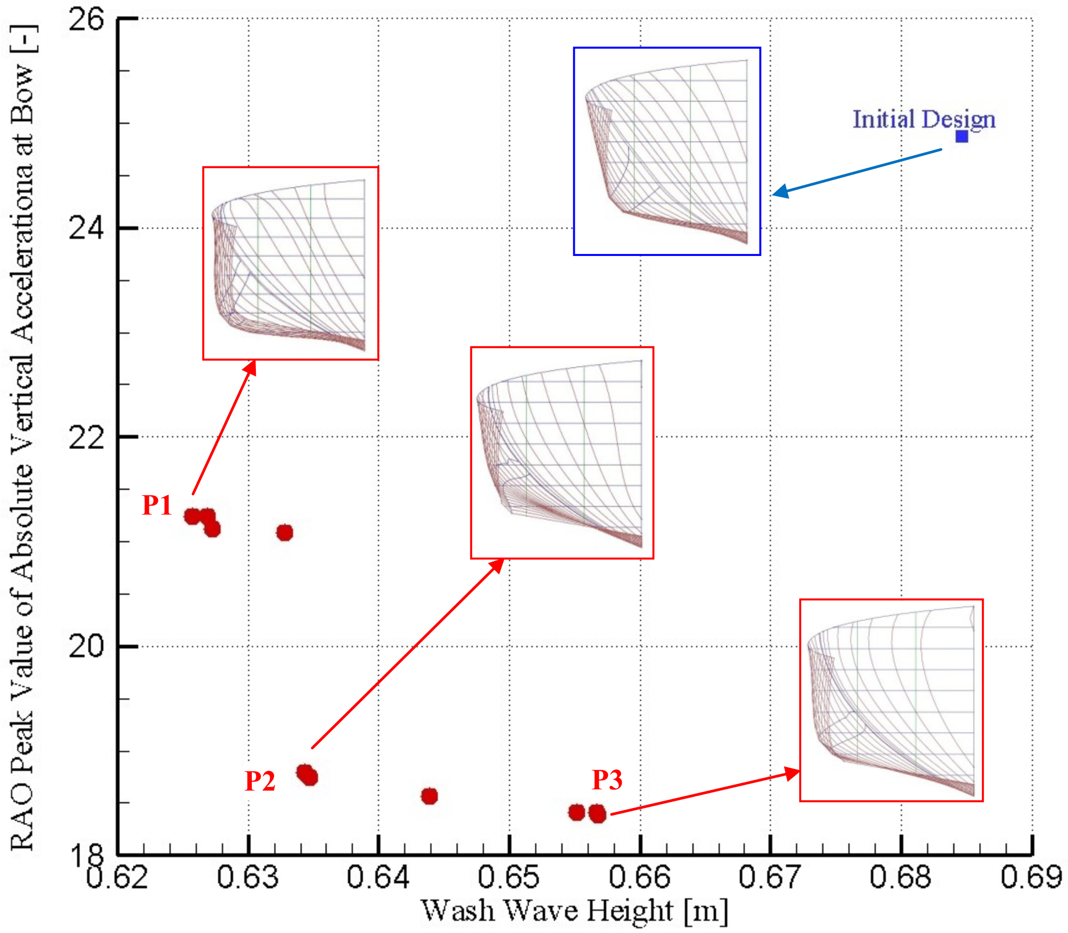

Figure 7: Double–chine hull form design. Front of non-dominated solutions obtained using the DMAEA.

5.0 CONCLUSIONS

In this work two modern ferry hull forms, a displacement and a semi-displacement one are optimized for their performance in calm water and in waves. In the former case, various optimization options were implemented to reconfirm that DMAEA is better performing in terms of CPU cost. Using this option, hull forms with highly improved characteristics compared to the parent one were derived in both test cases. Although only two disciplines were selected for the hull form optimization in this paper, additional disciplines can be included in the proposed procedure in a straightforward manner.

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