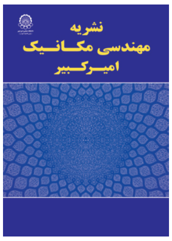

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Multi-objective Optimization for Simultaneous Ship System Design

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ABSTRACT: The optimization of ship system has always been one of the most important aspects of design to reduce the costs, mechanical losses and to increase component life. The proposed design methodology represents a new approach to optimize the propeller-hull system simultaneously. In this paper, two objective functions are considered, the first objective function is lifetime fuel consumption and the other one is cost function including trust, torque, open water and skew efficiencies. For a comprehensive optimization, the hull form and the propulsion system are considered as an integrated system and the emission profile of the vessel is used to minimize both objective function. The cavitation and propeller stress also are used as problem constraints. The well-known evolutionary algorithm based on NSGA-II is employed to optimize multi-objective function, where the main propeller and hull dimensions are considered as the design variables. The results are presented for a series 60 ship driven by the L51/60DF engine and B-series propeller. The results showed the proposed method is an appropriate and effective method for simultaneous design of propeller-hull system and is able to minimize both objective functions significantly.

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1- Introduction

Optimization of ship system is one of the most important aspects of ship design and leads to ship cost reduction, improving performance and increasing propulsion system lifetime. For a comprehensive and detailed ship hydrodynamic optimization, all objective functions influencing problem solving need to be considered, because it is clear that consideration of an objective function without the other ones gives unrealistic and impractical results. In addition to the parameters that usually are considered in the propeller design and optimization, the skew can be used as other important parameters in the propeller design. This parameter affects cavitation and propeller efficiency. Most of the work that has been done in the design and optimization of hull and propeller problem has been optimized only propeller or hull [1-4]. In the recent years, some studies were done on reducing Life Fuel Consumption (LFC). They considered the propeller, prime mover, and vessel as one integrated system and employed the probabilistic operational profile of the vessel to minimize LFC [5, 6].

Therefore, this paper concentrates on multi-objective evolutionary optimization of the coupled propeller and hull system of a vessel using the well-known NSGA-II. Two main objectives were considered: total LFC of a vessel and linear combination of propeller open water and skew efficiencies, thrust and torque as cost objective function. The ultimate objective is to design a ship system with minimum LFC and cost that considers cavitation and blades stress of propeller as constraints.

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2- Methodology

The total calm water drag of a ship at a given speed is made up of two components: the viscous drag, due to moving the ship through a viscous fluid and the wave drag, due to moving the ship on the surface of the water. The former is computed by combining of an experimental formula and ITTC-1957 model-ship correlation line and the latter is calculated by Michell's theory. This theory is a relatively simple and time saving method which presents an integral equation to compute wave resistance. This theory is valid only under certain restrictive conditions that the fluid is homogenous, incompressible, inviscid and hence the flow is irrotational, surface tension effects can be neglected, the slope of the hull surface relative to the center-plane is small (slender hull), the wave heights generated by the ship hull are small compared with their lengths, the ship does not experience any sinkage or trim and that the water infinitely deep and laterally unbounded [7].

The Blade Element Theory (BET) is one of different methods for calculating propeller performance. The BET in contrast to the momentum theory is concerned with how a propeller generates its thrust and how this thrust depends upon the shape of the propeller blades.

By considering the probabilistic ship speed profile along with the ship resistance and the Specific Fuel Oil Consumption (SFOC) of the engine, performance comparisons can be made between different ship designs that consider the system performance over its design life. To consider the life time of the vessel in the optimization process the LFC and Cost functions, two life time objective functions used in this work, are computed by taking into account the probabilistic mission profile of the vessel. The Cost function is a linear combination of propeller open water and skew efficiencies, thrust and torque loads as already mentioned. Two constraints are used in the NSGA-II algorithm as optimization algorithm including cavitation based on Keller criterion and propeller strength constraint cantilever beam theory. Finally, the algorithm is repeated and once the algorithm reaches its maximum generation, the Pareto front is drawn and the final optimal solution is selected from it based on owner's or designer's conditions. The parameters changed in the algorithm are known as design variable which in this study ship length to beam ratio, beam to draft ratio, draft, propeller expanded area ration, number of blades, diameter, pitch ratio, advance coefficient and skew angle make up the design variable vector.

Weight amounts of thrust, torque, open water and skew efficiencies are given in Table 1. Because the two performances torque and skew efficiency do not play a role in obtaining LFC function, the other two performances thrust and open water efficiency have greater weights in cost function.

Table 1. The performance weights in cost function

Skew efficiency	Efficiency	Torque	Thrust
0.3	0.2	0.3	0.2

3- Results and Discussion

The results and analysis of the optimization run using the previously defined objective and constraint functions are presented in this section. Calculations were made on a Windows-based personal computer having 2.4-GHz CPUs. The required time for running this program code is about 5 hour.

As a result of the evolutionary process, the NSGA-II promotes spreading of the individuals along the Pareto front, as shown in Fig. 1. The end part of generations is utilized by the algorithm to distribute the solutions as uniformly as possible on the front. This is a consequence of maintaining of a diverse set of solutions in the non-dominated front by using the NSGA-II. This uniform distribution is more due to the selection mechanism of the best solution in the optimization algorithm. We select the solution that is as close as possible to utopia point and is called compromise solution as shown in Fig. 1. The results confirm that there is an apparent conflict between the LFC and cost objective function, that is, increasing in LFC will lead to decreasing in Cost and vice versa. The result also show that the values of both objective function of compromise solution in comparison with those of initial solution are improved significantly.

Considering the probabilistic speed profile of the vessel, V = 12.35 m/s is assumed as the ship design speed for comparing the main characteristics of the ship system. The percent of the characteristics variations of initial and compromise solutions at the design speed is reported in Table 2. As can be seen in this table the amount of the torque reduction is more than that of thrust and the open water and skew efficiencies are also increased, therefore the amount of both the objective functions are improved.

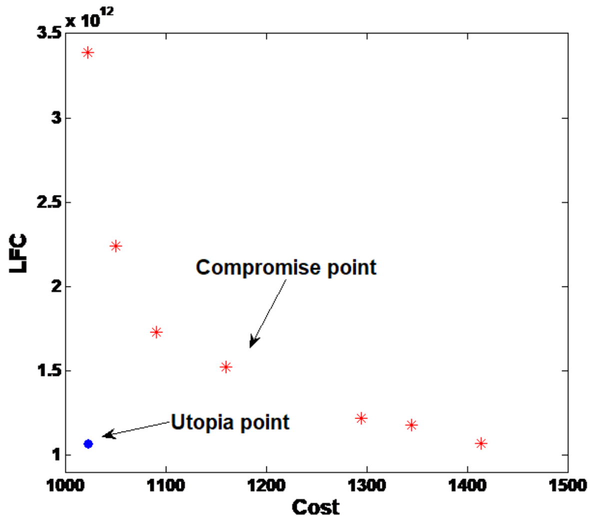

Figure 1. The Pareto front, utopia and compromise solutions.

Table 2. Variation percent of the main characteristics of the ship system

Characteristic	η_{Skew}	η_o	Q	T	R_T
Initial solution	0.678	0.693	419.04	269.45	249.75
Optimal solution	0.713	0.714	88.47	94.55	87.63
Variation percent	5	3	78	65	65

4- Conclusions

It is apparent from this study that the technique proposed here has high capability and is appropriate for preliminary design of ship system. From the results, it can be shown that all performance of ship system except the required thrust have been improved and in general the LFC and cost functions have been minimized significantly.

The effect of skew angle is important on the hydrodynamic characteristics and is a new operating parameter to estimate propeller efficiency in this investigation.

Because the obtained design variables of the optimal hulls are relatively constant and equal to each other, it can be concluded that the hull variables have converged faster than those of the propeller and the difference of the optimal objective functions is more influenced by the propeller variables.

One of the key factors for approximating total ship cost is the LFC, thus improving the propeller and a hull performance which minimizes the LFC function could have a significant impact on reducing the lifetime cost of the vessel.

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