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Design and optimization of Ship Hull for better fuel efficiency

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Abstract

Fuel economy and environmental friendliness are attracting lot of interest in the marine sector because of ever strict environmental laws and erratic fuel costs. By cutting drag and hence lowering carbon dioxide emission and fuel consumption, an effective hull shape may increase the general efficiency of a maritime vehicle. Hull design influences not just ship stability but also general performance in efficiency. Various techniques used in recent years to lower the fuel consumption of maritime vehicles are examined in this work. Techniques for weight minimization, micro bubble utilization and innovative coating application, hull shape optimization. The YOHANA hull design, materials, and variables like pressure, velocity, draft and channels of flow are being optimized using the analysis tool quite well. The outcomes of the simulation are in line with current knowledge and literary debates.

Keywords: Efficient Hull; Fuel Consumption; Marine Vehicle: Design; Efficiency and Ecofriendly.

1. Introduction

Global shipping is the foundation of global commerce. The great bulk of products are transported by ship. Simultaneously, shipping faces a variety of economic and regulatory obstacles. Economically, shipping challenges long-term high fuel oil costs, excess capacity, and poor freight rates. On the regulatory front, new environmental restrictions will be or are expected to be implemented in the future years. Increasing energy efficiency reduces fuel costs and emissions [1]. So, hull form design and optimization are critical topics in the shipbuilding business. Because an efficient hull shape will aid to minimize total resistance acting on the vessel, resulting in fuel savings and lower emissions. We are primarily concerned with reducing fuel consumption by addressing the ship's hull construction, since the ship's hull structure is the primary factor determining any impacts on the ship. In ship design, the form of the hull is one of the most significant design characteristics that must be decided as soon as feasible. This is owing to its influence on overall performance efficiency [2]. In 2010, a vessel saved 9% by decreasing its speed, which spurred future ship manufacturers to decrease the installed power on ships to boost fuel economy. It is, nevertheless, critical to ensure that adequate propellant power is available to navigate through difficult weather circumstances. As a result, optimizing hull shape with speed in mind should not only lower the hull's constant resistance but also assure performance and agility in rough sea conditions.

2. Literature Review

Optimization strategies have existed for a long time. The Simplex algorithm, for example, goes back to 1947. By the 1960s, "classical" (local) optimization techniques had been reported and proven for a variety of optimization problems.

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Initially, efforts were made to integrate thin-ship or slender-body theory with formal optimization to obtain "minimum resistance" hull forms, but the resultant hull shapes often appeared weird, with wavy waterlines or decanter-like hull sections in the bow. Boundary element approaches (panel methods) for propellers and wave resistance of hulls have advanced to industrial maturity, as reviewed. Viscous CFD approaches arise in various sectors, and around 1990, the first RANSE (Reynolds averaged Navier-Stokes equation) simulations of ships appear in research applications.

By the year 2000, wave resistance codes (based on potential flow theory) have become industry standard tools, as noted. These codes have been thoroughly evaluated, and their capabilities and drawbacks are widely recognized in the ship hydrodynamics field. Typical representations are SHIPFLOW (XPAN), RAPID, nu-SHALLO, and FS-Flow. Viscous CFD applications (with RANSE solvers) evolve dynamically. Free-surface RANSE applications that capture breaking waves, as well as moving-grid applications (for propeller-hull interaction with moving propellers), are particularly relevant to hull shape design (optimization), as noted [3]. Genetic algorithms (GAs) become considerably more appealing with the introduction of parallel computing. As a result, GAs and similar evolutionary methods (e.g., particle swarm optimization) became common technologies and were included into optimization shells. Optimization shells got more powerful and user-friendly, with graphical user interfaces and the ability to execute programs across many operating systems [4].

Currently, improvements are being made to the size of ships and hull shapes in order to lower overall weight and go quicker while using less fuel. Increasing the length while decreasing the beam and keeping the draft, displacement, and block coefficient (Cb) unchanged often results in improved hull efficiency, assuming extra ballast is not required to maintain acceptable stability. A larger length/beam ratio tends to decrease wave resistance, but a lower beam/draft ratio tends to reduce wetted surface and hence frictional resistance. They advocated reducing fuel efficiency by improving the ship's hull construction [5].

The improvement areas include:

- Fore body optimization
- Aft body optimization
- Propeller wake optimization

2.1. Fore body optimization

The properly designed bulbous bow reduces wave-making resistance by creating its own wave system that is out of sync with the hull's bow wave. This leads to a cancellation effect and a decrease in total wave-making resistance. The flow has a mostly horizontal direction, so reducing the occurrence of eddy effects at the front bilge. Bulb optimization considers physical attributes such as volume, vertical displacement of the centre of volume, longitudinal displacement, and shape. Enhancing bulb characteristics is a complex process. We need to choose the appropriate bow that complements the design. Various bulbous bow designs exist, such as the pear-shaped bow, gooseneck bow, V-shaped hull, and others. These modifications may be implemented utilizing sophisticated computer software to smooth the B-spline and monitor pressure variations in the vicinity of the hull.

Bow flare impacts velocity and introduces resistance to waves. V-shaped flares are preferred over U-shaped flares due to their ability to reduce velocity while avoiding an increase in resistance. The current lack of information of the increased resistance caused by noticeable flare in heavy seas is leading to its neglect throughout the design phase. However, efforts are being made to get a better understanding of this phenomenon.

2.2. Aft body optimization

The aft body optimization comprises attempts to reduce stern waves, optimize flow into the propeller, and eliminate eddy effects. A correctly built stern may lessen aft shoulder crest, deep wave trough, and stern waves. Improving the nature of the stern flow may increase propulsive efficiency. Because of the presence of appendages like as a rudder and propeller, optimizing the aft body is more difficult than optimizing the front body. Single screw sterns front of the propeller might be V-shaped, U-shaped, or bulb shaped. The bulb form is now preferred because the better wake lowers cavitation and vibration. This is an environmentally beneficial design since Pram type stern hulls are being utilized to transfer the longitudinal Centre of Buoyancy (LCB) aftwards, allowing for smoother forward shoulders and lower waterline entry angles, hence reducing resistance [7 - 8].

Considering the many difficulties and trends mentioned previously, smart design may be built by merging the design automation process with computation intelligence while taking into account through-life design in i4. An intelligent hull automation design tool may be created by integrating evolutionary tactics (genetic algorithms), surface morphing techniques for geometry manipulation, and sophisticated simulation methods such as computational fluid dynamics (CFD). This tool may be used to automate the process of designing and optimizing the shape of a ship's hull. It can also be integrated with smart manufacturing and smart goods throughout the lifespan of the product, leading to the creation of more innovative hull designs.Evolutionary computer approaches, like as Genetic Algorithms (GA), have shown to be quite beneficial and have become common in many HFDO processes. GA is a nature-inspired search heuristic approach based on Darwin's Theory of Natural Selection and the 'survival of the fittest' concept. Unlike traditional optimization methods, GA has many desirable characteristics and provides considerable benefits in effectively navigating a wide and hard design search space to create globally optimum non-dominated solutions. The concept of 'genes' and 'chromosomes' is fundamental to GA's operation. Information interchange between these chromosomes occurs across many rounds via genetic operators like as selection, crossover, and mutation, with the fittest solutions replacing weaker ones, ultimately resulting to a set of optimum solutions [9].

A numerical fairing procedure may be used in early design to obtain high-quality ship hull form geometry. The approach uses variational optimization to lower a fairness measure tied to surface curvature while adhering to geometric restrictions to ensure the final form has the appropriate geometric features. A B-spline surface with the initial hull shape is controlled by the optimization variables. The problem is solved via nonlinear direct search. The notion is used to traditional ship designs to show that suitable design objectives and geometric limits may provide hull forms with better fairing. The fairness objective function greatly affects hull surface quality. Highly nonlinear exact fairness functionals provide high-quality surfaces but need a lot of computation. Three-dimensional fair hull form is a key marine vehicle design factor. The finished hull must be shaped and function well. Early in the design process, there is limited data to construct a fair hull shape, thus the designer may start with a rough sketch or a few experience- or empirical-based criteria. Offsets are control points that shape a ship's hull. Sketchers and designers have traditionally utilized physical splines to construct smooth curves with offset points. The manual method requires repetitive two-dimensional design curve fairing on numerous planes. However, this iterative technique needs a significant amount of time and skilled workers, both of which are unlikely to be available in a fast-paced contemporary ship design process. However, since the hulls have a complicated shape with many offsets, it is not unexpected that forms with wrinkles or other faults on the surface appear [10].

2.3. Research on deep learning method in ship hull form optimization

This study describes a multi-objective optimization for ship design with no linear waves that use the Deep Belief Network (DBN) technique. The DTMB5512 ship with three variables is optimized using no linear waves. The MOPSO is chosen as the best algorithm. To increase the computation efficiency of CFD-based optimization, a DBN technique is presented to estimate the total resistance coefficient Ctw, the heave transfer function TF3, and the pitch transfer function TF5. The optimization findings suggest that the strategy used in this research can reduce the DTMB5512 ship's overall resistance, as well as its heave and pitch transfer functions. The optimization goal values were lowered by roughly 4.05%, 0.63%, and 1.01%, respectively [11]. The present work focuses on the following point given below:

- To investigate on the different hull optimization technique and choosing the efficient way.
- To determine the main size of the ship without affecting the stability of the ship.

3. Experimental Design and Plan

3.1. Hull Design

The hull is the watertight body of a ship. The shape of the hull dependent upon the need of the design, Shape ranges from nearly box structure, to a sharp surface of revolution (Table.1 and figure.1). The used software for designing the hull structure is delft ship. We have chosen Yohana ship which is a commercial RORO type ship which has IMO number 7812880 sailing under the flag state of Eritrea.

3.2. Hull materials

Most of the time widely used materials are steel, fiberglass, aluminum, wood and composite material.

3.3. Steel

It is robust, but it weighs around 30% more than aluminium. The material rusts unless it is shielded from water (by painting it). Sheet or plate may be utilized for a whole metal hull or for individual structural elements.

3.4. Fiberglass

Fiberglas is a composite of glass fibre reinforcing material and plastic resin. The resultant structure is robust under tension, but it must frequently be put up with several heavy layers of resin-saturated fiberglass or reinforced with wood or foam to give rigidity. GRP hulls are essentially corrosion-free; however, they are not typically fireproof. These may be solid fiberglass or sandwich (cored), with a core of balsa, foam, or other similar material placed after the exterior layer of fiberglass is put to the mold but before the inner skin. Most fiberglass boats are now built in an open mold, with fiberglass and resin poured by hand (hand-lay-up process) [12]. Some are now made via vacuum infusion, which involves laying out the fibers and pulling the resin into the atmosphere. This produces stronger pieces with less mold resin and more glass, but it necessitates the use of unique materials and advanced technical understanding.

3.5. Aluminum

Aluminium is either employed in sheet for all-metal hulls or for isolated structural production procedures, building equipment, and components. The material is unique for making huge boats (requiring 15-20% construction expertise). It is the lightest material (lighter than polyester and 30% lighter than steel). Aluminium is quite costly, and amateur builders seldom utilize it [12]. While it is simple to cut, weld, and also needs heat treatments such as precipitation nations, aluminium is difficult an issue with aluminium, especially strengthening for most purposes. Corrosion occurs below the waterline. It is mostly utilized in small leisure and fishing motor boats.

3.6. Wood

Material used in the hull and spar construction. It is the conventional method of manufacturing buoyant boats, which are commonly accessible and easy to deal with. It is a common material for small boats, such as dinghies and sailboats, with a length of 6 meters (20 feet). Plywood is very popular for amateur building, but only marine plywood with watertight glues and laminates should be used. Cheap construction plywood often has gaps in the inside layers and is not ideal for boat building because the spaces retain moisture, accelerate rot, and physically weaken the plywood. No plywood is rot resistant; it needs be treated with epoxy resin and/or a decent paint system.

Table 1 Ship Specifications

S. No	Specification terms	Data
1.	LOA	92.07m
2.	LBP	79.5m
3.	Beam	18.02m
4.	Depth	7.91m
5.	Displacement	5387t
6.	Speed	11.5knot
7.	CB	0.79
8.	Engine Horse Power	2 ×1400=2800
9.	Draft	4.21m

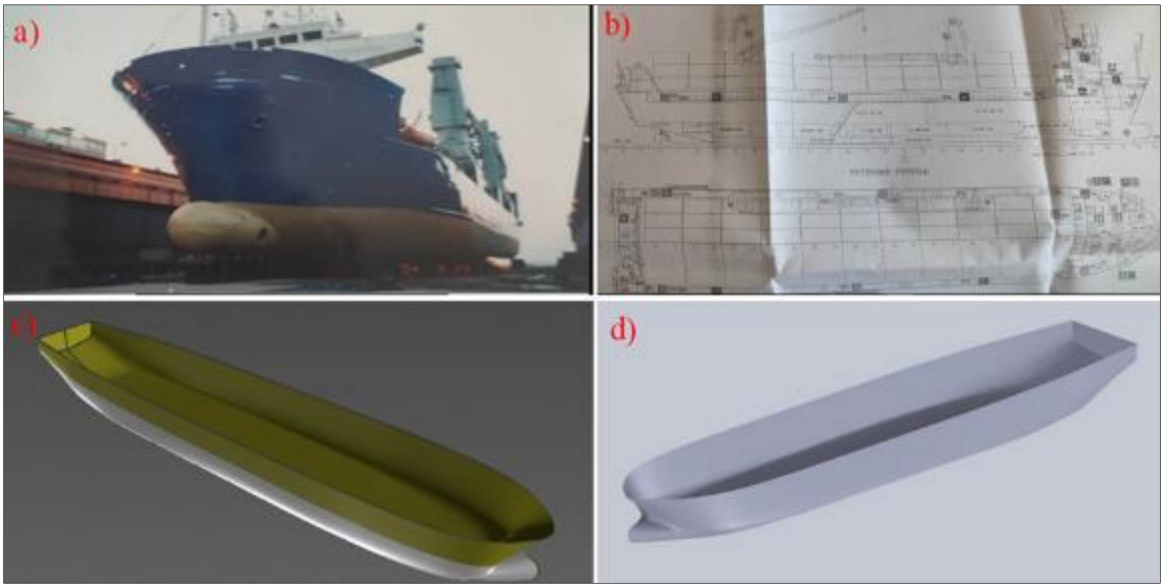

Figure 1 a) YOHANA Ship sailing under state of Eritrea b) YOHANA Ship Plan c) Perspective View of the Ship and d) Hull structure in 3D solid

4. Simulation Results and Discussion

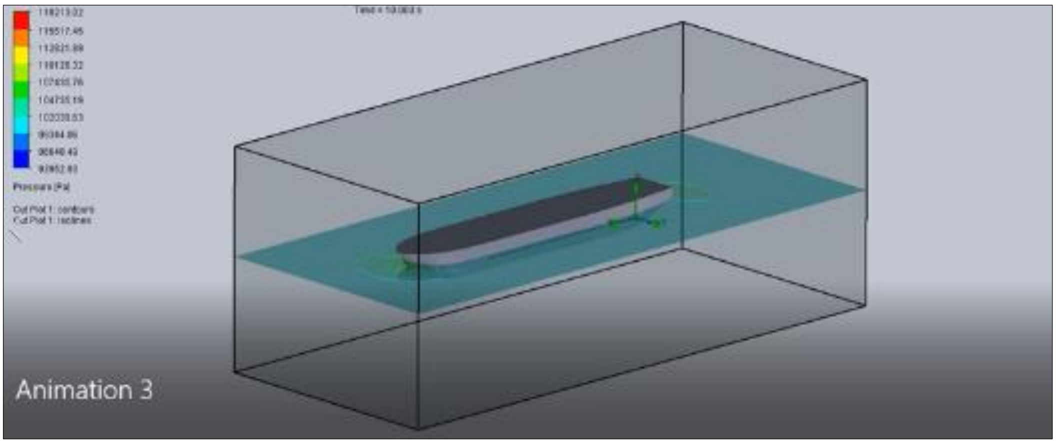

Figure 2 Flow simulation that shows the pressure analysis of YOHANA

The analysis is carried out on solid work software, flow simulations are measured for YOHANA ship of the pressure analysis, velocity analysis, flow analysis and optimization analysis configured below with the figures. (figure.2, figure.3, figure.4 figure.5). The analysis was run after the design was done on Delftship [13-14].

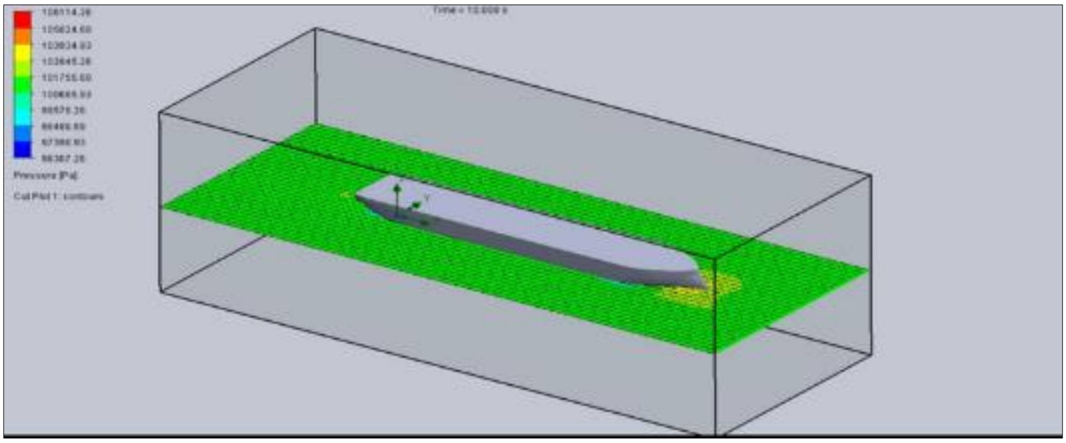

Figure 3 Flow simulation that shows the pressure analysis of the Optimized

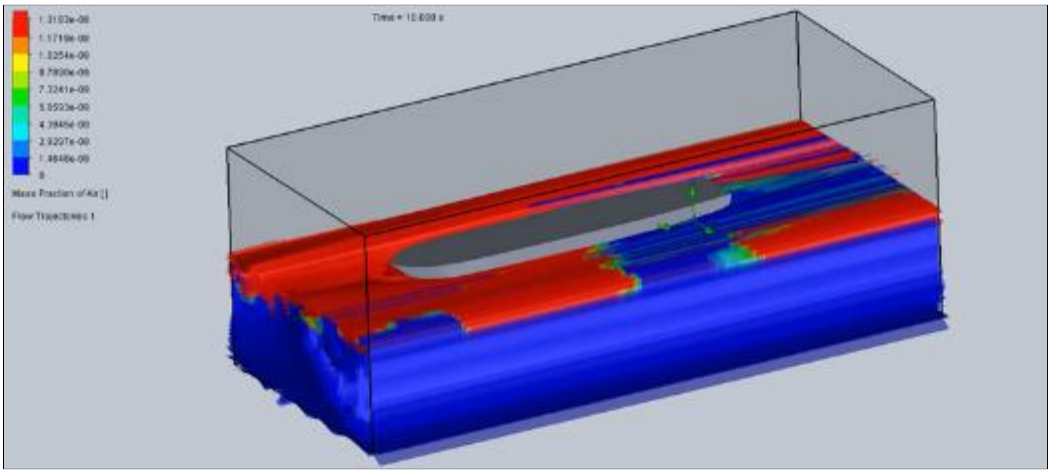

Figure 4 Flow trajectory on YOHANA SHIP

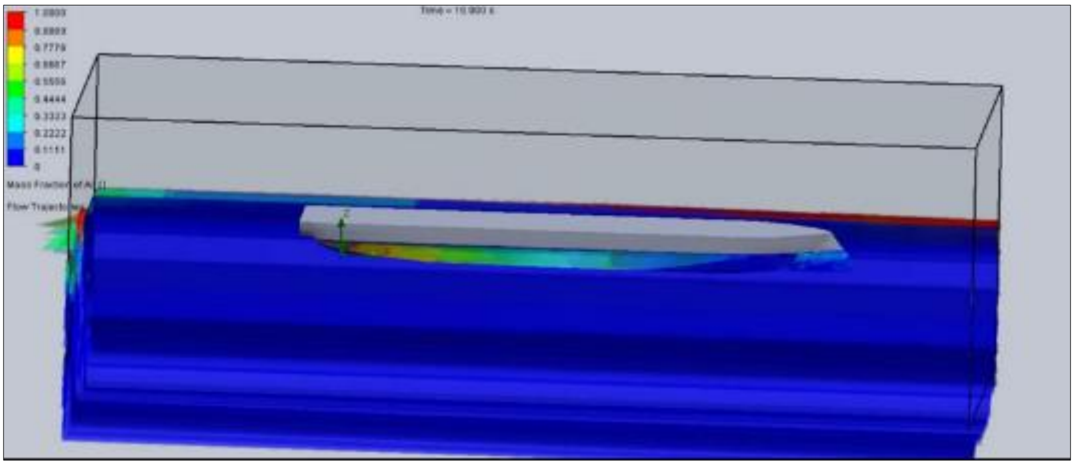

Figure 5 Flow trajectory of the optimized ship

5. Conclusions

Although Eritrea has natural resources like gold and other rare elements, the money derived from their exploitation cannot barely cover half of the country's budget for fuel imports. Thus, by using an air lubrication system and improving a previously constructed ship hull (YOHANA), fuel consumption may be lowered by around 13.4%. While the lowered beam/draft ratio tends to reduce wetly surface and thus the frictional resistance, the fore body optimization in which by greater length/beam ratio tends to lessen wave creating resistance. Using an air lubrication system is another way to help the ship's drag force be lessened. Ulstein X-Bow is the third way, implanting a new form of efficient hull that can move smoothly epically in the forward section of the ship. Fourth approach is in the coating system because we know the major impact of ships to raise the fuel consumption of the ship by raising the dead weight of the ship thus in order to lower this effect, we have used new coating type rather than the old one which was employed. Based on these all strategies we have used to lower the fuel consumption we have obtained; so, the daily fuel consumption has dropped by over 13.4%.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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