SOCIALIST REPUBLIC OF VIET NAM
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SUMMARY OF DOCTORAL THESIS

Thesis title: Application of Computational Fluid Dynamics (CFD) to optimize bulbous bow shape

Major: Mechanical Engineering

Sector code: 9520116

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Formation course: 2016

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1. Thesis summary

The use of a bulbous bow is not only an effective solution to reducing resistance but can also improve most of the ship's features, thereby, reducing fuel consumption, increasing speed, stability, and some economic-technical efficiencies for seagoing ships. For fishing vessels, a bulbous bow improves fishing efficiency due to better trim and pitch motion. Until now, the optimal design and required power prediction of the vessel with a bulbous bow has still been difficult due to the complex interference between the waves generated by the bulbous bow, and the waves of the hull when the ship moves. In case of positive interference between these waves, the ship resistance can be reduced by about (12-15)%, but a negative interference can greatly increase the resistance. Previous studies have often performed model tests for a series of hull and bulb shapes and based on that to find the optimal bulb, corresponding to the smallest ship resistance, however, such model tests are often time-consuming, and especially very expensive. One of the most comprehensive and well-known model testing studies was performed by M.Kracht (1978), in which he analyzed the test data of many bulb models to establish design graphs, called Kracht charts, used to design the bulb for current seagoing ships, however, this method also has limitations that need to be

completed and improved. Recent studies have often optimized the bulb for ships that already have this bow shape, by varying its sizes and using the modern CFD method (Computational Fluid Dynamics) to predict the value of a single objective function in terms of the ship's total resistance. From the above analysis and the recent policy of modernizing the state's fishing fleet, the author has selected the thesis topic as "Application of computational fluid dynamics (CFD) method in the optimization of the bulbous bow shape" with the objective of designing a bulbous bow for fishing vessels, and appying the CFD method to find an optimal bulbous bow to achieve the maximum reduction in ship's total resistance.

Based on synthesizing and analyzing relevant studies and theoretical bases, the author has determined research directions and necessary scientific databases to solve the research objectives and contents of the thesis, and has achieved new research results, specifically as follows:

(1) Predicting resistance of computation vessel with expected accuracy using CFD

Current studies on resistance predicting for bulb optimizing are often performed for existing hull models without a solution to ensure the accuracy of CFD-based results. This research has been applied to predict the resistance of fishing vessels FAO 72 and FAO 75, with the expected accuracy based on ensuring the accuracy of input parameters, including 3D hull models, domain computation size, and turbulence model coefficients.

(2) Completing and improving the method of designing the bulb using the Kracht charts

The most efficient bulb design method today is to use Kracht charts, but this method is applicable to vessels with a block coefficient (C_B) in the range of (0.56 - 0.82), the bulb sizes are only close to optimal, and without joining the bulbs to the rest hull. The research results have completed and improved the design bulb method using Kracht charts by determining the interpolation and extrapolation curves to design the initial bulb of the FAO 75 vessel with a block coefficient of 0.524 outside range of (0.56 - 0.82), with length L_{PRo} = 1.50 m, breadth B_{Bo} = 1.70 m, and height Z_{Bo} = 2.1 m, then use AutoShip to contour and join the bulb to the rest hull so that the transition surface between the bulb and the rest hull are smooth, and the bulb parameters are unchanged.

(3) Establishing a mathematical model and optimization method for fishing vessel bulbs

Current bulb optimization studies are often based on a single-objective function of resistance which is unsuitable for fishing vessels, and do not provide constraints or bases for changing bulb sizes, leading to bulb variants are set incompletely or unnecessarily. The research results have established a mathematical model and an optimization method for bulbous bow with a multi-objective function of effective power reduction suitable for the operating modes of the fishing vessels to maximize the efficiency of the bulb, define the limits and constraints to establish a suitable matrix of the bulb size variants, and solve the optimization problem using a combination of CFD and surrogate models. An optimal bulb of FAO 75 vessel was obtained with length LPRop = 1.65 m, breadth BBop = 1.91 m, height ZBop = 2.10 m based on a change of 0.11 m in length and 0.21 m in the breadth of the initial bulb, and maximum total resistance reduction of about 14%.

2. The necessity of the thesis

Using the bulbous bow is not only an effective solution to reduce the total resistance but also improves most important performances of the ships, and thus to enhance safety and economic-techno efficiency for seagoing ships such as increasing speed, decreasing fuel consumption, improving stability and seakeeping, etc. However, due to the complexity of the interactions between the wave systems above and the bulb also not being efficient at all ship speeds, the design and prediction of the capacity of a bulbous bow ship has always been complicated and controversial. Under favorable circumstances, a bulb will produce the bow waves that interfere positively with the waves generated by a hull, resulting in a reduction in total resistance (12 -15%). Conversely, a negative interference between these two wave systems can occur and greatly increase the resistance. In the past, the bulbous bow and position were determined through model testing, but such tests took a lot of time, effort, and expense. Along with the development of computers is the appearance of the CFD (Computational Fluid Dynamics) method which effectively solves many practical problems in general and the bulbous bow optimization problem in particular. In recent times, along with the strong development of the fishery industry and the support of the State through Decree No.67/2014/NĐ-CP, a series of steel fishing vessels under 30 m have been built to serve offshore fishing operations. These ships are built according to domestic designs, most of which have not been model tested, so, in fact, there are some models that are not really suitable for the fishing industry, leading to low maritime features and efficiency. Due to the lack of data on the operation of the bulbous bow, most fishing vessels in our country are designed with a straight bow, not equipped with a bulb. This also affects the ship's performance when traveling in waves, especially with resistance and shaking properties, which are essential maritime features for fishing vessels. With the policy of modernizing the fishing fleets, the State is very eager to develop the design of modern steel fishing vessels with a length of over 40m to reach offshore fishing grounds and protect national maritime security. From the practice of the fishing fleets, we have proposed to develop small and medium-sized steel fishing vessels that have been tested by the United Nations Food and Agriculture Organization (FAO) in famous test tanks with the desire to use these models as a basis for designing fishing vessels that ensure features and are suitable for fishing activities in our country today.

That is the reason for the implementation of the thesis entitled *"Application of Computational Fluid Dynamics (CFD) to optimize bulbous bow shape"* to develop a method to design and optimize the bulbous bow for ships in general and for steel fishing vessels in particular to serve the current database of steel fishing vessel designs in our country.

3. Objective of study

The objective of study is to apply CFD in optimizing the bulbous bow based on ensuring the maximum reduction in the total resistance of the ship and satisfying the constraints set forth in terms of geometry and marine features.

4. Object and scope of study

The objects of study are the FAO's small and medium-sized steel fishing vessels with and without bulbs that were model tested to determine resistance. With such objects of study, the scope of study is as follows:

- The ships move in a straight line in still water, not affected by the wave system and air resistance, with unlimited depth.

- The fluid used for simulation is homogeneous, viscous, and incompressible.

- Resistance test data in the test tank for comparison is considered accurate and is the basis for evaluating and correcting simulation parameters when calculating resistance of ships by CFD method.

5. Research method

The method used is theoretical research combined with the use of available experimental data of calculated ship samples to test and correct the theoretical research results to match the calculated ship types.

6. Scientific and practical significance of the thesis

In terms of scientific significance, the thesis contributes the following specific results:

- Building a theoretical basis and practical application of CFD to accurately calculate the resistance of a specific type of ship, particularly medium and large steel fishing vessels, slow running, short body length, with or without bulbous bow, including the following contents: building and examining the accuracy of the 3D ship model, determining the simulation parameters (input parameters for the CFD solution) suitable for the type of ship being calculated to ensure the differences between the results calculated from the CFD and the model experiment within the allowable limit (less than 5%).

- Proposing a method to optimize the form of the bulbous bow, including building an optimal model, analyzing and selecting the calculation modes suitable for fishing vessels, building plans for calculating the bulb, and building and calibrating the surrogate model to determine the optimal bulb alternative.

- Serving as the basis for solving many hydrodynamic problems of ships in general and fishing vessels in particular, especially the problem of optimizing ship form.

In terms of practical significance, the thesis contributes the following specific results:

- Supporting the design of bulbous bows for ships in general and large steel fishing vessels in particular.

- Providing teaching and research materials in the field of ships in general and fishing vessels in particular.

7. New contributions of the thesis

- Applying the CFD method to accurately calculate the resistance of a specific type of ship, in this case FAO steel hull fishing vessel models, based on ensuring accuracy when building 3D geometric models and determining the reasonable values of the simulation parameters, including the dimensions of the computational domain and the parameters of the entanglement model, which are turbulent kinetic energy k and turbulent kinetic energy diffusion rate ω.

- Proposing the use of Kracht graph to design bulbous bows for ships with block coefficients that are not within the scope of application of this graph and applying it in the design of bulbs for calculated ships with block coefficients out of range of graph application and integrating bulb form into design ship line to ensure even smoothness between two surfaces, not changing defined form and bulb parameters.

- Proposing models and methods to optimize the form of the bulbous bow of fishing vessels, including: Building of a multi-objective function according to the typical working modes of a fishing vessel; Analysis and selection of changing ranges of design variables and constraints; and method of solving bulbous bow optimization problem based on the alternative option and model methods.

8. Structure of the thesis

The thesis is structured into four chapters as follows:

Chapter 1. Literature review

Presenting an overview of studies related to the topic of the thesis and, based on that, analyzing and choosing a research direction to solve the goals and contents set out in the thesis.

Chapter 2. Calculation of ship resistance by CFD

Presenting an overview of CFD theory and research results on the application of the CFD method in calculation of resistance of ship models.

Chapter 3. Optimal design of fishing vessel's bulbous bow

Presenting the geometrical features of the bulbous bow and the research results on building a model and a method to solve the problem of optimizing the bulbous bow form for ships in general and fishing vessels in particular.

Chapter 4. Conclusions and recommendations

Presenting new findings, conclusions, and recommendations drawn from the research results and future research directions.

Ho Chi Minh City, April 28th, 2022

Science supervisors | **PhD candidate**

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