

Studies of the resistance optimization of underwater vehicle based on multiple-speed approximate model

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Abstract. An automated approximate model generation platform integrating the vehicle type generation, grid division and CFD resistance calculation is established, and the approximate model is obtained based on underwater vehicle resistance. Three approximate models of RSM model, RBF model and Kriging model were compared, and the error results were analyzed. The four-order RSM model with different speed is established, and the different speed model is weighted fitting and the approximate model of multi-speed fitting is obtained, which can be applied to the resistance optimization of multi-speed interval. Based on the intelligent optimization platform of fitting approximation model, MIGA algorithm is adopted to optimize the displacement volume, the longitudinal position of the floating center and the resistance, and get the optimal underwater vehicle type.

1 Introduction

Due to the depletion of resources on the land, people will focus on the vast and abundant marine resources. Along with the rapid progress of science and technology, the method of exploring underwater resources is more diverse, and underwater vehicle as an important resources of underwater detector, has very broad application, such as marine resources survey, submarine topography search, search and rescue in the sea, deep sea equipment inspection and maintenance and marine biological tracking tasks. As a result, underwater vehicle is becoming more and more widely used[1]. Because of modern marine engineering and deep-water projects facing more complex and more diverse problems, these need to be more diverse requirements are put forward for underwater vehicle, such as far distance, a wide range of regional search skills and the ability to cruise for a long time[2].

2 CFD grid division

In the process of the resistance of underwater vehicle calculation, CFD numerical simulation method is commonly carried out on 3D modeling and the flow field around it, divided flow field of a structured grid, and numerical simulation in the flow basin. Due

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to the accuracy of the underwater vehicle resistance calculation, it is necessary to avoid the influence of the boundary on the hull resistance. Basin, therefore, selects the length of 15L (L for body length), the width of 25d (d for hull diameter) of the square area. The specific basin form and grid are shown in figure 1.

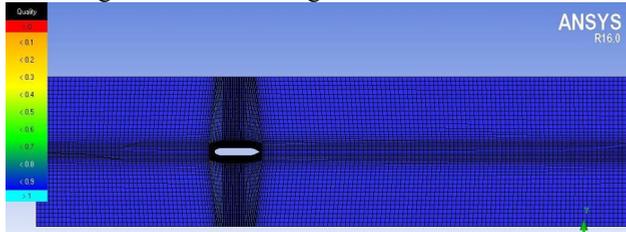


Fig. 1. Schematic diagram of subsea basin grid.

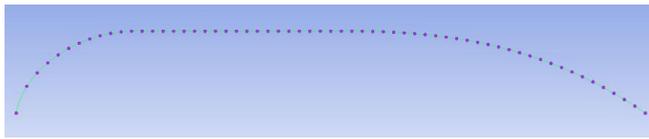


Fig. 2. Lines profile of an underwater vehicle.

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3 Approximate model platform and multi-speed fitting.

3.1 The formation of hull model

The Myring type is a commonly used underwater vehicle type. Its hull is a typical three-stage structure, which can be decomposed into the first segment, middle segment and tail section. Where, the equation of the first segment lines is:

$$r(x) = \frac{1}{2}d \left[1 - \left(\frac{x-1}{a} \right)^2 \right]^{\frac{1}{n}} \tag{1}$$

The equation of the middle segment lines is:

$$r(x) = \frac{1}{2}d \tag{2}$$

The equation of the tail section lines is:

$$r(x) = \frac{1}{2}d - \left(\frac{3d}{2c^2} - \frac{\tan \theta}{c} \right) (x-a-b)^2 + \left(\frac{d}{c^3} - \frac{\tan \theta}{c^2} \right) (x-a-b)^3 \tag{3}$$

where, a for the length of the head section, b is the middle length, c is the tail section length, d is the middle diameter. x is the longitudinal distance at the vertex of an underwater vehicle, $r(x)$ is the radius of rotation at the point, n and θ respectively

express the saturation degree control parameters of the head and tail part of the hull. The bigger n and θ is, the more full the hull is [3].

According to the equation of lines, the lines generator of Myring underwater vehicle can be compiled by MATLAB software. The program can output the TXT type value point text file which can be recognized by ICEM, Solidworks and other model software as long as it is entered into a set of underwater vehicle value parameters (a , b , c , d , n , θ). figure 2 shows the hull contour map after the TXT type value file obtained after running MATLAB is imported into ICEM.

3.2 Automatic division of watershed grid

ICEM software, as a professional CAE preprocessor, can perform professional model building and grid division. therefore, ICEM software can be used to carry out the reading of the TXT file of MATLAB output, the establishment of the model and the basin, the division of the watershed grid, and finally the output of MSH files and other operations. In the ICEM software, you can record each of the mentioned steps in the RPL file as a flow command. Then, write the batch command bat file to start and run ICEM software. By running the bat batch file, ICEM software startup, model establishment, and grid division can be fully automated to generate MSH pre-processing files for CFD numerical simulation.

3.3 Automatic calculation of hull resistance

FLUENT software is the most comprehensive, widely applicable and most widely used commercial CFD software[4]. In the FLUENT setting, in order to obtain the results that are close to the actual situation, the turbulent SST k-model is usually adopted, and the Reynolds average equation method of three-dimensional incompressible fluid is adopted directly in the solution process [5]. Like ICEM software, in the process of using FLUENT software, every step of the software can be recorded in the jou file as a flow command [6]. Next, write the batch command bat file to start and run the FLUENT software. Starting batch command bat file, means automatically starting FLUENT software, setting up solution adjustment, solving underwater vehicle resistance, finally outputting resistance result file, and saving in TXT text format.

3.4 Construction of full automation platform

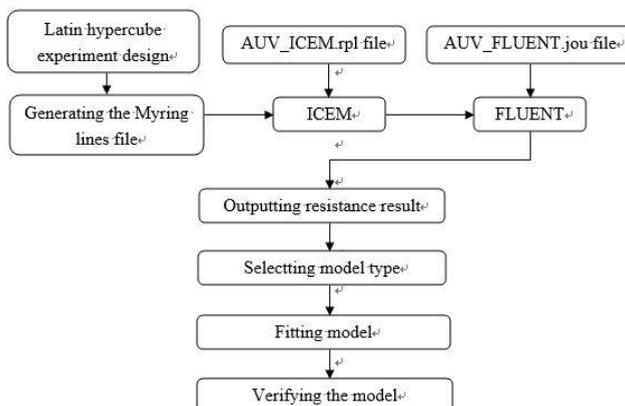


Fig. 3. Flow chart of the automation platform.

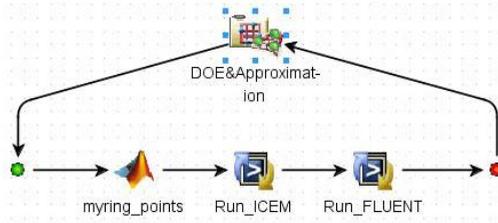


Fig. 4. Automated platform model diagram.

The approximate model method is approximate to a set of input variables (independent variables) and a set of output variables (corresponding variables) by mathematical model method [7]. The approximate model method is a comprehensive application method integrating mathematical statistics, experimental design and optimization algorithm. Since the underwater hull resistance of CFD numerical simulation takes a certain amount of time (about 2 hours), the intelligent optimization algorithm needs to conduct a large number of iterations (10,000 times) in the selected scope space, so it is quite necessary to substitute the approximate model for CFD numerical simulation. In the process of establishing the approximate model, it is inevitable to carry out a large number of repeated underwater hull resistance calculation. In order to avoid the repeated manual modification and setup work, it is necessary to build multi-platform automatic operation module to realize automatic operation and automatic approximation model establishment. The automation platform can integrate the three modules of MATLAB, ICEM and FLUENT, and call the bat batch command of each module to complete the automatic modeling, automatic grid division and self-resistance calculation of Myring underwater craft, as shown in figure 3.

This automated platform selects 60 Latin hypercube experiments designed as inputs in a certain space, and the automatic platform will be able to run and output the underwater hull resistance data. The approximation models were then approximated using three approximation models of the fourth order RSM, RBF and Kriging. To define six impact factors (a, b, c, d, n, theta) as input parameters for an automated platform, the hull resistance value Drag as an output parameter. figure 4 represents the running model of the automated platform.

3.5 Approximate model comparison

To verify the accuracy of the approximation model, 40 sets of approximate model test points were randomly selected to compare the error between the CFD numerical simulation results and the approximate model calculation results. It can be seen from that comparison result shown in table 1 that by comparing the Kriging approximation model, the RSM approximation model and the RBF approximation model, the fourth order RSM approximation model has a low simulated error and a better fit, with the maximum error of only 0.63%. Therefore, it is accurate and efficient to replace the CFD numerical simulation with a four-order RSM approximation.

Table 1. Approximate model error comparison table.

Approximate model	Leveling error	Maximum error	Root mean square error	R2 Fitting
RSM	0.01066	0.06	0.01548	0.99554
RBF	0.01552	0.181	0.03206	0.97499
Kriging	0.07946	0.352	0.10742	0.80999

3.6 Multi-speed fitting approximation model

Generally, approximate model is set up, usually only for one design speed, that is, a speed corresponding to an approximate model. However, there is a significant nonlinear change between the resistance and the speed of the underwater vehicle. Therefore, modeling and optimization of single speed only does not meet the demand for hull drag reduction, which is of great limitation. In practice, the underwater vehicle will experience different conditions such as the startup phase, the deceleration phase, the steering phase, and the flow interference phase, and the velocity corresponding to each phase is of multiple denaturation. Therefore, in the study of underwater vehicle resistance, we hope to find the optimal model of hull resistance for the multi-speed section. This is an in-depth study of these questions, and the approach to the fitting model of the resistance to a multi-speed range has been applied to the method of the multi-speed range. According to the normal speed interval of the underwater vehicle ($v_s = 0.5, 1.0, 1.5, 2.0$), a four-order RSM approximation model of each speed is established separately, and then the approximate model of the multi-speed model can be obtained by weighted fitting of the approximate model of all speed segments. The approximate model formula is as follows:

$$Drag_{all} = \sum_{i=1}^4 \omega_i Drag_i(v_s), \quad v_s = 0.5, 1.0, 1.5, 2.0 \quad (4)$$

where, $Drag_{all}$ is the total resistance after the four speed weighted fitting; $Drag_i(v_s)$ is resistance to underwater vehicle for each speed; ω_i for the weight value of different speed, it indicates the importance of each speed and demands $\sum_{i=1}^4 \omega_i = 1$ satisfaction. The weight needs to be set according to the different tasks in the actual problem. Given the fact that under the circumstances of the underwater vehicle and the rate of the speed of the hull, the speed of $v_s = 0.5, 1.0, 1.5, 2.0$ m/s is equal to $\omega_i = 0.1, 0.2, 0.5, 0.2$.

The fit of the multi-speed approximation model is available for approximate modeling of the drag of the underwater vehicle in a wide range of speeds. This fitting approximation model can be applied to the hull optimization to obtain the excellent hull shape.

4 The resistance optimization of fitting approximation model

4.1 The optimization goal

The intelligent optimization algorithm, a part of the modern optimization algorithm, is inspired by natural phenomena, social biology, and the human intelligence. By simulating a biological genetics and natural selection mechanism, a random search algorithm constructed by artificial method has the advantages of global, parallel, non-dependent on gradient information, efficient, and versatile [8]. In the optimization of actual underwater vehicle, it is necessary to optimize the existing conditions of vehicle, which is to require the vehicle to achieve the minimum target optimization of the hull resistance under the premise of satisfying a certain load quantity, with the displacement and the longitudinal coordinate of the center of buoyancy as the fixed value objective function. Select a type commonly used underwater vehicle as standard prototype of optimization, the hull type parameters as follows: $a = 400$ mm, $b = 500$ mm, $c = 600$ mm, $d = 300$ mm, $n = 2$, $\theta = 30^\circ$. The underwater vehicle has a displacement of about

80 kg, the longitudinal center of the floating center is about 600 millimeters. The optimization objectives are as follows:

$$\text{Objectives: Minimize drag } (N), \text{ Target disp} = 80 \text{ kg}, \text{ Target } xb = 600 \text{ mm} \quad (5)$$

$$\text{Constraints} \begin{cases} 200 \text{ mm} \leq a \leq 600 \text{ mm}, 400 \text{ mm} \leq b \leq 800 \text{ mm}, 400 \text{ mm} \leq c \leq 800 \text{ mm} \\ 200 \text{ mm} \leq d \leq 400 \text{ mm}, 0.6 \leq n \leq 3, 5^\circ \leq \text{theta} \leq 40^\circ, \\ L = a + b + c \geq 1200 \text{ mm}, \text{ disp} \geq 70 \text{ kg} \end{cases} \quad (6)$$

where, *disp* is the displacement of underwater vehicle, *drag* for underwater resistance value of the hull, *xb* for underwater vehicle longitudinal position of buoyancy.

4.2 Optimizing the platform

To ensure that the intelligent optimization algorithm is sufficiently calculated, it is possible to use the established multi-speed, fourth-order RSM model to replace the relatively time-consuming CFD numerical simulation. To establish an automated optimization platform, the platform needs to integrate the four-order RSM multi-speed fitting approximation model, intelligent optimization algorithm, and the displacement and the longitudinal position of the floating center, as shown in figure 5, the operation model diagram of the automatic optimization platform.

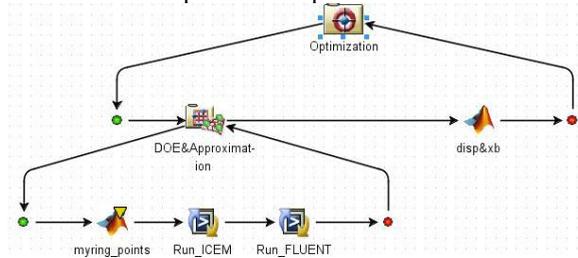


Fig. 5. Automatic optimization platform model diagram.

4.3 The optimization results

Table 2. optimization of hull parameters comparison table

Optimization	a m	b m	c m	d m	n °	theta °	Drag N	Disp kg	Xb m
Fitting type	468.0	503.3	756.2	287.1	2.439	16.99	8.457	80.18	599.99
1.5 m/s type	508.4	604.7	537.3	286.7	2.282	19.14	8.386	79.99	599.98
Original type	400.0	500.0	600.0	300.0	2.000	30.00	9.181	80.19	603.00

In the case of the target function, the MIGA optimization algorithm is used to do 10,000 iterative calculations, and it has the right results. Table 2 shows the comparison of the hull parameters of the multi-speed fitting optimized vehicle type, 1.5m /s speed and the initial standard vehicle type. Figure 6 and figure 7 show the shapes of the underwater vehicle with the multi-speed fitting type and 1.5m /s speed type respectively.

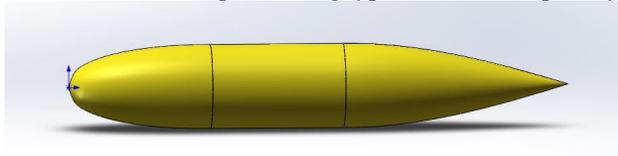


Fig. 6. Multi-speed fitting optimization type.

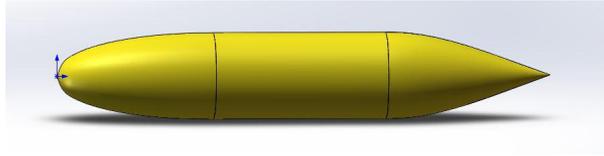


Fig. 7. 1.5m /s speed optimization type.

5 Conclusion

According to the CFD numerical simulation of three kinds of underwater vehicle including the multi-speed fitting type, 1.5m/s speed type and the original standard type, the resistance comparison diagram of the three types of vehicle at different speeds can be obtained, as shown in figure 8. It can be seen from the figure that the optimization effect of the multi-speed fitting optimization type and 1.5m/s speed optimization type is obvious. Multi-speed fitting optimization type can reduce 15.9% of the average resistance, and 1.5 m/s speed optimization type can be an average 9.3% reduction in resistance. Moreover, the resistance curve of the multi-speed fitting type and 1.5m/s speed type is observed: although the resistance value of 1.5m/s model is slightly better than that of the fitting model at the speed of 1.5m/s, the average resistance of the multi-speed fitting model is smaller for the whole multi-speed range, that is, the multi-speed fitting model can better be applied to the complex condition of multi-speed.

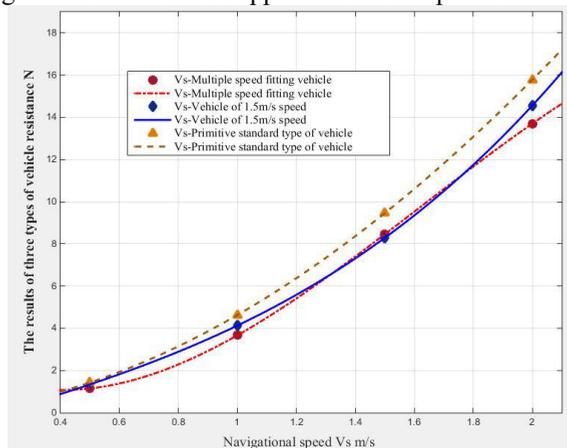


Fig. 8. Comparison diagram of three types of underwater vehicle resistance

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