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HULL FORM OPTIMIZATION TO LOWER RESISTANCE IN STILL WATER AND ADDED RESISTANCE IN WAVES

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ABSTRACT

In order to improve operating economy of a container ship, its hydrodynamic performance is improved by optimizing bow and stern hull-forms with parametric hull form generation method. Different optimization algorithms are deployed to obtain the optimum hull form at the condition of design draft and design speed when displacement is defined as a basic constraint. The paper uses STARCCM+ to calculate the resistance in still water, while added resistance is calculated by STF strip method. By comparing the numerical results, a satisfying hull form can be found. Both powering performance and seakeeping performance are improved.

Key words: Calm water resistance; Added resistance in waves; Parametric hull form generation.

1 INTRODUCTION

In most of the time, a ship is sailing in different sea conditions, and the ship resistance will be increased due to waves. But ship hull form optimization generally is based on calm water resistance, that is why the obtained hull form is mostly not the optimum one. Simulation Based Design (SBD) technique is the combination of hull form deformation technique, optimization technique and numerical prediction technique[1]. SBD technique has rapidly been developed in recent years, for its superiority in hull form optimization. In this paper, a feeder container ship is optimized with a parametric modelling software called CAESES which has built-in FFD (Free Form Deformation) technique and can be connected to STARCCM+. This paper uses this configuration to optimize the calm water resistance at design speed and design draft. To improve the seakeeping performance of this ship, this paper chooses several control points at designed waterplane to change the shape of bow.

2 FREE DEFORMATION APPROACH

FFD is an important part of computer graphics technology, and it is raised by Sederberg and Parry[2] in 1986. FFD is a flexible geometric deformation method and can be implanted into popular parametric modelling softwares. It is widely used in geometric modelling, computer animation, image and video processing and other fields.Mathematically, the basic idea of this technology is to establish a three-dimensional mapping from the space to be deformed to the target space. The definition domain is the point set of the object to be deformed, and the range is the point set of the deformed object. The core part is how to construct the mapping.

The basic principles of FFD technology are as follows: firstly, a cuboid called lattice is determined according to the deformed region, and the object to be deformed is linearly embedded into the lattice by local coordinate transformation; secondly, a control point grid is defined on the lattice to make the lattice become a three-dimensional tensor product Bezier body; finally, the lattice is deformed by adjusting the control points , and the deformation is transferred to the object. Sederberg and Array used three-variable tensor product Bernstein polynomials and control frames to construct maps. Detailed mathematical models can be found in references.

In this paper, a feeder container ship is optimized, its model and parameters are shown in Figure 1 and Table 1.

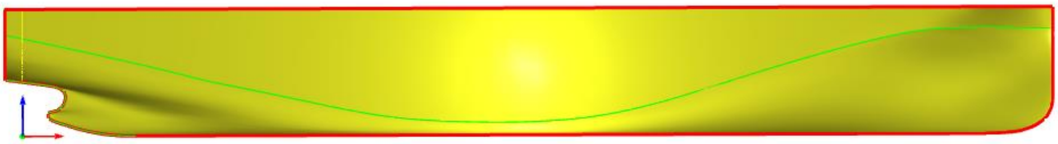


Figure 1: Geometric model of the ship model

Table 1: The parameters of ship model

Parameters	Values
Lpp/m	6.51
Beam/m	1.16
Depth/m	0.80
Draft/m	0.32

The constraints that the ship needs to meet during the optimization process are as follows:

(1) Keep the Lpp, Beam and Depth unchanged;

(2) The displacement at design draft can not be reduced by more than 2%;

(3) The displacement at scantling draft can not be reduced by more than 1.6%;

In this paper, FFD is chosen to optimize the ship's bow and stern simultaneously. When using FFD for parametric deformation, a certain area is deformed by choosing control points. A deformation frame with a length of 3.32m, a width of 0.58m and a height of 0.80m is built at the bow, and a deformation frame with a length of 2.64m, a width of 0.58m and a height of 0.80m is built at the stern. Schematic diagram of deformation is shown in Figure 2.

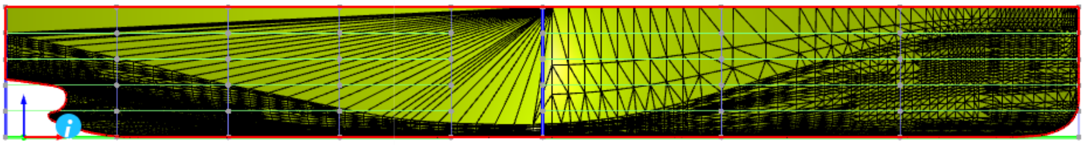


Figure 2: Schematic diagram of deformation

The bow's deformation frame has 4 rows in the direction of the ship's length, 4 rows in the direction of the ship's width, and 6 rows in the direction of the ship's height. The third row in the direction of the ship's height is as high as design draft. When the bow is deformed, the choice of control points is mainly based on the following points:

(1) Because the X-direction control point can affect the hull shape in the direction of the ship's length, the X-direction deformation of the ship is performed by selecting the 48 points marked yellow in Figure 3.

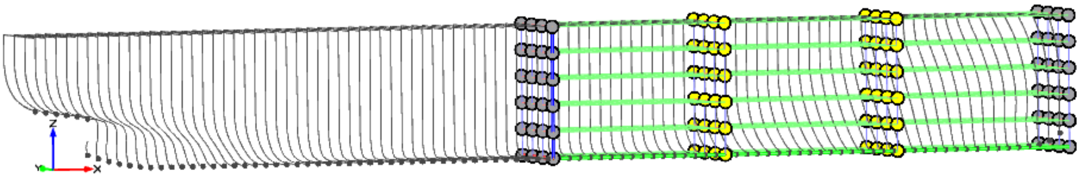


Figure 3: Selection of control points for X

(2) In addition to optimize the calm water resistance of the container ship, it is also hoped to complete the optimization of the added resistance. The added resistance is mainly concentrated in the bow, and the smaller water plane area helps reduce it[3]. Therefore, the paper chooses 4 control points at design draft for Y-direction deformation in Figure 4.

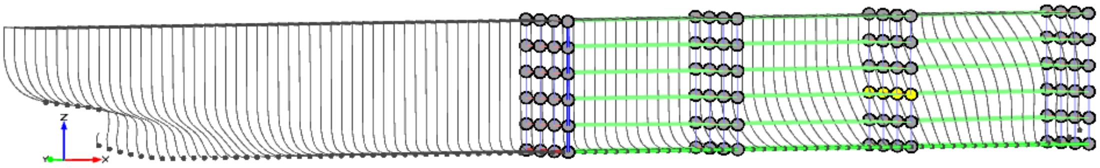


Figure 4: Selection of control points for Y

(3) In view of the need to fully deform the hull in order to obtain the best possible hull shape, it is still necessary to select the Z-direction control point to change the position of each station line. If the points at the bottom of the ship are selected as control points, excessive deformation will occur at the bottom of the ship. This paper chooses 8 control points to deform the ship in the direction of height in Figure 5.

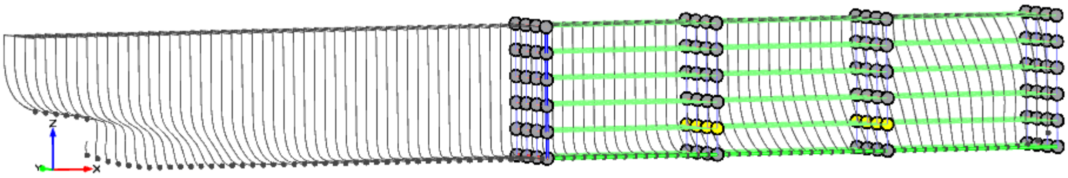


Figure 5: Selection of control points for Z

The stern's deformation frame has 5 rows in the direction of the ship's length, 4 rows in the direction of the ship's width, and 6 rows in the direction of the ship's height. Because the hull shape of the stern is complicated, many overlapping faces will be generated if drastic deformation happens. When the stern is deformed, the choice of control points is mainly based on the following points:

(1) The X-direction deformation of the stern is performed by selecting the 72 points in Figure 6.

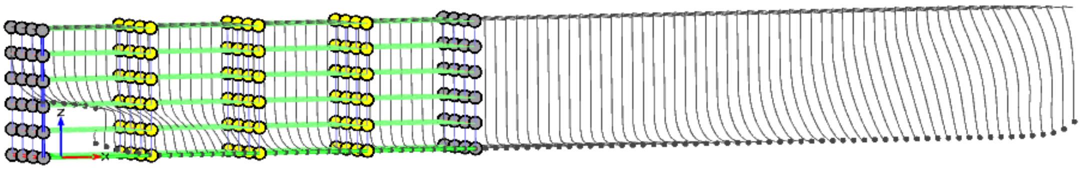


Figure 6: Selection of control points for X

(2) The Y-direction deformation of the stern is performed by selecting the 4 points in Figure 7.

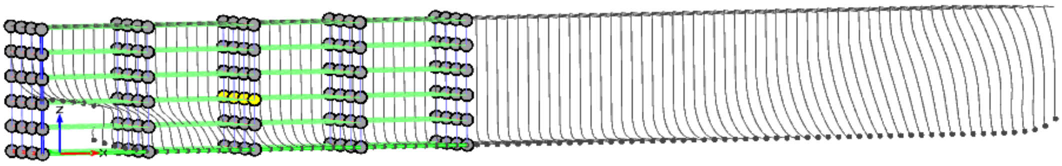


Figure 7: Selection of control points for Y

(3) The Z-direction deformation of the stern is performed by selecting the 4 points in Figure 8.

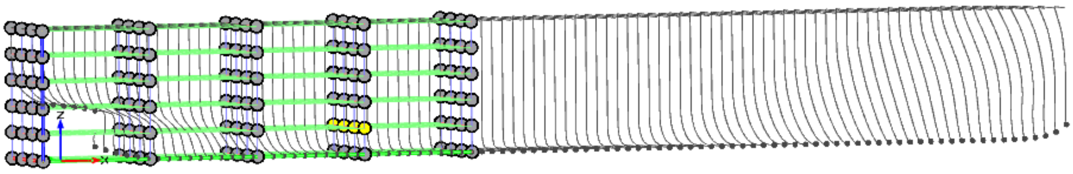


Figure 8: Selection of control points for Z

When setting the variation ranges of the design variables, each design variable must ensure that the hull shape is not overly deformed while causing obvious changes in it. The range of design variables varies as shown in Table 2.

Table 2: Ranges of design variables

Bow		**Stern**	
Design variables	**Ranges**	**Design variables**	**Ranges**
X1	[-1.2,0.5]	X2	[-0.4,0.4]
Y1	[-1,-0.2]	Y2	[-0.4,0.2]
Z1	[-0.8,0.5]	Z2	[-0.3,0.3]

3 OPTIMIZATION ALGORITHM

The optimization technology is one of the key technologies for hull form optimization based on SBD. This technology provides an important scientific solution for hull form optimization. At present, the optimization theory has experienced rapid progress in recent years, and has been widely used in engineering.

3.1 Sobol Algorithm

The sobol algorithm has good stability, wide coverage, and the distribution of design variables in the design space is very uniform. Therefore, when using this algorithm for optimization, it is possible to conduct an accurate exploration and evaluation of the entire design space. This paper generates 240 cases with sobol algorithm.

3.2 Genetic Algorithm

Because the genetic algorithm has good robustness, operability, stability and parallelism, the algorithm has wide applicability and strong global search ability[4]. It can handle any form of objective function and constraints. Therefore, it is very suitable for engineering optimization design.

The parameters that have significant impacts on operational performance in genetic algorithms are population size, crossover rate, mutation rate, and maximum algebra. Rational ranges and values of basic parameters of genetic algorithm are shown in Table 3.

Table 3: The values of basic variables for genetic algorithm

Basic parameters	**Ranges**	**Values**
Population size	[20,100]	24
Crossover rate	[0.4,0.99]	0.9
Mutation rate	[0.0001,0.1]	0.01
Maximum algebra	According to needs	10

4 NUMERICAL CALCULATION AND MODEL TEST

4.1 Calculation of Resistance in Still Water

This paper takes the minimum hydrostatic resistance at design speed (Fn=0.234) as the optimization target, and STARCCM+ is used to compute the flow.

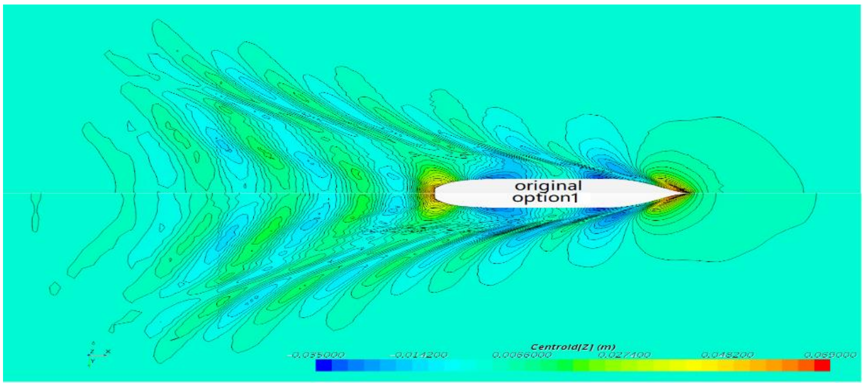
In this paper, the finite volume method is used to discretize the momentum equation. The pressure coupling problem is calculated by the classical semi-implicit method. The convection term adopts the second-order upwind difference format, and the diffusion term adopts the central difference format. The Euler multiphase flow model and the three-dimensional implicit indeterminate solver are selected. Free surface is treated by VOF, and the standard K-Omega model is selected as the turbulence model. Wall functions are used. In order to ensure the same numerical calculation method for each generated hull shape, the grid scale is consistent. Table 4 shows the design variables of the best in calm warter resistance. The best which is got with sobol algorithm is called option1, and the best which is got with genetic algorithm is called option2. Table 5 shows the calculating results of calm water resistance. Figure 9 is the comparison of free surface wave between the original ship and the modified one.

Table 4: The values of design variables

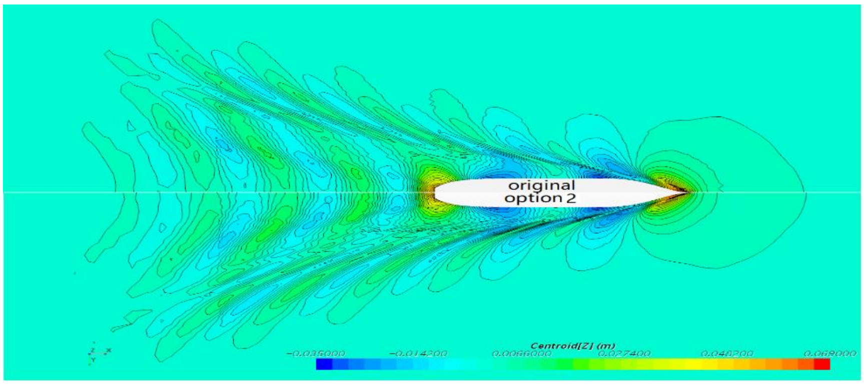
	X1	**Y1**	**Z1**	**X2**	**Y2**	**Z2**
Option1	-0.403	-0.925	-0.191	-0.175	-0.00625	0.131
Option2	-0.228	-0.827	0.357	0.315	-0.273	0.197

Table 5: Calculating results of calm water resistance

	Values/N	**Changes/%**
Original ship	60.14	—
Option1	59.08	1.76%
Option 2	58.66	2.46%



(a) Comparison of free surface between original ship and option1



(b) Comparison of free surface between original ship and option2

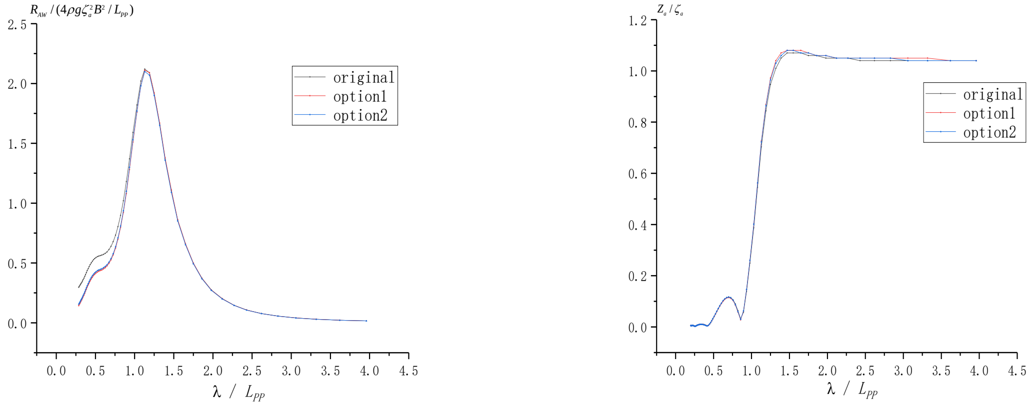
Figure 9: Comparison of free surface wave

4.2 Calculation of Added Resistance in Waves

The added resistance consists the added resistance due to ship motions and the added resistance due to wave reflection, so the value of the added resistance can be calculated and summed by calculating the two parts. Because the value of the added resistance is mainly affected by the pitch and heave motion of the ship, the calculation of them should be first solved by STF strip theory. The added resistance due to ship motions is calculated by radiation energy method, and the added resistance due to wave reflection is calculated by total reflection formula. The irregular waves can be regarded as a linear superposition of the regular waves of each unit, so the value of the irregular waves can be linearly superposed by the wave spectrum and the added resistance in the regular waves. In this paper, the JONSWAP spectrum is selected for the calculation of irregular waves. Figure 10 shows the dimensionless curves of added resistance, pitch and heave motions. Table 6 shows the calculating results of irregular waves. The calculating parameters of added resistance are shown in the table6.

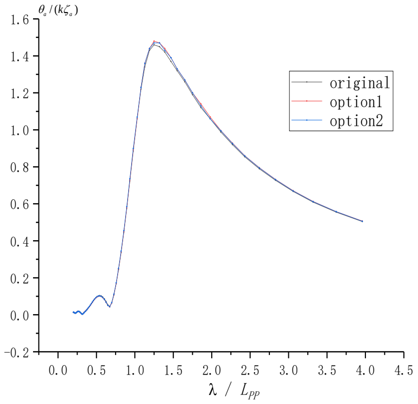
Table 6: Calculating parameters

Parameters	**Values**
Significant Wave Height/m	1.75
Wave Period/s	7
Wave direction/°	180
Fn	0.234



(a) Contrast of added resistance

(b) Contrast of heave motion



(c) Contrast of pitch motion

Figure 10: Contrast of dimensionless curves of added resistance, pitch and heave motions.

Table 7: Calculating results of irregular waves

	Heave/m	**Changes/%**	**Pitch/°**	**Changes/%**	**Resistance/KN**	**Changes/%**
Original ship	0.0339	—	0.0721	—	33.86	—
Option1	0.0340	0.29%	0.0720	-0.14%	24.13	-28.73%
Option 2	0.0342	0.88%	0.0725	0.55%	24.29	-28.26%

From the above calculation results, it can be found that option2 is much better than option1 in terms of calm water resistance, but option1 is slightly better than option2 in terms of seakeeping performance. Finally, this paper chooses option2 as the solution. Figure 11 shows the comparison of line type.

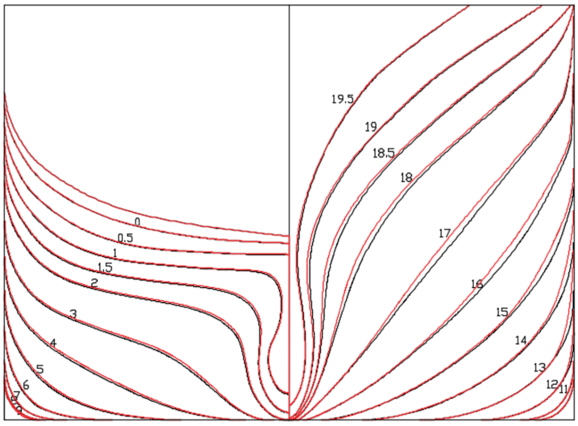


Figure 11: Comparison of hull lines between original and option2 (the red one)

4.3 Model Test

This paper conducts a model test of option2 at design draft and design speed to verify the validity of the computation for calm water resistance. The value of resistance obtained by the test is 58.43N, so the error between computation and test is just 0.39%.The experimental procedure is shown in Figure 12.

Figure 12: The picture of model test

5 CONCLUSION

(1) This paper uses CAESES to optimize the calm water resistance at design speed of a feeder container ship, and improves the seakeeping performance of this ship by choosing several control points at designed waterplane to change the shape of bow. And the final results prove the effectiveness of this deformation method.

(2) In terms of optimization algorithm, this paper chooses sobol algorithm and genetic algorithm to optimize the ship respectively. After comparing the calculating results, the scheme obtained by genetic algorithm is selected. Finally, both hydrostatic resistance and added resistance in wave are obviously improved.

(3) In order to verify the accuracy of the calculation method, the ship model test is carried out. The calculation error of hydrostatic resistance is only 0.39%, which proves the validity of the calculation method.

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REFERENCES

[1] ZHAO feng, LI Sheng zhong. “An overview on the design optimization of ship hull based on CFD techniques”. In: Journal of ship Mechanics, 14 (2010), 812-821.

[2] Sederberg T W, Parry S R. “Free-form deformation of solid geometric models”. In: Proc. SIGGRAPH’86, Computer Graphics, 20 (4), 151-159.

[3] Kishv, R. “Practical design of hull forms with mini-mum added resistance waves”. In: Proc.4 Osaka Col-loquium on Seakeeping Performance of Ships, 2000.

[4] SUN Chu Qiao. A Study on Hydrostatic Optimization for Ship-hull Based on Parametric Representation, Wuhan University of Technology, 2015.