

Parametric Design of Maintenance Catamaran and Optimization of Resistance Performance

Yunping Xie, Tianmin Gao, Chenlu Jin, Zijian Zhao

Abstract— Based on the main influence parameters of the 25m twin-body wind power operation ship type, combined with the parametric design concept, the NAPA Basic language macro program was compiled to realize the parametric modeling of the series ship type. The resistance performance prediction of the ship model is carried out by STAR-CCM+ numerical simulation software, the calculation results are imported into Isight optimization software, MIGA is used to optimize the resistance performance, and finally the optimal combination of ship type parameters is obtained. It can provide some reference for the design of catamaran type wind power maintenance ship.

Index Terms— Maintenance in wind farm; catamaran; parametric design; numerical simulation; resistance optimization

I. INTRODUCTION

With the high concentration of the global wind power industry market and the rapid development of emerging markets[1-2], wind power operation and maintenance vessels are indispensable tools for daily maintenance of offshore wind farms. Because offshore wind farms are often affected by wind, waves, currents, tides and climatic conditions, the ship is required to have good navigation performance. Therefore, it is very important to study the professional offshore wind power operation and maintenance ship, especially it is necessary to study its resistance performance[3].

In this paper, the 25m offshore twin-body wind power maintenance ship is taken as the basic ship type, and the main parameters of its resistance influence are determined. The NAPA macro language parametric modeling is used to generate a series of ship types, and the resistance numerical simulation is carried out. With the minimum hydrostatic resistance as the optimization goal, the response surface model and the multi-island genetic algorithm (MIGA) optimization technology in Isight software are used to realize the effective integration of the modeling of the optimization process and the hydrodynamic performance software STAR-CCM+. The results show that the optimized resistance performance has been improved significantly, and there is a certain reference and reference for the ship type design of this type of ship.

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II. SERISE SHIP TYPE GENERATION

A. Determination of cross-section parameters and establishment of mathematical model

The geometry of the hull and its performance are also affected by a series of parameters with the main dimensions, drainage volume and floating center position unchanged. For resistance, the prismatic coefficient is a very important influence parameter[4]. To this end, based on the basic ship type, the influence on the resistance is studied for the maximum profile cross-section line and determining its shape influence parameters.

In the case of ensuring that the control ship width and design draught are constant, this paper will change the middle cross-section coefficient C_m by changing the parameter keel width f , the mid-section bottom elevation angle β , and the crotch radius R . With the middle cross-section of the basic ship as Example (as shown in Figure 1) to build a mathematical model, the specific segmentation is as follows:

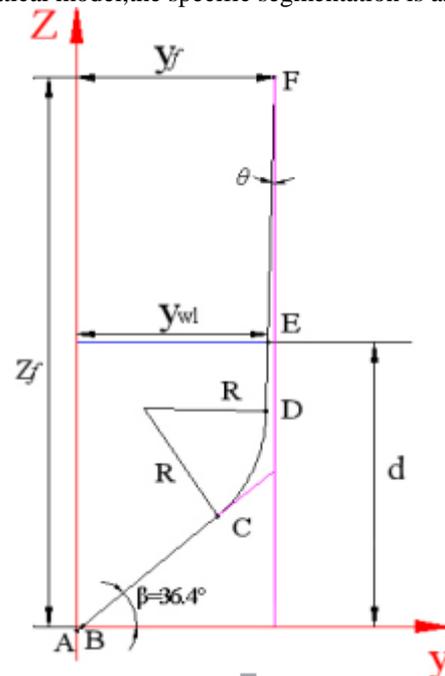


Fig.1 Middle cross line of the basic ship

(1) It can be known from the characteristics of the ship that the line segment AC is a straight line segment:

$$Z = y \cdot \tan \beta + k \quad (1)$$

Through mathematical expressions, substitute a point B(f,0)

$$k = -f \cdot \tan \beta \quad (2)$$

Then the mathematical expression of the AC equation of the straight line segment is:

$$Z_{AC} = y \cdot \tan \beta - f \cdot \tan \beta \quad (3)$$

(2) It can be known from the ship type that the curve CD is a quadratic curve (arc), and the center of the arc CD is the point G(m,n), then the curve CD formula is:

$$(y_{CD} - m)^2 + (z_{CD} - n)^2 = R^2 \quad (4)$$

Let the CD arc equation be: $(y_{CD} - m)^2 + (z_{CD} - n)^2 = R^2$, the two boundary conditions of the point C $(y_C, y_C \cdot \tan \beta - f \cdot \tan \beta)$ and the arc at the point C $(K = \tan \beta)$ can be used to solve the unknown coefficient:

$$m = \frac{R \tan \beta}{\sqrt{1 + \tan^2 \beta}} + y_C \quad (5)$$

$$n = y_C \tan \beta - f \tan \beta - \frac{R}{\sqrt{1 + \tan^2 \beta}} \quad (6)$$

then the mathematical expression of the CD equation of the arc segment is:

$$(y_{CD} - \frac{R \tan \beta}{\sqrt{1 + \tan^2 \beta}} - y_C)^2 + (y_C \tan \beta - f \tan \beta - \frac{R}{\sqrt{1 + \tan^2 \beta}} - z_{CD})^2 = R^2 \quad (7)$$

(3) It can be known from the characteristics of the ship that the line segment DF is a straight line segment:

$$Z_{DF} = py + q \quad (8)$$

The expression $F(y_f, z_f)$ and $E(y_{wl}, d)$ is substituted into the expression from the contour of the basic ship, where z_f is the deck height ($z_f = 2.9m$), y_f is the deck half width ($y_f = b/2 = 1.15m$), y_{wl} is the design waterline half width ($y_{wl} = 1.115m$), d is the design draught ($d = 1.5m$), and the straight line segment DF equation coefficient is obtained: $p = 40, q = -43.1$, then the mathematical expression of the straight line segment DF equation is:

$$Z_{DF} = 40y - 43.1 \quad (9)$$

According to the equations of the arc segment CD and the straight line segment DF, the mathematical expression of the D point is solved as:

$$1601y_D^2 - (2m + 80n + 3448)y_D + m^2 + 1857.61 + 86.2n + n^2 - R^2 = 0 \quad (10)$$

Due to the complexity of the digital formula, mathematical solutions are used to solve the problem, the coefficient of the equation

is: $aa = 1601, bb = -2m - 80n - 3448, cc = m^2 + 86.2n + n^2 - R^2 + 1857.61$, then find y_D as:

$$y_D = \frac{-bb + \sqrt{bb^2 - 4aa \cdot cc}}{2aa}, Z_D = 40y_D - 43.1 \quad (11)$$

Set the parameter maximum profile bottom elevation angle β , keel width f and crotch radius R , use the NAPA macro language text editor tool to draw cross-section lines on the parameters β, f and R (as shown in Fig.2). And through the macro statement, the error between the cross-sectional area $A_m = 2.420m^2$ of the calculated output and the cross-sectional area $A_m = 2.431m^2$ of the basic ship is only between 0.01, so the above mathematical model can be considered to meet the design accuracy requirements.

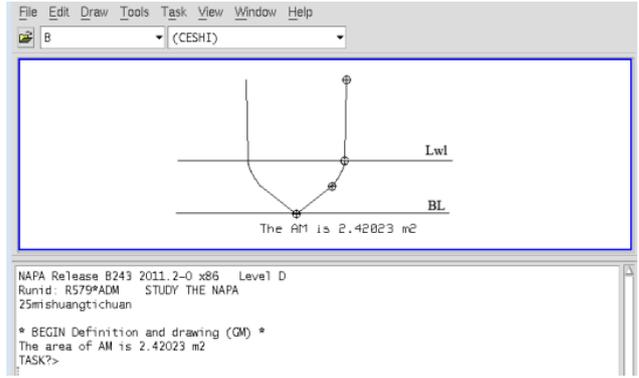


Fig.2 Establish a middle cross section in NAPA and solve the area

B. Establishment of Mathematical Model of Cross Section Area Curve

There are many methods for generating cross-sectional area curves in ship profile design[5]. In practice, more methods are used to modify the parent model[6], but the premise of this method is to ensure that the coefficient of the cross-section C_m is constant, so it is not applicable in this paper.

For a medium-high speed ship without a parallel middle body, the cross-sectional area curve can be regarded as consisting of two parts, the intersection point is at the maximum cross section. Through repeated verification and inference, the cross-sectional area curve of the basic ship is transformed by establishing a mathematical expression (see Equation 12).

$$y = \frac{A_1 - A_2}{1 + (x/a_0)^p} + A_2 \quad (12)$$

Through the curve fitting of the mathematical expression, the cross-sectional area curves of the front and rear half of the basic ship are respectively fitted and the precision of each parameter is obtained. It is found that the cross-sectional area curve fitting precision of the first half is above 0.999. The cross-sectional area curve fitting accuracy of the latter half exceeds 0.992. Therefore, the mathematical expression established on the cross-sectional area curve meets the design requirements.

Taking the maximum cross-section as the boundary line, for the second-half cross-sectional area curve, the parameter A_1 is the cross-sectional area of station 0, the parameter A_2 is the maximum cross-sectional area, and the parameter $P = 2.98$; For the first half cross-sectional area curve, the parameter A_1 is a linear function ($A_1 = A_m(1 + R)$) of the maximum cross-sectional area A_m and the radius R of the ankle, parameter A_2 is fixed at -0.726 , parameter $P = 2.98$. The parameter a_0 is a relational relationship between the keel width f , the mid-sectional bottom elevation angle β , the crotch radius R , and the middle cross-sectional coefficient C_m . The expression of the parameter a_0 is as follows:

$$a_0 = \begin{cases} A_0 + \frac{0.1 \cdot f \cdot R}{(1.15 - f) \tan \beta \cdot \delta C_m} & x_0 \leq x \leq x_{am} \\ A_0 - \frac{0.27 \cdot f \cdot R}{(1.15 - f) \tan \beta \cdot \delta C_m} & x_{am} \leq x \leq x_{10} \end{cases} \quad (13)$$

The above formula δC_m is the difference between the changed mid-section profile coefficient and the basic ship, and A_0 is obtained according to the basic ship's a_0 .

In summary, the expression of the cross-sectional area curve of the series of ships is :

$$y = \begin{cases} \frac{0.53622 - A_m}{1 + (x/(A_0 + \frac{0.1 \cdot f \cdot R}{(1.15 - f) \tan \beta \cdot \delta C_m}))^p} + A_m & x_0 \leq x \leq x_{am} \\ \frac{A_m(1+R) - (-0.726)}{1 + (x/(A_0 - \frac{0.27 \cdot f \cdot R}{(1.15 - f) \tan \beta \cdot \delta C_m}))^p} + (-0.726) & x_{am} \leq x \leq x_{10} \end{cases} \quad (14)$$

After verifying the mathematical expression, the function maintains continuity at x_{am} , that is, the values of the first half and the second half at x_{am} are the same, then the function expression is valid.

C. Half-width waterline value generation

According to the mathematical model determined above, the cross-sectional line and cross-sectional area curves of the series of ships can be obtained. In the derived cross-sectional area curves, measure the same amount of change δX_i (shown in Fig.3) for the cross-sectional area of the basic ship and the series of ships at each station, and plot the abscissa and cross-sectional area of the half-width watermark. Corresponding to the figure, in the water line diagram of the basic ship through the NAPA macro language, the half width of each station is the y_i ordinate, and the sum of the station distances and the corresponding station change amount δX_i is the abscissa, that is, the half width water line type, which in turn produces the half-width waterline and cross-section of the series of boats (Fig.4).

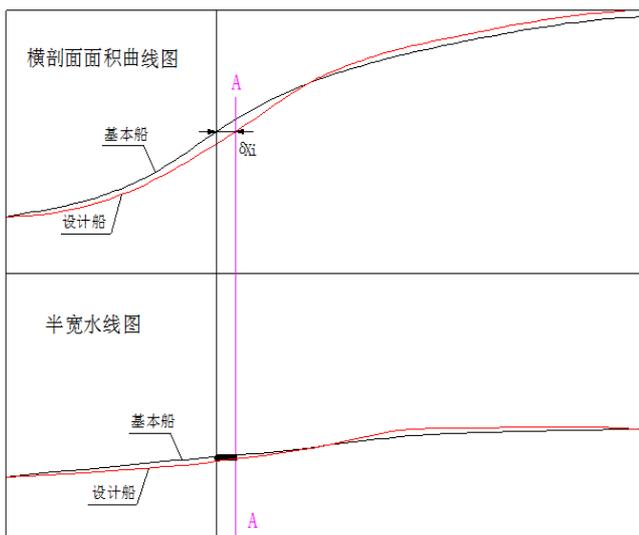


Fig.3 Half-wide waterline transformation of a series of ships

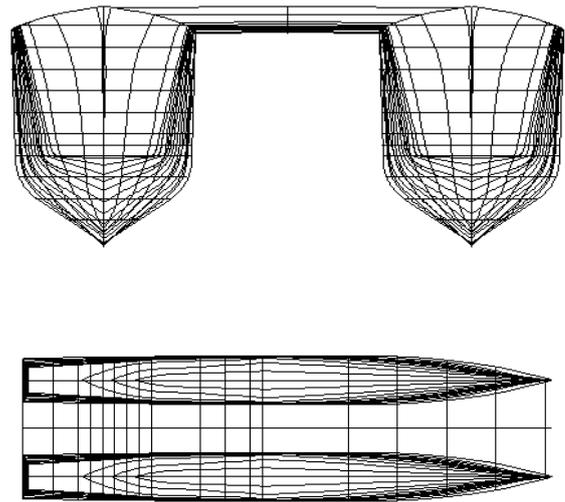


Fig.4 Design ship's profile

III. RESISTANCE NUMERICAL SIMULATION

A. Geometric model

This ship type is a catamaran type, the main elements of which are shown in Table 1. A series of ship geometry models with different cross-section parameters can be generated by using the compiled macro program. Figure 5 is a geometric model diagram of the hydrodynamic performance software STAR-CCM+ environment. The model scale ratio used for the calculation is $\varepsilon = 10$.

Tab.1 Main elements of catamaran ship model

Ship element	unit	Numerical value	Ship element	unit	Numerical value
Total length	m	2.500	Draught	m	0.150
Long line length	m	2.327	Displacement	kg	70.572
Total width	m	0.690	Center of gravity vertical height	m	0.248
Center distance	m	0.460	Center of gravity	m	1.168

B. Resistance simulation

Reference[7] resistance numerical simulation method, using STAR-CCM+, to capture the free surface by VOF method, can obtain the hydrostatic resistance of the calculated working condition design speed $V_s = 22 \text{ Kn}$ (model speed of ship model is $V_m = 3.579 \text{ m/s}$) for 200s. In order to better conform to the actual flight conditions, the voyage in the still water releases the hull freedom (pitch and heave), and the DFBI model is set to simulate the resistance performance of

the catamaran movement under the coupling of the hydrostatic plane. Fig. 5 is a graph showing the hydrostatic resistance curves of the series of boats obtained by changing the parameter keel width f , the mid-sectional bottom elevation angle β and the crotch radius R , which are automatically captured by the Excel software in the optimization process.

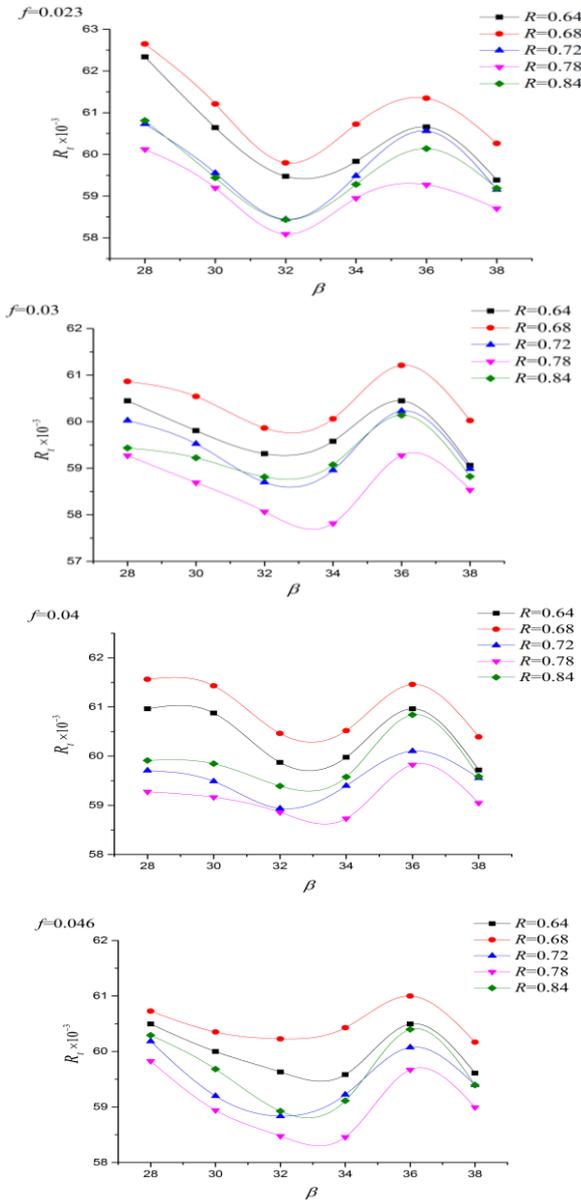


Fig.5 Hydrostatic resistance curve of different ankle radius R

It can be seen from Fig. 5 that when the keel width f is the same, there is a minimum value in the range of $\beta=32\sim34^\circ$ with the increase of the bottom elevation angle β of the middle section, and it is extremely small as the keel width f increases. The closer the point is to $\beta=34^\circ$. When the elevation angle β of the crucible section is the same, as the radius R of the ankle increases, the total resistance of the catamaran is larger when the radius R of the ankle is 0.68 m. Conversely, when the radius R of the ankle is 0.78 m. The total resistance of the catamaran is small.

IV. RESISTANCE OPTIMIZATION

Among the Isight optimization software, the global exploration methods are: multi-island genetic algorithm

(MIGA), automatic optimization expert algorithm (Pointer) and adaptive simulated annealing (ASA)[8].The resistance optimization algorithm uses the Multi-Island Genetic Algorithm, which searches the global optimal value in the entire design space, avoiding the situation where the optimal solution appears locally.The MIGA method is an optimization choice based on the statistical probability results. Each sample point is analyzed and calculated, and the survival and inferior method is used to judge and reanalyze. Preferably, iterative iteration reaches the convergence value to generate the optimal solution[9-10].

In this paper, the design variable of the hydrostatic resistance of the ship type is 3, the population number is 10, the subgroup size is 30, the iteration number is 50, the migration interval algebra is 5, the running times = population size \times population number \times iteration number = 15000.Ship type optimization problem is:

Optimize the target: $\text{Min}R_t$
 Optimization: Multi-island genetic algorithm
 Design variable: Middle section bottom angle β Keel width f Radon radius R

Design variable value range (see Table 2) :

parameter	Ranges
β	$28^\circ \sim 38^\circ$
f	0.023 ~ 0.046
R	0.64 ~ 0.84

Restrictions:

(1) Discharge error φ :

$$\varphi = \frac{|\Delta - \Delta|}{\Delta} \times 100\% < 2\% \quad (15)$$

Δ' represents the optimal displacement, Δ represents the displacement of the basic ship.

(2) Floating center longitudinal position error ψ :

$$\psi = \left| \frac{X_C - X_B}{X_B} \right| \times 100\% < 2\% \quad (16)$$

X_C indicates the position of the floating center of the optimized ship, and X_B indicates the position of the floating center of the basic ship.

Optimization Results:

Optimized design results and basic ship design pairs are shown in Table 3:

Tab.3 Comparison of parameters before and after optimization

	f	β	R	R_t	Optimization ratio
Basic ship design	0.030	36.00	0.71	60229.3	
Optimized design	0.028	32.29	0.76	57774.1	4.25 %

V. CONCLUSION

In this paper, combined with the characteristics of the ship type of 25m twin-body wind power operation and maintenance ship, the parametric design method of the upper twin-body wind power operation ship is explored through relevant mathematical expressions. The parameterized modeling macro language is written and imported by NAPA Basic module. The computational fluid software STAR-CCM+ performs the simulation calculation of the total resistance performance, and then uses Isight software to seek the optimal model of the ship with the goal of minimum hydrostatic resistance. The following conclusions were obtained through the above studies:

- 1) The mathematical model established for the maximum transverse section and cross-sectional area curves has high precision, and the series of ship models generated by the developed parametric design macro program are more reliable.
- 2) When the catamaran ship model parameters (middle section bottom lift angle $\beta = 32.29^\circ$, keel width $f = 0.028\text{m}$, crotch radius $R = 0.763\text{m}$), the resistance achieves the best optimization effect, which is 4.25% lower than the basic ship type.

The research methods and research results of this paper provide some reference and reference for the similar ship type design and its performance optimization, but it is still to be further studied in combination with wave increasing resistance.

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