Unmanned Wing-in-Ground-Effect Ship Design with Optimized Propulsion Mode

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Abstract. In order to solve the existing deficiencies of the unmanned WIG ship, a new type of unmanned WIG ship with the optimized propulsion unit was designed, where the lift-type water-air amphibious doubleducted-fan propulsion unit increased the drainage and navigation speed of the unmanned WIG ship by a large margin, and the load at the junction between the propulsion unit and ship body was reduced to a great extent. Through simulation and theoretical analysis, it is verified that the unmanned WIG ship with the optimized propulsion mode can further accelerate the drainage and navigation speed of the unmanned WIG ship and reduce the load at the junction between the propulsion unit and ship body during the navigation in water, so its operating performance and safety are both strengthened. Therefore, this newly developed unmanned WIG ship can deliver good social and economic benefits.

1 Research Background

With the ever-increasing intelligent level, unmanned ship – a research hotspot in many countries across the globe [1] – has been extensively applied to various fields such as marine geologic survey, water quality monitoring and water area surveying & mapping by virtue of its high intelligent level, low cost, and moreover, its ability to carry a variety of equipment [2]. However, it can hardly navigate in turbulent water due to a small body and weak water resistance [3].

The emergence of unmanned wing-in-ground-effect (WIG) ships in recent years has effectively compensated for the failure of ordinary unmanned ships to navigate in turbulent water. Unmanned WIG ships integrate the virtues of higher working efficiency and better load-carrying performance thanks to the ground effect. Nevertheless, when navigating on the water surface, most unmanned WIG ships cannot further elevate the drainage and navigation speed, showing poor working performance on the water surface. In addition, the loading of a high-thrust ducted fan propulsion unit not only enlarges the load at the junction between device and ship body, but also brings about certain potential safety hazards to the operation of unmanned WIG ships on the water surface.

Given this, an unmanned WIG ship design with optimized propulsion mode was proposed, which compensates the deficiencies of the existing unmanned WIG ships while guaranteeing their basic performance. Therefore, the drainage and navigation speed of the unmanned WIG ship was further accelerated when it was navigating on the water surface, the load at the junction between propulsion unit and ship body was reduced, and the potential safety hazards were removed to a certain extent while the operating efficiency on the working surface was improved.

2 Design Principle

2.1. Overall appearance design

The whole unmanned WIG ship stated in this study is tabular. A cabin, which can accommodate multiple types of equipment, is set at the central part of the ship body, triangular main wings are arranged at two sides of the cabin, and floating plates are set at the two ends of the wingspan, at the tail of which is a horizontal tail. The main parameters of the unmanned WIG ship are listed in Table 1, and its overall appearance is shown in Figure 1 and Figure 2.

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Item	Parameter	Item	Parameter
Molded	864.1 mm	Navigation	25 km/h
length		speed on the	
		water	
		surface	
Molded	716 mm	Navigation	60 km/h
breadth		speed in air	
Height	146 mm	Number of	2
		ducts	

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Figure 1. WIG Ship on Water Surface



Figure 2. WIG Ship in Air

double-ducted-fan propulsion unit are listed in Table 2, and its appearance is shown in Figure 3 and Figure 4.

2.2. Propulsion	unit design
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The lift-type water-air amphibious double-ducted-fan propulsion unit mainly consists of a metal rack carrying locating pin hole, locating pin device controlled by hydraulic pole, and two ducted fans, where the metal rack is connected to the locating pin device via slideway, and the two ducted fans are installed in the metal rack. The related parameters of the lift-type water-air amphibious

Table 2. Propulsion U	Unit Parameters
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Item	Parameter	Item	Parameter
Number of	12	Screw pitch	12 mm
blades			
Duct	64 mm	Rotation	660/46.7
diameter		speed in	rad/s
		air/water	



Figure 3. Propulsion Unit on Water Surface

Figure 4. Propulsion Unit in Air

2.3. Operating principles

During the operating process of an unmanned WIG ship on the water surface, the lift-type water-air amphibious double ducted fans are operating in the water and provide a greater thrust compared with that provided when operating in the air [4], which accelerates the drainage and navigation speed of the unmanned WIG ship and enable the ship to efficiently operate on the water surface. When the ship is navigating in the air, the hydraulic pole will regulate the metal rack to move upward along the slideway, and the ducted fans operating in the air in cooperation with the main wing.

3 Confirmatory Analysis

3.1. Overall flow field simulation analysis

As the unmanned WIG ship is navigating on the water surface, only ducted fans and metal rack are in the water and they are small in comparison with the overall ship form, so only air is needed as the medium for the ship to navigate on the water surface. Under a temperature, pressure intensity and navigation speed on the water surface of 293.2 K, 101,325 Pa and 25 km/h, respectively, the overall flow field simulation in the navigation on the water face is shown in Figure 5.



Figure 5. Overall Flow Field Simulation of WIP Ship Navigating on Water Surface

The simulation analysis results show that the overall streamlined design of the unmanned WIG ship greatly reduces the resistance it faces, elevates the drainage and navigation speed, and improves the operating efficiency on the water surface. Thanks to the floating plates at two ends of the wingspan, the ship can navigate more steadily on the water surface, thus enabling the ship to operate safely. is mainly composed of two ducted fans and a related metal rack, where the metal rack has a minor influence on the fluid simulation analysis of the propulsion unit, and the two ducted fans are totally the same, so it is only necessary to conduct the flow field simulation analysis on one single ducted fan during the operation in the air. The working conditions are set as follows: the temperature is 293.2 K, the pressure intensity is 101,325 Pa, and the rotation speed of ducted fans in water 46.7 rad/s. The simulation analysis results are shown in Figure 6.

3.2. Flow field simulation analysis of the propulsion unit

The lift-type water-air double-ducted-fan propulsion unit



Figure 6. Operation Simulation of Ducts in Water

According to the simulation analysis results, when the unmanned WIG ship is navigating on the water surface, the lift-type water-air amphibious double-ducted-fan propulsion unit can propel the ship in an efficient and steady way, and thus improve the operating efficiency on the water surface.

3.3. Strength simulation analysis of the propulsion unit

When the lift-type water-air amphibious double-ducted-

fan propulsion unit is operating in the water, the main stress-bearing part is the metal shell where the ducted fans are installed, so we only need to conduct strength simulation analysis on the metal shell. According to the stress condition when the unmanned WIG ship is navigating on the water surface, a load is applied to the metal shell. The simulation analysis results are presented in Figure 7 and Figure 8.



Figure 7. Displacement and Deformation of Metal Shell



Figure 8. Stress Distribution on Metal Shell

It can be known from the simulation analysis results that when the propulsion unit is operating in the water, the symmetrical structure of the metal shell prevents the stress from being concentrated on one part, thus reducing the load at the junction between the propulsion unit and ship body. Furthermore, the stress at the weak part of the metal shell is much smaller than its yield stress, so the usage requirement is satisfied.

3.4. Theoretical thrust analysis of propulsion unit

The mathematical expression of thrust and thrust coefficient is shown as below:

$$F = \frac{\pi N^2}{4 \times 60^2 (D/p)^2} n^2 (D/1000)^4 \rho$$
$$K_F = \frac{\pi N^2}{4 \times 60^2 (D/p)^2}$$

wherein *F* is thrust; *N* is number of blades; *D* is duct diameter; *p* is screw pitch; *n* is rotation speed of fan blade; ρ is medium in the duct operating scenario; K_F is the thrust coefficient. Based on Table 2 and the above equation, the ratio of thrust provided by the propulsion unit in water to that in the air is about 3.87, which means when the unmanned WIG ship is navigating on the water surface, the thrust ratio in water is greater than that in air, so the drainage and navigation speed of the unmanned WIG ship on the water surface has been elevated.

4 Conclusion

In order to solve the existing deficiencies of the unmanned WIG ship, a new type of unmanned WIG ship with the optimized propulsion unit was designed, where the lifttype water-air amphibious double-ducted-fan propulsion unit increased the drainage and navigation speed of the unmanned WIG ship by a large margin, and the load at the junction between the propulsion unit and ship body was reduced to a great extent. Through simulation and theoretical analysis, it is verified that the unmanned WIG ship with the optimized propulsion mode can further accelerate the drainage and navigation speed of the unmanned WIG ship and reduce the load at the junction between the propulsion unit and ship body during the navigation in water, so its operating performance and safety are both strengthened. Therefore, this newly developed unmanned WIG ship can deliver good social and economic benefits.

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