The Design of Warship and Aircraft Collaborative Operation Analytical System Based on Ocean Hydrometeorological Data

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Abstract. The launch of China's first aircraft carrier marks a qualitative change in the requirements of China's maritime defense forces for the carrier battle group [1]. In this paper, the Marine hydrometeorological data is combined with the mathematical model of ship performance calculation to preliminarily construct a software model to analyze the influence of the hydrological meteorological environment on the cooperative operation of the ship aircraft. This system uses ORACLE11g [2, 3] to create the corresponding database to storage data, and uses QT5.6 [4, 5] to build the front-end interface and compile calculation module algorithm. The calculation module of ship performance includes three aspects: seakeeping, maneuverability and rapidity, with it the users can select input data to get the calculation results in charts or other forms. The ocean hydrological data acquisition module, ship performance calculation module and corresponding display window of this system can help users obtain the required information intuitively. Finally, the system can achieve the function of conduct command and judgment of auxiliary fighters.
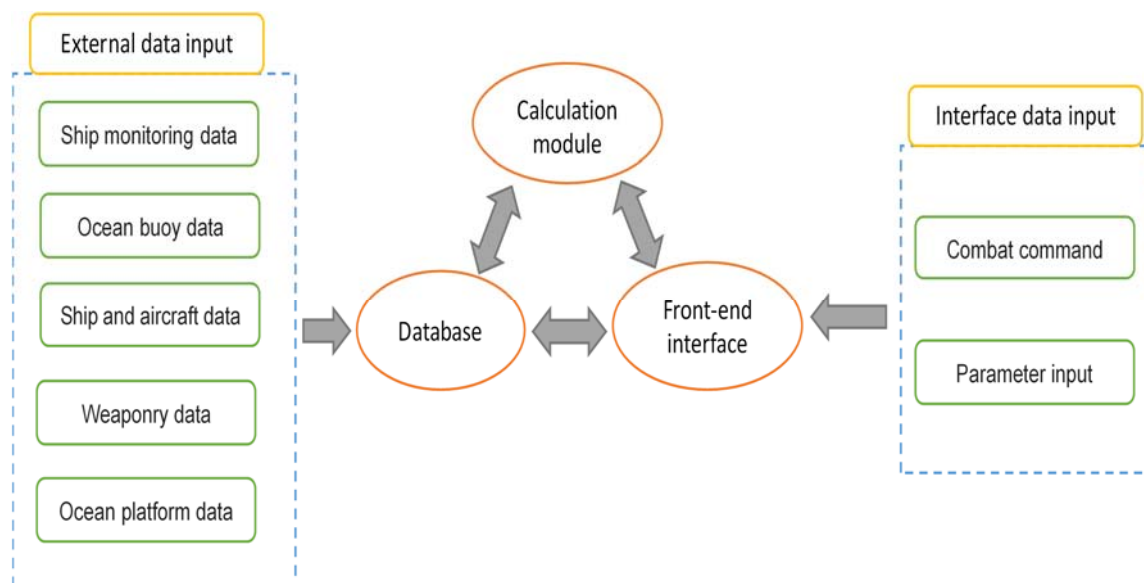
1. Introduction

Although the carrier-based aircraft [6] evolved from land-based aircraft, the performance of the aircraft was significantly different due to its special operational environment. The aircraft carrier movement and the marine environment have a great impact on the cooperative operation of aircraft carrier and carrier-based aircraft and the performance of the carrier-based aircraft. For the carrier-based aircraft performance, one of the most important factors is that the carrier-based aircraft landing techniques. At the same time, the movement and speed of the ship in the marine environment will also have an impact on the landing of carrier-based aircraft. At present, the research of naval aircraft cooperative combat system is mainly in the stage of theoretical analysis and conceptual design. In some literatures, prior research generally confirms that the impact of ship's longitudinal oscillation on the carrier aircraft, or only to simulate the take-off and landing of carrier-based aircraft. The content of the research is a little single, and it can not analyze the cooperative operation performance of warship and carrier-based aircraft in marine environment more comprehensively. This paper attempts to analyze the influence of ship oscillation, ship maneuvering and wave resistance on the cooperative operation of ship aircraft from the analysis of real-time hydrological data and ship performance calculation. This system uses ORACCLE11g to create database storage data and uses QT to design the front-end interface. The

mathematical model of ship performance calculation is compiled in QT, which is convenient for software integration, data call and data visualization. The calculation results of ship performance are output in the form of charts, the ocean data is displayed in the form of lists. According to the calculation results and corresponding data the system can analyze and give advice on aircraft take-off and landing.

2. Process Design of the Cooperative System

According to the requirements of warship and aircraft cooperative combat system and the actual application, it can be divided into the underlying database module design, the middle layer calculation module design and front-end display interface module design. The specific design process and processing flow of each part of the system will be described in the following paragraphs. The overall process design of the system is shown in figure 1.

Figure 1. Overall process design.

2.1. Logical Design of the Database

Due to marine hydrometeorological data is very complex, in addition to other vessels related information also need to be stored in the database, which requires the data store tool needs to have good compatibility, portability, data storage, and can guarantee the integrity of the data and other performance. Taking into account the above characteristics, this system uses ORACLE11g data storage management tools, and use ORACLE11g's structured query language PL / SQL query and programming [7]. According to the data requirements, the function of the database module can be divided into external data import (ocean hydrological data, etc.), the front-end data input (command news release) and database data to the calculation program and the front-end interface output. Part of the database build table code is shown in Figure 2. The system development environment and tools are shown in table 1.

```
execute immediate 'create table tb_platform_data(
                            platformdata_id   int primary key not null,
                            platform_id varchar2(16) null,
                            platform_name  varchar2(32) null,
                            longitude number(8,5) null,
                            latitude number(8,5) null,
                            water_dt date null,
                            water_wt number(6,2) null,
                            water_sl number(6,3) null,
                            water_wl number(4,1) null,
                            water_waveheight number(4,1) null,
                            air_dt date null,
                            air_at number(5,2) null,
                            air_bp number(8,2) null,
                            air_hu number(4) null,
                            air_rn1 number(8,1) null,
                            air_rn2 number(8,1) null,
                            air_ws1 number(4,1) null,
                            air_wd1 number(3) null,
                            air_ws2 number(4,1) null,
                            air_wd2 number(3) null,
                            air_ws3 number(4,1) null,
                            air_wd3 number(3) null,
                            air_wt3 date null,
                            air_ws4 number(4,1) null,
                            air_wd4 number(3) null,
                            air_wt4 date null,
                            air_visibility   number(8,1) null
                            )';
execute immediate 'create sequence seq_platform_data start with 1 increment by 1';
execute immediate 'create index index_platform_id on tb_platform_data(''platform_id'')';
execute immediate 'create index index_platform_longitude on tb_platform_data(''longitude'')';
execute immediate 'create index index_platform_latitude on tb_platform_data(''latitude'')';
execute immediate 'create index index_platform_air_dt on tb_platform_data(''air_dt'')';
execute immediate 'create index index_platform_water_dt on tb_platform_data(''water_dt'')';
```

Figure 2. Part of the table code.

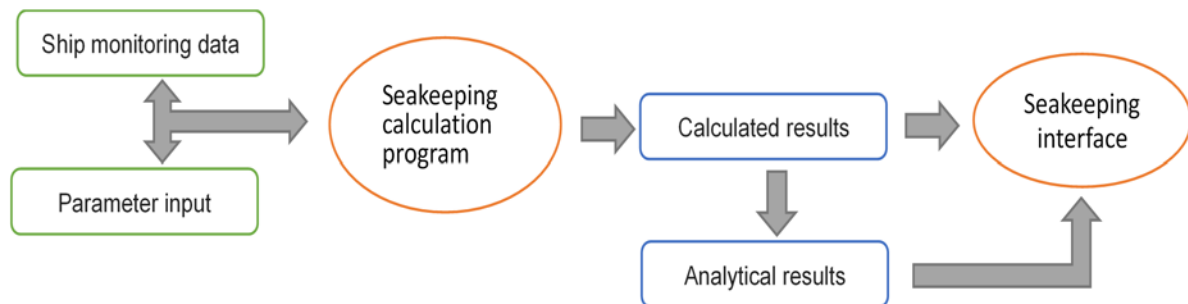**Table 1.** Development environment and tool table.

Tools	Function
QT	Program development tools
Oracle	Database
Mingw32	C++ compiler
PL/SQL	ORACLE compiler

2.2. Ship Performance Calculation Logic Design

The ship movement will bring many hidden dangers to the carrier-based aircraft. When ship sail in the ocean, it will produce six degrees of freedom. Among them, the three main factors that affect the landing of the carrier are rolling, pitch and heaving. The oscillation of the ship affects the take-off status of the carrier. The loss of speed caused by the increase of resistance and ship's maneuvering will affect the carrier-based aircraft safety. Therefore, this system considers the influence of ship motion on carrier-based aircraft from the aspects of ship maneuverability, wave resistance and rapidity.
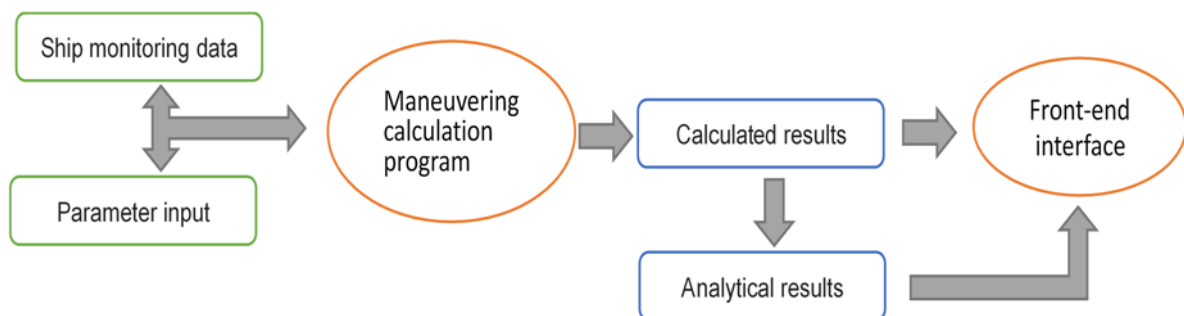
2.2.1. Seakeeping. The user selects wave parameters and corresponding ship information as input information of the calculation program in ship's seakeeping computing interface. After calculation, the frequency response function of the ship in the regular wave motion is obtained, and the statistical oscillation characteristics of the ship's motion in irregular waves are calculated by means of statistical analysis. According to the obtained oscillation statistics, we can give some suggestions on the take-off

and landing of the aircraft, and show the frequency response function curve, calculation result and the command suggestion together in the seakeeping interface. The specific processing flow is shown in figure 3.
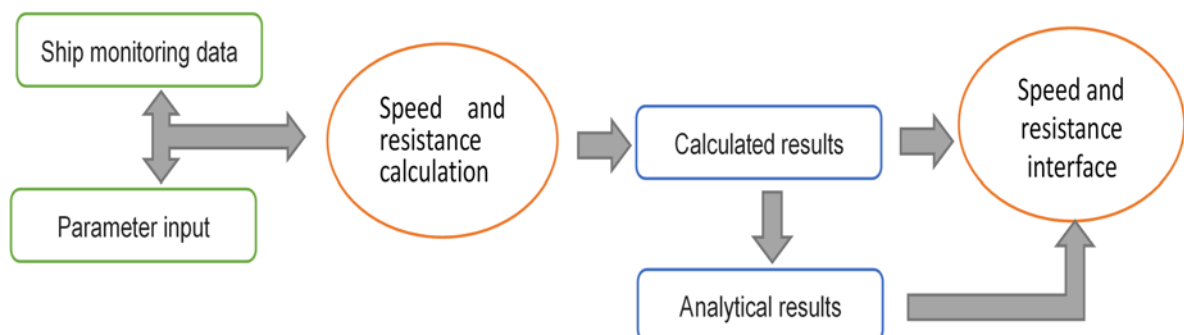

Figure 3. Ship seakeeping processing flow chart.

2.2.2. Maneuverability. Through setting up the steering time and steering angle and other parameters, combining with the corresponding ship information, the calculation results are shown in the front end interface in rectangular coordinates. The ship maneuverability processing flow is shown in figure 4.

Figure 4. Ship maneuverability processing flow chart.

2.2.3. Rapidity. The ship type selected by the front-end interface has already determined the static water resistance and frequency response curve. The increment of the ship's resistance in the wave is estimated by the ship's rapidity calculation program. The processing flow of ship speed and resistance is shown in figure 5.

Figure 5. Ship speed and resistance processing flow chart.

3. Ship Performance Calculation Mathematical Model

The last section introduces the software system of ship seakeeping, maneuverability and rapidity three aspects function structure and data processing, this section will in detail the construction of the mathematical model of three parts.

3.1. Seakeeping

Seakeeping ability [8] is a measure of how well-suited a watercraft is to conditions when underway. A ship which has good seakeeping ability is said to be very seaworthy and is able to operate effectively even in high sea states. The following part describes the mathematical model of ship seakeeping.

  1) Wave spectral density formula

  In this paper, the sea-wave spectral density calculated in the process of the frequency response function is based on the two-parameter spectrum recommended by ITTC (International Shipboard Experiment Conference).The wave spectrum formula is shown in equation (1).

$$S_\zeta(\omega) = \frac{A}{\omega^5} exp\left\{-\frac{B}{\omega^4}\right\} \tag{1}$$

Among equation (1) $A = \frac{173\overline{h}_{\frac{1}{3}}^2}{T_1^4}$; $B = \frac{691}{T_1^4}$;ωis the wave frequency; $\overline{h}_{\frac{1}{3}}$ is the significant wave height;T_1 is the wave period.

  2) Ship in six degrees of freedom movement in irregular waves.

  According to the irregular wave theory and the stationary stochastic spectrum analysis, the ship's movement in the wind and the waves shows the response of the linear system to the irregular wave input. The formula of ship response spectral density is shown in formulas (2) - (4).

$$S_\theta(\omega_e) = |W_\theta(i\omega_e)|^2 \times S_\zeta(\omega_e) \tag{2}$$

$$\omega_e = \omega - \frac{\omega^2 V}{g}\cos\mu \tag{3}$$

$$S_\zeta(\omega_e) = \frac{S_\zeta(\omega)}{1-\frac{2\omega}{g}V\cos\mu} \tag{4}$$

In formulas (2) - (4), $S_\theta(\omega_e)$ is the spectral function for the ship movement; ω_e is the encounter frequency; $|W_\theta(i\omega_e)|^2$is the ship's frequency response function; $S_\zeta(\omega_e)$ is the frequency spectrum of the encounter frequency;V is the speed of the ship;g is the acceleration of gravity; μ is wave to the angle; $S_\zeta(\omega)$ is a random wave circle frequency spectrum function. We can get the ship's six-degree-of-freedom movement variance by calculating integral of formula (2),as shown in equation(5).
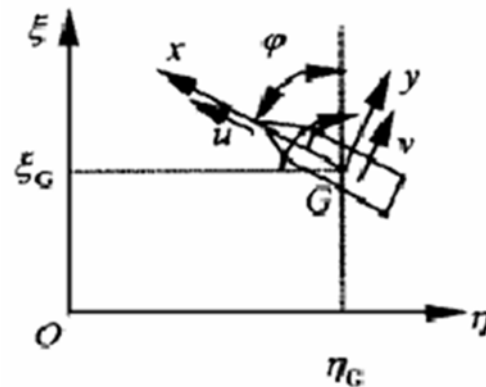
$$\sigma^2 = \int_0^\infty S_\theta(\omega_e)\,d\omega_e = \int_0^\infty |W_\theta(i\omega_e)|^2 \times S_\zeta(\omega_e)\,d\omega_e \tag{5}$$

3.2. Maneuverability

Ship maneuverability refers to the performance of the ship in keeping or changing its motion state according to the intention of the sailor, mainly in the aspect of turning and heading keeping [9]. The ship at sea will generate six degrees of freedom, and the mathematical model is as follows:

  1) Coordinate system

  Take the fixed coordinate system as Oξηζ, as shown in figure 6. Moving coordinate origin at the center of gravity of the ship.

Figure 6. Ship maneuvering movement coordinate system

2) MMG mathematical model

Assuming that the ship is a rigid hull and sails in an infinite depth of water, the MMG nonlinear mathematical model motion equation is as follows:

$$\begin{cases} m \cdot (\dot{u} - v \cdot r) = X_H + X_P + X_R \\ \quad m \cdot (\dot{v} - u \cdot r) = Y_H + Y_R \\ \quad\quad I_Z \cdot \dot{r} = N_H + N_R \end{cases} \tag{6}$$

In equation (6), m is the mass of the ship; u, v, r are the ship longitudinal velocity, lateral velocity and angular velocity respectively; $\dot{u}, \dot{v}, \dot{r}$ respectively for the ship longitudinal acceleration, lateral acceleration and angular acceleration; I_Z is the moment of inertia of the ship's mass to the OZ axis; X is the component of the hydrodynamic fores on the OX, Y is the component of the hydrodynamic fores on the OY, N is the moments on the OZ axis(Subscripts H, P, R representing the hull, the propeller and rudder).The specific solution process of each coefficient in equation can refer to the literature [9].

3) Input and output of the model

With entering the input data like the ship's basic information, the rudder and the rudder angle, the corresponding ship's gravity coordinates, the longitudinal velocity, the transverse velocity and the forward angle changing with time will be shown in the output data.

Table 2. Input data information.

Item	Value	Unit
Length of the ship	49.6	m
Draft	2.47	m
Ship width	8.0	m
Square coefficient	0.44	\
Ship quality	360000	kg

Table 3. Output data information.

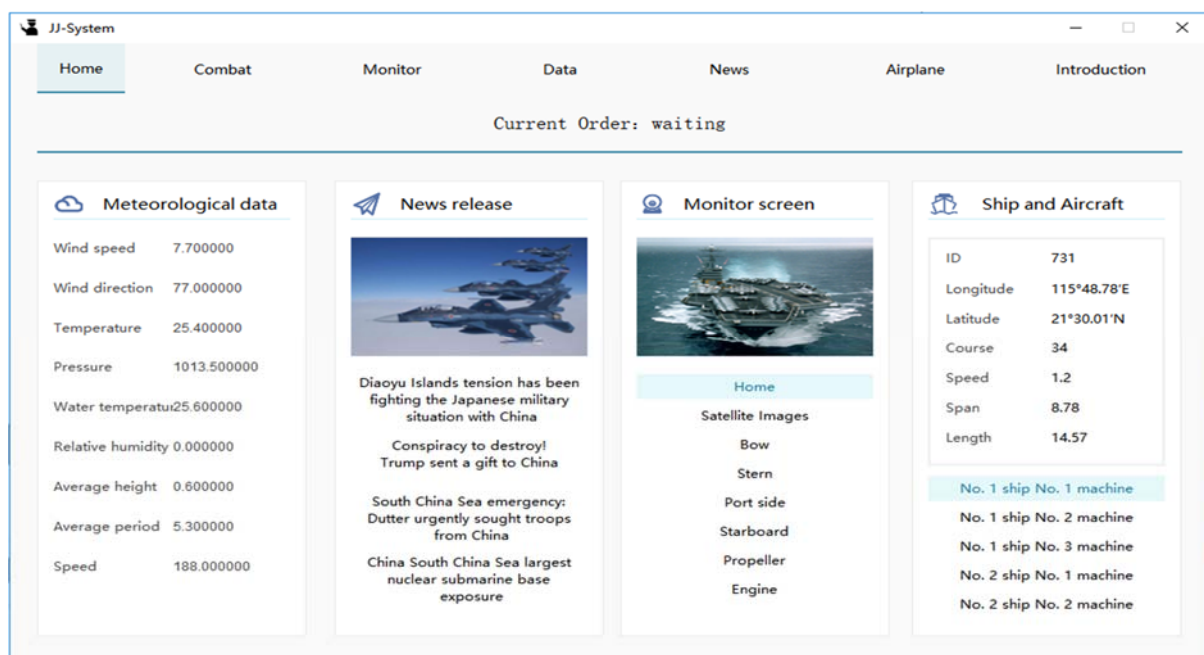| Absccissa	Ordinate	Time step	Longitudinal velocity	Lateral velocity	Radial angle
0.0000	0.0000	0.0000	8.0000	0.0000	0.0000
0.8000	0.0000	0.1000	7.9970	-0.0017	0.0000
1.5997	-0.0002	0.2000	7.9941	-0.0033	0.0009
2.3991	-0.0005	0.3000	7.9912	-0.0047	0.0028
3.1982	-0.0009	0.4000	7.9883	-0.0060	0.0057

3.3. Rapidity

According to the selected wave scale, ship heading and speed, the resistance increment of the ship under certain conditions and the percentage of resistance increase can be estimated by the calculation procedure of ship's rapidity. The dimensionless formula for wave propagation is shown in formula (7).

$$\frac{\sqrt{\Delta Rw}}{\zeta_a}\sqrt{\frac{1}{\rho_m g D_m^2/L_m}} \tag{7}$$

In the formula,ΔRw is the difference between wave resistance and hydrostatic resistance;ρ_m is the density of water;D_m is the density of water; L_m is the length of the main body of the ship; g is the acceleration of gravity. Similar to the ship seakeeping forecasting process, according to the input information selected previously, we can determine the frequency response curve of the wave resistance of ship in the regular wave. And then with it the response spectrum of the irregular wave resistance of ship can be analyzed and predicted. The difference here is that the wave spectrum selected here is the ITTC one-parameter spectrum.
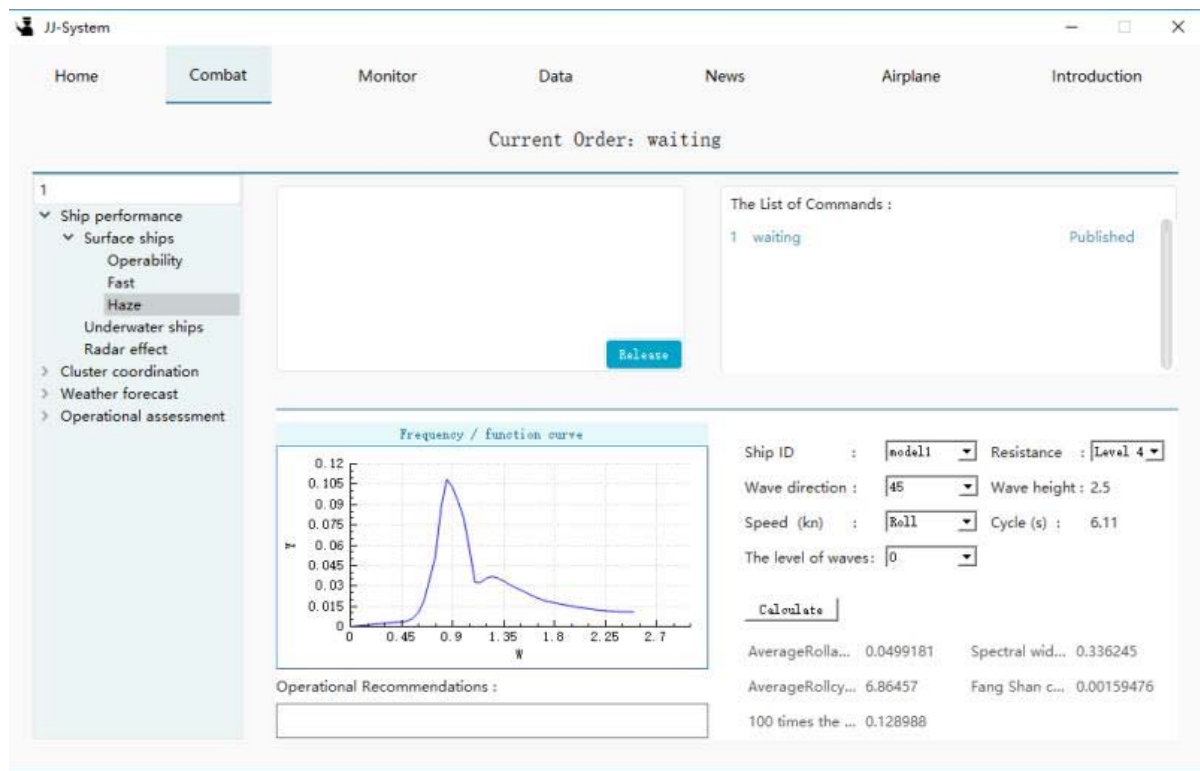
4. System design interface

Combined with the process design and mathematical model analysis of the previous two sections, the system uses QT to program the whole system. The front interface of this system is divided into home page, combat window, monitoring page, data acquisition, news release, ship aircraft and software introduction seven parts. Home page is shown in Figure 7, including information overview options such as hydrological data, ship and aircraft and more.
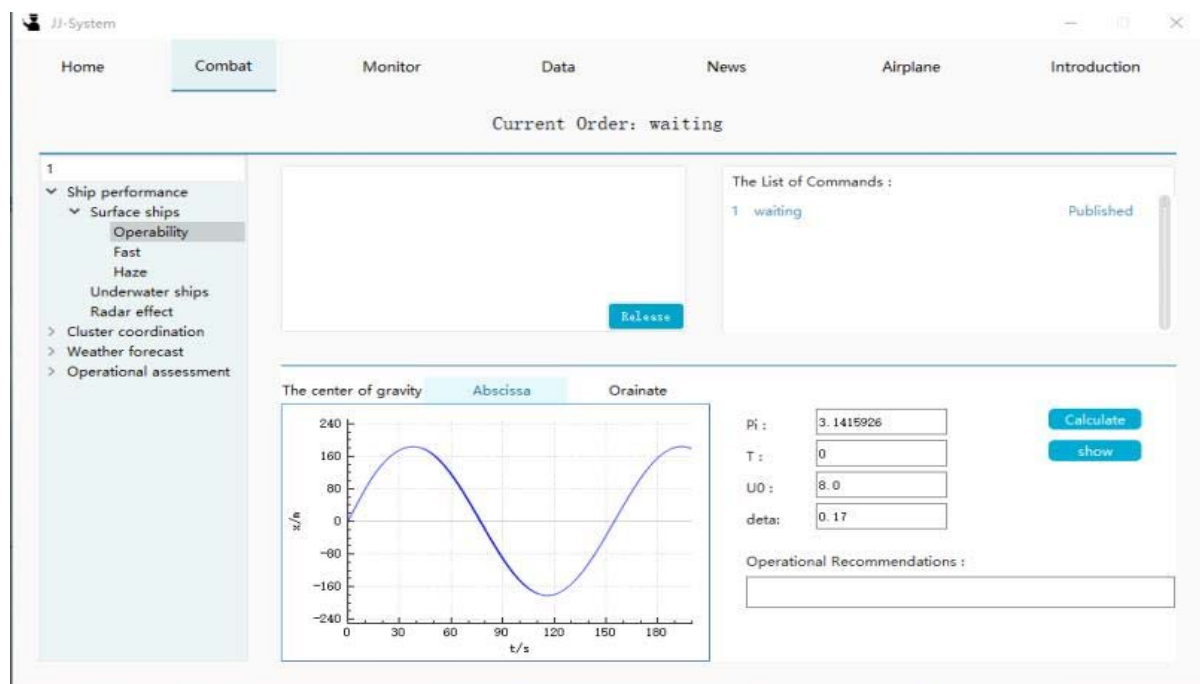

Figure 7. Home page

Figure 8 shows the ship's seakeeping computing interface in the ship's performance calculation module, including the parameter selection bar, the result display bar and the command edit release window, etc.

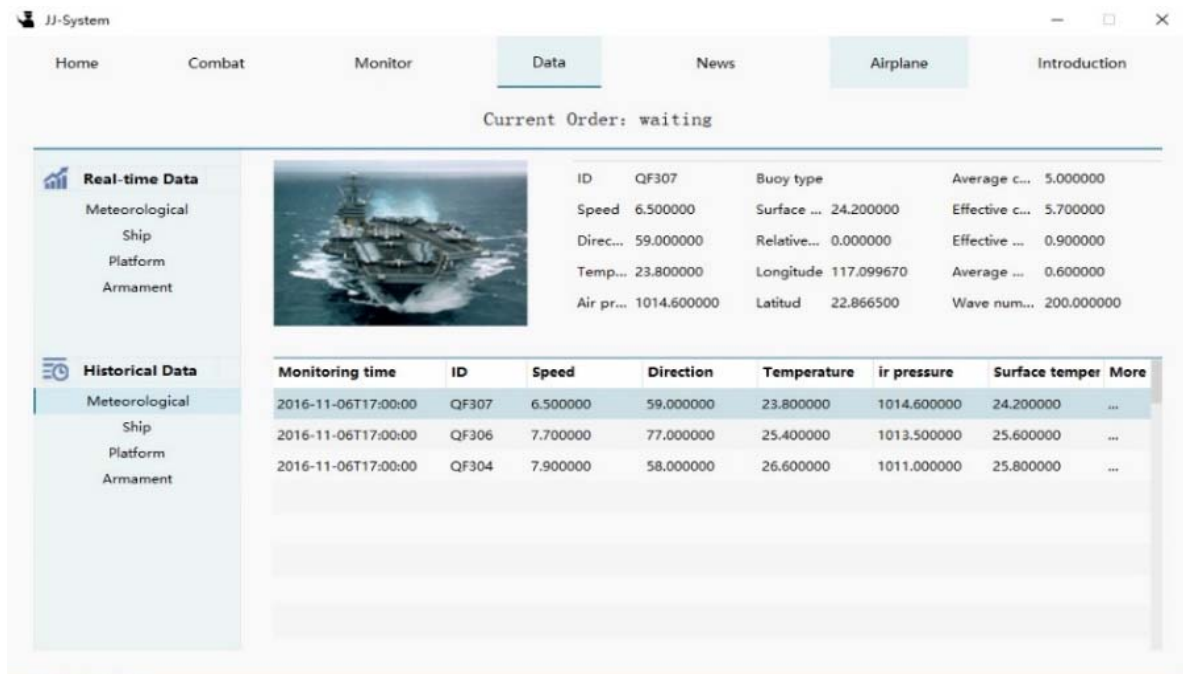**Figure 8.** Seakeeping calculating interface

Figure 9 shows the ship maneuverability computing interface, mainly including the trajectory of the ship's center of gravity, steering time and rudder angle and other information.

Figure 9. Ship maneuverability computing interface.

Figure 10 shows the data acquisition and display interface, mainly including the data of ocean buoys, ocean platform data, ship data and weapons and equipment.

Figure 10. Data acquisition and display interface

5. Conclusion

By establishing the mathematics model of ship performance calculation and using software QT to connect with the database, this paper explores a system interface of ocean hydrological meteorology to the shipboard cooperative influence analysis. Since its fast calculation capabilities on ship's seakeeping, maneuverability and rapidity, the users can easily browse hydrological data, edit and send combat commands. The design of warship and aircraft collaborative operation analytical model of system can lay a foundation for further research on the cooperative combat system.

References

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