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On Prediction of Longitudinal Attitude of Planing Craft Based on Controllable Hydrofoils

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Abstract: The purpose of this research study was to examine the attitude response of a planing craft under the controllable hydrofoils. Firstly, a non-linear longitudinal attitude model was established. In the mathematical model, effects of wind loads were considered. Both the wetted length and windward area varied in different navigation conditions. Secondly, control strategies for hydrofoils were specified. Using the above strategies, the heave and trim of the planing craft was adjusted by controllable hydrofoils. Finally, a simulation program was developed to predict the longitudinal attitudes of the planing craft with wind loads. A series of simulations were performed and effects of control strategies on longitudinal attitudes were analyzed. The results show that under effects of wind loads, heave of fixed hydrofoils planing craft decreased by 6.3%, and pitch increased by 8.6% when the main engine power was constant. Heave decreased by less than 1% and trim angle decreased by 1.7% as a result of using variable attack angle hydrofoils; however, amplitude changes of heave and pitch were less than 1% under the control of changeable attack angle hydrofoils and longitudinal attitude.

Keywords: planing craft; jet propulsion; attitude prediction; controllable hydrofoil

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1 Introduction

The high-speed planing craft is considered to be small, fast and agile. Therefore, it can be applied in both civil and military fields. During high-speed navigation, the static buoyancy is reduced markedly, because the craft is raised by lift acting on the bottom of a planing craft. Under the intensity of strong winds, high waves and currents, some violent attitudes such as slamming, spraying, broaching and even porpoise-like attitudes possibly will occur. Thus, both prediction and control of a high-speed planing craft are difficult yet significant, enough that the topic has attracted many scholars' attention.

Dong and Wu (2005) performed an experimental research study on longitudinal motion of deep-V planing craft model. He completed the measurement of the resistance and heave/pitch movement of the craft and discussed the heave and pitch movement response in regular wave. He pointed out that with the increase of velocity and wave amplitude, the heave acceleration, the pitch acceleration and the vertical acceleration of the planning craft presented nonlinear characteristics. At the same time, he carried out a theoretical research of prediction method on craft longitudinal motion, which included the effects of the planing lift, planing lift moment, as well as the motion prediction program. Carrica *et al*. (2006, 2007) completed planing craft in head sea motion response of prediction in the single-phase flow based on RANS equation. Gao and Zhu (2008), researchers of Harbin Engineering University, analyzed the hydrodynamic and the movement characteristics. In addition, a control means on fuzzy-neural network was provided which controlled the ship's attitude through accommodating the water jet. Next, the MATLAB software was used to simulate the system and get the result. The result shows that the controller using the fuzzy-neural network was efficient to reduce the ship's roll and control its attitude. Wu *et al*. (2010) design of the basic motion control strategy for the under-actuated unmanned surface vehicle (USV) was undertaken as well. The full controlling of the surface vehicle in various sailing states was achieved, and its maneuverability and agility was improved. Subsequently, the software architecture for the control system was designed using this plan. Finally, the USV motion control simulation tests were undertaken in different sailing states. And the simulation validates the effectiveness of the human-simulation control strategy.

Wilson *et al*. (2006), at university of Iowa in USA, prepared six degrees of freedom (DOF) movement response CFDSHIPIOWA of surface ship by unsteady RANS methods, which forecasted the free surface detouring flow field and its characteristic of attitude response in a variety of navigations in numerical value. CFDSHIP-IOWA calculated added mass, damping coefficient along with restoring force coefficient, and gave hydrodynamic force and attitude characteristic of the non-linear time domain simulation by 2D+t theory and complete nonlinear boundary element method (Sun and Faltinsen, 2007).

Zhu *et al*. (2012) conducted prismatic planing craft response of motion in regular head wave, and further anlysis response regularity of planing craft in the frequency domain. Arribas and Fernandez (2006) numerically calculated water

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pressure load and damping force by improved slicing theory of the high-speed planing craft for vertical attitude (heave and trim). Liang and Zong (2011) based on hydrofoil lift linear theory, completed the 3D hydrofoil hydrodynamic load analysis under different attackangle. As noted, the researchers point out that the ship speed and dynamic load had an important influence on the attitude response characteristics. In this paper, a longitudinal 3DOF motion model was established. Control strategies based on hydrofoils were implemented in the attitude model. Based on the model, the attitude of the planing craft can be predicted. The attitude response of the planing craft under wind loads was discussed.

2 The attitude model of the planning craft

According to maneuvering movement separation model (MMG), longitudinal three degrees of freedom dynamic equations of planing craft was established as

$$\left.\begin{aligned}&(m+m_{11})\dot{u}+(m+m_{33})\dot{\theta}w=X_H+X_t+X_{\text{wind}}+X_{\text{hyd}}\\&(m+m_{33})\dot{w}-(m+m_{11})\dot{\theta}u=Z_H+Z_t+Z_L+Z_G+Z_{\text{hyd}}\\&(I_y+\Delta I_y)\ddot{\theta}+(m_{11}-m_{33})uw=M_H+M_t+M_L+M_{\text{wind}}+M_{\text{hyd}}\end{aligned}\right\}\quad(1)$$

where $m_{11}\approx 0.1\dfrac{Z_H}{g}$, $m_{33}\approx\dfrac{Z_H}{g}$, $\Delta I_y\approx I_y$, $I_y=(0.25l)^2m$.

This means

$$\left.\begin{aligned}\dot{u}&=\frac{X_H+X_t+X_{\text{wind}}+X_{\text{hyd}}-(m+m_{33})\dot{\theta}w}{m+m_{11}}\\\dot{w}&=\frac{Z_G+Z_H+Z_t+Z_L+Z_{\text{hyd}}+(m+m_{11})\dot{\theta}u}{m+m_{33}}\\\ddot{\theta}&=\frac{M_L+M_H+M_t+M_{\text{wind}}+M_{\text{hyd}}+(m_{33}-m_{11})uw}{2I_y}\end{aligned}\right\}\quad(2)$$

where m is the mass of planing craft, I_y is the moment of inertia, $\dot{u},\dot{w}$ are accelerations in X, Z directions respectively, $\ddot{\theta}$ is trim angle acceleration, m_{11}, m_{33} are added mass, I_y is added moment of inertia, X_t is effective thrust in X direction, l is wetted length, X_H is resultant force of water dynamic drag (R_H) and friction drag (R_f), X_{hyd} is hydrofoils drag, X_{wind} is wind drag, Z_H is the buoyancy of planing craft, Z_L is dynamic lift, M_L is the moment of dynamic lift, M_H is static buoyancy moment, M_t is thrust moment, M_{wind} is wind drag moment, and M_{hyd} is the moment caused by hydrofoils.

2.1 Determination of drags and moments

According to 1957 ITTC (Chen and Zhu, 2010), the formula of viscous drag coefficient is as follows:

$$C_f=\frac{0.075}{(\lg Re-2)^2}\quad(3)$$

where Re is the Reynolds number.

Roughness compensation coefficient is described below:

$$\Delta C_f=0.4\times10^{-3}\quad(4)$$

Frictional drag R_f is written as

$$R_f=\frac{1}{2}\rho V^2S(C_f+\Delta C_f)\quad(5)$$

where S is the area of wetted body surface, $S=\dfrac{\lambda B_w^2}{\cos\beta}$; λ is length-beam ratio of wetted length, $\lambda=\dfrac{l}{B_w}$ and B_w is beam of draught.

$$B_w=\begin{cases}B & T_w\ge D_k\\2.58+0.44T_w+(0.01-0.0097T_w)\theta & 0.4\le T_w<D_k\\2T_w\tan(90^\circ-\beta)+\varepsilon & 0<T_w<0.4\end{cases}\quad(6)$$

where D_k is the height at transverse chine lines, β is deadrise angle, T_w is draft, and ε is the width compensation factor concerning with craft type, generally from 0.2 to 0.5.

Considering the influence of displacement and trim angle θ, the formula of wetted length l is derived from hydrostatic state to sliding state, which is described as:

$$\begin{cases}l_{kk}=\left(l_k-l_g-\dfrac{(l_k-l_g)\sin\theta-T_w}{\sin\theta}\right)\cos\theta & \left(l_k-l_g\right)\sin\theta-T_w>0\\l_{kk}=\left(l_k-1_g\right)\cos\theta & \left(l_k-l_g\right)\sin\theta-T_w\le 0\end{cases}\quad(7)$$

$$\begin{cases}l_{cc}=\left(l_c-l_g-\dfrac{(l_c-l_g)\sin\theta-T_w}{\sin\theta}\right)\cos\theta & \left(l_c-l_g\right)\sin\theta-T_w>0\\l_{cc}=\left(l_c-1_g\right)\cos\theta & \left(l_c-l_g\right)\sin\theta-T_w\le 0\end{cases}\quad(8)$$

$$l'_k=l_{kk}+l_g\cos\theta,\quad l'_c=l_{cc}+l_g\cos\theta$$

$$l'=\frac{l'_k+l'_c}{2},\quad l=\frac{l'+\sqrt{l'^2+1.6B_wl'}}{2}\quad(9)$$

where l_k is wetted keel, l_g is longitudinal center of gravity, l_c is wetted chine line; θ is trim angle, and $Re=\rho Vl/\mu$ is Reynolds number.

The formula of static buoyancy is written as

$$Z_H=\frac{2C_b\rho gT_w^2l}{\tan\beta}\quad(10)$$

The vertical arm to the gravity center of the static buoyancy is written as

$$x_B=\frac{\left(\dfrac{\lambda-0.8}{3\lambda+1.2}-\dfrac{l_g}{l}\right)l}{\dfrac{\lambda-0.4}{\lambda+0.4}}\quad(11)$$

Static buoyancy moment is written as

$$M_H=Z_Hx_B\quad(12)$$

The hydrodynamics of the hull was calculated by using Shuford-Brown semi-empirical theory. However, in the formula, the movement attitude of the hull was not taken into account. Therefore, in this paper, the formula was extended by considering the movement attitude.

Dynamic lift coefficient is defined as

$$C_L = \frac{\pi}{4}\sin 2\alpha \cos\alpha\left[\frac{(1-\sin\beta)\lambda}{1+\lambda} + \frac{1.33\lambda \sin 2\alpha \cos\beta}{\pi}\right] + 0.314\sin 2\alpha\left(\frac{\lambda}{Fr_B}\right)^2 \tag{13}$$

Dynamic drag coefficient is

$$C_D = C_L \tan\alpha + \frac{\lambda C_f}{\cos\alpha \cos\beta} \tag{14}$$

Hydrodynamic lift is

$$Z_L = \frac{\rho V^2 B_w^2 C_L}{2} \tag{15}$$

Hydrodynamic drag is

$$R_H = \frac{\rho V^2 B_w^2 C_D}{2} \tag{16}$$

The vertical distance from hydrodynamic lift location to the center of gravity is described as:

$$x_L = 0.75l + 0.08\frac{\lambda^{0.865}}{\sqrt{Fr_B}} - l_g \tag{17}$$

Dynamic lift moment is

$$M_L = Z_L x_L \tag{18}$$

where $Fr_B = \frac{V}{\sqrt{gB_w}}$ is wide Froude number.

2.2 Wind pressure drag and moment

According to the table of wind force scale, the wind speeds in different wind forces are 12 m/s at 6, 15 m/s at 7 and 18 m/s at 8 respectively. The empirical formula of the air drag (Zhang and Yin, 2007) is

$$X_{\text{wind}} = C_a \frac{\rho_a}{2}(V \pm V_a)^2 S_x \tag{19}$$

where ρ_a is the density of air and the density of saturated wet air is 17.1–31.5 kg/m^3, chosen as 17.1 kg/m^3, V_a is wind speed, taking the headwind as positive, the downwind as negative, C_a is air drag coefficient changing from 0.3 to 0.5, chosen as 0.4, S_x is projected area in cross section of craft body above water line, which does not include the superstructure.

Planing craft model was simplified as a rectangle and trapezoid. Wind area computation formula is described as:

$$S_x = \frac{(D - D_k)B}{\cos\alpha} + \frac{BD_k}{2\cos\alpha} \tag{20}$$

where B is beam, D is draught.

Arm of wind drag is

$$Z_{\text{wind}} = \frac{D_k}{3\cos\alpha} + \frac{D + D_k}{4\cos\alpha} - Z'_G \tag{21}$$

where Z'_G is the center of gravity.

Wind pressure moment is written as

$$M_{\text{wind}} = X_{\text{wind}} Z_{\text{wind}} \tag{22}$$

2.3 Jet propulsion

Jet propulsion was used in the planing craft, which produces thrust by pump rotation. Effective thrust was generated by jet propulsion after the ship:

$$T_p = \rho Q(v_a - v_e) \tag{23}$$

where ρ is the density of water, Q is jet pump flow, v_a is nozzle flow velocity, and v_e is inlet velocity.

Effective thrust in X direction:

$$X_t = T_p \cos\alpha \tag{26}$$

Effective thrust in Z direction:

$$Z_t = T_p \sin\alpha \tag{27}$$

Thrust moment generated by the planing craft

$$M_t = T_p x_t \sin\alpha \tag{28}$$

x_t is the longitudinal distance between the thrust location and the center of gravity.

3 The control strategy of hydrofoil

3.1 The control strategy of hydrofoil varying with angle of attack

It is the control objective that heaves under different speeds which are the same as the heave under V_{wind}. Besides, it is the control strategy that both speed and lift are calculated under different wind speeds with a constant engine power. The control strategy can be explained in Table 1.

Table 1 The change of ship speed and lift at different wind speed

Wind speed	Ship speed	Lift	Change of lift
V_{wind1}	V_1	Z_{L1}	ΔZ_{L1}
V_{wind2}	V_2	Z_{L2}	ΔZ_{L2}
V_{wind3}	V_3	Z_{L3}	ΔZ_{L3}
…	…	…	…
$V_{\text{wind}n\text{-1}}$	V_{n-1}	Z_{Ln-1}	ΔZ_{Ln-1}
$V_{\text{wind}n}$	V_n	Z_{Ln}	ΔZ_{Ln}

The area of hydrofoils is described as follows:

$$S_{\text{hyd}} = (1+\xi)\frac{2\Delta Z_{L\max}}{\rho \pi \tau_{\max} V_{\min}^2} \tag{29}$$

where ξ is a shape compensation factor, from 0.1 to 0.3, and $\tau_{\max}$ is the maximum adjustment angle of attack in radians (given in advance) of dynamic hydrofoil.

Suppose that

$$\boldsymbol{A}=\begin{bmatrix}V_{\text{wind1}} & V_{\text{wind2}} & \cdots & V_{\text{wind}n}\end{bmatrix}$$

$$\boldsymbol{B}=\begin{bmatrix}V_1 & V_2 & \cdots & V_n\end{bmatrix}$$

$$\boldsymbol{C}=\begin{bmatrix}\Delta Z_{L1} & \Delta Z_{L2} & \cdots & \Delta Z_{Ln}\end{bmatrix}$$

$$\boldsymbol{E}=\begin{bmatrix}1 & 1 & \cdots & 1\end{bmatrix}$$

$$\boldsymbol{D}=\begin{bmatrix}\left(A^{\mathrm{T}}\right)^3 & \left(A^{\mathrm{T}}\right)^2 & A^{\mathrm{T}} & E^{\mathrm{T}}\end{bmatrix}$$

$$\boldsymbol{F}=\left(\frac{C}{0.5\rho\pi S_{\text{hyd}}B^2}\right)^{\mathrm{T}}$$

The generalized least squares method is

$$\boldsymbol{K}=(\boldsymbol{D}^{\mathrm{T}}\boldsymbol{D})^{-1}\boldsymbol{DF}$$

where

$\Delta Z_{Li}=Z_{Li}-Z_{L\text{aim}},\ i=1,\cdots,n$; $\Delta Z_{L\max}=\max\left(\Delta Z_{L1}\quad \Delta Z_{L2}\quad \cdots\quad \Delta Z_{Ln}\right)$; $V_{\min}=\min\left(V_1\quad V_2\quad \cdots\quad V_n\right)$.

Angle of attack could be described by wind speed as

$$\tau=\boldsymbol{K}^{\mathrm{T}}\boldsymbol{U}^{\mathrm{T}} \tag{30}$$

where $\boldsymbol{U}=\begin{bmatrix}V_{\text{wind}}^3 & V_{\text{wind}}^2 & V_{\text{wind}} & 1\end{bmatrix}$. V_{wind} is wind speed. Lift caused by hydrofoils locating at the center of gravity is written as

$$Z_{\text{hyd}}=0.5\rho\pi\tau S_{\text{hyd}}\boldsymbol{U}^2 \tag{31}$$

Drag caused by hydrofoils can be as follows:

$$X_{\text{hyd}}=Z_{\text{hyd}}\tan\tau+0.5\rho C_f U^2 S_{\text{hyd}} \tag{32}$$

3.2 The control strategy of hydrofoil longitudinal movement

In order to keep trim angle the same as the one at V_{wind}, ship speed, lift, and trim angle should be calculated in different wind speeds. In the constant host power, ship speed, moment, trim angle in different wind speed are shown in Table 2.

Table 2 The change of ship speed, moment and trimming angle in different wind speed

Wind speed	Ship speed	Moment	Trimming angle	Change of moment	Change of angle
V_{wind1}	V_1	M_1	θ_1	ΔM_1	$\Delta\theta_1$
V_{wind2}	V_2	M_2	θ_2	ΔM_2	$\Delta\theta_2$
V_{wind3}	V_3	M_3	θ_3	ΔM_3	$\Delta\theta_3$
…	…	…	…	…	…
$V_{\text{wind}n\text{-}1}$	V_{n-1}	M_{n-1}	θ_{n-1}	ΔM_{n-1}	$\Delta\theta_{n-1}$
$V_{\text{wind}n}$	V_n	M_n	θ_n	ΔM_n	$\Delta\theta_n$

The hydrofoils trip length is

$$\text{hyd}L=\frac{\Delta M_{\max}}{\cos\theta_{\text{aim}}Z_{\text{hyd}\max}} \tag{33}$$

Moment caused by hydrofoils is described as

$$M_{\text{hyd}}=-Z_{\text{hyd}}\text{hyd}L\sin\left(\frac{\pi\Delta\theta}{2T}\right)\cos\theta \tag{34}$$

where $\Delta M_i=M_i-M_{\text{aim}}$, $\Delta\theta_i=\theta_i-\theta_{\text{aim}}$, $i=1,\cdots,n$; $\Delta M_{\max}=\max\left(\Delta M_1\quad \Delta M_2\quad \cdots\quad \Delta M_n\right)$, $T=\max\left(|\Delta\theta_1|,|\Delta\theta_2|,\cdots,|\Delta\theta_n|\right)$, $\Delta\theta=\theta-\theta_{\text{aim}}$, θ_{aim} is aim trim angle, θ is trim angle, Z_{hydmax} is maximum lift generated by hydrofoil.

4 The main parameters of planing craft

The main parameters and dynamical systems of this planing craft came from some patrol boat data. The main parameters are shown in Table 3.

Table 3 The basic parameters of model of planing craft

Total length/m	11.3	Beam/m	3.15
Moulded depth/m	1.25	Draught/m	0.43
Displacement/t	6.7	Block coefficient C_b	0.65
Initial angle of attack/(°)	5	Main engine power/kW	420

5 The analysis of controllable hydrofoil planing craft's vertical movement forecasting in various wind apeeds

According to the vertical 3 degrees of freedom mathematical model of controlled hydrofoil planing craft, in the prediction process, not only movements including ship speed, heave, trim angle, buoyancy, and the change of attack angle, but also hydrodynamics such as drag, thrust, and dynamic lift are given in different wind speeds. Accordingly, the response of hydrofoils was obtained.

5.1 Planing craft movement and the characteristics of dynamic response

Fig. 1 shows the curve of ship speed varies with wind speed. When the wind speed was less than 4 m/s, ship speed of fixed hydrofoil planing craft was larger than that of dynamic hydrofoil planing craft including both variable attack angle and variable attack angle with vertical movement. When wind speed was larger than 4 m/s, ship speed of fixed hydrofoil planing craft was less than that of dynamic hydrofoils including two types. Ship speed of fixed hydrofoils planing craft decreases by 15.8%, while that of dynamic hydrofoils including two types' decreases by 13.1%. It was revealed in Fig. 2 that when the wind speed was less than 4 m/s, the sailing drag of fixed hydrofoil planing craft was less than that of both changeable attack angle hydrofoil and that of two types of changeable attack angle and longitudinal attitude hydrofoils. That's because the increase of wind drag caused by low wind speed air load was small, which caused a small influence on the trim angle and the heave. Meanwhile, the increase of drag induced by control was higher than decrease of friction. When the wind speed was larger than 4 m/s, the increase of drag was larger along with wind speed air load, which had a great influence on the heave and trim angle. The increase of drag caused by hydrofoils was larger than the decrease of friction. Drag caused by the fixed hydrofoils increases by 59.8%, and drag caused by the dynamic hydrofoils including two types increases by 53.1% under the effect of the wind force 0–8. Fig. 2 and Fig. 3 indicate that drag and thrust can keep balance during sailing. Fig. 4 and Fig. 5 show that even though the weight of the body was supported by the buoyancy and dynamic lift, dynamic lift provides the main support; dynamic lift of fixed hydrofoil planing craft decreases by 2.1%, and static buoyancy increases by 22.8%. Dynamic lift of dynamic hydrofoil planing craft was obviously not changed under the effect of the wind force 0–8.

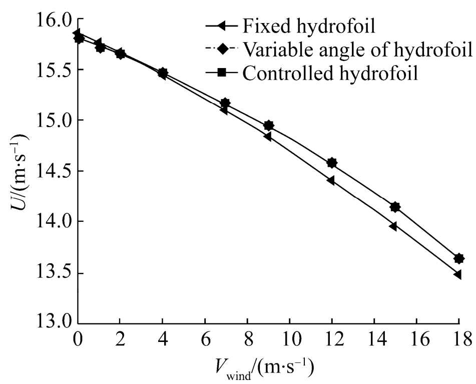

Fig. 1 Curve of wind speed and ship speed

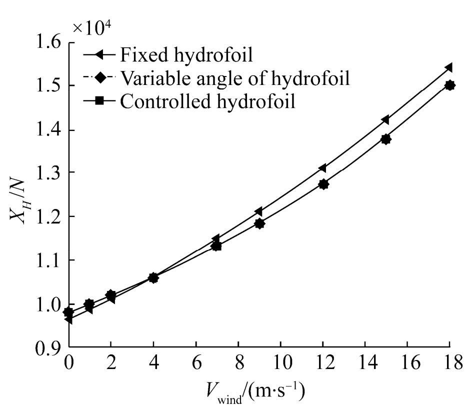

Fig. 2 Curve of wind speed and drag

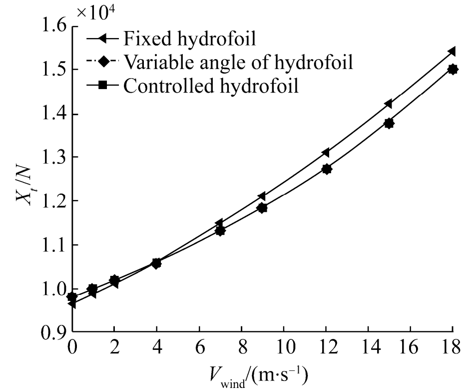

Fig. 3 Curve of wind speed and thrust

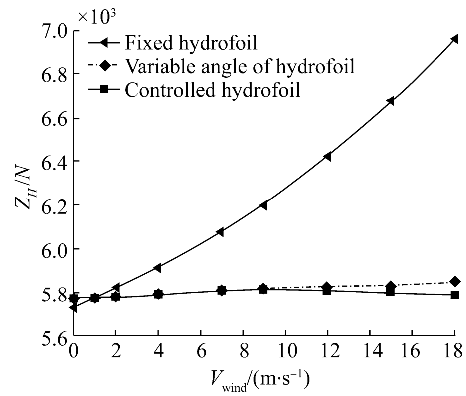

Fig. 4 Curve of wind speed and buoyancy

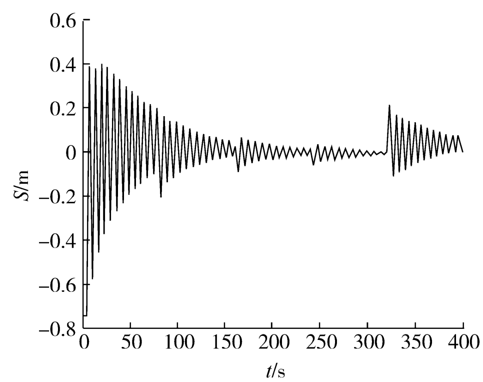

Fig. 5 Curve of wind speed and trip of hydrofoils

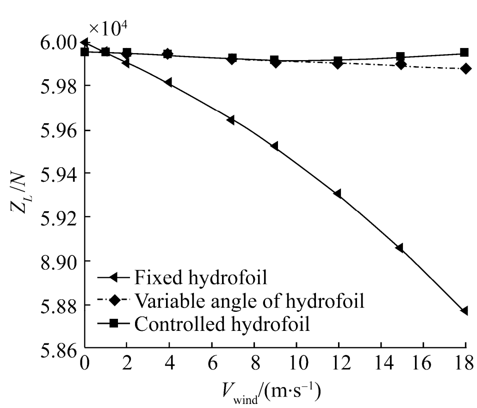

Fig. 6 Curve of time and dynamic lift

5.2 Hydrofoil movement and dynamic response analysis

The controllable hydrofoils create corresponding movement owning to the control strategy in different wind speeds. Fig. 6 shows the longitudinal attitude of controllable hydrofoils varying with time under 0–8 random winds (wind speed changes every 40 s). Fig. 6 shows the response of hydrofoils under different loads. Figs. 7–10 show the response of dynamic hydrofoils including two types of attitudes changing with wind speed.

Fig. 7 shows attack angle of hydrofoils changing from 0° to 4.2° with the wind speed varying from 0 to 18 m/s. It can be seen from Figs. 8, and 9 that within a certain range, attack angle of hydrofoils increases, and the lift of hydrofoils are much larger than the drag. Besides, attack angle of hydrofoils changing from 0° to 4.2°, the lift changes from 0 to 12 000 N, and the drag changes from 190 to 1 000 N. It can be seen from Fig. 15 that the dynamic hydrofoils under variable attack with vertical movement can control moments. The moment of hydrofoils changes from 0 to 750 N·m under the wind force 0–8.

5.3 Attitude control results of planing craft

The hull drag grows with the increase of wind speed, which induces the drop of ship speed, the decrease of dynamic lift, the decline of heave, the rise of buoyancy and the growth of trim angle. Dynamic lift and moment generated by hydrofoils compensate for dynamic lift and moment reduced by the hull so as to achieve the control of heave and trim angle. Both Fig. 11 and Fig. 12 show that curve of heave and trim angle changing with wind speed and control results under three conditions. When heave and trim angle controlled by the dynamic hydrofoils under two types of attitude.

As the wind speed changes from 0 m/s to 18 m/s, the heave controlled by the dynamic hydrofoil under variable attack angle decreases by less than 1%, and the corresponding trim angle decreases by 1.7%. Heave and trim angle controlled by dynamic hydrofoils under variable attack with vertical movement changes by less than 1%, compared with force 0 wind. Meanwhile, for fixed hydrofoils planing craft, heave decreases by 6.3%, and trim angle increases by 8.6%.

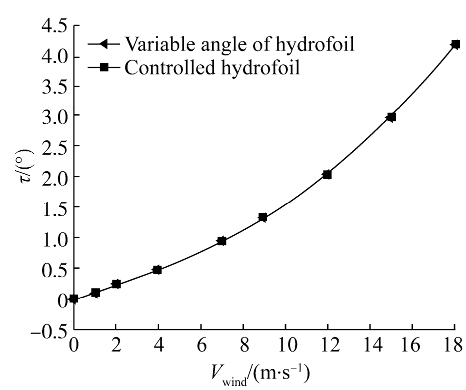

Fig. 7 Curve of wind speed and attack angle of hydrofoils

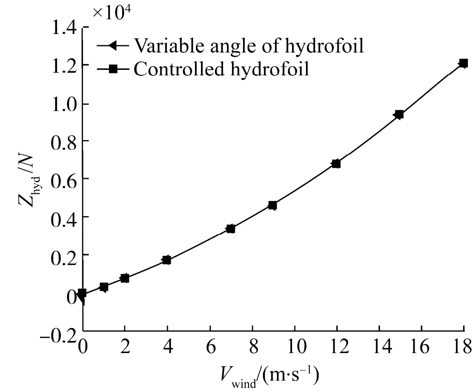

Fig. 8 Curve of wind speed and dynamic lift of hydrofoils

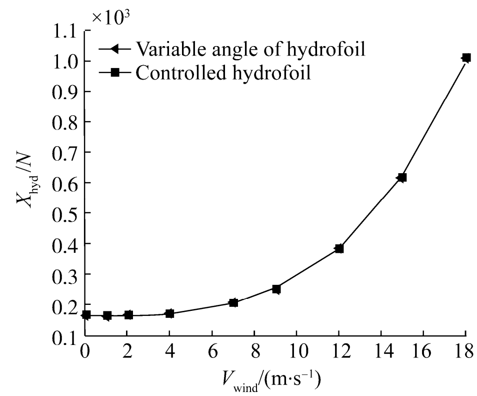

Fig. 9 Curve of wind speed and drag of hydrofoils

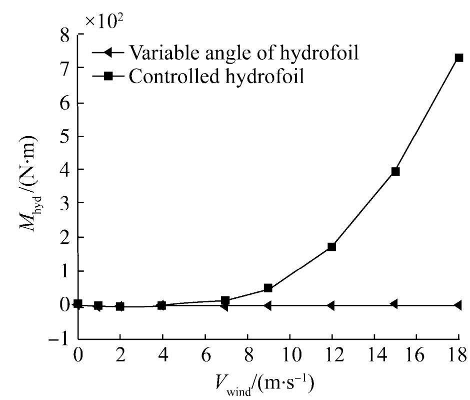

Fig. 10 Curve of wind speed and moment of hydrofoils

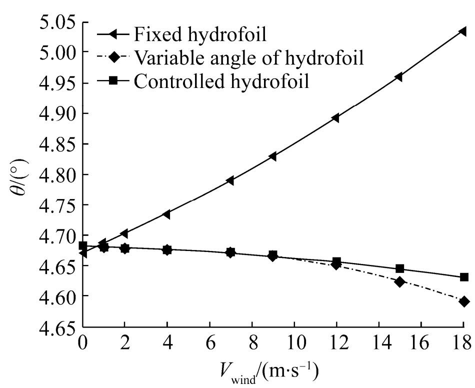

Fig. 11 Curve of wind speed and trim

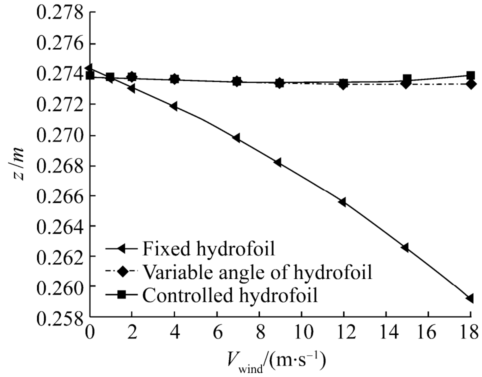

Fig. 12 Curve of wind speed and heave

6 Conclusion

This paper analyzed the fluid dynamic characteristics of controllable hydrofoil planing craft at high speed under wind loads. A prediction model was also established in unsteady navigation of high-speed planing craft. Based on the control strategy, forecasting results show that the method to control heave and trim angle utilizing controllable hydrofoils is feasible and the desired control objectives are achievable.

1) Attack angle of hydrofoil could control the heave of planing craft.

2) Hydrofoil longitudinal motion could control the trim of plaing craft.

The control method has a certain engineering practicality, and provides effective means and methods for planing craft movement control in complex navigations.

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