STABILITY OF A PLANING CRAFT IN TURNING MOTION

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1. Introduction

For a planing craft in turning at high speed, the stability quality is a very important factor for its safety. However, the characteristics of hydrodynamic forces acting on a planing craft in turning condition have not been clarified yet.

In the present study, six component hydrodynamic forces acting on a model obliquely towed at constant high speed are measured for various attitudes, rise, heel and trim, in the towing tank of Osaka Prefecture University.

The measured data shows that the hydrodynamic forces significantly depends on the running attitude, that the restoring roll moment becomes negative for moderate heel angle, and that it decreases with increasing yaw angle, or angle of attack rapidly.

2. Experimental Setup

The model used in the experiment is a 1/4-scale model of a personal watercraft with waterjet propulsion. The principal particulars of the model are shown in Table 1. The hull is harchine type, and has a duct without any impeller.

The experimental setup is shown in Fig.1. The model is captured by a 6-component load cell, and towed by an unmanned carriage the maximum speed of which is 15m/s. The rise H (mm), heel angle ϕ (deg), trim angle τ (deg) and yaw angle β (deg) are systematically changed as shown in Table 2. The rise here is defined by vertical displacement of the center point of rotation to change trim angle, which is located at 0.178m from the keel line at midship. The zero levels of all measured forces are set at rest just before starting of the carriage. The measured roll, pitch and yaw moments around the load cell are converted into the values about the standard location of the center of gravity of the craft.

Table 1. Principal particulars of model

length(m)	L	0.630
breadth(m)	B	0.223
depth(m)	D	0.100
draft(m)	d	0.055
Ship weight(kgf)	W	5.796
KG(m)		0.107
LCG from transom(m)		0.255
Deadrise angle(degree)		22

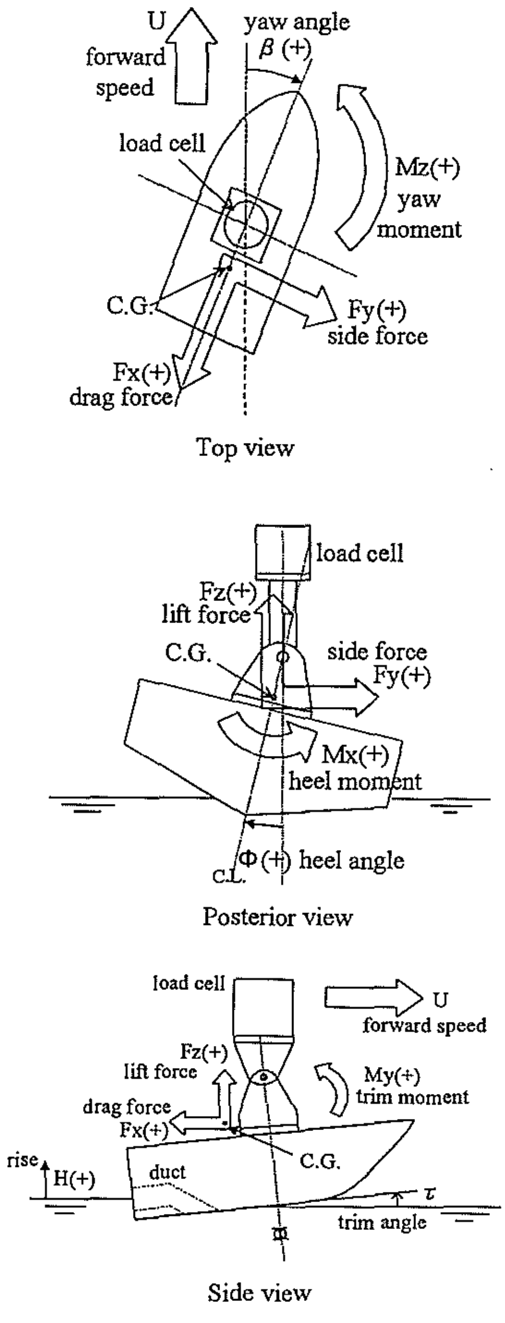
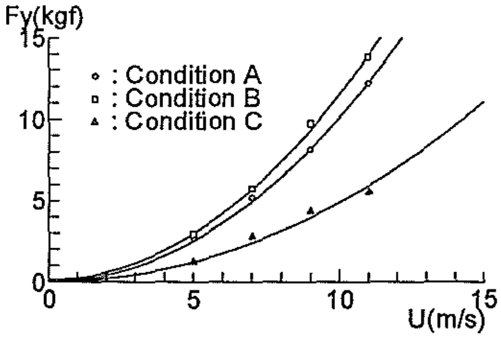


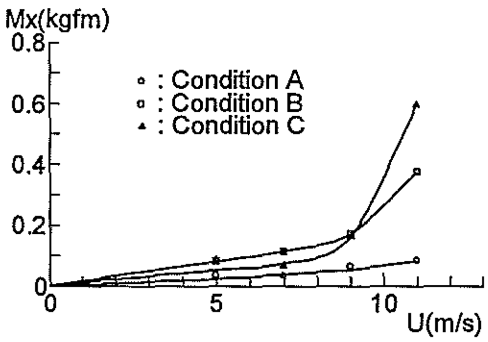
Fig.1 Schematic views of experimental setup and coordinate system

Table 2. Experimental conditions

Condition	A	B	C
rise H(mm)	20	30	40
heel ϕ (degree)	20	30	10
trim τ (degree)	2	4	4
yaw β (degree)	10	10	10



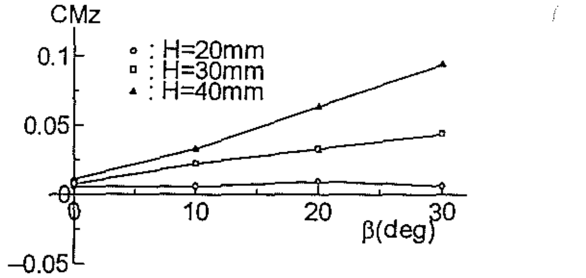
Side Force



Roll Moment

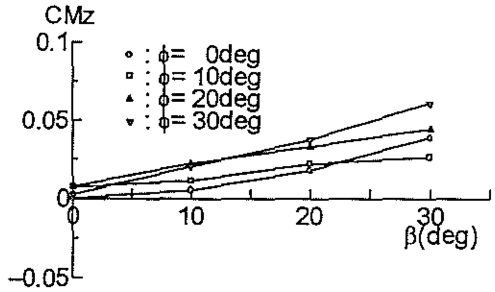
Fig.2 Effects of advance speeds on forces acting on fully captive model

Rise



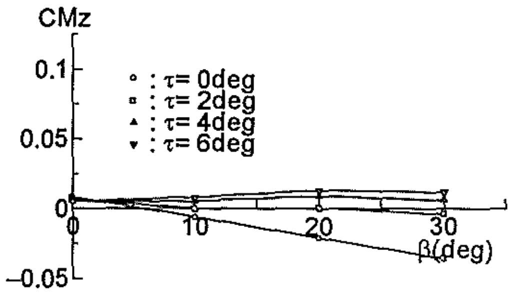
at heel ϕ =20deg, trim τ =4deg

Heel



at rise H=30mm, trim τ =4deg

Trim



at rise H=20mm, heel ϕ =20deg

Fig .3 Effect of running attitude on yaw moment coefficient

The measured forces are nondimensionalized as follows,

$$C_{Fx} = \frac{Fx}{0.5\rho SyU^2} \quad (1)$$

$$C_{Fy} = \frac{Fy}{0.5\rho SyU^2} \quad (2)$$

$$C_{Mx} = \frac{Mx}{W \cdot B} \quad (3)$$

$$C_{My} = \frac{My}{0.5\rho SxLU^2} \quad (4)$$

$$C_{Mz} = \frac{Mz}{0.5\rho SyLU^2} \quad (5)$$

$$C_{Fz} = \frac{Fz}{0.5\rho SzU^2} \quad (6)$$

where, Fx: resistance, Fy: transverse force, Fx: vertical lift, Mx: roll moment, My: trim moment, Mz: yaw moment, Sy: projected area of wetted body from side, Sz: waterplane area, L: overall length of a craft, B: breadth, W: displacement and ρ : density of water. In them, Sy and Sz are calculated for each attitude without any disturbance on free surface.

3. Experimental Results

Effect of advanced speed

Measurements of hydrodynamic forces acting on the hull are carried out for various advanced speeds in the range of Froude number between 2.0 and 4.4. Measured transverse force and roll moment are shown in Fig.2. The results of transverse force are in proportional to square of advanced speed as shown in this figure. It was confirmed that the results of resistance, vertical lift, trim moment and yaw moment show the same tendency too. Measured roll moment, however, is not in proportional to square of speed at high advanced speed.

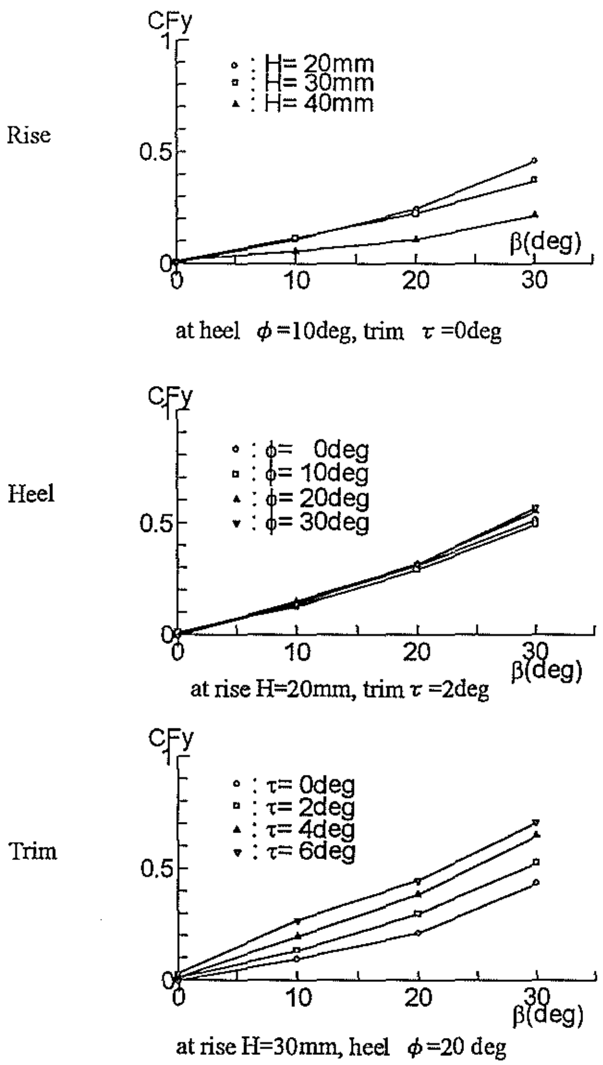


Fig.4 Effect of running attitude on side force coefficient

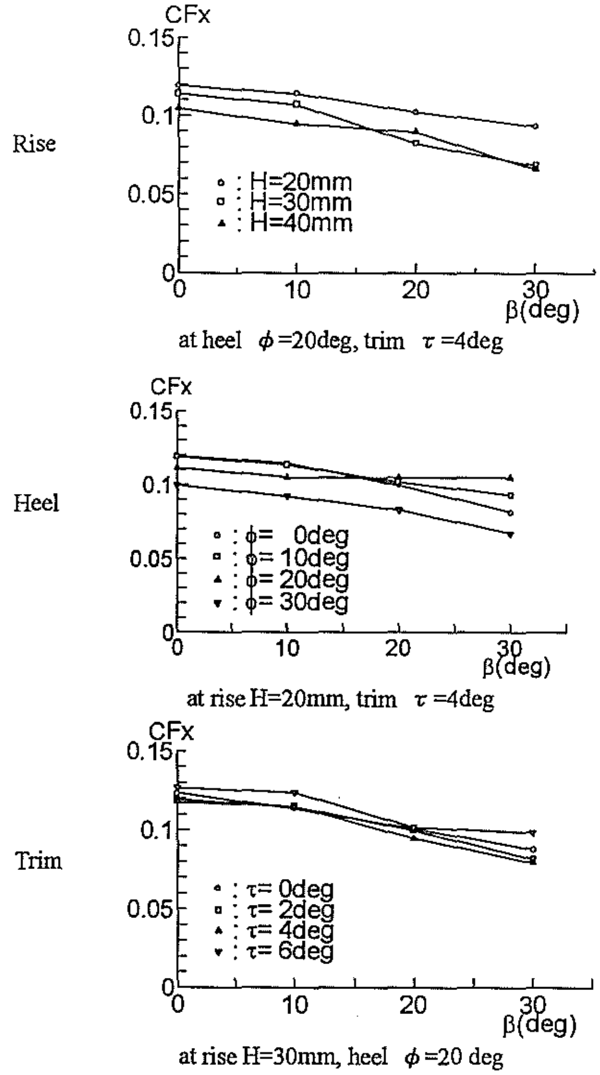


Fig.5 Effect of running attitude on drag coefficient

Experimental results

Some typical results of measured hydrodynamic forces are shown in Figs.3-8.

4. Discussions

Yaw moment

Yaw moment significantly affects the maneuverability of a craft. The measured results are shown in Fig.3, in which the value is positive when the restoring moment is acted. The results shown in Fig.3 show that the yaw moment is usually positive, and the positive value increases as a craft rises. This suggests that a planing craft has a good course keeping ability in planing condition. This fact is in good agreement with the conclusion by Kobayashi et.al.(1995). The experimental results show that for attitude with zero trim and small rise yaw moment becomes negative. This suggests that turning ability of such a craft becomes good for such attitude.

The experimental results at zero yaw angles demonstrate that yaw moment is generated by heel angle.

Transverse force

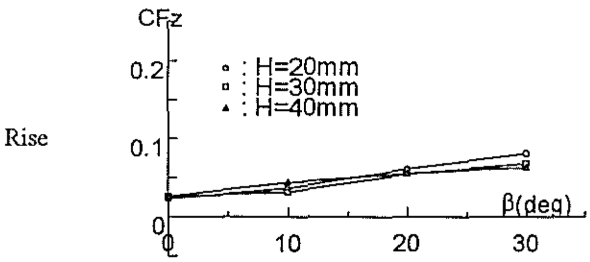
Measured transverse force is shown in Fig.4. The force is in proportional to yaw angle, or angle of attack. The effect of rise on transverse force is not significant except when trim angle is zero. The effect of trim angle on it is significant as shown in this figure.

Resistance

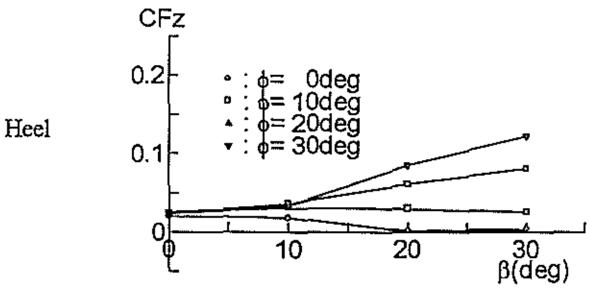
Resistance may affect speed reduction in maneuvering motion. Measured force is shown in Fig.5. The results show that resistance in oblique towing condition gradually decreases with increasing yaw angle.

Vertical lift force

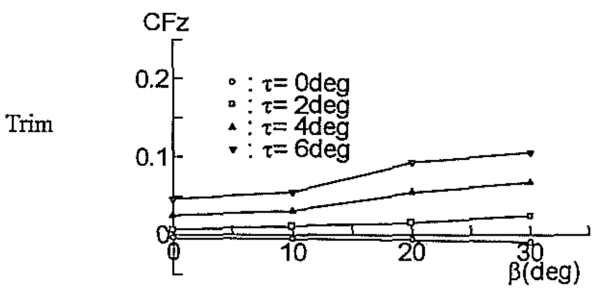
Vertical lift may affect planing condition in turning motion. Measured results are shown in Fig.6. The results show that



at heel ϕ=20deg, trim τ=4deg

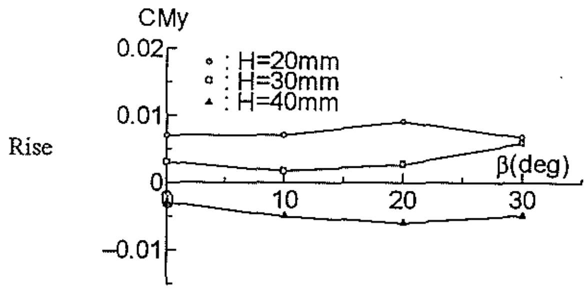


at rise H=20mm, trim τ=4deg

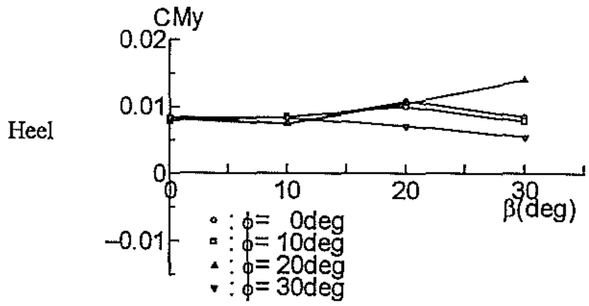


at rise H=30mm, heel ϕ=20 deg

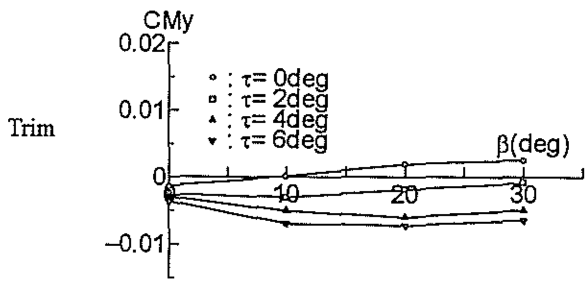
Fig.6 Effect of running attitude on vertical lift coefficient



at heel ϕ=10deg, trim τ=4deg



at rise H=20mm, trim τ=6deg



at rise H=40mm, heel ϕ=10 deg

Fig.7 Effect of running attitude on trim moment coefficient

vertical lift force mainly depends on trim angle, and the effect of rise on it is small. When yaw angle is small (β < 10deg.), the lift is independent of heel angle. When yaw angle is large, however, the lift force increases with increasing heel angle. At large yaw angle, the lift force decreases with yaw angle when heel angle is small, and increases up to several times of the value at β=0. This may be because the increase of heel angle works as increasing angle of attack.

Trim moment

Trim moment is one of most important factor for planing because vertical lift force depends on it. Measured trim moment is shown in Fig.7. The trim moment is almost constant without any effect of yaw angle when heel angle is moderate (ϕ < 20deg). The moment significantly depends on rise. At small rise, bowup moment is acted on the hull. As rise increases, the bowup moment decreases, and when rise is large bowdown moment becomes to be acted on it. At large heel condition, the trim moment is significantly affected by trim and yaw angles.

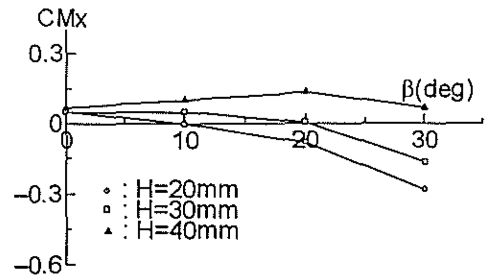
Heel moment

Measured heel, or roll moment is shown in Fig.8. The values in this figure show dynamic component of roll restoring moment, which does not include static component at Fn=0. The results demonstrate the roll moment decreases with increasing yaw angle, and becomes negative at large yaw angle.

5. Stability at High Speed Turning

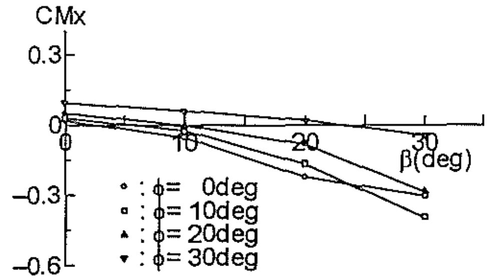
GZ curves are calculated from the measured heel moment shown in previous chapter and calculated static restoring moment as shown in Figs.9-11. The results demonstrate that large negative moment is acted on the hull at large yaw angle. Certain amount of the negative moment may be cancelled by drift force and horizontal component of thrust force of waterjet as shown in Fig.12. However, large negative moment may cause large heel in high speed turning.

Rise



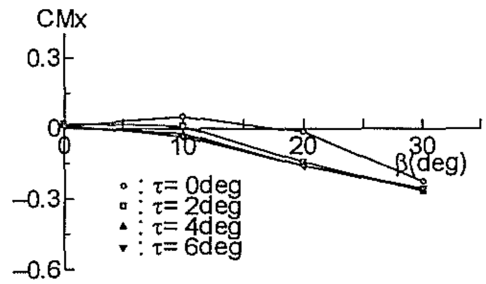
at heel ϕ=20deg trim τ=4deg

Heel



at rise H=20mm trim τ=4deg

Trim



at rise H=30mm heel ϕ=0 deg

Fig.8 Effect of running attitude on heel moment coefficient

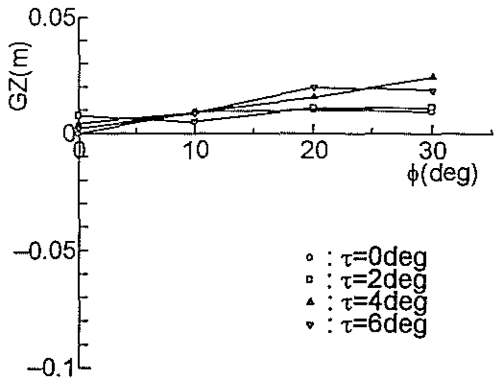
6. Conclusions

Measurements of 6-component hydrodynamic forces acting on a planing hull obliquely towed in constant speed are carried out for various attitudes in a towing tank, and following conclusions are obtained.

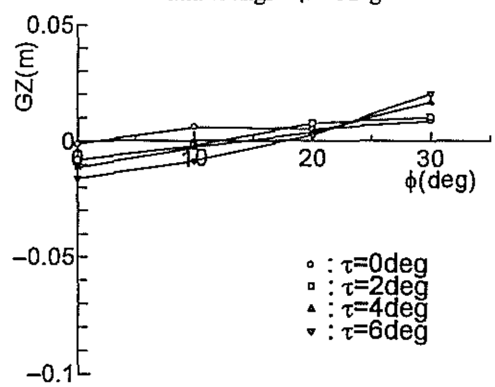
(1) Hydrodynamic forces acting on a planing hull obliquely towed significantly depend on running attitudes. Therefore, in maneuvering of such planing craft it should be needed to take into account the effects of attitude on hydrodynamic derivatives.

(2) At planing condition, strong restoring moment in yaw is acted on the hull. Therefore, the craft have good course keeping performance at high speed.

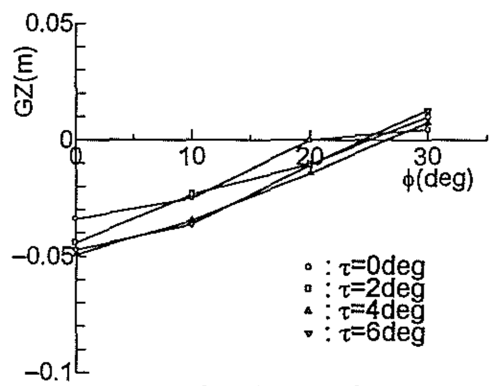
(3) Dynamic forces decreases roll restoring moment at large yaw angle. Therefore large heel can occur in high speed turning for a planing craft.



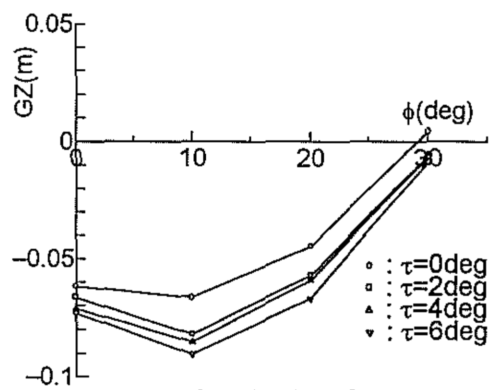
attack angle β=0deg



attack angle β=10deg



attack angle β=20deg



attack angle β=30deg

Fig.9 GZ curve at H=20mm

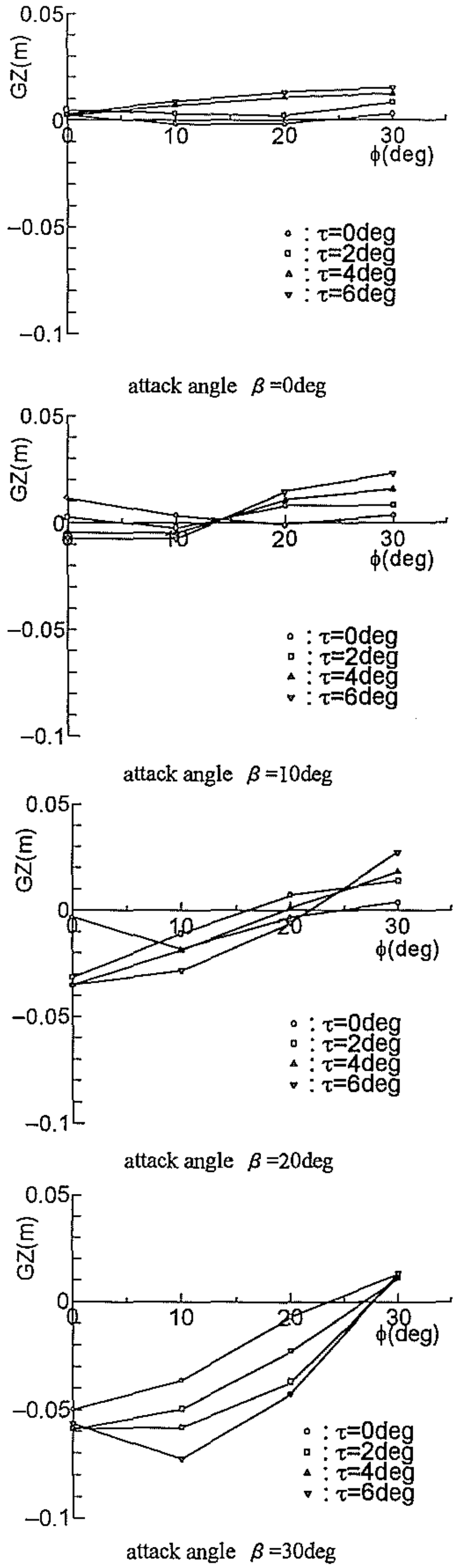


Fig.10 GZ curve at H=30mm

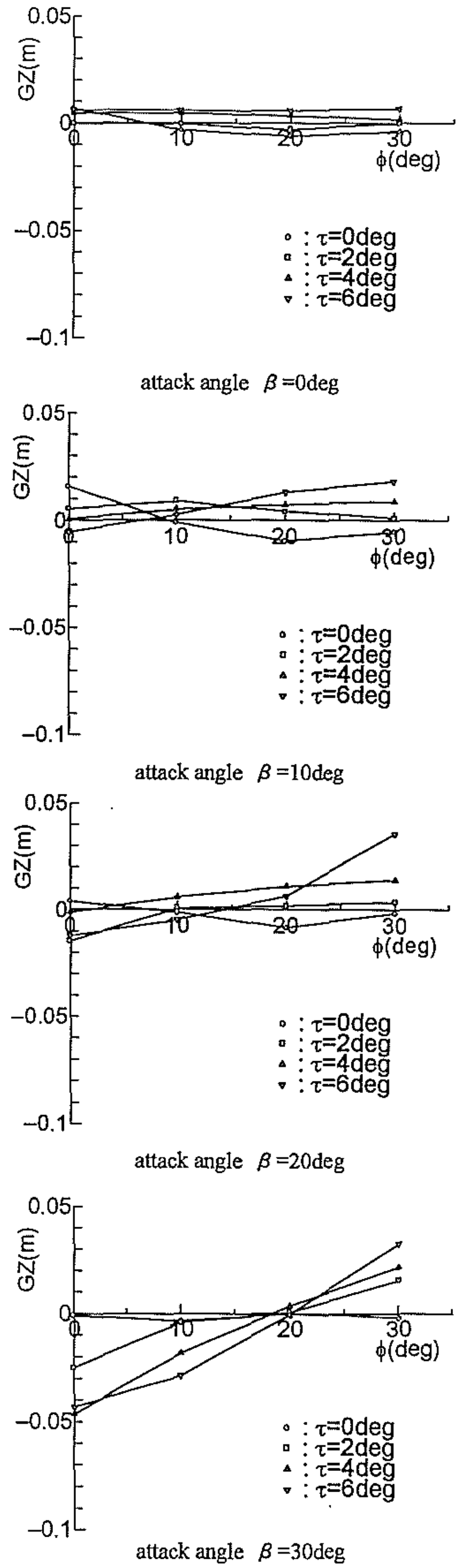


Fig.11 GZ curve at H=40mm

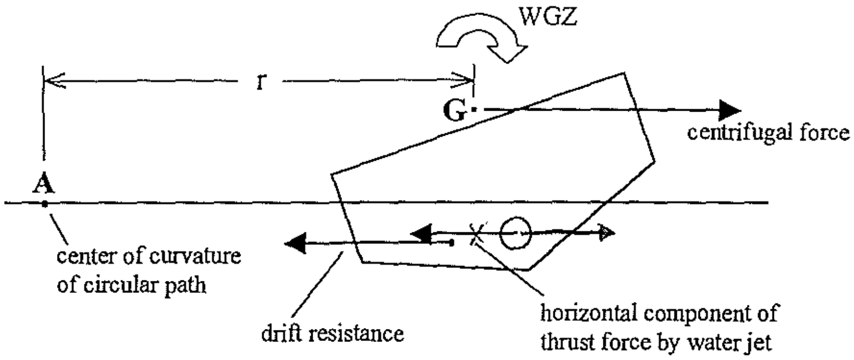


Fig.12 Forces acting on a planing hull during steady turning motion

References

Hiroaki Kobayashi, Yasuo Arai, Atsushi Ishibashi, Shigeyuki Okuda, Yasuhiro Okamoto and Akifumi Takeuchi (1995), A Study on the Maneuverability of High-Speed Boat. Journal of the Kansai Society of Naval Architects, Japan, 223, 81–90, (in Japanese)