An Experimental Study on the Improvement of Transverse Stability at Running for High-Speed Craft

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ABSTRACT

It is well known for high-speed crafts that transverse instability might occur at running higher than a certain speed. In this study model experiments in the towing tank were carried out to examine the transverse instability at various speeds and $\overline{GM}$ values with the hard chine hull form and to develop a device for improvement of transverse stability. The captive model tests were carried out to search for the range of instability, and were done at various speeds in three different conditions of $\overline{GM}$ values to examine hydrodynamic forces such as heel moments and sway forces acting on the hull in specified instability conditions. As a result, it is confirmed this ship model loses transverse stability at higher speed and smaller $\overline{GM}$ as expected. For the improvement of transverse stability, three types of effective spray strip including ordinary one were added to the hull as appendages respectively and its effect were examined. As a result, so-called "Reaction Flap" on the fore part of the hull which is one of three types, showed remarkable improvement. The existence of "Reaction Flap" results in being almost negligible for the resistance. This "Reaction Flap" makes conventional mono-hull form possible to be more stable at relatively higher speed without specific design.

1. INTRODUCTION

It is known for high-speed crafts that transverse instability might occur at running higher than a certain speed even though they posses adequate static stability applied relevant criteria (Marwood et al., 1968), (Millward, 1979), (Schwanecke et al., 1992), (Suhrbier, 1978).

Generally a hard chine hull is relatively more stable than a round bilge hull at the same conditions at running. However even for a hard chine hull, a effective device for improvement of transverse stability is required because there is a possibility of instability at higher speed at running.

In this study model experiments in the towing tank

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were carried out to examine the transverse instability at various speeds and $\overline{GM}$ values for a high-speed craft with conventional hard-chine. Then, for the improvement of transverse stability, three types of spray strip including ordinary one were added to the hull as appendages respectively and were also examined to be effective for the transverse stability.

The resistance test with the most effective appendages chosen among them was also carried out in order to grasp the influence upon the propulsive performance.

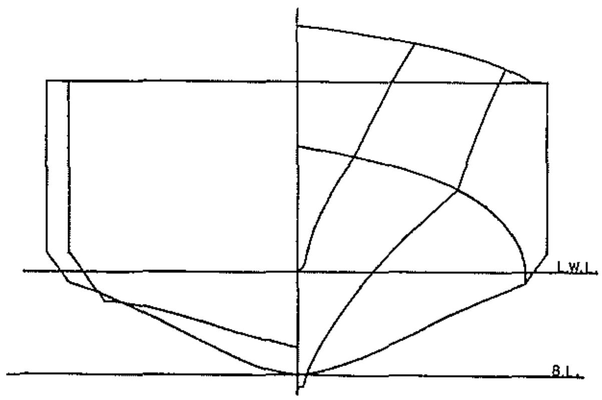

Fig.1 Hard-chine type hull form used in the present experiment

2. EXPERIMENTS

2.1 Ship Model

A typical example of a hard chine hull form is shown in Photo. 1, which one of the authors applied to the large high-speed passenger craft.

In this study model experiments in the towing tank were carried out to examine the transverse instability at various speeds and $\overline{GM}$ values. The ship model was used the typical type of a hard chine hull form shown in Fig.1 in order to search the range and limit of instability for higher speed or smaller $\overline{GM}$ in comparison with the original planned values.

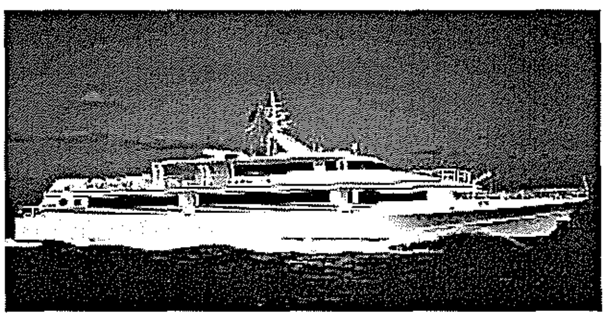
Photo. 1 Conventional Hard-Chine type High-Speed Craft at running

The principal dimensions of the ship model are 3.8m in length, 0.63m in breadth, 0.14m in draft, and the scale ratio is 1/12.3 to the full scale ship.

In order to improve the transverse stability, it seems easy to increase the breadth of ship. Because it is known by the results of recent research that wider breadth is so effective as larger $\overline{GM}$ value, or lower center of gravity.

However, too much wide breadth might give bad effects upon other characteristics such as propulsive performance and seakeeping quality etc. So generally it is easier way for designers to change the type of ships from mono-hull to twin hull, so-called catamaran to improve transverse stability with keeping the other performance as it is.

It must be important for naval architects how to improve the hull form and optimize total performance of ships at a practical design stage.

It will be preferable to improve the transverse stability without changing to other types from mono-hull because mono-hull has many advantages in comparison with other types of hull forms. In this point of view, some ideas for a mono-hull are already proposed such as special types of stabilized fins and outriggers added to the outside of hull, but most of them do not always give better results to keep a same performance of original hull.

In this study the methods of improvement which keep advantages of a mono-hull are proposed and the experiments by using a towing tank were carried out to examine the effects as expected.

As it is known by the recent research (Suhrbier, 1978), spray strips are effective for the improvement of transverse stability, three types of spray strip including ordinary one were added to the hull as appendages individually as shown in Fig.2 and Fig.3.

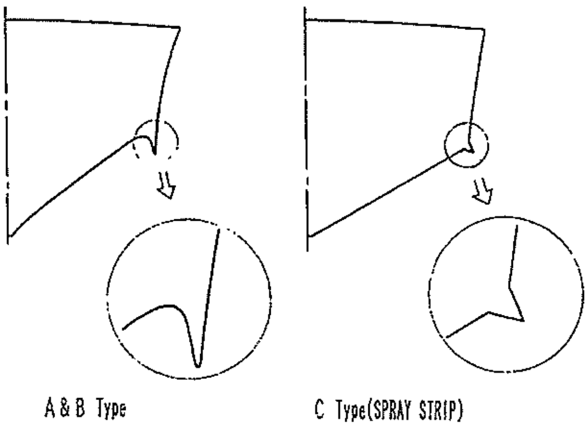

Fig.2 Section of "Reaction Flap" and spray strip

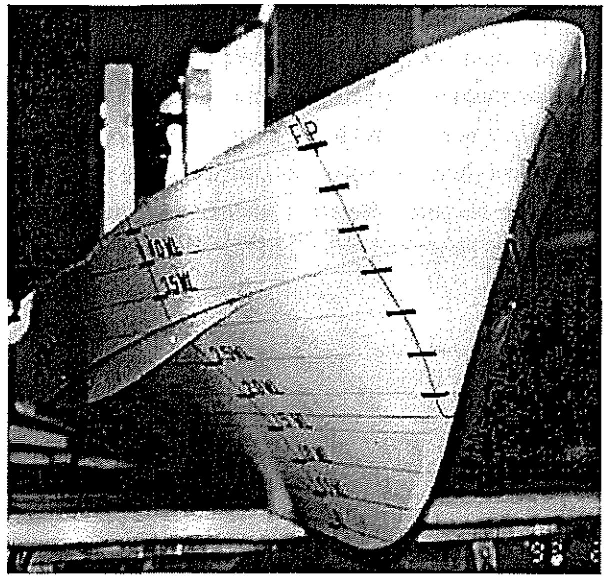

Photo. 2 Ship model with "Reaction Flap"

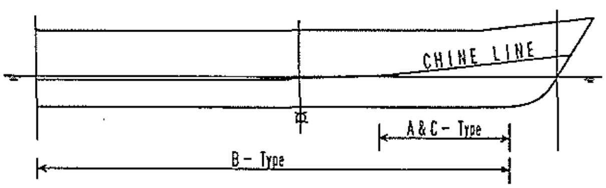

Fig.3 Applied zone of "Reaction Flap" and spray strip

These appendages are intended to make use of the restoring force against transverse instability which is produced by bow waves creeping up above the still waterline at high-speed and colliding against these appendages as shown in Photo. 1.

A-type and B-Type are given as name of "Reaction Flap" which form an upset-U-shaped cross section by themselves and the side hull platings so as to produce a restoring force against bow waves.

A-Type is provided at the fore parts of the hull alongside the chines above still waterline, and B-Type is the extension of A-Type to the aft end of the hull alongside the chines which submerge below still waterline at after part of the hull. The Photo. 2 shows the model with "Reaction Flap" of A-type.

C-Type is ordinary spray strip which form wedge shaped cross section only at the fore parts of the hull alongside the chines above still waterline as A-Type.

2.2 Method of Measurement

For high-speed crafts the transverse instability might occur at running higher than a certain speed.

This phenomenon is observed as the ship will begins to heel firstly by instability at running, and then to turn not to keep the course and finally capsizes in the worst case. Therefore it is very difficult to simulate thus phenomenon perfectly by using a towing tank for the restriction of measurements, so many experiments were carried out by using a ship model restricted motion (Baba et al., 1982), (Millward, 1979).

In this study firstly the experiments were carried out under the fixed condition of sway and yaw motion, and finally done for various speeds in three different $\overline{GM}$ chosen under the fixed condition of all motion.

In the experiments under the fixed condition of sway and yaw motion, the degree of change of running trim and heel, and the range of instability were measured as a change of $\overline{GM}$ value and speed.

The experiments under the fixed condition of all motion were carried out to examine hydrodynamic forces such as heel moments and sway forces acting on the hull for specified instability conditions. The heel moments and the side forces were measured at various heeling angles under the same conditions such as running trim and dipping gained from the results of experiments under fixed condition of sway and yaw motion.

For the experiments of the ship model fixed all motion, the schematic diagram of measurement is shown in Fig.4, and the coordinate system and symbols in Fig.5.

The model has twin hanging rudders, but not propellers. And all experiments were done at the Towing Tank of Nagasaki Research and Development Center, Mitsubishi Heavy Industries, Ltd.

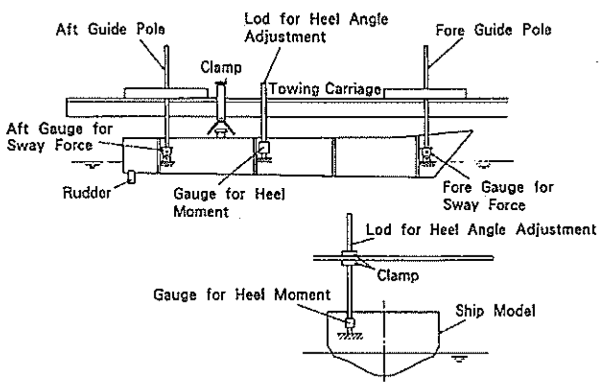

Fig.4 Schematic diagram of measurement

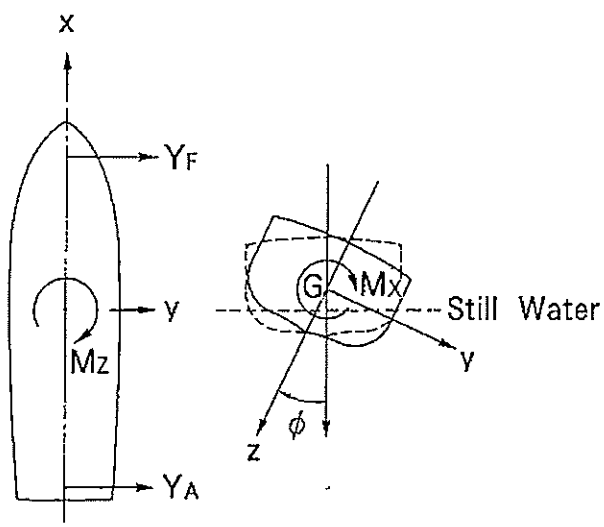

Fig.5 Coordinate system and symbols

3. RESULTS OF EXPERIMENTS

3.1 Results of Experiments for Transverse Stability

At first, experimental results for the ship model without appendages for improvement of instability are described. This model is called by "the original hull" hereinafter.

By the experiments of using the original hull fixed sway and yaw motion, it was observed to be stable by maintaining certain heel angle at relatively lower speed, but not to be stable at higher speed and to result in capsizing finally at further high speed.

The tests were started from searching for such limits of $\overline{GM}$ value and speed which might cause a transverse instability resulting in capsizing finally, and then tests were done at various speeds for three different conditions of $\overline{GM}$ values chosen.

The results of experiments, measured heel angles : ϕ which were saturated values finally for individual speed are shown in Fig.6(a). (The values of figures hereinafter correspond to the model scale.)

As shown in Fig.6(a), the heel angle : ϕ increases in larger value as increasing speed and finally the model capsize for all $\overline{GM}$ chosen.

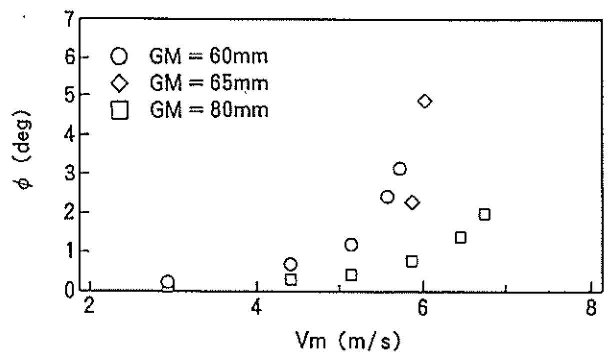

Fig.6(a) Measured heel angle

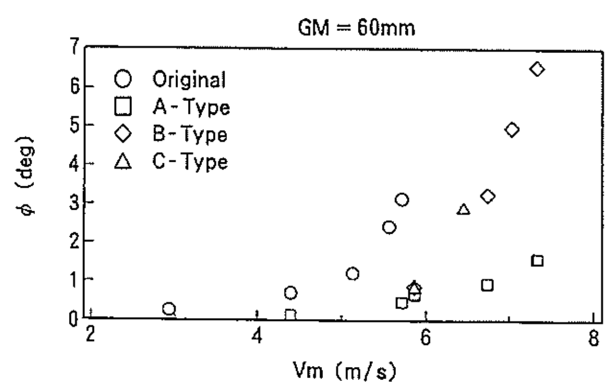

Fig.6(b) Measured heel angle

Also the time histories of heel, heave and pitch measured at running in the case of $\overline{GM}$=60mm are shown as Fig.7(a) and Fig.7(b) for reference.

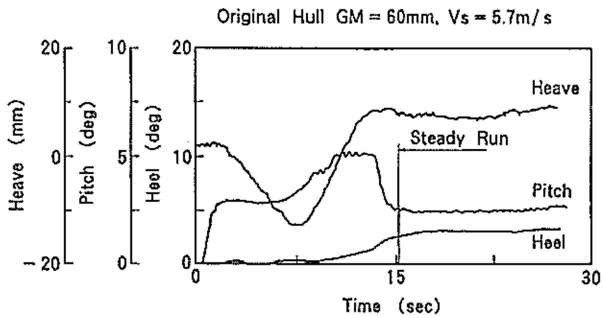

Fig.7(a) Time history of heel, heave and pitch measured at running

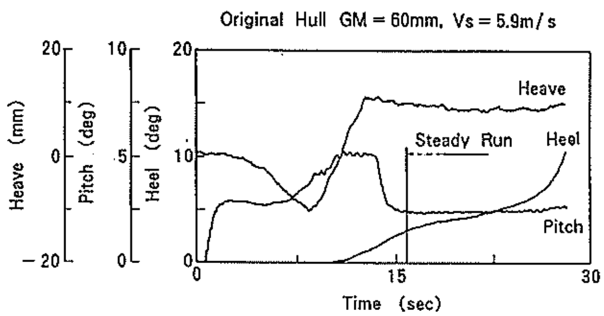

Fig.7(b) Time history of heel, heave and pitch measured at running

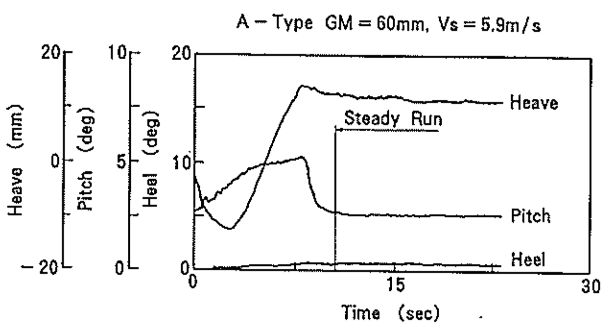

Fig.7(c) Time history of heel, heave and pitch measured at running

Fig.7(a) is a time history in the case of the model speed of Vs=5.7m/s which shows heave and pitch motion vary with a large amplitude in the range of transient acceleration before the model reaches to run steady, and reaches to be stable and a saturated certain levels.

Fig.7(b) is also a time history in the case of the model speed of Vs=5.9m/s which shows heave and pitch motion are reached to be steady state and a saturated certain value when the model reaches to run steady as in the case of Vs=5.7m/s, but the heel angle does not reach to be stable and grows rapidly until resulting in capsizing at last.

The speed of the model at capsizing was Vs>5.9m/s in the case of $\overline{GM}$=60mm, Vs>6.1m/s in the case of $\overline{GM}$=65mm and Vs>7.0m/s in the case of $\overline{GM}$=80mm.

Thus it is found by the experiments the hull form used in this study is so unstable as the speed is higher and $\overline{GM}$ value is smaller.

Fig.6(b) shows the measured results under the conditions of models with appendages such as "Reaction Flap" and spray strips with $\overline{GM}$=60mm.

Comparing with the results of the original hull at the same speed, heel angles are reduced by adding the above all appendages of A-Type, B-Type and C-Type. In particular, A-Type, so-called "Reaction Flap", extending along both side platings nearly from a bow in a direction towards a stern shows remarkable improvement in comparison with other appendages, in which heeling angle : ϕ is very small even at the speed of Vs=7.3m/s.

Fig.7(c) shows a time history of heel, heave and pitch measured at running of Vs=5.9m/s in the case of "Reaction Flap", A-Type. The heel angle : ϕ of the model with A-Type keeps as a constant small value at steady running in comparison with the original hull as shown in Fig.7(b) which heel angle is still increasing after steady running.

Side views of the original hull and that with "Reaction Flap", A-Type at running are as shown in Photo. 3.

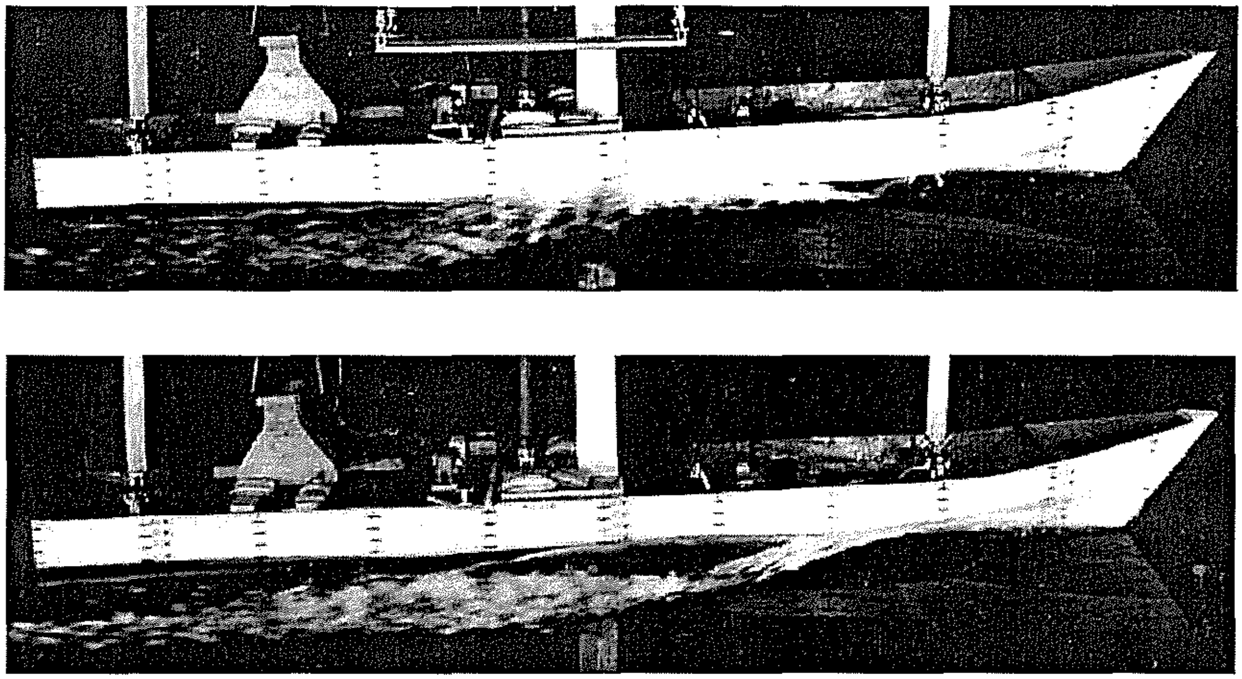

Photo. 3 Side view of original hull and that with "Reaction Flap" at running

By considering the results of above, the experiments under the fixed condition of all motions were carried out only for the original hull with and without "Reaction Flap", A-Type. Also the tests were done for a constant value of $\overline{GM}$=60mm at two cases of speed, one is at Vm=4.4m/s and at Vm=5.9m/s, which are stable and heavy unstable respectively for the original hull.

Measured heel moments : Mx for the above are shown in Fig.8(a) and Fig.8(b).

For the original hull heel moment : Mx against heel angle : ϕ is relatively very small at the speed of Vm=4.4m/s which means to become unstable when the model is forced to heel by some disturbance. And at Vm=5.9m/s, the heel angle : ϕ increases more and more by some disturbance and finally capsizes because heel moment : Mx has a positive slope against heel angle : ϕ as shown in Fig8(a).

On the contrary in the case of the hull with A-Type, the model is stable at both speed of Vm=4.4m/s and 5.9m/s even when heeling because heel moment : Mx has a negative slope against heel angle : ϕ as shown in Fig8(b).

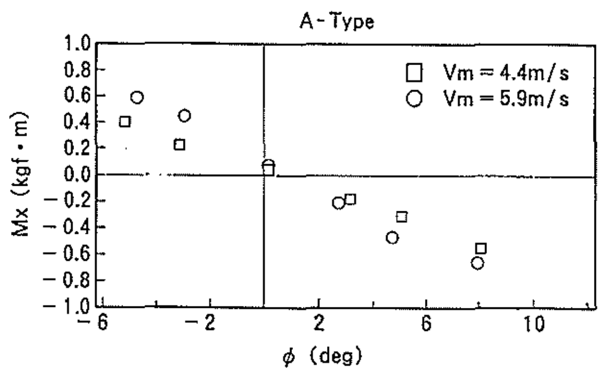

Fig.8(a) Measured heel moment

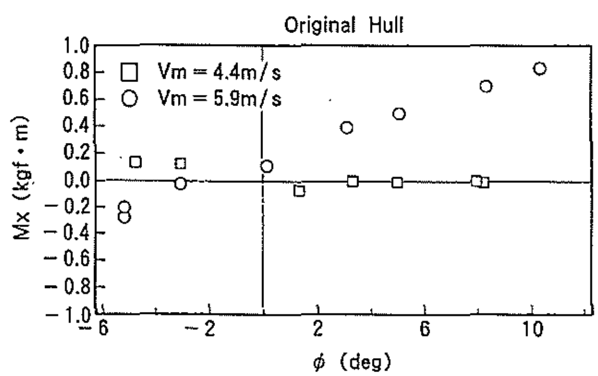

Fig.8(b) Measured heel moment

Then Fig.9(a) and Fig.9(b). show measured sway forces at the positions of fore and aft perpendiculars of the model at the speed of Vm =5.9m/s.

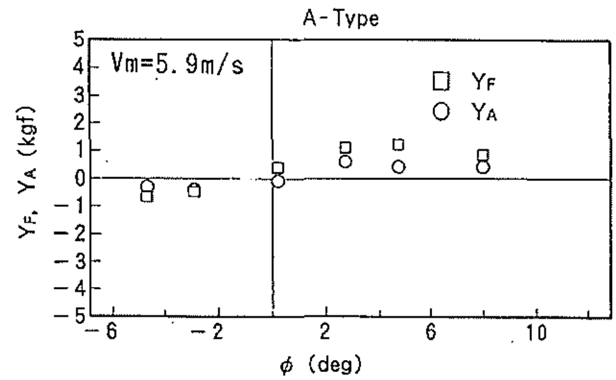

Fig.9(a) Measured sway forces

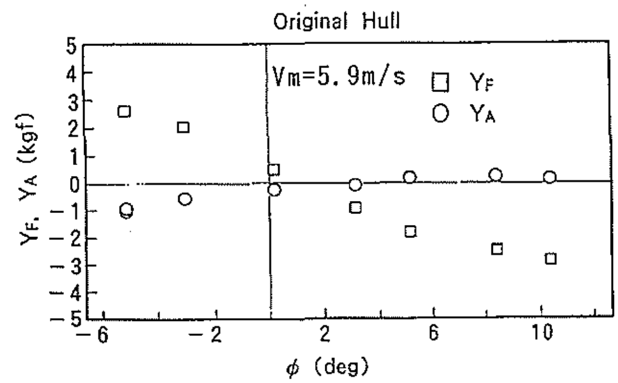

Fig.9(b) Measured sway forces

For the original hull when the model heels starboard side (ϕ >0), the value of sway force at the fore perpendicular : Y_F is negative (direction of the force is from starboard side to port side) and the value of sway force at the aft perpendicular : Y_A is zero. Then the hydrodynamic force acts to turn the model to the port side. When ϕ <0, vice versa.

Yaw moment increases as increase of sway force $|Y_F|$ by growing heel angle : ϕ , therefore a turning circle decreases. And then heel angle : ϕ increases more and more because centrifugal force to the hull becomes larger.

However for the hull with A-Type, both of absolute values of Y_F and Y_A are small and have a positive slope against heel angle : ϕ. This means the model results in being stable at running because yaw moment is small and turning direction is opposite to the original hull which makes heel angle : ϕ decrease even if the model might slightly sway to the heeling side.

Concluding the results of experiment, it is found "Reaction Flap", A-Type shows remarkable improvement of transverse stability at high-speed running.

3.2 Result of Resistance Test

The resistance test with "Reaction Flap" of A-Type was carried out in order to examine the influence upon the propulsive performance. The test were done under the fixed condition of sway, yaw, and roll motion.

The result of resistance test is shown as compared to that of the original hull in Fig.10. The existence of "Reaction Flap" on the fore part of the hull, A-Type results in being almost negligible for the resistance.

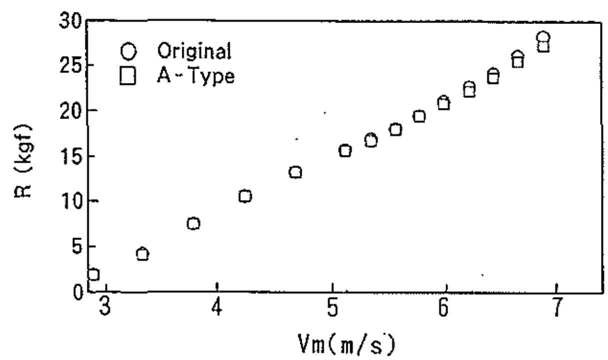

Fig.10 Resistance test result

4. CONCLUDING REMARKS

It is well known for high-speed crafts that transverse instability might occur at running higher than a certain speed.

Taking the above characteristics into consideration, in this study a research of the method to improve transverse stability at running are carried out through experiments without loosing advantageous characteristics of mono-hull as possible such as propulsive performance and seakeeping quality etc.

At first the range or limits of instability for various speeds and different $\overline{GM}$ values were experimentally examined for the ship model of a hard chine high-speed craft.

Then three types of effective spray strip including ordinary one were added to the original hull as appendages respectively and were also examined transverse stability.

As a result, so-called "Reaction Flap", one of three types, extending along both side hull platings nearly from a bow in a direction towards a stem shows remarkable improvement in comparison with other appendages although other types of strip are found to be also effective to improve the transverse stability.

And the existence of "Reaction Flap" on the fore part of the hull is also found to be negligible for the resistance.

This "Reaction Flap" shows one of possibilities for conventional mono-hull form to develop more stable at relatively higher speed without changing hull form or principal dimensions. Also it is useful to keep transverse stability by adding the "Reaction Flap" in the case of demands for raising the center of gravity or increasing speed when planning conversion of the ship.

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