POLISH MARITIME RESEARCH 1(85) 2015 Vol. 22; pp. 22-27
10.1515/pomr-2015-0004

TEST STUDIES OF THE RESISTANCE AND SEAKEEPING PERFORMANCE OF A TRIMARAN PLANING HULL

Weijia Ma, Ph.D.
Hanbing Sun, Ph.D.
Huawei Sun, Ph.D.
Jin Zou, Prof.
Jiayuan Zhuang, Ph.D.

ABSTRACT

Towing tank tests in calm water were performed on a trimaran planing hull to verify its navigational properties with different displacements and centres of gravity, as well as to assess the effects of air jets and bilge keels on the hull's planing capabilities, and to increase the longitudinal stability of the hull. Hydrostatic roll tests, zero speed tests, and sea trials in the presence of regular waves were conducted to investigate the hull's seakeeping ability. The test results indicate that the influence of the location of the centre of gravity on the hull resistance is similar to that of a normal trimaran planing hull; namely, moving the centre of gravity backward will reduce the resistance but lower the stability. Bilge keels improve the longitudinal stability but slightly affect the resistance, and the presence of air jets in the hull's channels decreases the trim angle and increases heaving but has little effect on the resistance. Frequent small-angle rolling occurs in waves. The heaving and pitching motions peak at the encounter frequency of , and the peaks increase with velocity and move towards greater encounter frequencies. When the encounter frequency exceeds, the hull motion decreases, which leads to changes in the navigation speed and frequency.

Keywords: trimaran planing hull; appendix; resistance; seakeeping; model test

INTRODUCTION

Trimaran planing hulls exhibit excellent navigational performance. These hulls are composed of a main hull and two auxiliary appendages. A trimaran planing hull combines the advantages of a normal planing hull, a high-speed multihull vessel, and a ship that uses a gas layer to reduce the resistance. It has good hydrodynamic and aerodynamic performance characteristics and will plane at normal speeds. Due to their high speed and good adaption to different sea states, trimaran planing hulls have both military and civil applications.

The effects of different positions of the centre of gravity, steps, air injection quantities, and attempts to control the resistance of planing crafts have been studied extensively [1-4]. The resistance characteristics of a planing hull with and without spray strips under various displacements and centres of gravity have been investigated, and model tests have been used to explore the influence of steps on the navigation performance and resistance of trimaran planing hulls. The results of these studies provide guidance for designing hulls which will reveal the assumed features. Numerous model tests of planing vessels have been carried out in waves, including tests of prismatic planing hulls in regular and irregular waves [5-6]. In addition, experiments have been conducted on the longitudinal movement of high-speed planing crafts [7] and deep-V planing hulls [8] in the presence of regular waves.

To reduce the resistance of trimaran planing hulls, the present study examines selected additions to the model vessel. Two rows of air holes along the top of the channels on the back of the planing hulls were designed to investigate the influence of air jets on the fluid performance inside the channels, and a bilge keel was set above the bevel line of the main hull. Because of the complexity of the seakeeping performance of trimaran planing hulls, several model tests were performed in this study, including roll decay tests in calm water, zero speed tests, and sea trials in the presence of regular waves.

RESISTANCE TESTS OF THE TRIMARAN PLANING HULL

TEST MODEL

The ship model is made of fibre-reinforced plastic (FRP) and is shown in Fig. 1. The principal dimensions are shown in Tab. 1.

The main purposes of the tests were: (1) to verify navigation properties and resistance characteristics of the designed trimaran planing hull with different displacements and centres of gravity, (2) to assess the effect of the air jets in the channels and the bilge keels on the hull's planing capabilities, and (3) to explore measures of increasing the longitudinal stability.

Horizontal bilge keels and air jets are commonly installed inside the channels to reduce the resistance of a planing boat. Trapezoidal bilge keels arranged in the bilge area are actually spray deflectors that limit the main splash from the hull. They are located 3 cm above the main hull bevel along the hull and have an upper width of 3 mm, a base width of 7 mm, and a height of 8 mm (Fig. 2).

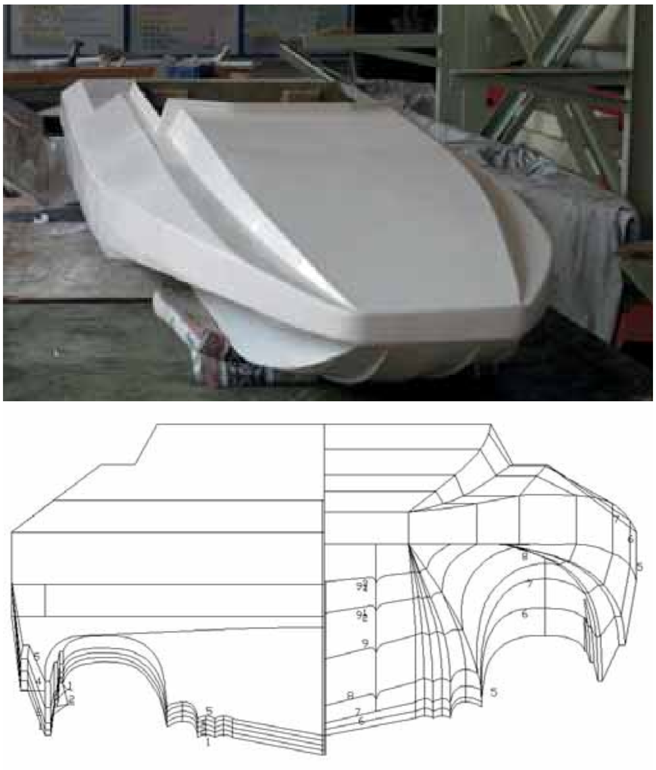

Fig. 1. Front view of the ship model

Tab. 1 Main hull parameters of the high-speed trimaran planing hull

Principal dimension	Values
Length (L/m)	2.4
Breadth (B/m)	0.75
Bevel line breadth of main hull (B_m/m)	0.38
Average dead rise angle $\beta/(°)$	11

Fig. 2. Bilge channel

Air jet devices are the inverted trapezoidal structures that are located inside the both channels of the planing craft. They have a top width of 22 mm, a base width of 10 mm, and a height of 9 mm. On the two bevels of the trapezoid, 2 mm-diameter holes are set every 3 cm, from which air ejects, as forced by an air pump installed in the hull (Fig. 3).

Fig. 3. Air jet devices

The details of the test schemes are shown in Tab. 2.

Tab. 2 Test schemes of the ship model

Scheme	Δ/kg	Longitudinal centre of gravity l/mm	Test condition
1	50	562	With bilge keel, without air jet
2	50	612	With bilge keel, without air jet
3	50	682	With bilge keel, without air jet
4	50	732	With bilge keel, without air jet
5	50	732	With bilge keel, with air jet
6	50	732	Without bilge keel, with air jet

ANALYSIS OF TEST RESULTS

The changes of resistance, heaving, and trim angle vs. the volume Froude number (Fr_∇) are shown in Figs. 4-6, for different test conditions listed in Table 2.

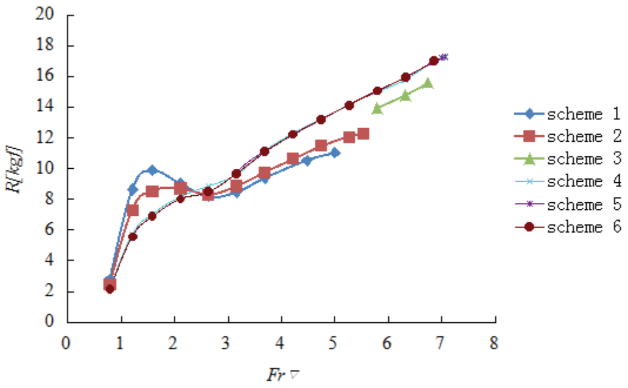

Fig. 4. Resistance changes vs. Fr_∇ for different test conditions

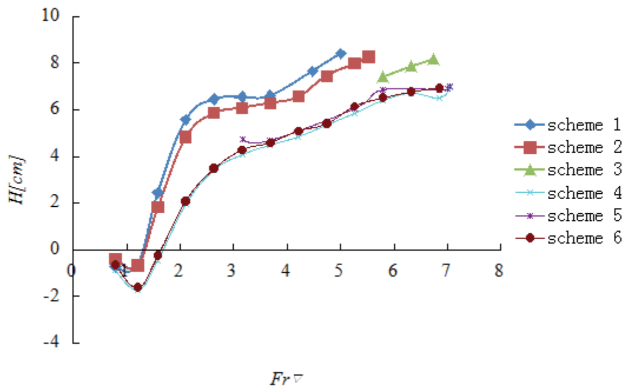

Fig. 5. Heaving changes vs. Fr_∇ *for different test conditions*

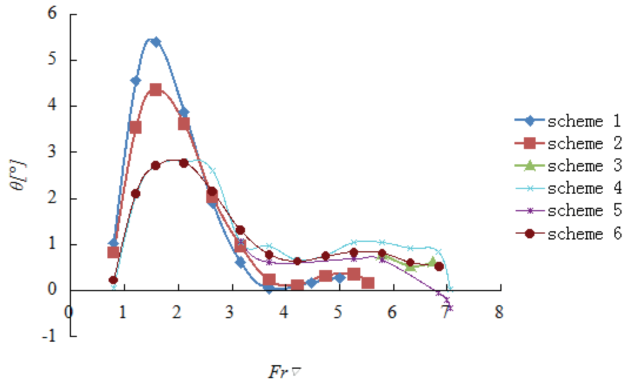

Fig. 6. Trim angle changes vs. Fr_∇ *for different test conditions*

(1) Influence of the centre of gravity on the ship's resistance.

For the same displacement, the maximum velocity increases with the increasing distance between the centre of gravity and the stern transom plate, and the maximum value of before the appearance of porpoising is 7.

The resistance curve for the trimaran planing hull has two peaks. The first peak appears at $Fr_\nabla<2.5$ and can be decreased or eliminated by moving the centre of gravity forward, thus reducing the consumption of engine power for acceleration. For $Fr_\nabla>2.5$, moving the centre of gravity forward will increase the resistance. Moving the centre of gravity backward at low speeds will increase the trim angle so much that the resistance (mainly pressure drag) will increase significantly and form an obvious drag crest. In contrast, at high speeds, moving the centre of gravity backward reduces the wetted length, which decreases the frictional drag related to the wet area as a result of the higher planing efficiency.

Fig. 5 shows that as the distance between the centre of gravity and the stern transom plate increases, the heaving decreases. This is because moving the centre of gravity backward reduces the wetted length, which aggravates the heaving.

Fig. 6 shows that like the resistance, the changes in the trim angle with the location of the centre of gravity can be divided into two phases. The trim angle reaches a peak at $Fr_\nabla<2.5$, and the peak decreases as the centre of gravity moves backward.

At $Fr_\nabla<2.5$, the trim angle does not change significantly, but the change increases when the centre of gravity moves backward.

INFLUENCE OF BILGE KEELS AND AIR JETS

In addition to the above presented tests, in this part of the study selected devices were used to reduce the drag of the trimaran planing craft. The results of schemes 5 and 6 were compared with each other to study the effect of bilge keels, whereas the comparison of schemes 4 and 5 aimed at assessing the effect of air jets in the channels.

The test results indicate that after installing the bilge keels the ship's drag decreases by approximately 1% in the high-speed stage (11-13 m/s). At moderate speeds, the ship's drag increases by approximately 1%, but the longitudinal stability improves. In addition, with bilge keels, the trim angle decreases at moderate to high speeds, and the impact increases as the velocity increases to the high-speed stage. This may be the result of a bow trim moment, generated when the spray in the channels is separated by the bilge keels. In addition, the heaving increases slightly with bilge keels.

If optimally arranged inside the channels, air jet devices should contribute to the formation of an air-water mixture in the channels, which then would decrease the frictional resistance. Fig. 7 and Fig. 8 show tests with and without air jets, respectively. The test results of schemes 4 and 5 show that the desired effect is not achieved. With the air jets, the resistance decreases by approximately 1% without an effect on the longitudinal stability, and porpoising occurs under both conditions at the same velocity. The air cushion formed by air jetting increases the heaving slightly. The trim moment decreases because the air jet holes are located near the stern.

Fig. 7. High-speed navigation at 13 m/s with air jets

Fig. 8. High-speed navigation at 13 m/s without air jets

TESTS IN REGULAR WAVES

The tests in regular waves included roll decay tests, beam wave tests at zero speed, and head wave tests. The tests were conducted with a wave height of ζ=50 mm, wavelengths of λ=2 m ÷ 12 m, speeds of V=2.3 m/s and 5.7 m/s, and the volume Froude numbers of $Fr_\nabla=1.21$ and 3.0.

RESULTS AND ANALYSIS OF ROLL DECAY TESTS

Trimaran planing hulls are still in the research and development phase, and it is still difficult to determine their rolling characteristics using theoretical methods. Thus, we made use of free decay rolling experiments to study the rolling motion. In those experiments the hull was set freely rolling in calm water. The three initial heeling angles were all greater than 10°, and the decay curves were recorded (Fig. 9). The natural rolling period   can be acquired from the decay curves and was calculated as equal to 1.1 s. The results show that the roll decay of the trimaran planing hull in calm water is very rapid.

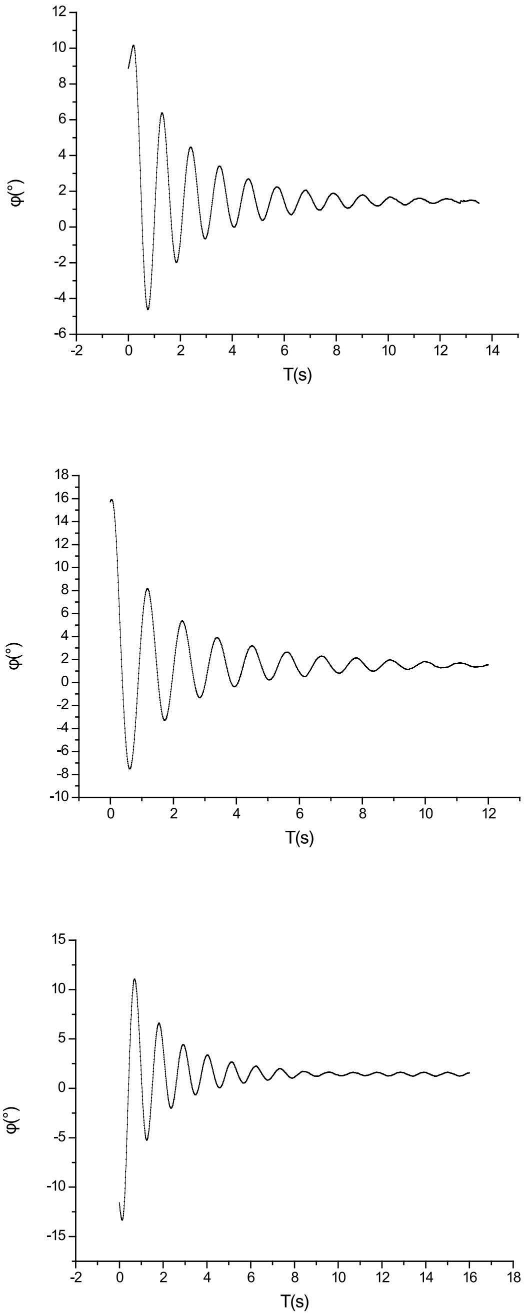

Fig. 9. Roll decay curves

Extinction curves can be obtained from the decay curve data when the rolling angle is smaller than 10° (Fig. 10). The abscissa in each graph is $\Delta\varphi = \varphi_k - \varphi_{k+1}$, and the ordinate is $\varphi_m = (\varphi_k + \varphi_{k+1}) / 2$. Extinction curves were fitted to obtain the extinction coefficient α, so the dimensionless decay coefficient $\mu_{\varphi\varphi}$ and roll damping coefficient $N_{\varphi\varphi}$ of the trimaran planing hull can be acquired.

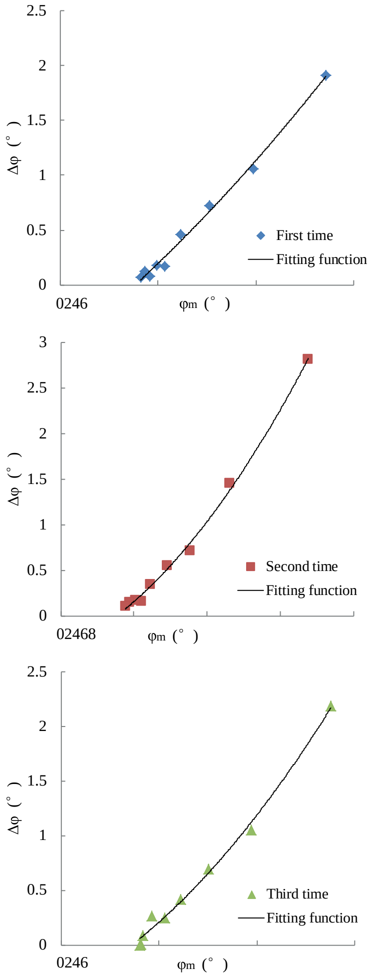

Fig. 10. Extinction curves

RESULTS AND ANALYSIS OF HEAD WAVE TESTS

The heaving and pitching response functions of trimaran planing vessels in waves are $|W_z(i\omega)| = \frac{z_a}{\varsigma_a}$ and $|W_\theta(i\omega)| = \frac{\theta_a}{k \times \varsigma_a}$, respectively, where ω_e is the encounter frequency, ζ_a is the recorded wave amplitude, Z_a is the heaving amplitude, θ_a is the pitching amplitude, and k is the wave number.

Figures 11 and 12 show changes of dimensionless heaving and pitching with circular frequency. At the same speed, as the encounter frequency increases, the hull's heaving and pitching first increase and then decrease. The heaving and pitching motions peak at $\omega_e \approx 7.0$, and the peaks increase and move to higher encounter frequencies with increasing velocity, which means that the ship's motion response worsens. At the same encounter frequency, higher velocities are associated with stronger motion responses, but the hull's motion decreases at encounter frequencies greater than 15. The main reason for this decrease is that the wave frequency at which the heaving and pitching resonances of the trimaran planing hull occur at high speed decreases, and the wave force increases. These motion response results are similar to those of high-speed vessels at high velocities. The testing process is shown in Figs. 13 and 14.

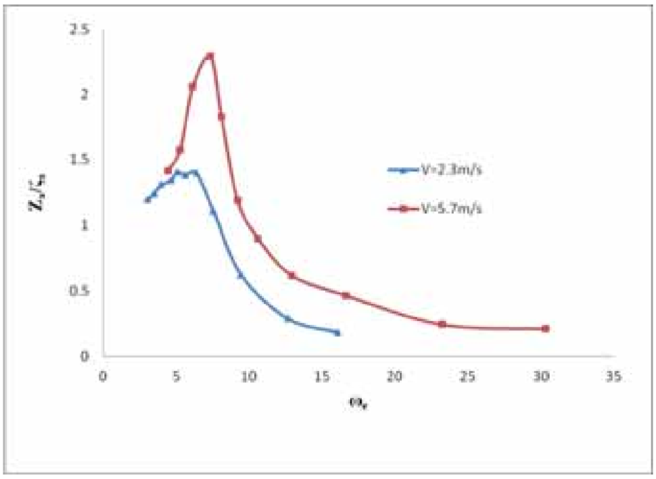

Fig. 11. Heave curve of the trimaran planing boat in waves

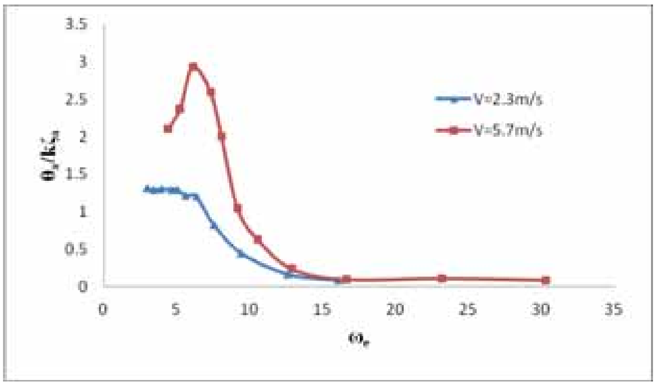

Fig. 12. Pitching curve of the trimaran planing boat in waves

Fig. 13. Seakeeping test for wavelength of 12 m at speed of 2.3 m/s

Fig. 14. Seakeeping test for wavelength of 12 m at speed of 5.72 m/s

CONCLUSIONS

The resistance of the trimaran planing boat is greatly affected by the longitudinal position of its centre of gravity. When the centre of gravity moves backward, the resistance decreases, but the longitudinal stability also decreases.

Installing bilge keels and air jet devices in the conducted tests had little effect on the resistance. Additional studies of the parameters of these devices and their effects on the resistance are needed.

The motion responses of trimaran planing crafts in waves are somewhat similar to those of common high-speed vessels; in particular, there is an encounter frequency at which the amplitude of the hull's motion is the largest. The higher the velocity, the greater the encounter frequency that corresponds to the maximum motion response.

ACKNOWLEDGEMENTS

This work was supported by the National Natural Science Foundation of China (No. 51409069 and No. 51409054). It was also supported by the Natural Science Foundation of Heilonhjiang (No. A201406) and by the Specialized Research Fund for the Doctoral Program of Higher Education (No. 20132304120011).

REFERENCES

1. Dong Wencai, Guo Rixiu: Effects of Different Air Injection Techniques on Resistance of Stepped Planing Boat [J]. Shipbuilding of China, 2000, 41(2), pp. 8-14

2. Dong Wencai,Guo Rixiu: Study on the mechanism of resistance reduction to the stepped planing craft by air injection [J]. Journal of Ship Mechanics, 2002, 6(6), pp.55-61

3. Dong Wencai, Guo Rixiu: Experimental investigation on the resistance reduction of stepped planing craft by formation of air cavity [J]. Journal of Hydrodynamics, 2002, 17(4), pp. 440-447

4. Xia Xiang: Matching performance of propulsion system for hypervelocity step planing boat [J]. Chinese Journal of Ship Research, 2008, 3(2), pp. 39-42

5. Fridsma, G.: A Systematic Study of the Rough-Water Performance of Planing Boat, Davidson Laboratory, Stevens Institute, Report R-1275, Nov, 1969

6. Fridsma, G.: A Systematic Study of the Rough-Water Performance of Planing Boat-Irregular Waves, Part II, Davidson Laboratory, Stevens Institute, Report R-1495, March, 1971

7. Toru KATAYAMA, Takashige HINAMI, Yoshiho IKEDA: Longitudinal Motion of a Super High-Speed Planing Craft in Regular Head Waves [C]. The 4th Osaka Colloquium on Seakeeping Performance of Ships, 2000, pp. 214-220

8. DONG Wen-Cai: Test Study of Deep V Planing Hull on Longitudinal Motion [J], 2004, 26(2), pp. 14-16

9. TAO Yao-Sen: Ship Seakeeping Performance [M], Shanghai Jiao Tong University Press, 1985, pp. 52-83

10. LI Ji-De: Ship Seakeeping Performance [M]. Harbin Institute of Marine Engineering Press. 1992, pp. 30-79

11. SHENG Zhen-Bang, LIU Ying-Zhong: Principles of Ship [M]. Shanghai Jiao Tong University Press,2004, pp. 376-433

12. WANG Yu-bin: Model Tests of Transitional Speedboat on Seakeeping Performance [J]. Engineer Equipment Research, 2005, 24(2), pp. 23-28.

CONTACT WITH THE AUTHOR

Hanbin Sun
College of Shipbuilding Engineering, Harbin Engineering University,
Nan tong Street Harbin,
HLJ, P.R. China,
e-mail: sun-han-bing@163.com

Weijia Ma
College of Shipbuilding Engineering, Harbin Engineering University,
Nan tong Street Harbin,
HLJ, P.R. China,
e-mail: maweijia@live.cn