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Effect of principal dimensions on seakeeping and wave loads of trimarans

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Abstract: In this paper, an investigation is carried out on how the hull form slenderness influences the seakeeping and global hull girder loads of a trimaran. By means of a ship hull variation method, a series of derived trimarans with the same displacement and different length to breadth ratios (*L/B*) from 12 to 19 are generated for a 1 000 tons trimaran. The longitudinal motion and wave load of the ships with forward speed in waves are calculated with the WASIM code based on a time-domain three dimensional Rankine source method. The statistics of the pitch and heave motion, sectional bending moment and shear force of the hull girder are analyzed with the wave spectrum in sea state 4 to 6. It is observed that as the *L/B* increases from 12.27 to 19.16, the peak value of pitch and heave motion is decreased by nearly 60% and 35% respectively, but the shear force is tripled and the bending moment is increased by 3.5 times. Furthermore, the wave loads comparison between direct calculation and British Lloyd's rules (LR) showed that the significant sectional shear force of the slenderest ship has already exceeded that in the Rules in sea state 6. These results show that the slenderness of the main hull has a contradiction impact on motion and wave load. The slenderer hull contributes to smaller motion response and better seakeeping performance, but leads to a sharp increase of total longitudinal bending moment and shear force, which is risky for the ship navigation on the high sea state conditions. Therefore, it is important to consider motion behavior and global longitudinal strength together when determining the principal dimensions of trimaran main hulls.

Key words: trimaran; hull form; series variation; ship motion response; wave load
CLC number: U661.3

0 Introduction

Trimaran is a modern high-speed marine vehicle which is often applied to the navy and civil transport. The structure of main hull and two side hulls endows it with the better lateral stability than ordinary monohull vessel. Therefore, compared with the monohull vessel, the main hull of trimaran can be designed to be slenderer to reduce the resistance and improve the speed greatly, which is also conducive to its seakeeping. According to the investigation on the current trimarans[1], the distribution statistics of principal dimension ratios of a trimaran (including *L/B* and *B/T* of main hull) have been obtained on the basis of the displacement size, as shown in Fig. 1. The ranges of main parameters of trimaran are shown in Table 1. It can be seen from Table 1 and Fig. 1 that the length to breadth ratio *L*/*B* and breadth to draft ratio *B*/*T* of main hull of trimaran are respectively from 12 to 18 and from 1.2 to 2.3, and the ratio Δ_S/Δ of side hull displacement to total displacement is no more than 7%. The slenderer main hull of trimaran can improve its seakeeping performance, however, it may also increase the wave load of the hull, thereby influencing the structural safety of the ship. In this paper, the quantitative analysis on the main hull form parameters, especially the comprehensive influence of the slenderness of the main hull on the ship motion response and wave loads, has been carried out.

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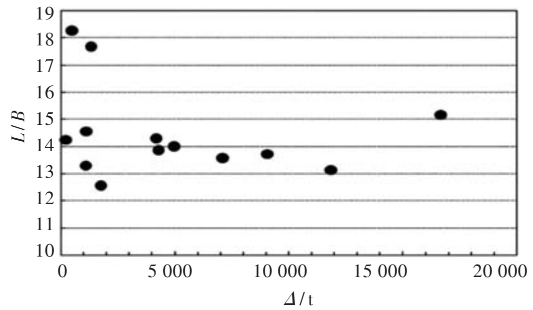
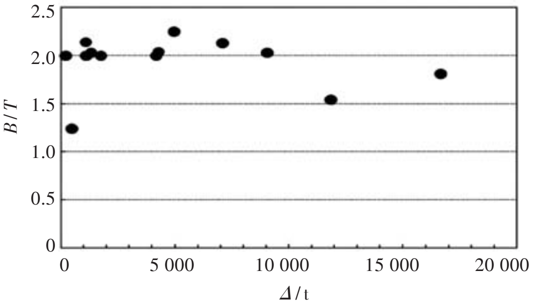


(a) *L/B* distribution



(b) *B/T* distribution

Fig.1 Statistics of *L/B*, *B/T* range of trimaran main hull

Table 1 Range of main particulars of trimaran

Parameter	Lower limit	Upper limit
Δ_s/Δ	3%	7%
L / B	12	18
B / T	1.2	2.30
L_s / B_s	12	38
B_s / T_s	0.35	1.30
L / L_s	0.25	0.50
B / B_s	0.15	0.30
T / T_s	0.30	0.80

The motion responses and loads of trimaran in waves are usually calculated based on the frequency-domain and time-domain potential theory, in which the frequency-domain method includes the pulsating source and moving pulsating source methods. Fang and Too[2] developed a three-dimensional pulsating source method used for predicting six degrees of freedom motion of the ships; Bingham et al.[3] applied the 3D moving pulsating source method to obtain the motion and load of trimaran in waves, who also pointed out that the frequency-domain method can only be used when *Fn* is less than 0.45. For higher speed, Faltinsen and Zhao[4] developed a 2.5D theory which has been applied to calculate the seakeeping of the multi-hull vessels by Duan et al.[5]. Besides, more researchers use the time-domain method, including the time-domain Green's function method and time-domain Rankine source method. For example, Peng[6] investigated the hydrodynamics of the multi-hull vessels through the 3D time-domain Green's function method, and Bruzzone and Grasso[7] analyzed the nonlinear motion[8] of trimaran in waves by synthesizing the frequency-domain and time-domain methods. The 3D time-domain Rankine source method is an effective method to solve the seakeeping-related problem of high-speed multi-hull vessels. On the basis of this method, the commercial code WASIM has been widely adopted by domestic and foreign researchers for the prediction of the trimaran's motion and wave loads[1], which has been recognized by the users due to its effectiveness and accuracy in solving nonlinear motion in high-speed condition.

1 Hull form variation

In order to study the influence of the main parameters of trimaran on the hydrodynamic results, a series of new hull forms are needed. In this paper, Hollister's offset-based hull form variation method is used in the hull form variation program[9]. The program includes four modules: stretch (STRETCH) module, sectional transform (CMVARY) module, prismatic coefficient transform (LACKENBY) module and hydrostatic force calculation (HYDROSTATICS) module. The workflow is shown in Fig. 2. During the iterations among the four modules, only the target and compensation parameters are changed while the others are constant. In the paper, due to the consistent displacement of the main hull and small proportion of the side hull displacement to the total displacement, the side hull can be simply transformed by scale transform, waterline adjustment and repositioning. Moreover, the relative distance between the hulls before and after transform does not change. With the consistent displacement of the main hull, six hull form parameters derived from the series variations are shown in Table 2.

2 Motion and load calculation

2.1 Numerical calculation method

The WASIM code can give a good result of the mo-

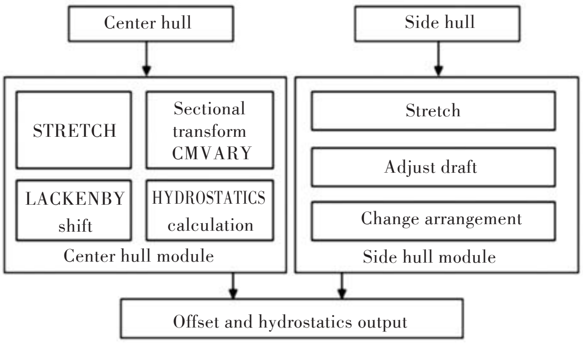


Fig.2 Workflow chart of trimaran hull variation

Table 2 Parameters of variated trimaran hulls

Name		Hull number					
		S1	S2	S3	S4	S5	S6
Main hull	Waterline length L_{wl} / m	104.000	88.000	96.000	112.000	120.000	128.000
	Molded breadth B / m	7.200	7.172	7.038	6.919	6.794	6.681
	Draft T / m	3.600	3.705	3.734	3.524	3.399	3.280
	Volume of displacement/m^3	1 116	1 116	1 116	1 116	1 116	1 116
	Block coefficient C_b	0.414	0.477	0.442	0.409	0.403	0.398
	Midship section coefficient C_m	0.689	0.794	0.736	0.680	0.670	0.662
	Prismatic coefficient C_p	0.601	0.601	0.601	0.601	0.601	0.601
	Length to breadth ratio L/B	14.444	12.270	13.640	16.187	17.663	19.159
Side hull	Waterline length L_{wlS} / m	36.000	30.500	33.200	38.600	40.200	42.000
	Molded breadth B/m	1.600	1.633	1.643	1.707	1.707	1.707
	Draft T/m	1.400	1.400	1.400	1.400	1.400	1.400
Total displacement Δ/t		1 188	1 187	1 194	1 213	1 206	1 207

tion and load of trimaran in waves. In the study, the longitudinal motion and wave loads are calculated in head sea condition. The pitch, heave, vertical bending moment and shear force in specific sea state can be obtained through the spectra analysis. The Froude number of every computation is set to Fn =0.322. The mass distributions of the six derived hull forms are shown in Fig. 3, and the side hull arrangements are shown in Fig. 4. The sterns of both the main hull and side hulls are transom.

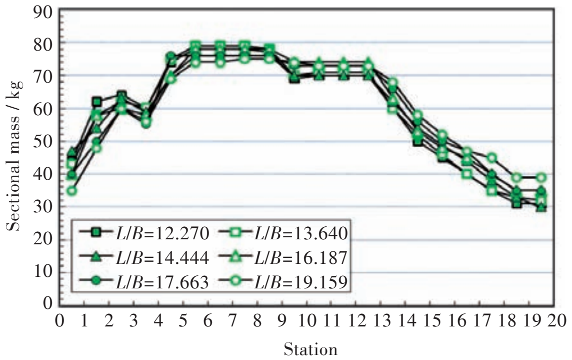


Fig.3 Mass distribution

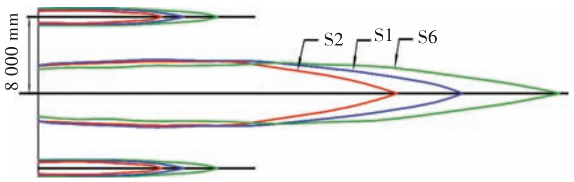


Fig.4 Arrangement of S1, S2 and S6 ships

2.2 Transfer functions of the motion and load in regular waves

For the six derived hull forms, the motion and load responses in the head-sea regular waves are calculated and the displacement is kept constant. The comparison of the transfer functions of the motion and load of six derived hull forms with different L/B is shown in Fig. 5 to Fig. 9, among which the abscissa ω represents the natural wave frequency, and the ordinates respectively represent the dimensionless transfer functions of heave, pitch, sectional shear force and bending moment in the specific sections.

Through the analysis of the frequency response of the heave and pitch motion, it is observed that the peak response value of the heave and pitch motion decreases as the L/B increases. When L/B is larger than 14.444, there is no obvious peak point in the pitch transfer function. It can be noted that the vessel with a slenderer main hull will have smaller mo-

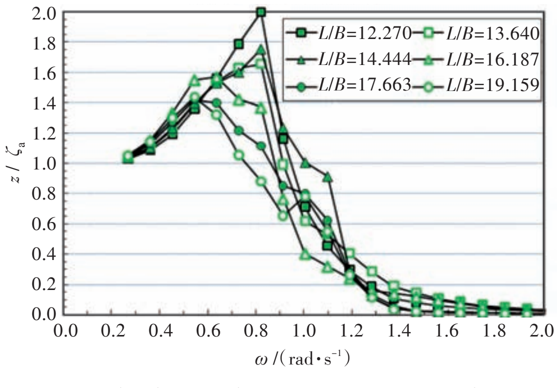


Fig.5 The change of heave transfer function with L/B

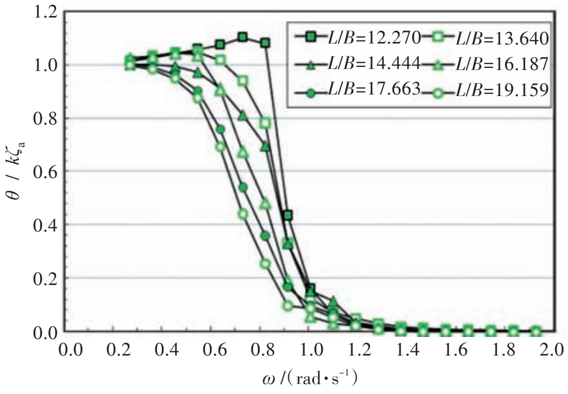


Fig.6 The change of pitch transfer function with L/B

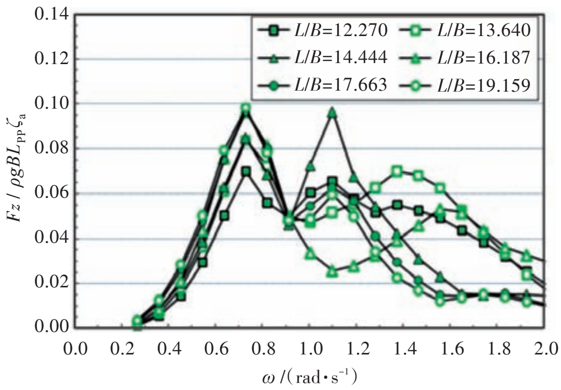


Fig.7 The change of shear force transfer function with *L/B* at station 5

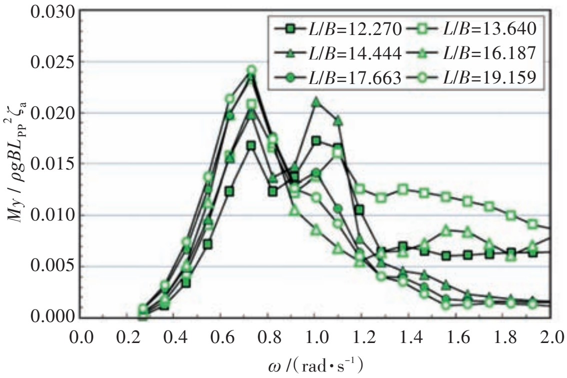


Fig.8 The change of bending moment transfer function with *L/B* at station 10

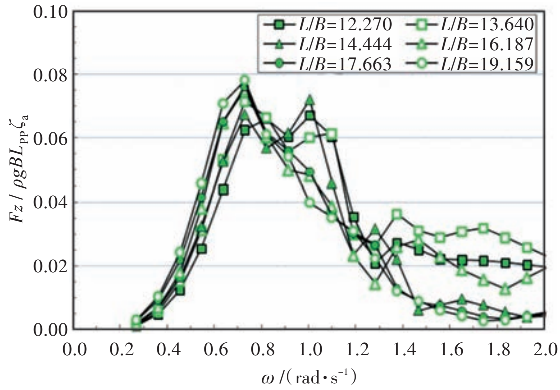


Fig.9 The change of shear force transfer function with *L/B* at station 15

tion response in regular waves and better seakeeping performance.

Since the loads comparison of different *L/B* ships should be based on the longitudinal sectional loads distribution under short-term condition, it is necessary to predict the short-term performance of seakeeping and wave loads.

2.3 Short-term prediction analysis in irregular waves

2.3.1 Statistical prediction of the pitch and heave motion

The short-term prediction is performed based on the spectrum analysis method, and in this paper, the Pierson-Moscowitz wave spectrum is used:

$$S(\omega)=\frac{5}{16}\frac{H_{1/3}^{2}}{\omega_{\mathrm{P}}}(\frac{\omega}{\omega_{\mathrm{P}}})^{-5}\exp[-\frac{5}{4}(\frac{\omega}{\omega_{\mathrm{P}}})^{-4}]$$

$$\omega_{\mathrm{P}}=\frac{2\pi}{T_{\mathrm{P}}}=\frac{2\pi}{1.408T_{\mathrm{Z}}} \tag{1}$$

where: $H_{1/3}$ stands for the significant wave height; ω_{P} for spectral peak frequency; T_{P} for the spectral peak period; T_{Z} for the zero-upcrossing period. For a comprehensive study of the sea states that trimaran may encounter, the series calculation covers the zero-upcrossing periods ranging from 4 s to 15 s. Fig. 10 to Fig. 12 respectively show the comparison of the short-term responses of the heave, pitch and vertical acceleration at bow of the six derived hull forms with different *L/B* ratios.

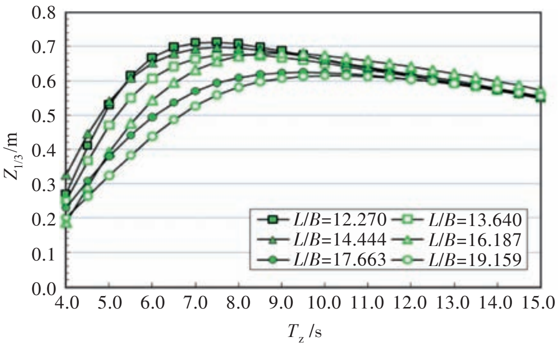


Fig.10 Comparison of heave short-term response of different *L/B*($H_{1/3}=1$ m)

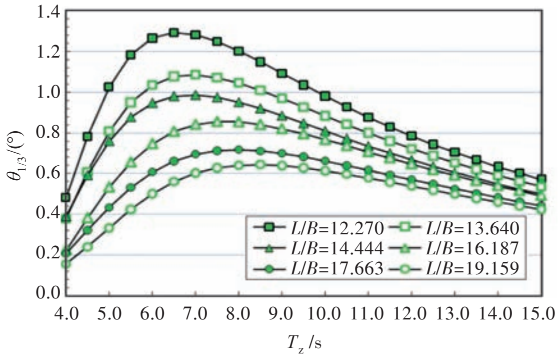


Fig.11 Comparison of pitch short-term response of different *L/B*($H_{1/3}=1$ m)

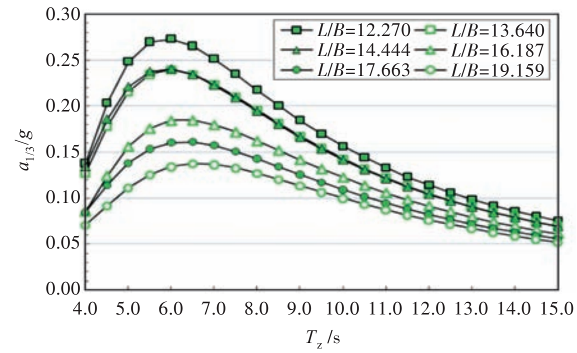


Fig.12 Comparison of vertical acceleration short-term response of different *L/B* ($H_{1/3}=1$ m)

The statistical results shown in Table 3 include the motion and acceleration when the zero-upcrossing period T_z is equal to 6, 8, 10 s and the significant wave height $H_{1/3}$ is equal to 1 m. It can be found from the table that the ships with larger *L/B* have obvious advantages in seakeeping during head sea navigation. When the zero-upcrossing period T_z is equal to 6 s, the heave motion response, pitch motion response, and vertical acceleration at bow of S6 decrease by 34.5%, 60.3%, and 50.8%, respectively. This indicates that with the slender main hulls and larger *L/B*, the motion in the irregular waves is more moderate, which is more favorable to the seakeeping.

Table 3 Short-term statistics of trimaran motion in unit siginificant wave height ($H_{1/3}$ =1 m)

Hull number	Length to breadth ratio *L/B*	Heave/m			Pitch/(°)			Vertical acceleration of the bow/*g*		
		T_z=6 s	T_z=8 s	T_z=10 s	T_z=6 s	T_z=8 s	T_z=10 s	T_z=6 s	T_z=8 s	T_z=10 s
S2	12.270	0.669	0.709	0.663	1.266	1.202	0.981	0.273	0.218	0.157
S3	13.640	0.608	0.677	0.651	1.038	1.048	0.886	0.240	0.196	0.143
S1	14.444	0.653	0.696	0.662	0.953	0.949	0.812	0.241	0.195	0.142
S4	16.187	0.544	0.672	0.674	0.750	0.857	0.770	0.184	0.162	0.122
S5	17.663	0.496	0.611	0.625	0.609	0.717	0.663	0.161	0.143	0.109
S6	19.159	0.438	0.582	0.615	0.502	0.643	0.616	0.134	0.127	0.100

2.3.2 Short-term prediction of the vertical shear force and bending moment

In this paper, the comprehensive structure loads in sea sates 4-6 are calculated. In sea state 4, the significant wave height $H_{1/3}$ = 2 m, and the zero-upcrossing period T_z = 6 s; in sea state 5, the significant wave height $H_{1/3}$ = 3 m, and the zero-upcrossing period T_z = 8 s; in sea state 6, the significant wave height $H_{1/3}$ = 5 m, and the zero-upcrossing period T_z = 10 s. The comparisons of the sectional vertical shear force and bending moment under different *L/B* are respectively shown in Fig. 13 to Fig. 18.

The maximum sectional shear force and bending moment under different *L/B* are shown in Table 4. Compared with the maximum shear force of S2(*L/B* = 12.27), the maximum shear forces of S6 (*L/B* = 19.16) in sea states 4, 5 and 6 increase by 112.8%, 171.7% and 190.1% respectively. Compared with the maximum bending moment of S2 (*L/B* = 12.27), the maximum bending moments in sea states 4 and 6

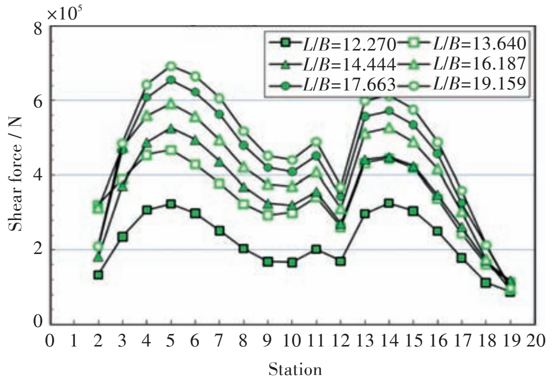


Fig.13 Comparison of vertical shear force of different *L/B* in sea state 4 (T_z =6 s, $H_{1/3}$ =2 m)

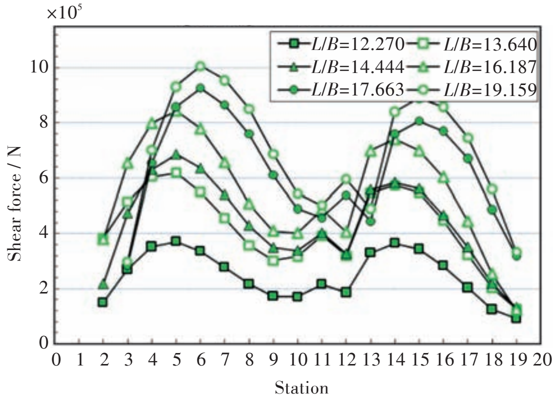


Fig.14 Comparison of vertical shear force of different *L/B* in sea state 5 (T_z =8 s, $H_{1/3}$ =3 m)

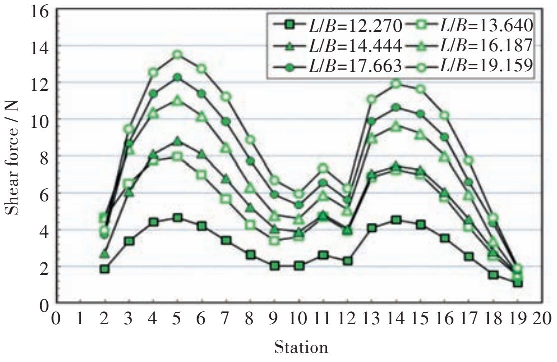


Fig.15 Comparison of vertical shear force of different *L/B* in sea state 6 (T_z =10 s, $H_{1/3}$ =5 m)

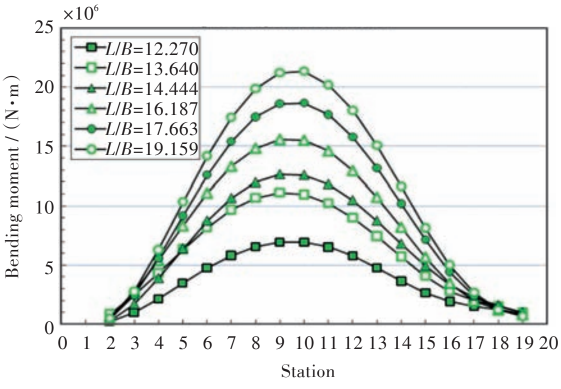


Fig.16 Comparison of vertical bending moment of different *L/B* in sea state 4 (T_z =6 s, $H_{1/3}$ =2 m)

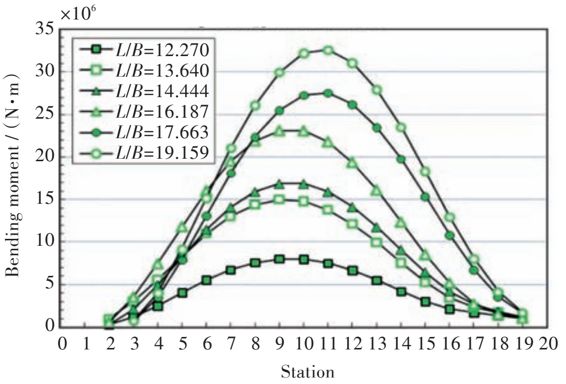


Fig.17 Comparison of vertical bending moment of different *L/B* in sea state 5 (T_z =8 s, $H_{1/3}$ =3 m)

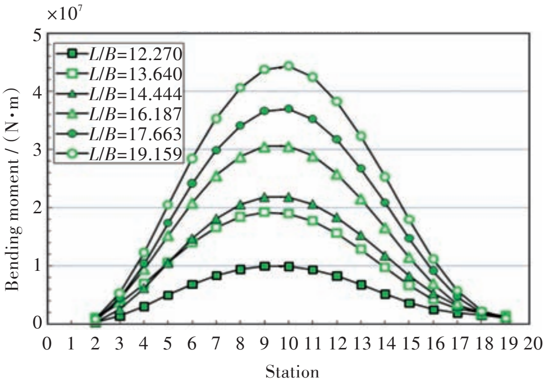


Fig.18 Comparison of vertical bending moment of different *L/B* in sea state 6 (T_z =10 s, $H_{1/3}$ =5 m)

Table 4 Maximum sectional load of different trimaran hulls

Hull number	Length to breadth ratio *L/B*	Maximum sectional shear force / N			Maximum sectional bending moment/(N·m)		
		Sea state 4	Sea state 5	Sea state 6	Sea state 4	Sea state 5	Sea state 6
S2	12.270	3.255×10^5	3.701×10^5	4.648×10^5	6.910×10^6	7.914×10^6	9.943×10^6
S3	13.640	4.668×10^5	6.188×10^5	7.955×10^5	1.110×10^7	1.492×10^7	1.921×10^7
S1	14.444	5.260×10^5	6.858×10^5	8.825×10^5	1.261×10^7	1.683×10^7	2.188×10^7
S4	16.187	5.919×10^5	8.435×10^5	1.104×10^5	1.557×10^7	2.306×10^7	3.050×10^7
S5	17.663	6.551×10^5	9.254×10^5	1.227×10^6	1.863×10^7	2.748×10^7	3.693×10^7
S6	19.159	6.926×10^5	1.005×10^6	1.348×10^6	2.132×10^7	3.254×10^7	4.430×10^7

increase by 208.5% and 345.6% respectively. Therefore, it can be concluded that the increase in the slenderness of the main hulls will result in a significant increase in the comprehensive structural load.

Table 5 shows the comparison results of the seakeeping and load between hull forms with the minimum *L/B* and maximum *L/B* in typical sea states. According to Table 5, in sea state 4, the pitch motion response of S6 decreases by 60.35% compared with that of S2, but the maximum bending moment increases by 208.54%, and the load changes sharply. Thus, an over slender main hull is very disadvantageous to the structural load.

Table 5 Summary of typical significant values of motion and load

		Hull number		Increase rate/%
		S2 (*L/B*=12.270)	S6 (*L/B* =19.159)	
Maximum shear force/N	Sea state 4	3.255×10^5	6.926×10^5	112.78
	Sea state 5	3.701×10^5	1.005×10^6	171.55
	Sea state 6	4.648×10^5	1.348×10^6	190.02
Maximum bending moment/(N·m)	Sea state 4	6.910×10^6	2.132×10^7	208.54
	Sea state 5	7.914×10^6	3.254×10^7	311.17
	Sea state 6	9.943×10^6	4.430×10^7	345.54
Heave/m	Sea state 4	1.338	0.876	−34.53
	Sea state 5	2.126	1.745	−17.92
	Sea state 6	3.313	3.075	−7.18
Pitch/(°)	Sea state 4	1.266	0.502	−60.35
	Sea state 5	1.202	0.643	−46.51
	Sea state 6	0.981	0.616	−37.21

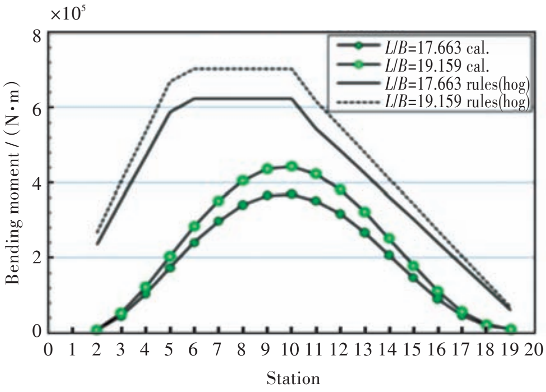
3 Comparison of direct load calculation with the British Lloyd's Rules (LR)

For the sake of safety of the ships, the Lloyd's Rules (LR) [10] formulated the comprehensive load rules. The equations for the vertical bending moment and shear force are as follows:

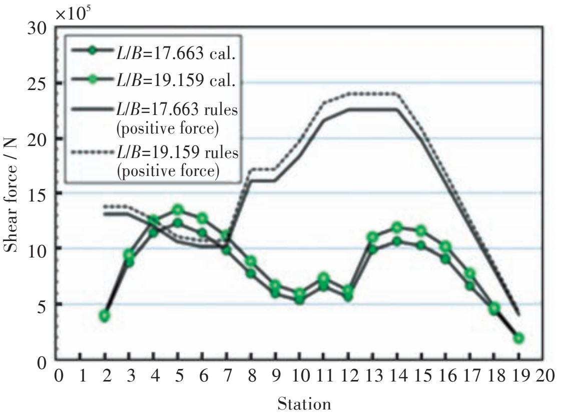
$$M_w = F_t D_f M$$
$$Q_w = 3K_f M_0 / L_R \qquad (2)$$

where: D_f and K_f respectively represent the distribution factors of bending moment and shear force; F_t is the coefficient associated with hogging and sagging; M_0 is the coefficient related to the ruled length L_R, breadth of the design ship and the block coefficient.

Fig. 19 compares the presented numerical results with the LR rule's results regarding to the load distribution of S5 and S6 derived ships in sea state 6. It can be seen that the numerical bending moments of the two ships are very close to the design loads in the LR and the maximum value may exceed the design value of rule; while the numerical result of the sectional shear force has exceeded the rule's result. This indicates that the extremely slender hull will result in a significantly high longitudinal load. Considering the hull strength and safety, Thus, as the hull strength and navigation safety in high sea states should be guaranteed, the total cost of the very slender trimaran must be greatly increased.



(a) Design hogging bending moment



(b) Design shear force

Fig.19 Comparison between design loads in LR and calculated vertical loads of S5 and S6 ship in sea state 6 (T_z=10 s, $H_{1/3}$=5 m)

4 Conclusions

In this paper, a series of derived hull forms are obtained from the survey of the variation range of the principal dimensions of trimaran and the hull form transformation method based on the offsets, under the condition that the displacement and prismatic coefficient of the main hull keep constant. Through the direct calculation of the motion response and wave load of the six derived ship hull schemes in head sea and the comparison between the total longitudinal load and the LR, the following conclusions are obtained:

1) The *L/B* of main hull of trimaran is between 12 and 18. With the increase of *L/B*, the transfer function and short-term forecast results show that the heave and pitch motion of the ships will decrease in head sea, indicating that the slenderer main hull contributes to better seakeeping performance.

2) The effect of the slenderness of main hull on the longitudinal wave load is contradictory to the motion. The hull load increases with the increment of the *L/B*. Very large slenderness of the main hull will has negative impact on the longitudinal structural load.

3) Slender main hull of trimaran is beneficial to the resistance and seakeeping. But in high sea state, it introduces high wave load which may exceed the design load in LR. This will lead to structural safety issues and cost problems. Hence, it is important to comprehensively evaluate the seakeeping and longitudinal wave loads when determining the principal dimensions of the main hull in the preliminary design of a slender trimaran.

References

[1] XIANG Jiuyang. The numerical calculation of trimaran s seakeeping and wave loads affected by hull form factors [D]. Wuhan: Wuhan University of Technology, 2008(in Chinese).

[2] FANG M C, TOO G Y. The effect of side hull arrangements on the motions of the trimaran ship in waves[J]. Naval Engineers Journal, 2006, 118(1): 27-37.

[3] BINGHAM A E, HAMPSHIRE J K, MIAO S H, et al. Motions and loads of a trimaran travelling in regular waves [C]//FAST 2001 The 6th International Conference on Fast Sea Transportation. [S.l.: s.n.], 2001.

[4] FALTINSEN O, ZHAO R. Numerical predictions of ship motions at high forward speed[J]. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 1991, 334(1634): 241-252.

[5] DUAN W Y, HUANG D B, HUDSON D A, et al. Comparison of two seakeeping prediction methods for high speed multi-hull vessels[C]//FAST 2001 6th International Conference on Fast Sea Transportation. [S.l.: s.n.], 2001.

[6] PENG H X. Numerical computation of multi-hull ship resistance and motion[D]. Halifax: Dalhouse Universty, 2001.

[7] BRUZZONE D, GRASSO A. Nonlinear time domain analysis of vertical ship motions[J]. Archives of Civil and Mechanical Engineering, 2007, 7(4): 27-37.

[8] SHIN Y S, BELENKY V L, LIN W M, et al. Nonlinear time domain simulation technology for seakeeping and wave-load analysis for modern ship design[C]// ABS Technical Papers 2003. [S.l.: s.n.], 2003: 257-281.

[9] HOLLISTER S M. Automatic hull variation and optimization[C]// The Meeting of the New England Section of the Society of Naval Architects and Marine Engineers, 1996.

[10] Lloyd's Register. Rules for the classification of trimarans[S]. Britain: Lloyd's Register, 2016.

[*Continued on page* 14]

planar elements method considering occlusion and secondary scattering[J]. Acta Acustica, 2011, 36(4): 377-383(in Chinese).

[15] BU Kaoying, FAN Jun. Echo Characteristic Calculation of Benchmark Submarine[C]//2005 年全国水声学学术会议论文集. Wuyishan: Acoustical Society of China, 2006(in Chinese).

潜艇艏端耐压舱壁构型对声目标强度的影响

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摘　要： 潜艇艏部目标强度偏大，影响潜艇的声隐蔽性。由目标强度贡献比例曲线发现，艏端耐压舱壁是潜艇艏部目标强度的主要来源。潜艇艏端耐压舱壁主要有(椭)球面和平面2种形状，声波自艏端入射时，刚性平面的目标强度显著高于有一定曲率的刚性椭球面的目标强度。建立了一系列具有不同曲率的椭球形艏端耐压舱壁模型，基于板块元方法分析了艏端目标强度随舱壁曲率的变化关系，并对结果进行对数拟合，再利用BEM数值方法对耐压壳体艏部近场回波进行仿真，得到散射声压云图。计算结果表明：耐压壳艏端舱壁采取椭球面构形能够减弱散射声场的指向性，从而显著降低目标强度(>10 dB)。曲率大于一定程度时，艏端目标强度值趋于稳定。

关键词： 目标强度；耐压舱壁；曲率；板块元；边界元

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主体瘦长度对三体船耐波性和波浪载荷的影响

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摘　要： 针对某千吨级三体船母型船，在保持排水量不变的前提下，调查长宽比对运动和载荷的影响，并通过船型变换得到长宽比在12～19之间的6种系列派生船型；应用三维时域Rankine方法软件WASIM对不同长宽比系列船体的纵向运动和波浪载荷进行频响计算，并进一步结合海浪谱分别计算4～6级海况下船体纵摇和升沉运动统计值以及船体剖面弯矩和剪力沿船长单位的分布。分析发现，当主体长宽比从12.27增加至19.16时，纵摇和升沉的最大峰值分别下降了近60%和35%，但剪力和弯矩的峰值则分别增大了2倍和3.5倍。进一步将直接计算的总纵弯矩和剪力与英国劳氏规范相比较，发现6级海况下剖面剪力有义值的计算结果已超过规范的规定。结果表明：主船体的长宽比对耐波性和波浪载荷具有相反的影响，即主体越瘦长，运动响应越小，耐波性越好；但主体越瘦长，总纵弯矩和剪力会大幅增加，对船体结构产生不利影响。因此，在设计之初确定瘦长三体船的主尺度，特别是瘦长度时，应兼顾考虑船体运动响应与波浪载荷的影响。

关键词： 三体船；船型；系列变换；船舶运动响应；波浪载荷