On the Stability Characteristics of Different High Speed Craft

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ABSTRACT

The demand of fast marine transportation has been increasing more and more during the last years and the sea transportation for passengers could became an alternative to land or air to transportation.

Therefore, during the last years, the research as been focused on the multihull vessels, which for its larger deck area, its easy machinery arrangement should be preferred to the monohull.

In previous works, the hydrodynamic characteristics of the different vessels with equivalent service capabilities have been examined, as regard powering performances.

In this paper the comparison is extended to the stability characteristics according to the present IMO regulations.

1. INTRODUCTION

The increasing demand of high speed vessels has led to search for new unconventional ship hull forms. The new multihull vessels, can be subdivided into catamarans, trimarans and, more recently also pentamarans. At the present, the catamarans due to their wide deck area, high stability and safety at sea are the leading commercial type for short distance coastal trade.

Fast marine transportation with larger craft sizes is now considered an attractive solution also for medium lines, where suitable high speed vessels could be used in competition with land and/or air transportation. The importance of this segment in the whole picture of marine transportation has called for further investigations, which suggested the study and the development of new multihull forms with lowest overall resistance and best seakeeping characteristics than the catamarans.

For this aim the trimaran and the pentamaran, based on a long slender main hull plus additional side hulls, with a very relatively small displacement volume, could be interesting possibilities for the medium range routes.

Nevertheless trimaran ships have had a very limited use till now and there is very little information about pentamaran hull form and configuration.

Therefore, it seems important a comparison of the hydrodynamic performances and of the stability characteristics among the catamaran and these new proposed high speed multihull ships.

Basic designs for the three different multihull vessels, catamaran trimaran and pentamaran, have been developed to achieve equivalent service capabilities for transportation of 800 passengers and 250-300 cars at a cruising speed of 35-40 knots.

In previous works the hydrodynamic characteristics of these different vessels have been examined.

Different configurations for each considered multihull have been studied by experimental model tests and by numerical code application as regard powering performances.

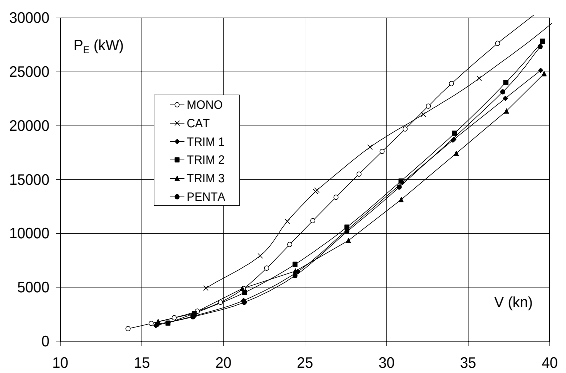

Fig 1. Effective horsepower for different multihulls and for equivalent monohull ship.

The prediction of trimaran and pentamaran resistance with a given main hull is substantially affected by dimension and location of the outriggers.

The hydrodynamic characteristics of trimaran and pentamaran configuration related to optimum outriggers location were compared in previous papers with those of equivalent catamaran.

Fig. 1 shows the comparison in the speed range V=15-40 knots among the effective horsepowers, evaluated by model tests with ITTC ’57 methodology correlation and frictional line, for configurations of one catamaran, three trimarans, one pentamaran and for an equivalent monohull ship presently in service.

This figure highlights that, as regard powering performances in the range of medium high speeds the pentamaran and the trimaran seem interesting possibilities due to the benefits given by their very slender main hull form compared to the catamaran and the monohull ship.

In the considered speed 35-40 knots the trimaran indicated in the following with no. 3 presents the better performance. Anyway, to get a more complete picture about the potential of the different till now proposed multihulls intact and damaged stability must be considered.

Therefore, in this paper the comparison among the different multihulls is extended to the intact and damaged stability characteristics according to the present IMO regulations.
Aim of this work is to verify if the catamaran and the considered hull configurations of the trimaran and pentamaran are suitable for a realistic ship to be used on medium range lines.

2. MULTIHULL FORMS FOR EQUIVALENT SHIP

First design requirements of multihull high speed ships to be used on medium routes for the transportation of 800 passengers and 250-300 cars are adequate deck area and displacement volume.

However, as the main dimensions of the passengers ships have constrains due to the port sizes, the maximum beam of all multihulls have been limited to 30 metres. So, hull designs of five different fast ships for equivalent service capabilities have been developed on the basis of a realistic general layout. They are:

- a hard chine catamaran (fig. 2);
- a first trimaran (fig. 3) having round bilge main hull derived from series 64 and outriggers having length 30% of the main hull length, and hull form derived also from series 64;
- a second trimaran (fig. 4) having the same main hull of the first trimaran and outriggers having length 30% of the main hull length, characterized by simple U section with a very small transom and a larger outrigger displaced volume in comparison with the first trimaran ;
- a third trimaran (fig. 5) having hard chine main hull form and the same outriggers of the second trimaran;
- a pentamaran (fig. 6) having the same main hull of the first trimaran with forward and after outriggers having length 20% of the main length, whose hull forms have been derived by geometrical affinity also from series 64

The principal characteristics of the five considered multihull ships in full scale are given in Table 1.

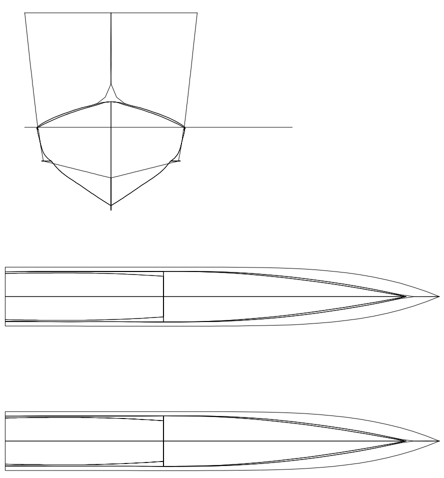

Fig 2. Catamaran hull form

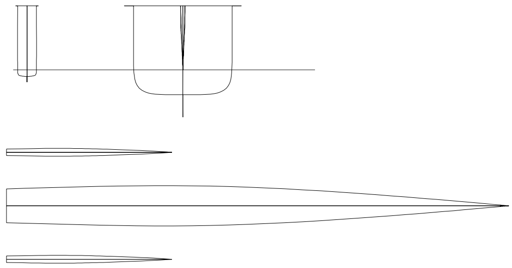

Fig 3. Hull forms and configuration of trim. 1

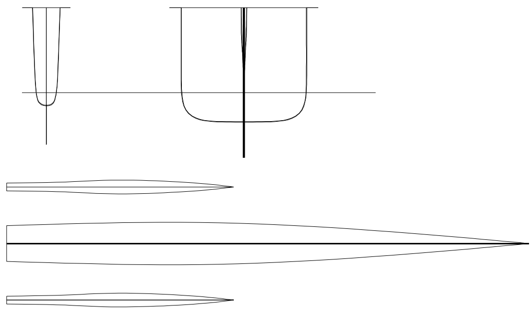

Fig 4. Hull forms and configuration of trim. 2

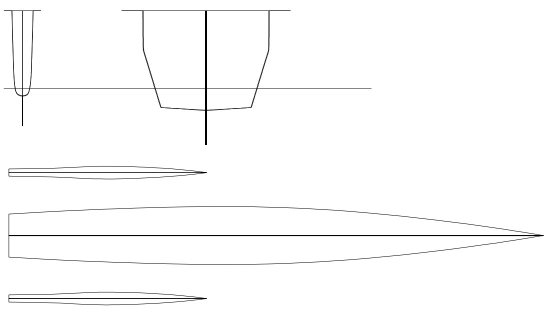

Fig 5. Hull forms and configuration of trim. 3

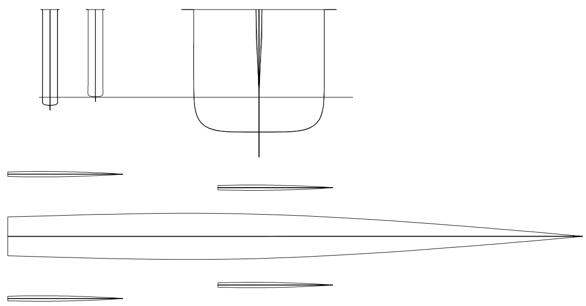

Fig 6. Hull forms and configuration of pentamaran

Tab.1 Main dimensions of the considered hullforms in full scale

	Trim.1	Trim. 2	Trim. 3	Pent.	Cat.
Δ [t]	2320	2320	2320	2320	2320
L_{WL}[m]	105.6	105.48	123.32	105.6	91.354
B [m]	25.137	25.699	30.477	24.796	28.016
T [m]	3.24	3.028	3.481	3.234	3.082
D [t]	9.4584	9.3798	10.4654	9.3872	9.6612

3. STABILITY CHARACTERISTICS

The considered ships with displacement volume of 2500 cubic metres and cruising speed of 35-40 knots have been treated as high speed craft, being this speed higher than

$$V(m/sec)>3.7\nabla^{0.1667}=13.5 \text{ m/sec} = 26.2 \text{ knots}$$

Therefore, the stability characteristics have been examined according to the International Code of Safety for high-speed craft (IMO HSC Code 2000).

3.1 Intact Stability

Fig. 7 shows the curves of the stability arms GZ versus heel angles for the following conditions of the five considered multihull ships:

- Freeboard-Beam ratio f/B= 0.20
- Height of gravity centre - depth moulded ratio KG/D= 0.60 (as the stability criterion has not been satisfied for the pentamaran, only for this ship has been considered also the value KG/D = 0.55).

In order to verify the stability criteria, the quantities HL_1, heeling lever due to wind and HTL, heeling lever due to wind+gusting + passengers crowding evaluated, as IMO Code, have been compared with the righting arm curves.

In applying both these criteria and those related to stability in damage condition, the total passengers weight 75 kg x 800 = 60 t, has been situated at 1.0 m of the ship's side.

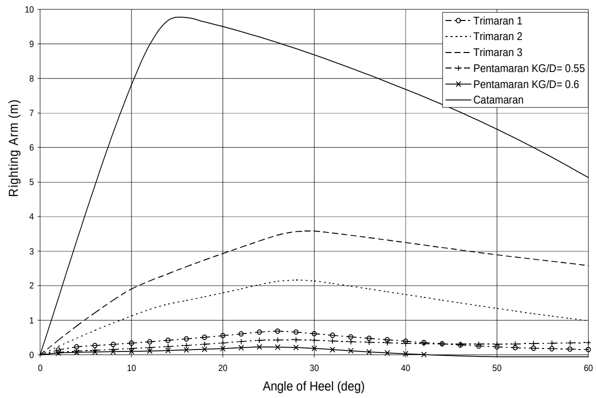

Fig 7. Intact stability curves for intact conditions of the hulls

Tables 2 report the obtained values for the required indexes of the intact stability related to the considered five ships:

- The area A_1 under the GZ curve which should be:
  A_1= 0.055x 30°/θ (m.rad) (determined for the angle θ at which the maximum GZ occurs)
- The residual area under GZ curve A_2,
- which should be at least equal to 0.028 m.rad (determined for the angle of roll θ_r, taken as15° in absence of model tests)
- The angle Θ_m at which the maximum GZ occurs , which should be at least 10°
- The angle of heel Θ_h due to heeling lever HL_1, which should not exceed 16°.

Tab.2 Evaluated stability indices *for intact conditions A_1 and A_2*

Δ 2320	Trim.1	Trim. 2	Trim. 3	Pent.	Pent.2	Cat.
KG [m]	5.675	5.628	6.279	5.63	5.163	5.80
GM_t [m]	3.939	6.938	12.18	1.8	2.272	47.3
Θ_h [°]	3.64	1.82	1.376	22.5	0.244	12.2
Θ_m [°]	26	28.2	29.3	24.4	15.3	27.8
HL_1 [m]	0.133	0.134	0.182	0.13	0.131	0.12
HTL [m]	0.214	0.215	0.287	0.21	0.211	0.2
A1 [m rad]	0.181	0.652	1.142	0.05	0.119	1.56
A2 [m rad]	0.039	0.208	0.347	.0039	0.032	1.48

The analysis limited to intact stability highlights that in the case of KG/D = 0.60 we have stability excessive for the catamaran, satisfactory for the three different trimarans, but unsatisfactory for the pentamaran. For this last ship the criteria have been satisfied only with the lower KG/D= 0.55.

However, the operability of catamaran on medium routes is sensibly reduced because its excessive stability and consequently the lack of the comfort on board due to the high roll induced acceleration, the heave and pitch motions at sea in rough weather.

Figg.8-9 show the histograms of the obtained values A_1 and A_2 compared with the required values.

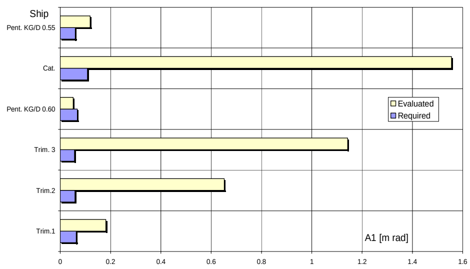

Fig. 8 Obtained values A_1 compared with the required values

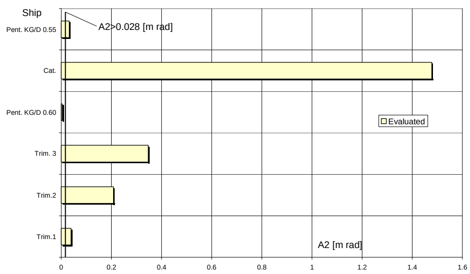

Fig. 9 Obtained values A_2 compared with the required value

3.2 Stability after damage

The following damages have been considered to occur separately on the surface of the hull from the most forward point of under water volume between the keel and the upper limit of the vulnerable area defined by IMO code (fig.10):

- For the single hull of the catamaran and for both the main hull of trimaran and pentamaran two damages, one on the bottom and one on the side.
- For the side hull of the second and the third trimaran only one damage on the bottom.

As required by IMO Code related to multihull high sped craft, the following damage dimensions were considered:

- longitudinal extension equal to 0.55% of the length L;
- penetration normal to the shell equal 0.5 m. (Fig.11);
- transversal extensions equal to 3.0 m being this dimension higher than the double of the required 0.1 $\nabla^{1/3}$ girth along the shell.

One of the side hulls of the pentamaran and the side hull of the first trimaran, because of their limited dimension, were considered completely flooded up to upper limit of vulnerable area.

In order to verify the stability criteria for damage condition the quantities HL_3, heeling lever due to steady wind and HL_4, heeling lever due to wind + passengers crowding, evaluated as IMO Code have been compared with the righting arm curves in damage condition.

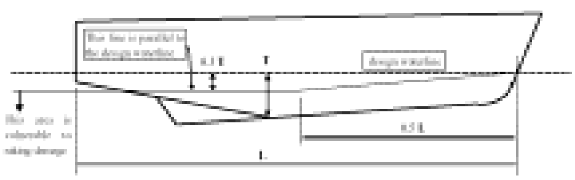

Fig 10. Vulnerable area

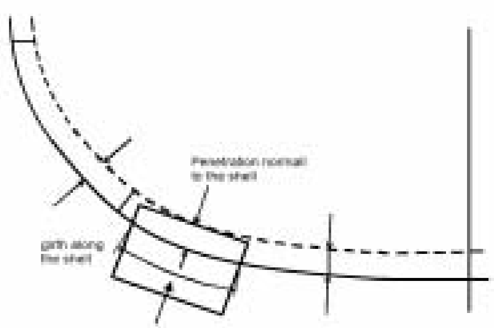

Fig 11. Transverse damage figure

Tables 3 and 4 give for the five examined multi-hull ships the obtained values HL_4, θ_h and A_2 related respectively to the damage on the bottom and damage on the side of the single hull of the catamaran and of the main hull of trimarans and pentamaran.

Table 5 give the same indices related to the damage, as above considered, on the outrigger of the trimarans and of the pentamaran.

The angle of heel θ_h due to the wind heeling lever, after damage, should not exceed 20°.

In figg.12,13,14 the residual stability curves related to the above mentioned damages are given. In figg.15,16,17 the corresponding histograms of the obtained values A_2 compared with the required value $A_2 \geq 0{,}028$ m.rad. are presented.

The analysis of histograms relating to stability indices after damage highlights that the residual stability in any case is insufficient for the pentamaran and fully sufficient for the other examined multihulls, but very high again for the catamaran.

Tab.3 Evaluated stability index A_2 for damage on the bottom condition

Δ 2320	Trim.1	Trim2	Trim. 3	Pent.	Pent.2	Cat.
KG [m]	5.675	5.628	6.279	5.632	5.16	5.797
Θ_h [°]	11.5	3.391	2.449	****	21.48	0.733
HL4 [m]	0.394	0.41	0.519	0.41	0.41	0.456
A2 [m rad]	0.049	0.202	0.334	****	0.012	1.457

Tab.4 Evaluated stability index A_2 for damage on the side condition

Δ 2320	Trim.1	Trim2	Trim. 3	Pent.	Pent.2	Cat.
KG [m]	5.675	5.628	6.279	5.632	5.16	5.797
Θ_h [°]	13.07	3.686	2.457	****	23.41	0.635
HL4 [m]	0.394	0.41	0.519	0.41	0.41	0.456
A2 [m rad]	0.044	0.193	0.328	****	0.002	1.468

Tab.5 Evaluated stability index A_2 for damage on the outrigger condition

Δ 2320	Trim.1	Trim2	Trim. 3	Pent.	Pent.2
KG [m]	5.675	5.628	6.279	5.632	5.16
Θ_h [°]	12.924	5.77	3.538	****	23.457
HL4 [m]	0.394	0.41	0.519	0.41	0.41
A2 [m rad]	0.043	0.185	0.319	****	0.003

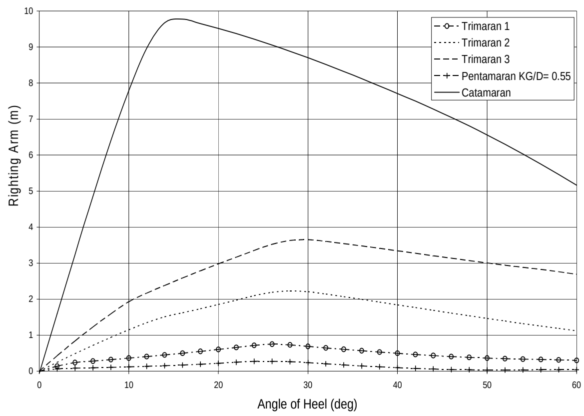

Fig 12 . residual stability curves for damage on the bottom

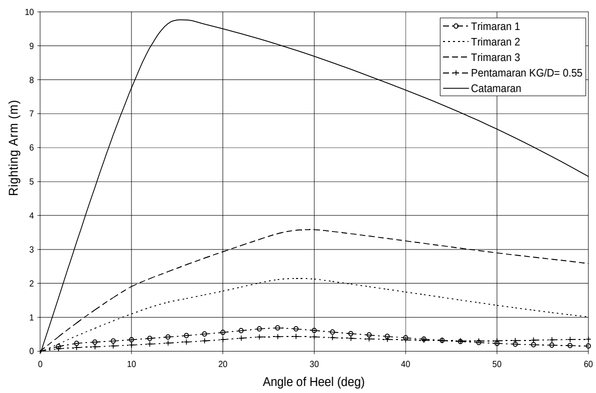

Fig 13. residual stability curves for damage on the side

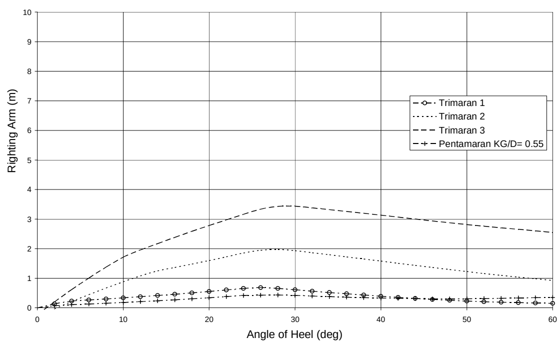

Fig14. residual stability curves for damage on the outriggers

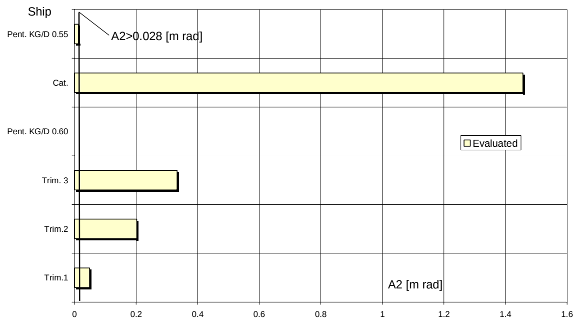

Fig 15. obtained values A_2 compared with the required values for damage on the bottom

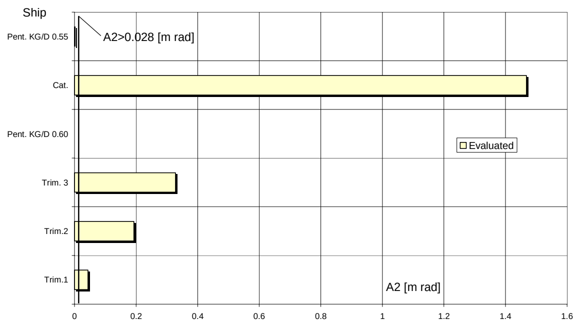

Fig16. obtained values A_2 compared with the required values curves for damage on the side

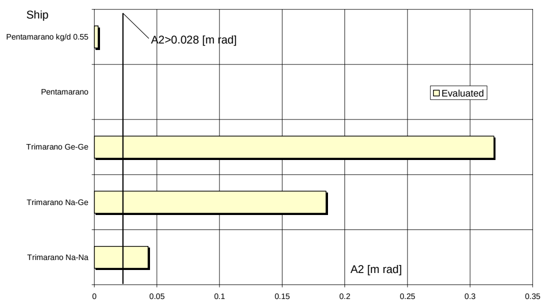

Fig 17. obtained values A_2 compared with the required values curves for damage on the outriggers

4. CONCLUSIONS

The speed of the marine vehicles has been increasing more and more during the last years.

Comparing the different high speed craft presently in service, it appears that the leading commercial types are:

- the catamaran for short routes ;
- the monohull for medium routes, being the operability of the catamaran on medium routes sensibly reduced because its excessive stability.

New proposed high speed craft, trimaran and pentamaran, with a very slender unstable central hull stabilised by very small side hulls, for their powering performances, stability characteristics and comfort on board, large deck area and cargo capabilities seem definitively better than the equivalent monohull at medium and high Fn.

However, for minimum resistance, the side hulls should be very small to provide stability the side hulls should be large above the waterline and it is very important the choice of their hull form and dimensions.

At the present time, although the research in the field of these new proposed high speed vessels is grown significantly in the last years, there is still little information on the suitable multi-hull forms, dimensions, configuration and on the comparison of the performance and of the safety among the different vessels.

This paper has outlined an investigation relating to one pentamaran configuration, to three trimarans of various hull forms and configurations and to an equivalent catamaran.

The comparison among the considered vessels, carried out in the previous researches on the resistance in the Froude Number range 0.55-0.65, which is operative for the considered ships, has been based purely on static stability calculations, that do not take into account the dynamic effects of the marine environments.

From the results obtained the trimaran configuration no. 3 presents better powering and stability characteristics than the other examined multihull configurations.

Further studies should be necessary also for the performance of these craft in a realistic sea state. This will give a clearer picture of the multi-hull ships performance.

The results of this study are applicable only to the considered hull forms and configurations.

Other hullform and configurations of multihull vessels should be examined; however, from the obtained results, it seems that the trimaran has to be seen as a possible competitor to the high speed monohull ship for medium routes.

5. ACKNOWLEDGEMENTS

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