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Stability Analysis of a Tricore

C. M. De Marco Muscat-Fenech, A.M. Grech La Rosa

Abstract**—**The application of stability theory has led to detailed studies of different types of vessels; however, the shortage of information relating to multihull vessels demanded further investigation. This study shows that the position of the hulls has a very influential effect on both the transverse and longitudinal stability of the tricore. HSC stability code is applied for the optimisation of the hull configurations. Such optimization criteria would undoubtedly aid the performance of the vessel for both commercial or leisure purposes

Keywords**—**Stability, Multihull, Tricore

NOMENCLATURE

a_n	Stagger between n[th] hull and the origin (m)
b_n	Separation between n^{th} hull and the origin (m)
C_b	Block coefficient
C_p	Longitudinal prismatic coefficient
C_{sr}	Slenderness ratio
n	Number of hulls
r	Distance away from centroidal axis (m)
x-	Coordinate axis, longitudinal
y-	Coordinate axis, transverse
z-	Coordinate axis, vertical
A	Area of an arbitrary shape (m^2)
A_{wl}	Waterplane area (m^2)
B_n	Beam of n[th] hull (m)
BM_l	Height from centre of buoyancy to metacentre in the longitudinal direction (m)
BM_t	Height from centre of buoyancy to metacentre in the transverse direction (m)
B_T	Total beam of multihull (m)
GM_l	Metacentric height in the longitudinal direction (m)
GM_t	Metacentric height in the transverse direction (m)
GZ	Righting Lever (m)
$I_{centroidal}$	Moment of inertia about the centroid of the hull (m^4)
I_{ln}	Longitudinal moment of inertia for the n[th] hull (m^4)
I_{tn}	Transverse moment of inertia for the n[th] hull (m^4)
I_x	Moment of inertia in the x direction (m^4)
KB	Height from keel to centre of buoyancy (m)
KG	Height from keel to centre of gravity (m)
KM_l	Height from keel to metacentre in the longitudinal direction (m)
KM_t	Height from keel to metacentre in the transverse direction (m)
L_n	Length of n[th] hull (m)
L_{OA}	Overall length (m)
L_{wl}	Length at water line (m)
LCB	Longitudinal centre of buoyancy (m)
LCF	Longitudinal centre of flotation (m)
T	Draught (m)
V	Volume displacement (m^3)
WL	Water line
δ	Draught ratio
σ	Stagger ratio
μ	Separation ratio
ρ	Density (kg/m^3)
θ	Angle of heel (deg)
Δ	Mass displacement (t)

C. M. De Marco Muscat-Fenech is a Lecturer with the University of Malta, Malta. (phone: +356 2340 2106; fax: +356 2134 3577; e-mail: claire.demarco@um.edu.mt).
A.M.Grech La Rosa, Graduate of B.Eng.(Hons.) in Mechanical Engineering from the University of Malta, Malta. (e-mail: andreagrechlarosa@gmail.com).

I. INTRODUCTION

A multihull is a vessel which by definition is made up of more than one hull. The independent hulls need not be of the same size, geometrical shape or have the same hydrodynamic performance. The most common forms of multihulls vessels have two or three hulls, however vessels with more hulls, such as pentamarans, are being produced. A trimaran implies a vessel made of three hulls with no reference to relative size or configurations. The term trimaran has in recent years been associated with a larger central main hull and two smaller side hulls called floats or outriggers. A vessel with three identical hulls is called a tricore [1]. There are several motives to invest in multihull vessels; an increase in deck area across the wider hull arrangements; the displacement would be approximately equal for all three hulls resulting in shallower draughts; machinery, equipment and engines need not be only placed in the main hull but can be evenly distributed; additional hulls remain if damage of one hull occurs; vessel is capable of attaining high cruising speed; an increase in transverse stability compared to a monohull of similar displacement; the three hulls are usually associated with high wave interference between the hulls, this results that for a range of speeds and hull configurations a reduced and minimised wave-making resistance can be observed, [2]-[11].

This investigation deals with the effect of positioning the various hulls such that both the transverse and longitudinal stability is optimized. The separation, stagger and draught together with compound analyses will act as a foundation for trimaran design. This optimization may be more important for sailing multihulls since the sail area is generally calculated from the transverse stability [12]. Non-sailing mulithulls, to which this investigation is directed, must still comply with various criteria in order for the vessel to pass different standardized codes such as the IMO High Speed Craft Code (HSC Guide) 2000.

II. THEORY

A. *Transverse and Longitudinal Stability*

A *GZ* curve is usually drawn over the range of angles in order to see the point of maximum stability and its corresponding value of righting lever *GZ*. Fig. 1 shows a typical example of a *GZ* curve for a monohull, catamaran and trimaran, highlighting the various features which aid in determining the stability of the vessel [13]. The value of the righting lever must be coupled with its corresponding angle of heel in order to determine the vessel's stability at that respective angle.

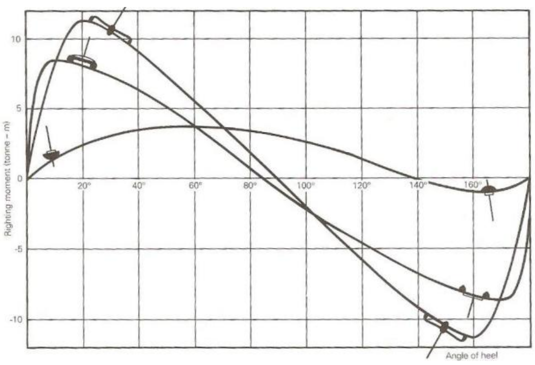

Fig. 1 Typical *GZ* curve for a monohull, catamaran and trimaran [12].

In accordance to the High Speed Craft code (HSC 2000, Annex 7 – Stability of Multihull Craft – Intact Condition), the investigation considered, amongst the other criteria as required by the code, that the maximum GZ value of a multihull shall occur at an angle of at least 10^o [14].

Fig. 2 shows how the centre of buoyancy changes with the angle of heel θ for different vessels. Another important characteristic is the draught of the lateral hulls. The situation depicted in Fig. 2 shows the catamaran having identical hulls at an equal draught on each hull whilst the trimaran has different hulls at different draughts.

Even though the vessel is symmetric about the centre line of the central hull, both outriggers are initially not displacing any fluid. This means that for the first few degrees, the catamaran is stiffer followed closely by the trimaran, however both multihulls are stiffer than the monohull. Since a monohull only consists of one hull, the maximum righting lever is constrained with the total beam of that one hull, and thus in order to increase the hull's stability, other high performance characteristics may be neglected [12].

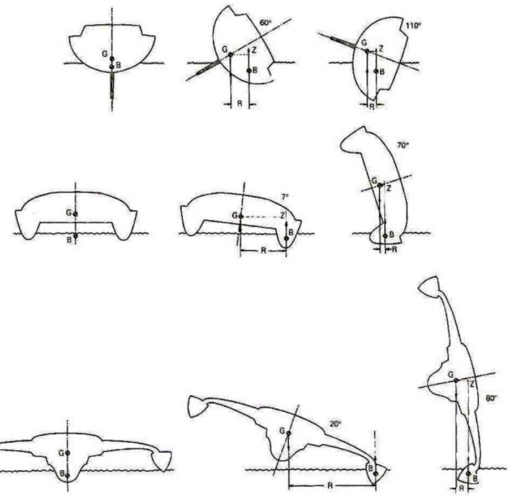

Fig. 2 Diagram showing the different effects of incline between a monohull, catamaran and trimaran [12]

The separation and stagger of a multihulled vessel have a great effect on the vessel's stability, since the transverse and longitudinal metacentre are dependent on the separation and stagger of the hulls.

Furthermore, one of the main disadvantages in high performance multihulled vessels is the intrinsically lower longitudinal stability. High performance multihulls have the tendency of possessing higher transverse stability compared to its longitudinal stability, which is the complete opposite situation of monohulls [12]. Ideally a vessel should have a balance between the transverse and longitudinal stability in order to improve the total stiffness of the vessel. A sailing multihull may be subjected to these moments when the sail's direction is such that a new couple is pitching it forward. This is emphasised each time the sailing craft is on a down wind and probably one of the reasons why the BMW Oracle AC45 suffered a diagonally pitched capsize, as depicted in Fig. 3.

In the event of a sailing monohull capsizing, the keel would right the vessel once the wind would die down enough. Since multihulls do not make use of keels owing to their intrinsically high transverse stability, this safety feature is non-existent. When sailing multihulls capsize, they turtle leaving the occupants in a hazardous situation unless some form of buoyancy was already placed at the head of the mast, (this is common practice on much smaller multihulls). The initial large force needed to actually capsize the vessel must be used again in order to right it back from either port or starboard. Knowing that multihulls generally suffer from having a lower longitudinal stability, ways and means have been devised in order to right the hulls, creating the least damage possible.

Even though the transverse stability is very large, there is still a possibility that it may capsize over the port or starboard side. The *GZ* curve described beforehand is only suitable for static equilibrium analysis. Once the vessel has to interact with the environment, large forces may be acting on the vessel, such as wind and waves which together may capsize the vessel.

Fig. 3 AC45 BMW Oracle catamaran capsizing forward [15]

The problems of small sailing and high performance multihulled vessels are well established, this knowledge and understanding is to be drawn upon when considering the HSC for which this investigation is directed. Vessels which require a large deck area and high cruising speeds can benefit from this tricore design, one typical example amongst others, are passenger/ferry vessels.

B. Calculation of the Metacentric Height

The equation relating the geometrical parameters between the keel, centre of buoyancy and metacentre, both in the transverse or longitudinal direction) is given as:

$$KM = KB + BM \tag{1}$$

BM_t may be expressed with the following equation [13]:

$$BM_t = \frac{I_x}{V} \tag{2}$$

Since the moment of inertia is complex due to the vessel being a multihull, the parallel axis theorem must be used.

$$I_x = I_{Centroidal} + Ar^2 \tag{3}$$

Once substituted into the expression for BM_t [14]:

$$BM_t = \frac{\sum_{n=1}^{N} b_n^2 A_{wtn} + \sum_{n=1}^{N} I_{tn}}{\sum_{n=1}^{N} V_n} \tag{4}$$

where:

$$I_{tn} = \int_{-L_{wl}/2}^{L_{wl}/2} \frac{y^3}{3} dx \tag{5}$$

Similarly, BM_l may be expressed in a similar manner [5].

$$BM_l = \frac{\sum_{n=1}^{N} b_n^2 A_{w\ln} + \sum_{n=1}^{N} I_{\ln}}{\sum_{n=1}^{N} V_n} \tag{6}$$

From the definition describing the centre of buoyancy, where y is used to denote the half ordinates and A_t is the transverse section of the plane.

$$KB = \frac{\int A_t y dz}{\int A_t dz} \tag{7}$$

Finally, the transverse metacentric height GM_t may be calculated using the equation:

$$KM_t = KG + GM_t \tag{8}$$

$$GM_t = KM_t - KG \tag{9}$$

III. The Virtual Model

The tricore simulations for the various combinations of the variables of stagger *a,* separation *b* and draught *T* were considered. The simulations were undertaken using the MAXSURF suite of software by Bentley Formation Design System version 17.02 using the packages of MAXSURF and HYDROMAX. This software is a well established software package which has been validated by the software providers and by industry [17].

From the results, a number of conclusions can be drawn. Each of these conclusions may now be considered throughout the design of the complete multihull, in order to create a vessel capable of achieving high performance standards. Naturally, the conclusions drawn are specific to multihull vessels having:

- symmetry about the total beam median
- all hulls are identical
- all hulls are at the same draught

During the design stage of the multihull, certain geometrical characteristics of each individual hull must be satisfied. If certain geometrical characteristics had to be prioritised, the slenderness ratio would definitely attain one of the highest priorities. This can be easily confirmed when comparing the value of the slenderness ratio of a multihull's individual hull to that of a conventional monohull such as the Series 60. Monohulls are generally restricted to a value of 5, whereas the individual hull of a multihull may attain higher values such as 16 [18]. The slenderness ratio alone does not give a form to hull, it merely gives boundary conditions for the hull's length and beam, which in turn, aid to predict the multihull's performance. The slenderness ratio must then be coupled with other constraints, which together, form the ideal hull shape.

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(a) Body Plan

(b) Profile

(c) Plan

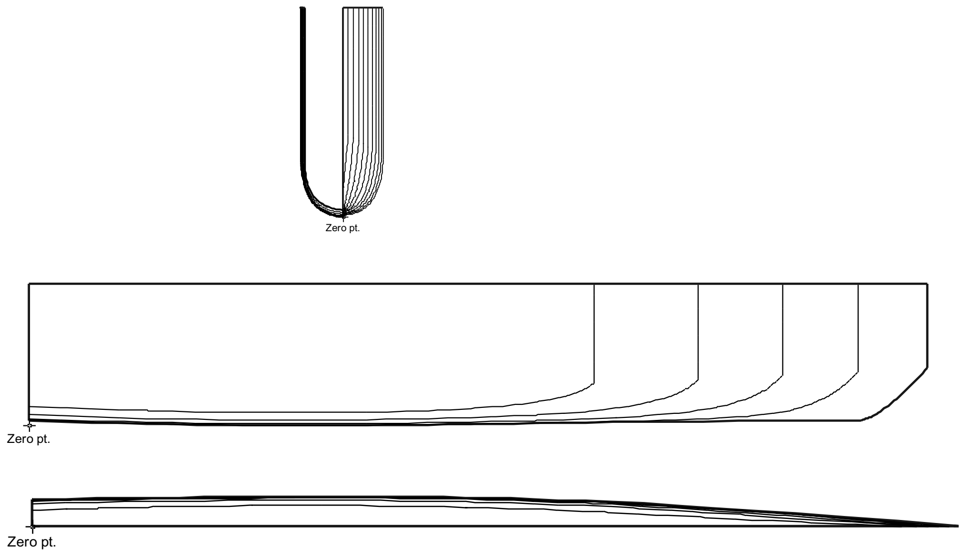


Fig. 4 Lines plans of and individual hull

When dealing with high-performance multihulls two dimensionless coefficients are analysed; the block coefficient C_b - to ensure that the underwater volume of the hull is as small as possible, the block coefficient of the separate hulls should have a value between 0.4 - 0.6 [16,18]; the prismatic coefficient c_p – used to control the sleekness of the individual hulls, the prismatic coefficient should be approximately 0.7, [16, 18].

The rendering function within the software, makes use of different light sources which may be activated accordingly, the designer can view any uneven surfaces or points of inflection on the hull being either convex or concave. Such inaccuracies prove detrimental if a resistance analysis is undertaken [2]. Also, the selection of surface types, will intrinsically affect the design of the hull. For the purpose of this investigation the B-Spline surface type was used. The stiffness of the curves joining the respective control points together was set to five in the longitudinal direction and three in the transverse direction in order to simulate the stiffness of construction material, possibly composite material composition, e.g. FRP.

Fig. 4 shows the lines plan of one of the individual hulls, being used to form this tricore. The duplicating function in MAXSURF was used to position the other identical hulls at fixed distance to achieve different separations, staggers and draughts; the draughts on each hull were maintained equal.

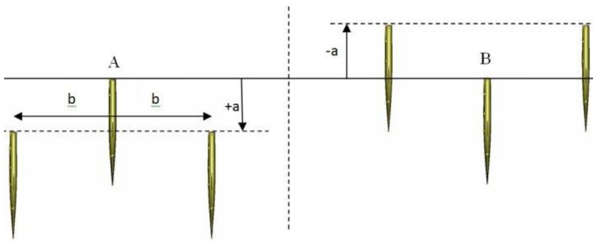
The investigation carried out required a vast number of hull configurations in order to understand the relation between one hull movement and the other. A systematic way of identifying the respective hull configurations was by means of 3 ratios, the draught, separation and stagger ratio.

These are defined with the following equations:

$$DraughtRatio : \delta = \frac{Draught}{OverallLength} = \frac{T}{L_{OA}} \tag{10}$$

$$StaggerRatio : \sigma = \frac{Stagger}{OverallLength} = \frac{a}{L_{OA}} \tag{11}$$

$$SeparationRatio : \mu = \frac{Separation}{OverallLength} = \frac{b}{L_{OA}} \tag{12}$$



(a) (b)

Fig. 5 Plan view for two staggered tricores [2](a) displays a positive stagger, and (b) displays a negative stagger

Fig. 5 shows the representation of the multihull set up together with the convention being adopted for stagger. The stagger convention is adopted from [2] which focused the work on the resistance analysis of a tricore. However, configurations as given in Fig.5(b) are only to be considered in this analysis and therefore the stagger ratio, σ will have negative values.

The hydrostatic data of an individual hull is given in Table I. The criteria related to high performance vessels are being satisfied. Based on the values of the hydrostatic data of the individual hull as given in Table I the draught, stagger and separation ratios considered in this investigation are as given in Table II.

TABLE I
HYDROSTATIC TABLE FOR AN INDIVIDUAL HULL

Overall Length, L_{OA} (m)	23.153		
Beam, *B* (m)	1.317		
Slenderness Ratio, C_{sr}	17.580		
Draught, *T* (m)	0.463	0.695	0.962
Displacement, *Δ* (t)	6 .713	12.23	19.15
Block Coefficient, C_b	0.487	0.531	0.568
Longitudinal prismatic coefficient, C_p	0.746	0.755	0.758
LCB length from transom (m)	8.57	8.747	8.885
LCF length from transom (m)	8.861	9.041	9.219
KB (m)	0.288	0.42	0.568
KG (m)	0.432	0.630	0.852
BM_t (m)	0.374	0.282	0.208
BM_l (m)	94.024	60.668	42.472
KM_t (m)	0.663	0.703	0.776
KM_l (m)	94.312	61.089	43.041

TABLE II
DRAUGHT, STAGGER AND SEPARATION RATIOS

Draught ratio: δ	Stagger ratio: σ	Separation ratio: μ
0.02	0.00	0.125
0.03	-0.5	0.250
0.04	-1.0	0.500
	-1.5	0.750
	-2.0	1.000
		1.250
		1.500
		1.750
		2.000

IV. RESULTS

The HYDROMAX software package, was used for the simulations relating to stability. Several conclusions have been made that would affect the overall performance of the vessel in conjunction with both transverse and longitudinal stability.

The analysis related to stability in this investigation focuses on the effects of varying the hulls' positions in both the transverse and longitudinal direction and seeing how the change affects the transverse and longitudinal stability. *KG* was taken as *1.5KB* [2]. The intrinsically high transverse stability attained by multihulls will easily conclude that the position of the centre of gravity will not affect the performance of the vessel because of the large metacentric height. *1.5KB* seems a reasonable approximation that should not hinder the calculation of GM_t and will thus be used as a datum for metacentric height measurements. The tricore configurations are free to trim according to the loadcase since the running trim in such vessels is seldom zero. If the trim is fixed to zero and not allowed to alter, the conclusions drawn may not reflect the true stability evaluation.

A. Transverse Stability

1. Variation in Separation and Stagger Ratio

A constant draught ratio, δ = 0.02 is considered to be indicative of what occurs if this ratio also increases to 0.03 and 0.04. The variation of separation ratio, μ and stagger ratio, σ are varied systematically according to Table II. Multiple combinations between the variables can be shown. One such combination the large angle stability, *GZ* curve for stagger ratio, σ = -1 and variable separation ratio, μ is given in Fig. 6

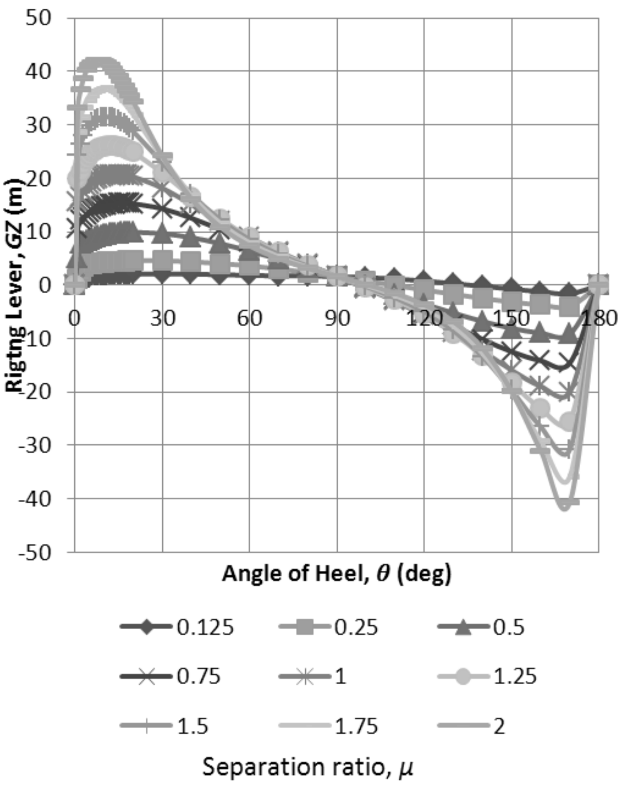


Fig. 6 Righting lever, *GZ* versus angle of heel, θ, for a draught ratio, δ = 0.02 and stagger ratio, σ = -1 for variable separation ratios, μ

Depending on the position of the hulls in the transverse and longitudinal direction the criteria in accordance to the High Speed Craft code (HSC 2000, Annex 7 – Stability of Multihull Craft – Intact Condition), is considered. The first criteria is that the maximum *GZ* value of a multihull shall occur at an angle of at least 10°; satisfying this criteria the further criteria considered in accordance to Annex 7 are evaluated. If all the criteria given by the code are passed then the tricore configuration is deemed to have passed, [14]. A typical pass configuration is draught ratio $\delta = 0.02$, separation ratio, $\mu = 1$ and stagger ratio, $\sigma = -1$. Table III shows the stability criteria used for the investigation according to [14].

TABLE III
HSC 2000 ANNEX 7 MULTIHULL INTACT CRITERIA

Criteria	**Value**	**Units**	**Actual**	**Status**	**Margin %**
1.1 Area 0 to 30				**Pass**	
from the greater of					
spec. heel angle	0.0	deg	0.0		
to the lesser of					
spec. heel angle	30.0	deg			
angle of max. GZ	14.4	deg	14.4		
first down flooding angle	n/a	deg			
higher heel angle	30.0	deg			
required GZ area at higher heel angle	3.1510	m.deg			
shall be greater than (>)	6.5809	m.deg	268.2139	**Pass**	+3975.67
1.2 Angle of max. GZ				**Pass**	
shall not be less than (>=)	10.0	deg	14.4	**Pass**	+43.64
1.5 Area between GZ and HTL				**Pass**	
Pass. crowding arm = nPass M / disp. D cos^n(phi)					
number of passengers: nPass =	100				
passenger mass: M =	0.075	tonne			
distance from centre line: D =	23.000	m			
cosine power: n =	0				
Turn arm: a v^2 / (R g) h cos^n(phi)					
constant: a =	1				
vessel speed: v =	20.000	kts			
turn radius: R =	200.000	m			
h = KG - mean draft / 2	0.200	m			
cosine power: n =	0				
Wind arm: a P A (h - H) / (g disp.) cos^n(phi)					
constant: a =	1.50102				
wind model	Pressure				
wind pressure: P =	70.0	Pa			
area centroid height (from zero point): h =	6.500	m			
additional area: A =	0.000	m^2			
height of lateral resistance: H =	0.288	m			
cosine power: n =	0				
Area integrated from the greater of					
angle of equilibrium (with heel arm)	0.5, 0.0	deg			
to the lesser of					
spec. angle above equilibrium (with heel arm)	15.0 (15.5), 15.0 (15.0)	deg			
first downflooding angle	n/a	deg			
angle of vanishing stability (with heel arm)	60.7, 96.7	deg			
Criteria: Area between GZ and heeling arms shall not be less than (>=)...				**Pass**	
Hpc + Hw	1.6040	m.deg	157.7214	**Pass**	+9733.00
Ht + Hw	1.6040	m.deg	279.2341	**Pass**	+17308.61
Intermediate values					
Pass. crowding heel arm amplitude (Hpc)		m	8.608		
Turning heel arm amplitude (Ht)		m	0.011		
Model windage area		m^2	148.936		
Model windage area centroid height (from zero point)		m	2.093		
Total windage area		m^2	148.936		
Total windage area centroid height (from zero point)		m	2.093		
Wind heeling heel arm amplitude (Hw)		m	0.144		
Area under GZ curve, from 0.5 to 15.5 deg.		m.deg	288.9914		
Area under GZ curve, from 0.0 to 15.0 deg.		m.deg	281.5520		
Area under Hpc + Hw, from 0.5 to 15.5 deg.		m.deg	131.2700		
Area under Ht + Hw, from 0.0 to 15.0 deg.		m.deg	2.3179		
3.2.1 Angle of equilibrium with gust wind HL2				**Pass**	
Pass. crowding arm = nPass M / disp. D cos^n(phi)					

number of passengers: nPass =	100				
passenger mass: M =	0.075	tonne			
distance from centre line: D =	23.000	m			
cosine power: n =	0				
Turn arm: a v^2 / (R g) h cos^n(phi)					
constant: a =	1				
vessel speed: v =	20.000	kts			
turn radius: R =	200.000	m			
h = KG - mean draft / 2	0.200	m			
cosine power: n =	0				
Wind arm: a P A (h - H) / (g disp.) cos^n(phi)					
constant: a =	1.50102				
wind model	Pressure				
wind pressure: P =	70.0	Pa			
area centroid height (from zero point): h =	6.500	m			
additional area: A =	0.000	m^2			
H = mean draft / 2	0.232	m			
cosine power: n =	0				
Criteria: Angle of equilibrium due to the following shall not be greater than (<=)...				**Pass**	
Wind heeling (Hw)	10.0	deg	0.0	**Pass**	+99.92
Intermediate values					
Model windage area		m^2	148.936		
Model windage area centroid height (from zero point)		m	2.093		
Total windage area		m^2	148.936		
Total windage area centroid height (from zero point)		m	2.093		
Wind heeling heel arm amplitude (Hw)		m	0.148		

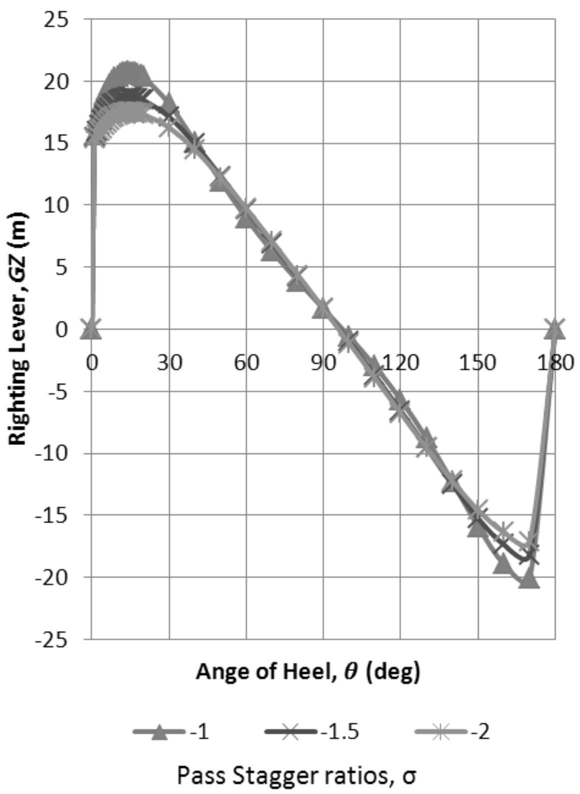


Fig. 7 Righting lever, GZ versus angle of heel, for a draught ratio, δ = 0.02 and separation ratios, μ =1 for variable pass stagger ratios

For a separation ratio, μ = 1, the pass variable stagger ratios, σ = -1, -1.5, -2 give the large angle stability, GZ curve shown in Fig. 7.

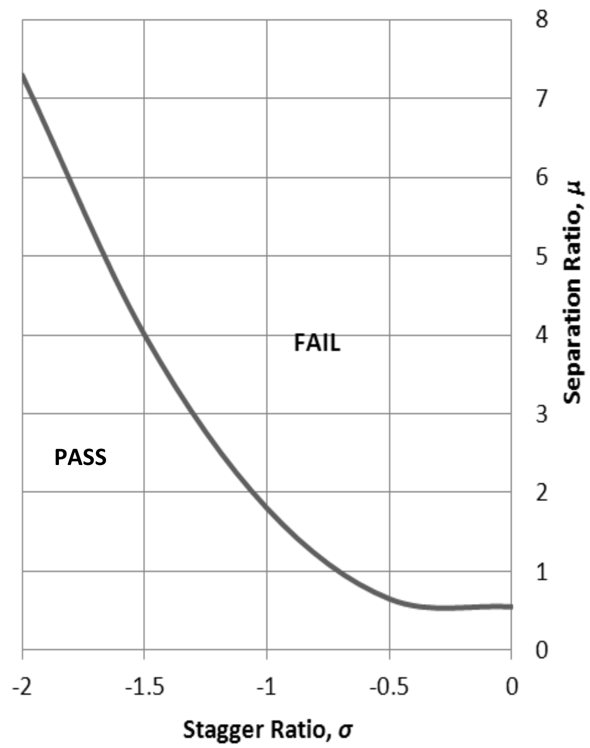


Fig. 8 Pass-Fail diagram for separation and stagger ratio configurations

The whole spectrum of separation and stagger allowing the tricore to trim according to the loadcase, as given in Table II, were investigated and Fig. 8 shows the resulting separation and stagger ratio pass-fail boundary giving a quick visual interpretation of the configurations for Annex 7 criteria analysis.

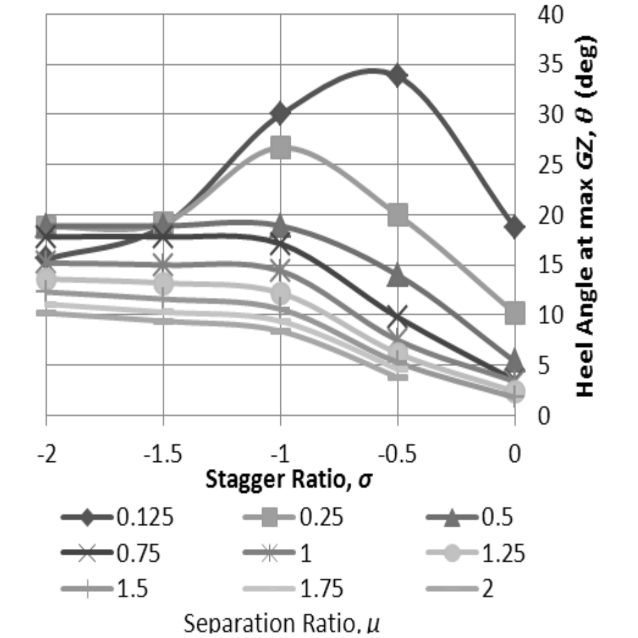


Fig. 9 Heel at max. *GZ* versus stagger ratio, σ with constant loci of separation ratio, μ

The results of the maximum *GZ* and angle of heel at which this occurs are shown in Fig. 9 and 10. Fig. 9 shows that for the smaller separation, μ < 0.5, values there is an optimum value of stagger ratio corresponding to the peak of the curves. The separation values, μ < 0.5, results in a narrow tricore configuration when this occurs.

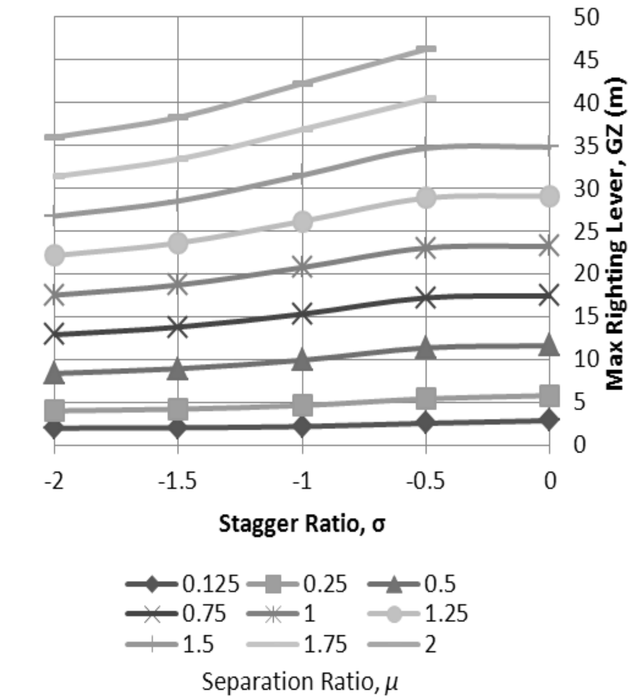


Fig. 10 Maximum rightng lever *GZ* versus stagger ratio, σ with constant loci of separation ratio, μ

Fig. 10 shows the systematic increase in the righting lever GZ as the separation ratio locus increases. Again for the narrow tricore separations, the *GZ* values are small, of the order as seen for monohulls. If the tricore is NOT free to trim, then no change in the max righting lever will be noted for the varying stagger at a constant separation ratio. This is clearly not the case, indicating that the free to trim condition must be applied.

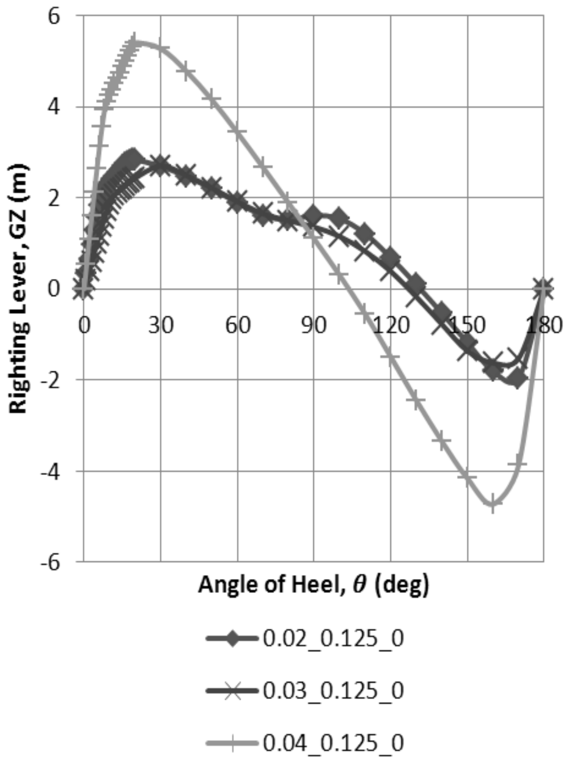


Fig. 11 Variable draught ratio, δ for a narrow tricore, separation ratio, μ = 0.125, with all the hulls in-line, stagger ratio, σ = 0

2. Variation in Draught

The draught ratio, δ is varied as given in Table II. Considering a narrow tricore, separation ratio, μ = 0.125, with all the hulls in-line, stagger ratio, σ = 0, Fig. 11 shows the pass *GZ* stability curves. The maximum righting lever is of a low value which is not representative of the large transverse stability associated for multihulls. Increasing the separation ratio to a mid value, μ = 1, and a very widely spaced tricore, μ = 2, as expected the maximum *GZ* values increase, since as the draught increases the position of the vertical centre of gravity of the tricore increases. The stagger ratio is varied, starting with the centre hull in-line, σ = 0 and increased to 1 hull length in-front, σ = -1, and subsequently up to 2 hull lengths in front, σ = -2. Fig. 12 and Fig. 13 show this increase in stagger. The *GZ* stability curves show the expected trend that as the draught ratio increases greater transverse stability is expected.

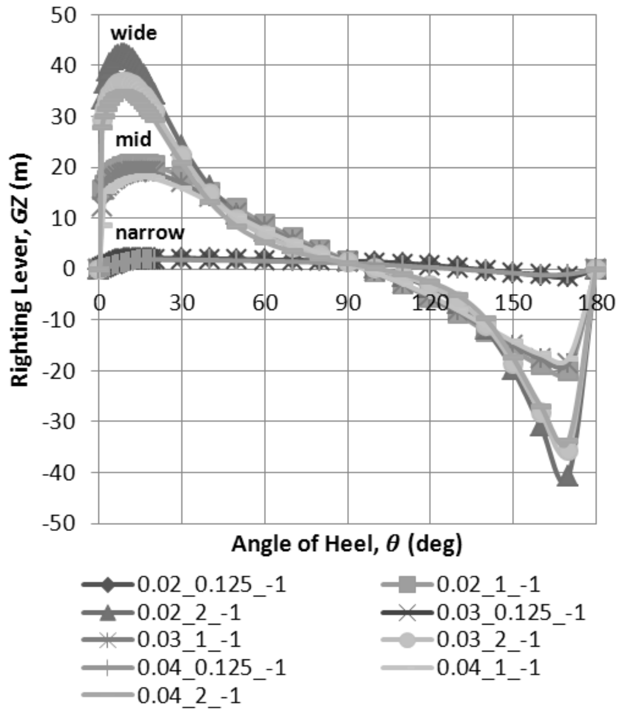


Fig.12 Variable draught ratio, δ for stagger ratio, σ = -1 (centre hull 1 hull length in front) for variable separation ratios; narrow, μ = 0.125, mid value, μ = 1, to widely spaced tricore, μ = 2

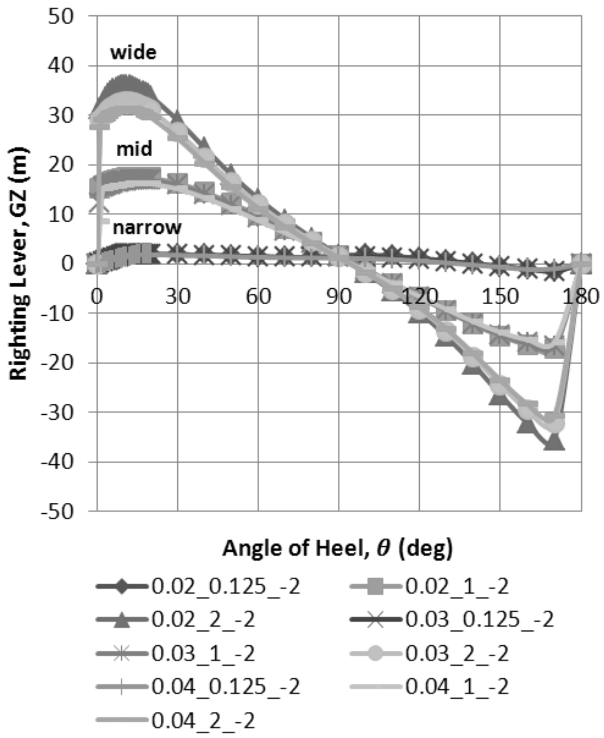


Fig. 13 Variable draught ratio, δ for stagger ratio, σ = -2 (centre hull 2 hull lengths in front) for variable separation ratios; narrow, μ = 0.125, mid value, μ = 1, to widely spaced tricore, μ = 2

3. Compound Analysis

In order to define the optimal hull configuration, the global picture must be considered in terms of all the variables, draught, separation and stagger ratios. When the tricore has an in-line configuration, stagger ratio, σ = 0, the analysis shows that, except in the cases of the narrow separation conditions, separation ratios, μ < 0.5, this configuration fails the stability (HSC Annex 7-Intact) criteria codes. In fact, as the separation increases, from 0.5 < μ < 2 the tricore becomes highly transversely unstable.

The transverse stability is improved by an increase in the stagger and separation ratio. This can clearly be seen in Fig. 12 and Fig. 13. These graphs portray the affect of combining different hull layouts and seeing their effect on the global stability of the tricore at hand. By producing such typical graphs, the optimal hull configuration may be selected such that the configuration provides the designer with the necessary information to suit the designed vessel.

From such typical results, it is established that, for combinations of separation and stagger ratios, as given in Table IV, the High Speed Craft code (HSC 2000, Annex 7 – Stability of Multihull Craft – Intact Condition), criteria are passed.

TABLE IV
PASS OPTIMAL COMPOUND CONFIGURATIONS

Separation Ratio: μ	Stagger Ratio: σ
1	-1
1	-2
2	-2

Fig. 14 shows the optimum pass configurations stability curves, for a draught ratio, δ = 0.02 (indicative of the varying draught behaviour), as described in Table IV.

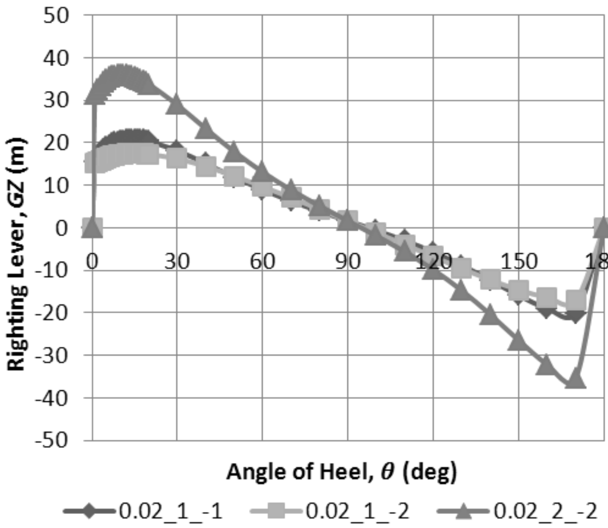


Fig. 14 Righting lever, GZ versus angle of heel for a draught ratio, δ = 0.02, with the optimized stagger and separation ratios

B. Longitudinal Stability

It is a well known fact that, in general, multihulled vessels are very stable in the transverse direction and the transverse stability could exceed the longitudinal stability condition, especially when compared to a monohull of similar length and displacement. The High Speed Craft code (HSC 2000, Annex 7 – Stability of Multihull Craft – Intact Condition) does not specify a maximum or minimum position for the longitudinal stability, as it does for the transverse stability. Improving the longitudinal stability will undoubtedly improve the performance and safety against capsize of the vessel. The quantity to be used to describe the increase or decrease in longitudinal stability is the longitudinal metacentric height GM_l. Since, in the longitudinal direction the distance of the centre of buoyancy to the longitudinal meatcentric height $BM_l \approx GM_l$, then the distance from the centre of buoyancy to the longitudinal meatcentric height, BM_l is used as the characteristic to describe the longitudinal stability.

An expected result, is that, for a constant draught ratio locus, δ and stagger ratio, σ, as the separation ratio, μ is varied no change in the initial upright longitudinal stability is noted *i.e.* BM_l remains unchanged, since the initial upright position of the centre of the flotation and therefore centre of buoyancy remain unchanged. For variable separation ratio, μ, for a constant draught ratio locus, δ and stagger ratio, σ, Fig. 15 shows this relation.

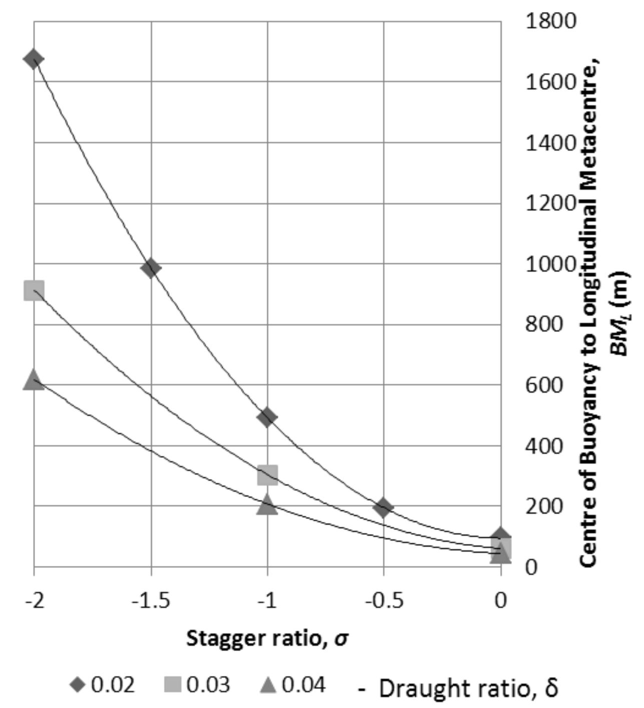


Fig. 15 BM_l versus Stagger ratio, μ for varying draught ratio, δ and separation ratio, σ

Fig. 15 shows the variation in BM_l only for the initial upright condition. However, it is evident that a staggered tricore, with the centre hull in-front separated by at least a multiple of a single hull lenth will increase the tricore longitudinal stability. It is proposed in a study, that is currently underway, that a similar set of graphs as for the transverse stability analysis, are to be obtained for the large angle stability in the longitudinal direction. This study is also to extend its investigation to include and develop polar *GZ* plots using analytical methods. The simulations using the MAXSURF software, is at present, not able of performing such analysis for tricores.

V. Conclusions

The analysis carried out through several simulations led to identify specific comparisons between identical hulls. The results derived from this investigation will act as a foundation for more advanced research on multihull vessels. However, clear findings have been established for a tricore, to optimise the hull layout with respect to stability theory.

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