Intact stability of SWATH ships

M.A. Shama, Y.M. Welaya and W.A. Amin
Department of Naval Architecture and Marine Eng., Alexandria University, Alexandria, Egypt

This paper presents the main factors affecting the intact stability of SWATH ships. These factors belong mainly to the main dimensions of the ship. A parametric study is carried out using an idealised vessel of the design T-AGOS19. The main dimensions are changed systematically in a non-dimensional form. Stability calculations are performed using the AUTOSHIP software. The results are evaluated using the IMO criteria, Code on Intact Stability-for All Types of Ships Covered by IMO Instruments, Resolution A.749(18), 1995. Finally, a comparison is carried out with an equivalent catamaran of the same displacement and the same hull separation distance.

يتناول البحث دراسة الاتزان العرضي لسفن السواث وتحديد العوامل الرئيسية التي تؤثر عليه أثناء مراحل التصميم الابتدائي من خلال عمل دراسة بارامترية تم فيها تغيير الأبعاد الرئيسية للسفينة. وقد استخدم نموذج مبسط لسفينة سواث موجودة حاليا وهي السفينة "T-AGOS-19" وتم تغيير أبعاد السفينة فى حدود ± ١٠% من القيم الأصلية. أجريت الحسابات باستخدام حزمة البرامج Auto Ship وقيمت النتائج حسب قواعد المنظمة البحرية العالمية IMO الخاصة بالاتزان العرضى لسفن السواث وقد أدت الدراسة إلى استتاج قيم حدية للبارامترات المؤثرة على الاتزان . وقد أجريت مقارنة بين سفينة السواث محل الدراسة وسفينة كاتاماران مكافئة لها فى الازاحة والمسافة العرضية بين البدنين فوجد أن السفينتان لهما نفس مدى الاتزان العرضى تقريبا وأن سفينة الكاتاماران لها اتزان دينامكي عرضى أعلى من سفينة السواث.

Keywords: Intact stability, Twin-hull, SWATH, Catamaran

1. Introduction

A SWATH is an acronym to the words Small Waterplane Area Twin Hull, which is a twin hull vessel like a catamaran but with thinned waterplane and redistributed buoyancy downwards into a fully submerged lower hulls [1, 2]. Fig. 1 presents a comparison between geometric features of the mono-hulls, catamarans, and SWATH ships. The use of this type of vessels as a passenger ferry requires the attainment of a considerable margin of safety. One of these safety requirements is ships' stability.

Stability of a vessel is the ability it has to return to the upright position when inclined away from that position. No doubt, that under ordinary condition of service a vessel cannot always remain upright. it is continually being forced away from the upright by external forces, such as the action of waves and wind. It is very important that the ship will have such qualities that guarantee that those inclinations have no effect on its safety [3-5].

There are three conditions, which must be fulfilled in order that a ship may float freely and at rest in a stable equilibrium:

1- The weight of water displaced must equal to the total weight of the ship.
2- The centre of gravity of the ship must be in the same vertical line as the centre of buoyancy of the submerged part of the ship.
3- The centre of gravity G of the ship must be below the transverse metacentre M, i.e., the ship has a positive metacentric height GM.

The vertical position of the centre of gravity depends on the loading condition of the ship and the vertical distribution of the ship's lightweight, while the metacentre M depends mainly on geometry and dimensions of the ship.

GM cannot be considered the only measure of ships' stability. It is more realistic to think in terms of the moment that the ship exerts to restore its position of equilibrium at various angles of inclination. This is called restoration moment or the righting moment. The righting moment depends on the righting arm GZ that changes with the inclination angle θ. Then, the actual representation of

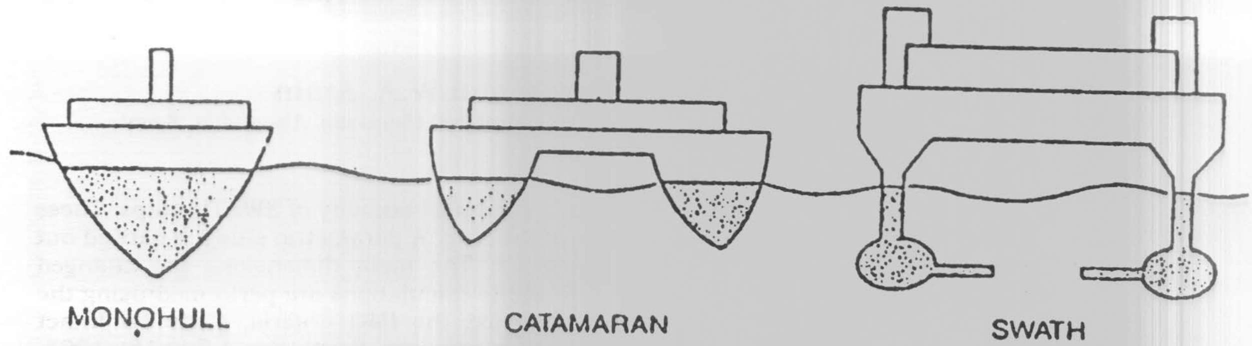

Fig. 1. Comparison of geometric features of different ships.

ship stability is to investigate the ability of the ship to right itself up with the change of the angle of inclination, θ. The plotted GZ against θ is called the statical stability curve. This curve gives a clear picture of intact stability as indicated by the following features:

1- The inclination of the tangent to the curve at the origin (expressed by GM_o).

2- The maximum GZ and the corresponding angle of inclination.

3- The range of stability.

The most comfortable ship at sea is one with a small GM_o, and if this is associated with such a position of the centre of gravity and such a freeboard that the curve gives a good maximum GZ and a good range of stability, the ship then has the most satisfactory conditions of comfort and seaworthiness. Study of ship stability and the criteria of assessment depend on the ship's type. Therefore, SWATH ships have to have special criteria. IMO [6] introduced a criterion to assess stability of SWATH ships based on a statistical approach depending on the properties of the static stability curve of various existing designs.

IMO, item 1.3.7, defines the SWATH ship as a surface unit, a type of Mobile Offshore Drilling Units (MODU). A surface unit is a unit with a ship or barge type displacement hull of single or multiple hull construction intended for operation in floating conditions. The stability criteria of surface units implies that:

1- The area under the righting moment curve to the second intercept or down-flooding angle, whichever is less, should not be less than 40% in excess of the area under the wind heeling moment curve to the same limiting angle, fig. 2.

2- The calculations are based on:

- Minimum wind speed of 70 knots in normal operating conditions.
- Maximum wind speed of 100 knots in severe operating conditions.

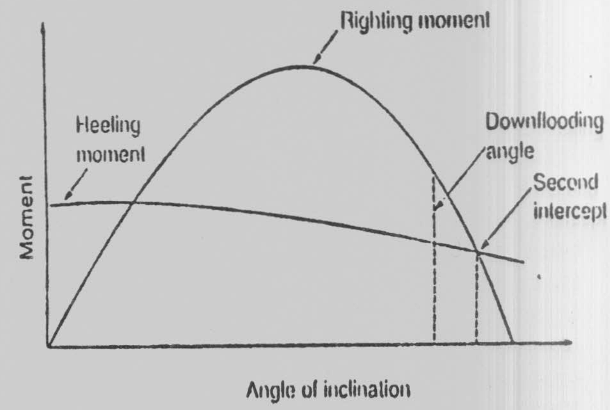

Fig. 2. Righting moment and heeling moment curves [6].

2. Factors affecting intact stability of SWATH ships

A parametric study is carried out using the AUTOSHIP software [7] based on the idealised hull form of the existing design T-AGOS 19 [8] as shown in figs. 3 and 4. The study used IMO Code on Intact Stability. The small waterplane area, which is required to minimise the accelerations of motion of SWATH ships, affects dramatically the location of the metacentre. The major parameter affecting KM is the separation distance between the two

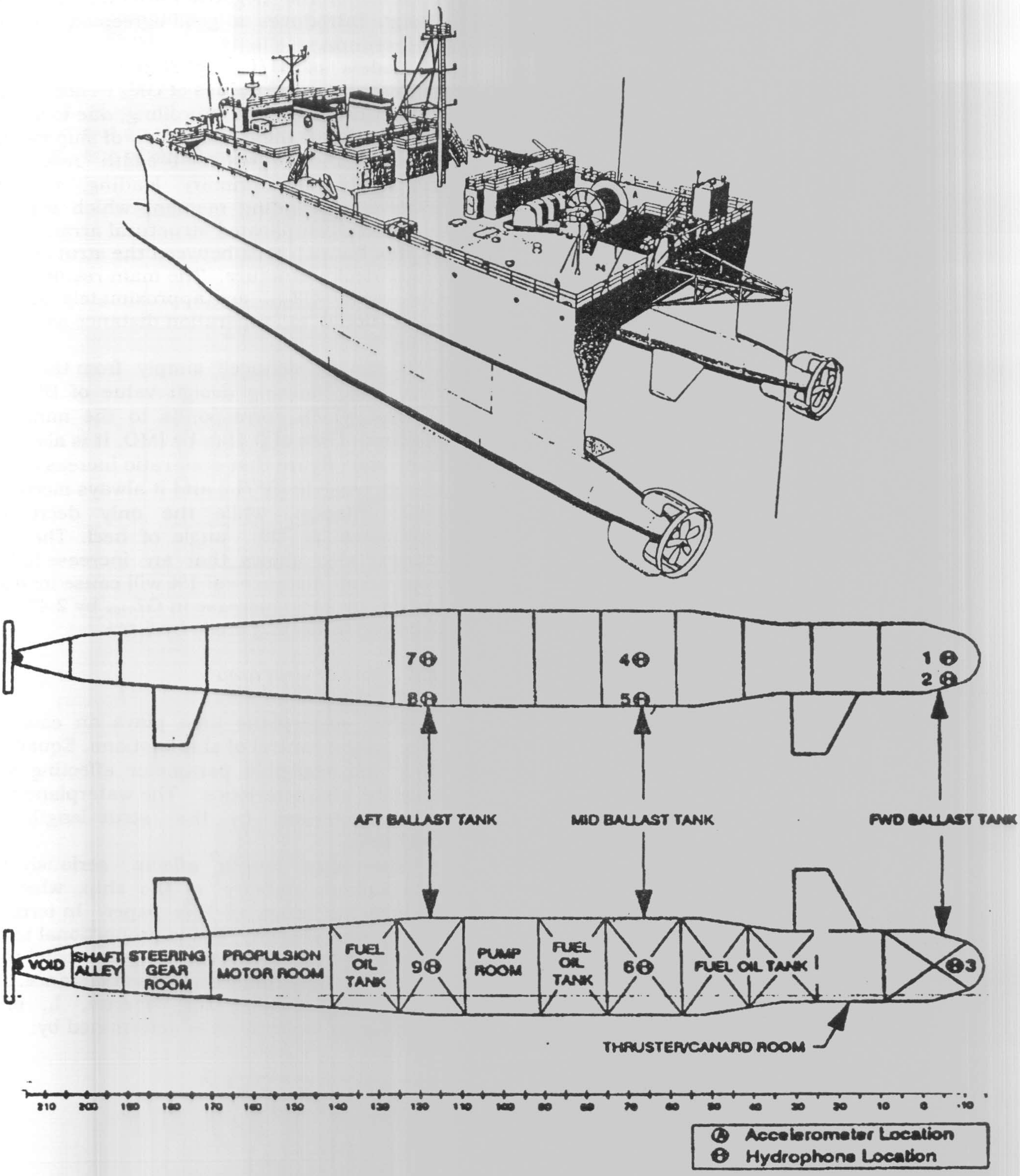

Fig. 3. T-AGOS 19 –Isometric view and lower hulls plan [8].

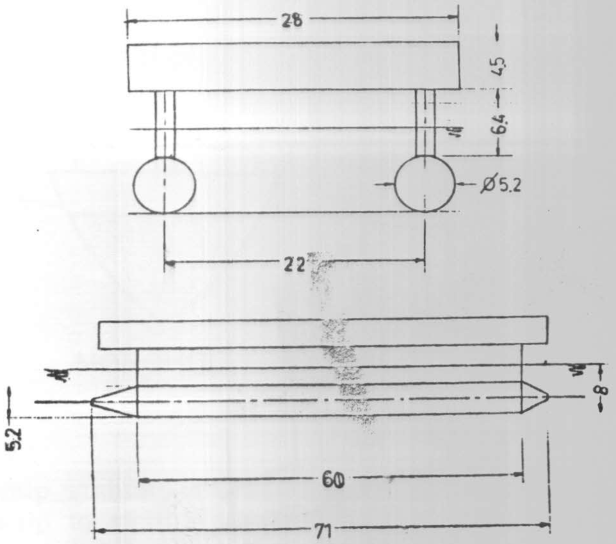

Fig. 4. The idealised SWATH ship of T-AGOS 19.

hulls B*, which leads to a considerable influence on the transverse moment of inertia of the waterplane area I_t, ($BM = I_t / \nabla$). The separation distance is not only the sole parameter but also there are other contributing parameters such as strut area (length and thickness), length of lower hull, lower hull diameter, and hull immersion. The relation between these parameters is not well defined and therefore, it is valuable to examine their effect on intact stability of SWATH ships

The parameters are changed in a non-dimensional form as follows:

1. Hulls' separation distance to strut length ratio B^*/L_s
2. Strut area / (lower hull length • separation distance)
3. Lower hull length to lower hull diameter ratio (L_h/d)
4. Hull immersion to depth ratio

2.1. Effect of hull separation distance

It is found that a slight change in the separation distance would affect dramatically GM_o and the area under the curve of static stability. Decreasing (B^*/L_s) leads to an angle of loll. It is found that (B^*/L_s) ratios of (0.300), (0.333), (0.350) and (0.358) do not fulfil the IMO criteria and are regarded as bad designs because of the negative initial GM. The basic design introduces a good agreement with the IMO criteria.

Models of (B^*/L_s) = (0.383), (0.400), (0.433) represent larger values of GM_o . These values make the ship stiff in rolling, due to shorter periods from the point of view of ship motion. Moreover, the greater breadth results in increasing the primary loading, i.e., the transverse bending moment which leads in turn to a complicated structural arrangement in the haunch area between the strut and the cross deck structure. The main result is that GM_o and GZ_{max} are approximately linearly proportional to separation distance as shown in fig. 5.

It can be deduced simply from the graph that the limiting design value of B^*/L_s is 0.367, which corresponds to the minimum required GMo of 0.15m by IMO. It is also seen from the figure that area-ratio increases with the increase in (B^*/L_s) and it always meets the IMO criterion, while the only decreasing parameter is the angle of heel. The case studied also shows that an increase in hull separation distance of 1% will cause increase in GM_o by 24%, increase in GZ_{max} by 2.4% and decrease in heeling angle by 5.6%.

2.2. Effect of strut area

The waterplane area plays an essential role in the control of ship motions. Equally, it is a non-negligible parameter affecting ship stability characteristics. The waterplane area is characterised by the strut length and thickness.

The strut length affects seriously the longitudinal stability of the ship, which is beyond the scope of this paper. In terms of transverse stability, GM is proportional to the cube of the strut thickness plus a second term depends on the hulls' separation distance. The transverse moment of inertia, I_t, of a rectangular waterplane is determined by:

$$I_t = \frac{2t^3 L_S}{12} + 2L_S t\left(\frac{B^*}{2}\right)^2 = \frac{tL_S}{2}\left[B^{*2} + \frac{t^2}{3}\right]. \quad (1)$$

The term $(t^2/3)$ is very small as compared to $(B^*)^2$,therefore the term $(t^2/3)$ may be ignored. Thus, the strut's area moment of inertia is more sensitive to the strut length rather than the strut thickness.

The study of the effect of strut area is carried out on three models namely: the basic design, one of smaller strut length, and one of larger strut length. It can be deduced from fig. 6 that GM_o increases linearly with the strut area. Heeling angle decreases with the increase of strut area, while there is a slight effect on area-ratio and GZ_{max} with the change in the strut area. It is observed that the limiting value for Strut area/ $(L_h.B^*)$ is about

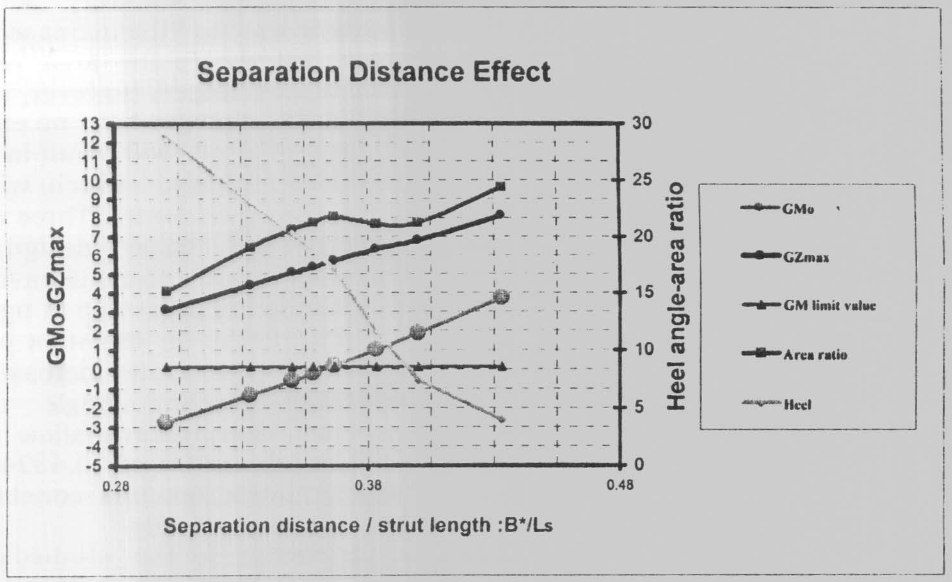

Fig. 5. Effect of hull separation distance on transverse stability.

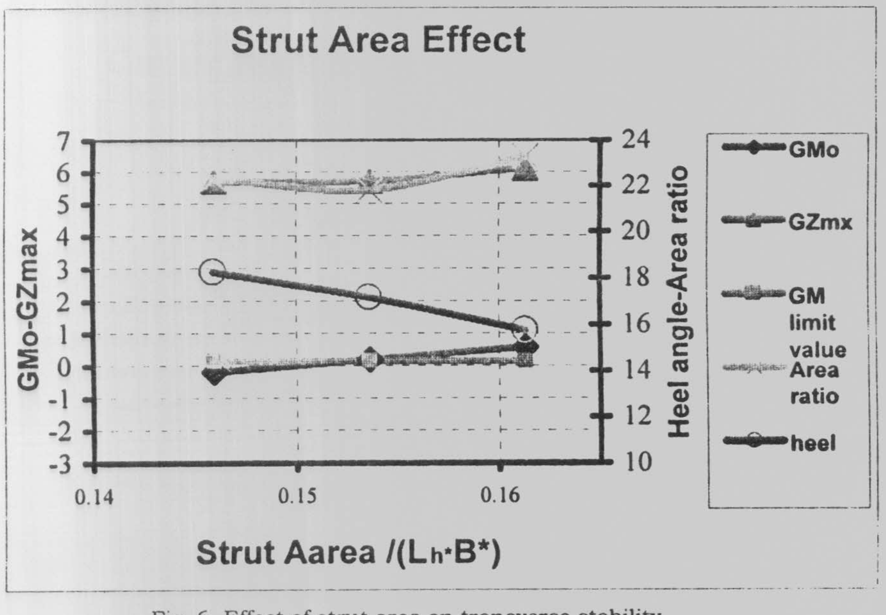

Fig. 6. Effect of strut area on transverse stability.

0.1536 for this case study, which corresponds to the minimum required GM_o by IMO. For the case studied, it is found that an increase in strut area by 1% will cause an increase in GM_o by about 57% and decrease in heeling angle by 2% while GZ_{max} and area-ratio are approximately constant.

2.3. Effect of hull length / hull diameter ratio, L_h / d

The underwater hull consists of the lower hull, which can be specified by length and maximum diameter, and a portion of the struts. Changing the lower hull length while, keeping the diameter constant will lead to a change in displacement and draft that must be held constant during the comparison to accomplish the effect of changing the length only. To keep these parameters (draft and displacement constant, the hull diameter must be changed with the hull length and therefore the ratio lower hull length/maximum diameter (L_h / d) is used. Three models are studied: the basic design, one having smaller (L_h/d) ratio, and one having larger (L_h/d) ratio. The results are presented in fig. 7. The trend of GMo can be presented as a second-degree parabola with a maximum GM_o of 0.211 corresponding to L_h /d of 14.13 and limiting values of L_h / d of 15.23 and 13.02, which correspond to minimum required GM_o of 0.15 by IMO.

That means that is a range of acceptable L_h/d or there is an upper and lower limit. It is found also that GZ_{max}, is approximately constant while area-ratio increases slightly with the increase in (L_h/d) ratio.

2.4. Effect of hull immersion

From the hydrodynamic point of view SWATH ships are very sensitive to draft changes due to the increased wetted surface area. The waterplane area remains constant with draft changes. However, it does not mean that draft changes have no effect on stability. Change of draft will result in a change in the displaced volume, which will consequently affect the metacentre. Three models are used namely: the basic design, one having shallower draft, and one having deeper draft. The results are presented in fig. 8.

In contrast to the other parameters, GM_o decreases with draft increase, while GZ_{max} is constant. Heeling angle and area-ratio increase sharply in shallow drafts up to a draft/depth ratio of 0.4324 and then the heeling angle remains constant while area-ratio increases slowly.

According to the studied case, it is found that an increase in draft by 1% will cause a decrease in GM_o by approximately 8%. The limiting value of draft/depth ratio is 0.4324 which corresponds to the minimum required GM_o of 0.15m.

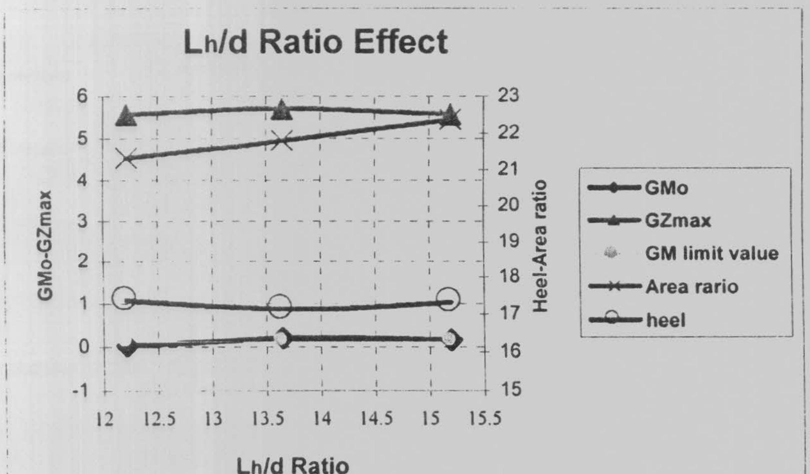

Fig.7. Effect of L_h/d ratio on transverse stability.

3. Comparison with an equivalent catamaran

It is reasonable to compare a SWATH ship with a catamaran as they belong to the same category rather than comparison with monohulls. An equivalent catamaran with the same displacement and having the same hulls separation distance is introduced for sake of comparison. The draft is adjusted to the draft at which the catamaran and the SWATH model have the same displacement. The curves of statical stability of both the catamaran and the basic design SWATH are plotted on the same graph, fig 9. It is shown from the graph that the catamaran and the basic design SWATH have approximately the same range of stability, while the catamaran has a higher energy content to resist heeling moments. Applying a wind heeling moment of 70 knots, the catamaran has proved to possess an absolute area-ratio 60% in excess of the basic design SWATH. The graph shows also a higher GM_o for the catamaran making it a very stiff ship compared to SWATH ships from the point of view of ship motions.

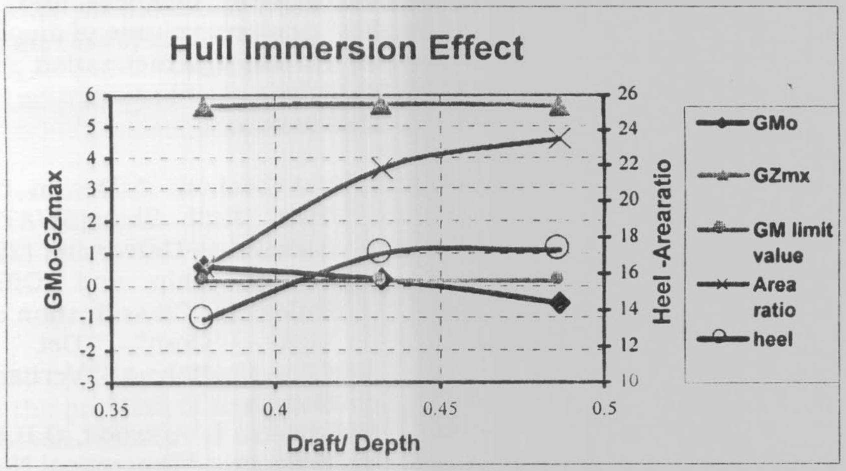

Fig. 8. Immersion effect on intact stability.

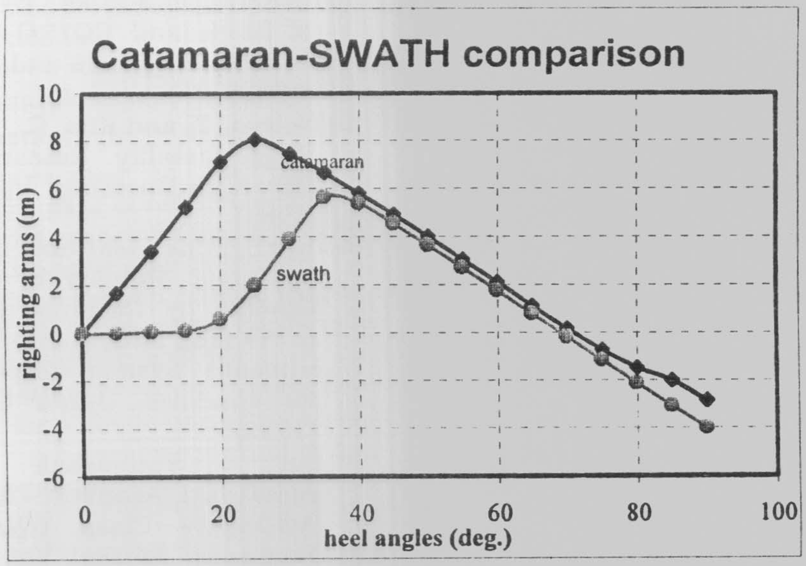

Fig. 9. Comparison between SWATH and equivalent catamaran.

5. Conclusions

Based on the above parametric study for the T-AGOS 19 SWATH, the following conclusions can be deduced:

1- The IMO Code on intact stability defines a stability criterion for SWATH vessels, where the SWATH ship is defined as a surface unit (a type of Mobile Offshore Drilling Units, MODU).

2- The most dominant factor that affects SWATH intact stability and has to be considered during the early design phase is the hull separation distance, and the strut area.

3- An increase in hull separation distance of 1% will cause a 24% increase in GM_o, a 2.4% increase in GZ_{max}, and a 5.6% decrease in heeling angle.

4- An increase in strut area by 1% will cause a 57% increase in GM_o and a 2% decrease in heeling angle, while GZ_{max} and area-ratio in dynamic stability (the area under the righting moment to the second intercept or the flooding angle, which ever is less, to the area under the heeling moment to the same limiting angle) are approximately constant.

5- The lower hull length to maximum diameter ratio, L_h/d, has a design range between 13.02 and 15.23.

6- An increase in draft by 1% will cause approximately 8% decrease in GM_o.

7- Heeling angle and area-ratio increase always beyond the IMO criteria and can not be considered during the preliminary design.

8- A SWATH has the same range of stability as an equivalent catamaran of the same displacement and hull separation distance.

9- The equivalent catamaran has a higher energy content to resist heeling moment. Area-ratio for the equivalent catamaran is about 60 % in excess that of the SWATH.

10- GM_o for the equivalent catamaran is higher than that of the SWATH making the catamaran a very stiff ship as compared to SWATH.

Nomenclature

B^*	hulls separation distance,
BM	distance from the centre of buoyancy to the metacentre,
d	lower hull maximum diameter,
G	centre of gravity,
GM	transverse metacentric height,
GM_o	initial metacentric height at, zero angle of inclination,
GZ	transverse righting arm,
GZ_{max}	maximum transverse righting arm
I_T	transverse moment of inertia,
KM	distance from the ship's keel to the Metacentre,
L_s	strut length,
L_h	lower hull length,
M	transverse metacentre,
t	strut thickness, and
∇	ship's volume of displacement,
θ	angle of inclination

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