COMPARATIVE ANALYSIS OF CONVENTIONAL AND SWATH PASSENGER CATAMARAN

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ABSTRACT

Catamaran as a surface vessel was not significantly improved from the mid of the last century. Conventional single-hull surface vessels were satisfying more or less sufficiently all sailing requirements. After complex theoretical and practical researches it was established that in relation to the conventional passenger vessels, catamarans offer many advantages related to the space, surface and stability in maritime exploitation.

Because of his high rate of stability, catamarans were established as a very convenient means for passenger transportation. Catamaran’s high rate of stability satisfy sailing requirements in the case of small angles of vessel's heel, but in the case of greater heel, catamaran’s stability is too high resulting in a short, fast rolling periods and extremely expressed inconvenience. To solve the problem SWATH catamarans was introduced. Generally, SWATH catamaran present surface vessels with reduced water line surface. Basic operational principle is that by the reduction of water plane area, where the most quantity of wave energy is concentrated, vessel generates a large amount of stability even in the case of rough sea conditions and high vessel's speed movement. With this principle SWATH catamarans place the most amount of displacement under the water line, where the impact of wave energy is minor.

Paper is aimed to compare technical and technological advantages and disadvantages of the both type of surface vessels and to present specific procedures of transformation process from conventional catamaran surface vessel to the SWATH catamaran.

1 INTRODUCTION

Nowadays, twin hull passenger vessels are common choice of many ship operators pushing out conventional monohulls of the same purpose. The reasons are more than obvious; passenger catamarans completely satisfy requirements regarding space and stability as well as other functional needs of the users. In the sense of catamaran quality evaluation, the most important operation conditions are maximal speed and seakeeping requirements accomplishing safety at sea requirements.

However, in the case of rough sea where high angles of heel occur, catamarans have short rolling periods. These short rolling periods cause great discomfort of passengers and crew members, even appearance of kinetosis, which can be the main obstacle for choosing marine transportation. Contrary, in the case of calm sea, catamarans have large amount of stability. These facts will be more precisely elaborated in the paper as well as the appearance of new coupled catamaran's motion.

Scientific studies and practical experiences demonstrated that persons are most sensitive to the vertical accelerations [1], which results in combination of vessel's heaving and rolling. To avoid the described problem and maintain technical characteristics of this kind of craft, the main accent are placed into the form of vessel's hull. The surface of the water line which is exposed to the external impact force, or wave input energy, has been developed. More accurately, conventional ship's waterplane was reduced to minimum in effort to avoid strong and rapid vessel response to the impact of external forces.

2 CATAMARAN

2.1 Some general particulars

Catamaran is surface vessel which consists of two separated hulls, placed collaterally at the certain distance one to another, brought together in one ship with box construction placed across the hulls. The essence of this kind of implementation is increasing of ship's stability by the use of stability form aspect. On the other side, the problem of monohull ship's stability is solved by the adequate loading of additional weights into the vessel (ballast) [2].

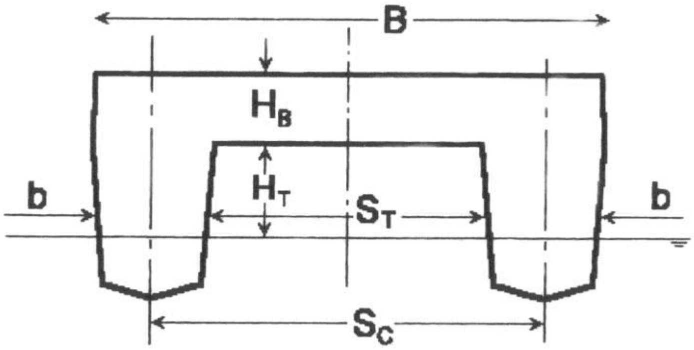


Figure 1: Basic Catamaran Dimensions
Source: Society of Naval Architects and Marine Engineers: Ship Design & Construction, vol.II., Sheridan Books, London 2004.

In the previous figure basic dimensions of the catamaran are presented. B means overall beam of the craft, b means beam of each hull, S_C means hull separation, S_T means width between the inside hull surfaces (the tunnel), H_T means height of the underside of the bridging structure and H_B means depth of the bridging structure [3].

The hulls provide buoyancy and housing of the propulsion machinery, whilst the bridging structure provides the transverse strength of the craft. This kind of vessel has been developed to use inherent advantages which are large deck area, reduced hull resistance, increased safety levels and attractive layout possibilities resulting from the wide beam.

2.2 Speed and propulsion

Service speeds of passenger catamarans have already passed 50 knots. That contributes lightweight construction of the crafts respected to the ship's building material (the aluminium manifested as perfect) and the large power of propulsion. The most common propulsion type is jet propulsion, where each water jet nozzle is connected with one propulsion device (two – for each hull one). Water jet propulsion is more effective than propeller propulsion at speed's exceeding 30 knots, when at propeller blades appears great cavity. Furthermore, combination of twin hulls with water jet nozzles results in excellent manoeuvring capabilities at lower speeds, i.e. during berthing and unberthing. In that case the most important is hull spacing which has to be proper because of satisfied effect of jet propulsion in manoeuvring conditions. Hull spacing is also one of the basic dimensions of the craft, as it is the main measure of its stability scope.

2.3 Hull shapes

The sectional hull shapes are generally divided into two types, round bilge and hard chine, as illustrated in the following figure. Hard chine hull shaped catamaran has a greater wetted surface area, which might be expected to increase the frictional drag. However, at higher speed this form generates more dynamic lift so the actual wetted surface area might be reduced. Conversely, a round bilge hull form may exhibit large amounts of dynamic trim at high speeds, with an associated increase in resistance [3].

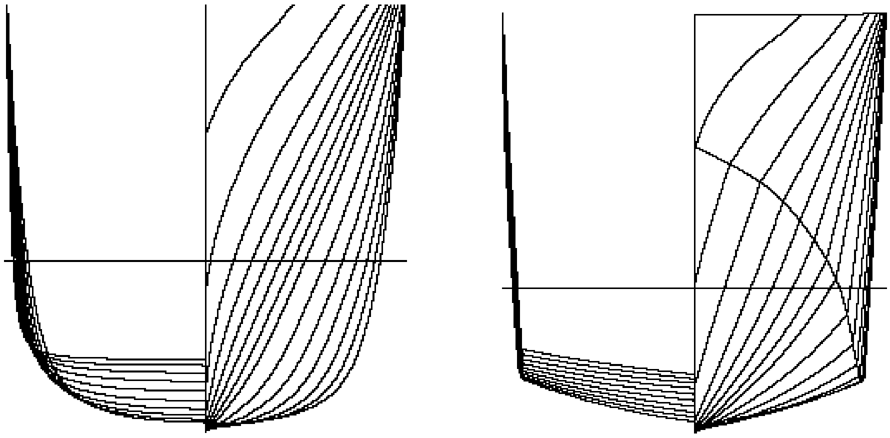


Figure 2: Round Bilge (left) and Hard Chine (right) Hull Shapes of Catamarans
Source: Prasanta K. Sahoo and Lawrence J. Doctors: Theoretical and Experimental Study of Motion Characteristics of High-Speed Catamaran Hull Form; Proceedings of The Ninth International Symposium on Practical Design of Ships and other Floating Structures, Luebeck-Travemuende, Germany 2003.

In accordance with mentioned a round bilge form is preferred for heavier and slower vessels and hard chine form is used on lighter weights and higher speed catamarans.

The principal hull characteristics, besides the hull spacing S_C, are the ratios of slenderness, $L/D^{1/3}$ and thinness L/b, where L is the waterline length, b is the individual hull beam, and D is the displacement.

2.4 Stability scope and resistance

In the case of conventional monohull vessels, stability scope is at the defined position of centre of gravity (G) dependent of the magnitude of weight shift of the centre of buoyancy (F) in the transversal plane. According to the shifting of the centre of buoyancy which could achieve maximum value of ¼ of vessel's beam, it is clear that the value of the upright moment is limited due to the ship's form. Catamaran's configuration enables significantly greater transversal shifts of the centre of buoyancy that is increase of ships up righting at the small heeling angles.

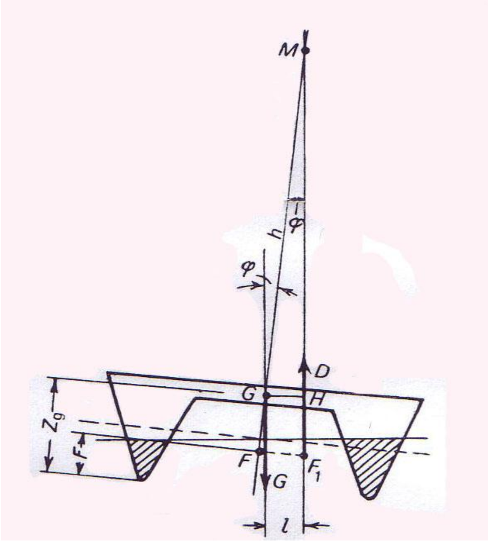


Figure 3: Initial Stability of a Catamaran
Source: Marine Encyclopaedia, vol. IV, Lexicographic Institute 'Miroslav Krleža', Zagreb 1983.

Catamaran's inertial moment is equal to the sum of inertia of each hull, increased for the product of each water line surface and square of centre of the water line from the ship's axis of symmetry. In other words, in this case the most important is value of hull spacing. By the adjustment of hull spacing it is possible to act to the reduction of total resistance of frontal catamaran's movement, as like to the reducing of heeling angles or accelerations, up to the specific degree.

With the reduction of hull spacing, magnitude of wavemaking resistance is changing. This is defined with mutual action of ships wave systems of both of the hulls, but also with the increasing of flow speed between them, and that determines a frictional drag. Interference of wave systems is noticeable at the value of Froude number F_n=0.3[1] [2].

Generally, the influence of hull spacing to the resistance is quite complex and depends of catamaran speed, hull form parameters and ratios between their dimensions. For example, at small thinness (L/b) hull form and hull spacing are equally influence the wavemaking resistance. On the other hand, high L/b ratio means that hull spacing have more influence than a hull form.

2.5 Seakeeping

Examinations have shown that the amplitudes of rolling of catamarans are almost 2,5 smaller than it is with equivalent monohulls (monohulls with same displacement). Small angles of heel are explained by the large amount of transverse stability that is overall breadth of twin hull vessels. Where a monohull will experience observable, high rolling caused by the waves, catamaran will maintain its position.

However, this advantage becomes an issue at greater heel angles; uprighting moment is so strong that produces powerful and sudden tendencies to return in primary condition, that is upright position. Furthermore, acceleration issue appears. By the evaluation of seakeeping, accelerations caused by ship's rolling are more essential than amplitudes. Because of great

[1] Froude number is the key factor affecting the magnitude of wavemaking resistance that must be overcome. It represents vessels speed relative to the square root of its length.

breadth of the catamaran, at rolling can appear high linear accelerations in their particular points.

A specific problem with this type of vessels is motion caused by the rough sea, which is generally quite high. Thin hulls of catamaran vessel are generating too small resistance to the pitching. A specific phenomenon here is slamming, when the structure above the water line comes into contact with water at high speed, causing a slam, which can be considerably uncomfortable for persons on board. Moreover, characteristic of catamaran motions manifests in their behaviour at quartering waves. In that case motions caused by rolling and those caused by pitching are coupled in so called corkscrewing motion. The cause to this motion is a fact that forces which occur at each hull are phase shifted.

Scientific study of motion sickness (kinetosis) began in World War II with the goal of improving the performance of troops being transported to battle in amphibious craft or aircraft. A key finding is that people seem to be most sensitive to vertical accelerations along the head to toe axis. At sea, such accelerations result from simple heaving motion of the ship, from vertical motions induced at the bow and the stern by pitching, and from vertical motions at the port or starboard deck edge due to rolling. Furthermore, it has been determined that the proportion of people who become sick depends not only on the magnitude of the acceleration but also on the frequency of the vertical motion [1].

3 SWATH CATAMARAN

Behaviour of catamarans in marine passenger transport at rough weather and sea conditions is quite unacceptable. Too large stability scope and small resistance elements are calling into question not only the health of passengers and crew affected but it also leads to the risk for drawback of travelling by sea.

Mentioned disadvantages can be reduced by the adjustment of hull spacing, as shown before, but not entirely. Alternatively, the problem can be approached from a different view: If there is an issue in too stable catamaran vessel, which at the external forces reacts too quick, same forces have to be utterly reduced.

More precisely, the seakeeping ability of the vessel is strictly determined by the shape and size of the waterplane. Reducing the same, external forces don't even have an opportunity to affect vessel's surface, at least not entirely. In that way the most effective design of the catamaran represent SWATH (Small Waterplane Area Twin Hull) catamaran

3.1 General particulars

Hull form of SWATH catamarans was derived from conventional hull forms in a way that the water line is considerably reduced, whilst the required buoyancy is provided with fully submerged hulls. Reduced water line is performed in the form of single or multipart struts. In this way, semi-submerged twin hull vessel consists of two fully submerged, torpedo-like hulls, connected with a box structure with two hydrodynamically derived struts.

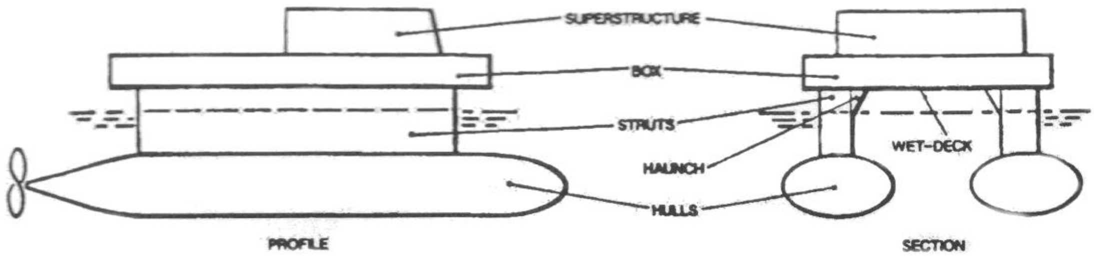


Figure 4: Main Features of a SWATH vessel
Source: Society of Naval Architects and Marine Engineers: Ship Design & Construction, vol.II., Sheridan Books, London 2004.

SWATH catamarans are the vessels which the most of vessel's displacement is placed below the water line, where there is less or no waves influence. Thus, vessel becomes very stable, even at higher speeds and in rough sea conditions.

The inboard top of each strut where it meets the cross deck or box structure flares out into a haunch. The underside of the box structure is known as the wet deck.

3.2 The history

The beginning of presented hull form idea can be traced back to 1880. with a patent for the first single-hulled semi-submerged ship, whilst SWATH vessel as such first time appears in presentation of Frederick G. Creed. He presented the idea for the small waterplane area twin hull aircraft carrier to the British Admiralty during the World War II. However, till the sixties of last century, inherent advantages of a form with a very small waterplane area and deeply submerged hulls which provide buoyant lift were not fully perceived. Using computers technology as well as by the acquisition of scientific researches it was possible to better understanding of ship's seakeeping ability and ship's motion at sea so small waterplane area ships became recognized

During years, not only twin hull vessels were improved with this method (given that the acronym SWATH is coined for a twin hull ship[2]), but also conventional monohulls. The concept was also proposed for mobile drilling platforms. In 1968, the first SWATH vessel was launched. It was *Duplus*, 40m long, low speed oil exploration support vessel. Designer of this 1.200-ton SWATH catamaran based his design on the fact that submarine lying at periscope depths experience little wave induced motion [1].

By provision of movable horizontal fins located aft of the vessel's centre of gravity, vessel trim and pitch motions are stabilized, what represents development of HSC SWATH Catamaran. Developments still continue; and there are more researches about the hull form of this kind of ship, as well as combination with new inventions (e.g. application of SWATH concept on vessels with more than two hulls).

Today, SWATH ships can be found in several branches, from military purposes to cruise ships. In 1992. Finnyards delivered the first and the biggest SWATH cruise liner, the 11.500 tons and 131 m long *Radisson Diamond*.

[2] The acronym SWATH is coined to distinguish this concept from conventional catamarans.

3.3 Vessel's form

The hulls can be designed with either high prismatic or low prismatic form, depending of the speed regime in which the particular vessel is intended to operate. The hulls are usually elliptical, with a ratio of 1.5 horizontally to 1.0 vertically, for reason of keeping the draught to a minimum, whilst preserving the essentially circular hull form for good hydrodynamics [3]. Likewise, hulls are bulbous because a craft with reduced waterplane area still requires a displacement volume.

The length of the struts relative to hull length is a design choice linked to the choice of rudder arrangement. A short strut is likely to result in the rudder being located on the hull rather than adopting the simpler spade arrangement behind the strut. However, choosing the strut to be shorter than the hull, resistance and pitch excitation is reduced. It also minimizes coupling of ships pitch and heave.

Most of the SWATH vessels have one strut per hull, although there are twin strut configurations3. Single strut per hull gives reduced drag by elimination of wave interference effects between the struts and better performance in extreme seas.

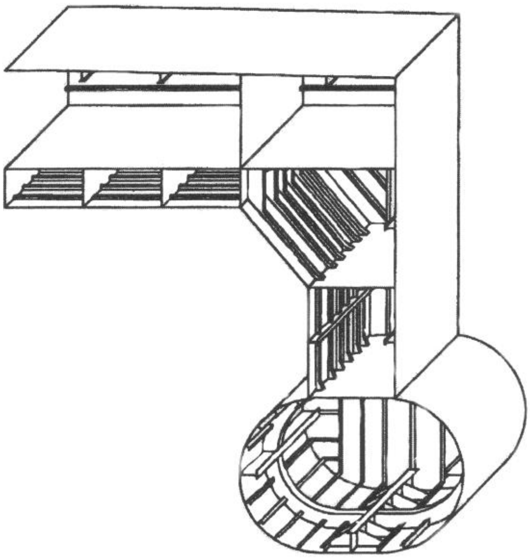


Figure 5: SWATH structure
Source: Society of Naval Architects and Marine Engineers: Ship Design & Construction, vol.II., Sheridan Books, London 2004.

3.4 Seakeeping

The SWATH primary attribute is its excellent seakeeping. SWATH configuration results in long natural periods in heave pitch and roll. Due to the mentioned, submerged hulls and the small waterplane of the struts, together with fins mounted on the inboard sides of the hulls increase vessels hydrodynamic damping achieving very significantly reduced responses at sea.

[3] *Kaimalino*, one of the first SWATH catamarans which was operated by the US Coast Guard had two struts each side.

SWATH catamarans are certainly far superior in relation to conventional passenger catamarans, which suffer from slamming and slam induced whipping and unpleasant coupled motions which can lead to fatigue damage and kinetosis. Furthermore, vibration and noise is dependent on the propulsion system adopted, but in general deep propellers and excellent flow conditions into the propellers greatly reduce vibration levels.

3.5 Speed and resistance

So far, all SWATH ships above 500 tons have relative low speed, 15 knots or lower. However, speeds well above 20 knots can be provided with reasonable amounts of power. Although slower than conventional catamarans, SWATH speed regimes are fully acceptable in marine passenger transport[4] [1].

Because SWATH vessels have forms optimized for high seas, they suffer from a resistance penalty in calm water. The resistance of SWATH is made up of skin friction and residual drag (wavemaking).

SWATH catamarans have significantly smaller length than equivalent conventional catamarans. The reason for that is to minimize the weight caused by the more deeply submerged hulls and the fact that smaller waterplane area makes neccessary wider hull spacing than a conventional catamaran. Smaller length also minimizes the frictional resistance of the submerged hulls which have considerably higher wetted area. Finally, SWATH configurations in general have relatively high wavemaking resistance because their length and greater structural weight make them less slender than would be desirable[5].

Solution which partly reduces mentioned resistance is narrow form at the fore end of struts, resulting that at higher speeds the vessel is piercing waves, instead of shoving them.

3.6 Propulsion characteristics

Due to reduced waterplane area SWATH ships are quite restricted to fit big and complex machinery systems, unlike conventional catamarans, where their transom stern provides more space for water jets which are favoured propulsion system for high speed crafts.

One of solution, although requires great basic changes of the forms of both of the vessels, is construction of Semi-SWATH catamaran. Semi-SWATH is a hybrid form with the forward half or the hulls SWATH like, with the goal to maintain good seakeeping and the after half more Catamaran like, enabling the vessel to incorporate preferred type of machinery installation.

[4] Fastest SWATH ships with displacement between 200 and 350 tons provide speeds of 27 to 28.5 knots. In this size range speed as high as 35 knots can be provided with new generations of power small gas turbines.

[5] For SWATH ship, a F_n value of 0.5 indicates maximum wavemaking resistance. Above that value, it slowly decreases.

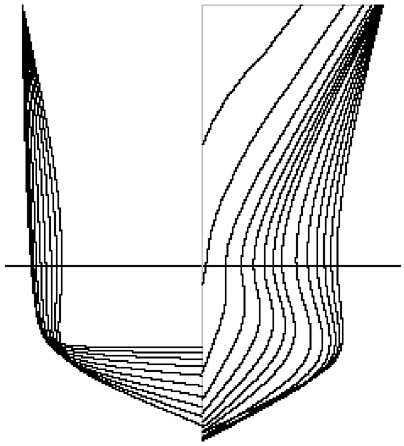


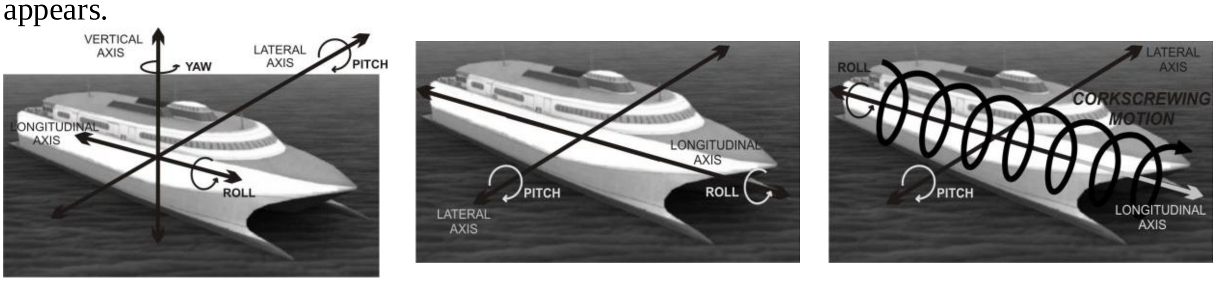
Figure 6: Semi-SWATH hull form

Source: Prasanta K. Sahoo and Lawrence J. Doctors: Theoretical and Experimental Study of Motion Characteristics of High-Speed Catamaran Hull Form; Proceedings of The Ninth International Symposium on Practical Design of Ships and other Floating Structures, Luebeck-Travemuende, Germany 2003.

So far, most common propulsion machinery in SWATH catamarans is Diesel engines and gas turbines, with fixed or controllable pitch propellers as propulsion devices.

4 FINAL COMPARISION

In relation to the conventional catamaran, SWATH catamaran appeared to be better choice regarding speed maintenance and seakeeping in rough sea due to wave exciting forces affecting the surface of vessel. The metacentric height of SWATH vessel is smaller, so that the roll and pitch natural periods are longer. Moreover, greater clearance to the underside of the connecting structure will allow the SWATH vessel to ride over the surface waves[6]. The figure below represents motion of a conventional catamaran when at high seas and quartering wave directions related to ship's course. It is the case when coupled corkscrewing motion appears.



Six degrees of freedom | Corkscrewing motion formation | Corkscrewing motion

Figure 7: Formation of corkscrewing motion

However, in calm water conditions conventional catamaran still shows better performance in comparison with SWATH catamaran. Satisfying characteristics of SWATH vessel, so essential at high waves, become thr problem in normal conditions. Because the total amount of strut waterplane area is decreased, the transverse spacing between the hulls must be

[6] This type of operating mode results in the smallest vertical motions and it's called Platforming.

increased to regain adequate transverse stability to resist heeling over moments. Increased hull spacing leads to greater breadth, which contributes in increasing of wavemake resistance in comparison with conventional catamaran. Great breadth also implies greater wetted surface of the vessel and additionally frictional drag occurs.

L/B ratios for SWATH ships are between values of 1,75 and 2,90, whilst the same ratios for conventional catamaran are between 3,30 and 4,0 [1]. Consistently, service speed of SWATH catamaran will be noticeably smaller than the speed of conventional catamaran.

Greater overall breadth means also shorter length of the vessel. However, it has some advantages; for low speed applications, short length is necessary to provide very long pitch natural period, which decreases vessel's pitch motions, whilst for higher ones reduced length is advantageous because reduces structural weight and, therefore, minimizes displaced volume and wetted area.

Draft of SWATH vessels is greater than at conventional catamarans, because of heavier construction and submerged hulls. Finally, construction of SWATH catamaran is more expensive in comparison with conventional catamaran.

5 CONCLUSION

Features of SWATH design catamarans and conventional catamarans separately have been analysed in the paper. Main technical and technological characteristics were generally studied which are common for both type of ships. It was established that good attributes of one catamaran appeared to become the problem in different, particular conditions, when characteristics of the other catamaran show to be more appropriate.

In calm water conditions and at lower angles of heel, conventional catamaran has excellent response to external forces caused by wave energy. This is explained by large amount of initial stability vessel possess. Great operational speed and good seakeeping characteristics are here on their best. By the worsening of sea condition, and increased angles of heel, this features change. Stability scope of the vessel causes unwanted motions due to strong and sudden upright moment. This results in appearance of vertical accelerations and coupled motions of the vessel, called corkscrewing motion, which can be extremely uncomfortable for the people on board. The aim of SWATH catamaran is to eliminate this accelerations, by reducing waterplane area and placing the most of the displacement below the water line. In this way, the surface affected by external forces is minor. The vessel maintains good seakeeping characteristics and required operational speed even in rough sea conditions and at great angles of heel. However, SWATH catamaran has disadvantages in calm waters. Due to vessel’s form, that is with reduced waterplane area, it suffers from greater resistance than a conventional catamaran. Additionaly, the speed of SWATH catamaran is usually lower than the speed of conventional catamaran. For calm seas, conventional catamaran appears to be more adequate choice.

Analysing both types of catamarans shows that using of each depend mainly on the navigational area and requested operational speed. In that way, conventional catamaran completely fulfils its purpose in coastal and relatively closed waters at short relations, whilst the SWATH catamaran are more efficient in long distance voyages, crossing open seas, where the accent is not in the speed, but in better and safer quality of passenger transportation.

Idea of finding catamaran with almost ideal characteristics is generally realised by construction of semi-SWATH vessel, which represents a combination of conventional and

SWATH catamaran. This type of catamaran integrates good hull features of each vessel into one, and it will be analysed in the future papers.

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