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Multi-Hulls: Some New Options as the Result of Science Development

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Review paper

The widespread development of multi-hull ships began in the second half of the twentieth century. Today, many hundreds of multi-hull ships of various designs are being built. This intensive development can be explained by the specific characteristics of multi-hull ships. A multi-hull ship can consist of various numbers of hulls and of hulls of various common or uncommon shapes and/or hulls with small water-plane areas (SWA ships). Any type of multi-hull ship differs from other multi-hulls and mono-hulls because of its own specific features, and its own advantages and disadvantages.

The main characteristics of multi-hulls are examined briefly here. Their larger deck area compared to that of mono-hull ships means that all multi-hulls are more economical for most types of "volume" cargoes, including passengers in cabins or saloons, cars and other wheeled vehicles, light containers, laboratories, weapons, aircraft and helicopters, and so on. Similarly, in comparison with corresponding mono-hulls, a sufficiently greater, and simply achievable, transverse stability is the important reason for higher safety in multi-hulls. A larger permissible aspect ratio of these hulls also makes them more energy efficient at higher speeds. The relatively large size of the hull connecting platform is the main reason for higher non-sinkability and higher safety. All multi-hull ships are generally more seaworthy than their mono-hull counterparts. The ships with small water-plane area (SWA) have the best performance characteristics regarding seakeeping. The strength specificity of multi-hulls plays the leading role in determining transverse loads.

Multi-hull ship specific features are the reason for possible wider application in order to improve the main characteristics of ships and/or for various other purposes. A general picture of multi-hulls, newly proposed by the author, is presented. Some examples of such options are given.

Keywords: *multi-hull, catamaran, small water-plane area, deck area, stability, performance*

Višetrupci: neke nove mogućnosti kao rezultat razvoja znanosti

Pregledni rad

Šira primjena raznih višetrupaca započela je u drugoj polovini dvadesetog stoljeća. Do danas je izgrađeno više stotina višetrupaca različitih tipova. Ovako intenzivni razvoj se može objasniti posebnostima višetrupih brodova. Višetrupni brod se može sastojati od različitog broja trupaca a sami trupovi mogu biti različitih uobičajenih i manje uobičajenih oblika i/ili trupova s malom površinom vodnih linija (SWA brodovi). Svaki tip višetrupnog broda se razlikuje od ostalih višetrupaca kao i od jednotrupaca zbog svojih posebnosti, prednosti i nedostataka.

Glavne posebnosti višetrupaca se ukratko preispituju u članku. Relativno velike površine paluba čine višetrupce ekonomičnijim i učinkovitijima u odnosu na bilo koju vrstu voluminoznog terete kao i za prijevoz putnika u kabinama ili salonima, automobila i vozila na kotačima, za lagane kontejnere, laboratorije, za smještaj suvremenog oružja uključivo zrakoplove i helikoptere i tako dalje. Slično tome, u usporedbi s jednotrupcima se postiže jednostavnije veća poprečna stabilnost koja osigurava veću sigurnost višetrupaca. Veći dopustivi omjer duljine i širine trupova je glavni razlog za energetsku učinkovitost kod velikih brzina višetrupaca. Srazmjerno velika platforma koja spaja trupove je glavni razlog za povećanu nepotonivost i veću sigurnost. Svaki tip višetrupnog broda u pravilu ima bolja pomorstvena svojstva od jednotrupnih. Za višetrupne brodove je odlučujuća uloga i važnost poprečne čvrstoće. Posebnosti višerupih brodova pružaju mogućnost njihove šire primjene za poboljšanje svojstava brodova i prilagođavanje različitim potrebama.

Ključne riječi: *višetrupac, katamaran, mala površina vodne linije, površina palube, stabilitet, svojstva*

1 Introduction

A wide development of various multi-hull ships began in the second half of the twentieth century. Today (2009), there have been built:

- hundreds, or possibly thousands, of small sized twin-hull boats for fishing, tourism, pleasure, working, and so on;
- hundreds of twin-hull ships to function as fast ferries (today about half of fast ferries are catamarans [1];

- hundreds of semi-submersible structures for drilling and auxiliary services at sea;
- about 70 twin-hull ships with small water-plane area;
- some triple-hull ships and boats (the main hull and two small side hulls – "outriggers");
- some twin-hull ships with a main hull and one small side hull (outrigger), known as "proas".

Such intensive development can be explained by specific features of multi-hull ships.

2 Multi-hull ship types

A multi-hull ship may consist of various numbers of hulls and of hulls of various common or uncommon shapes and/or hulls with a small water-plane area (SWA hulls). Different types of multi-hull ships differ from each other and from mono-hull ships due to their own specific features.

Firstly, it must be noted, that variously shaped hulls can be applied as parts of multi-hull ships, including SWA hulls, which have no transverse stability, unlike single hulls. Besides, these hulls can be asymmetric relative to their own longitudinal axes.

Figures 1 and 2 give an indication of the variability of multi-hull ship types [2], [3] and [4]; see the same references for extensive bibliographies dealing with related materials.

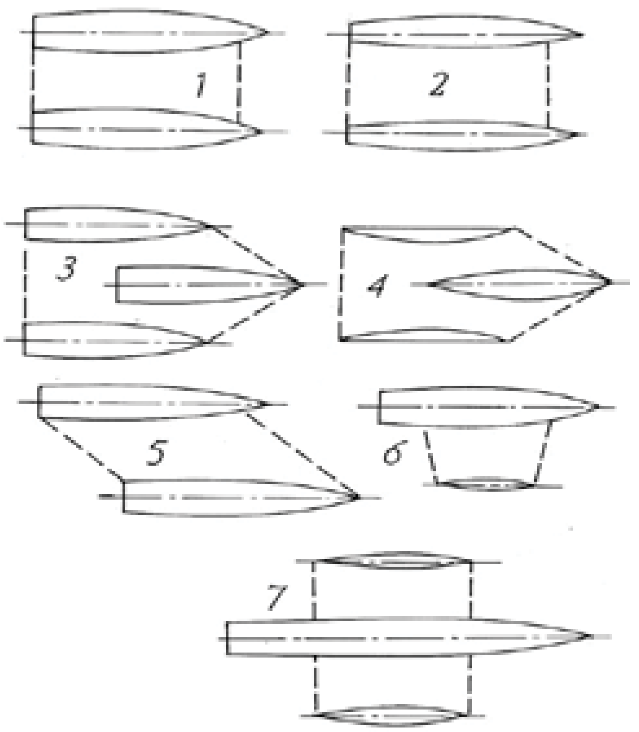


Figure 1 **Multi-hull ships with traditional hull shapes: 1,2 – catamarans, symmetrical and asymmetric hulls; 3,4 – trimarans, symmetrical and asymmetric hulls; 5 – catamaran with staggered hulls; 6 – proa; 7 – ship with (two) outriggers**
Slika 1 **Višetrupci s tradicionalnim oblicima trupova**

A twin-hull ship with identical conventional hulls is usually called a "catamaran". (It should be noted that sometimes the term catamaran is used to describe a twin-hull ship with any hull shape. However, the definition provided here is a more helpful one.)

Catamarans, as specific ship types, differ from all other types of ships in that they have the greatest degree of transverse stability. The catamaran's transverse stability can be equal to, and even higher than its longitudinal one. Furthermore, in contrast with a mono-hull ship, the superior stability of a catamaran does not mean large roll accelerations in side waves.

The term "trimaran" has been used in the Russian-language technical literature since the 1970s to refer to triple-hull ships with equal conventional hulls. A ship with a larger main hull and two smaller side hulls, all of which have a conventional shape, has been extensively researched in the UK and the USA, and is called a "trimaran" in the English-language technical literature; this difference in terminology needs to be noted to avoid confusion. A "staggered catamaran" is a very strange ship that has certain characteristics in common with both catamarans and trimarans. A "proa" is a twin-hull ship with one large hull and one smaller hull (outrigger) of a conventional shape.

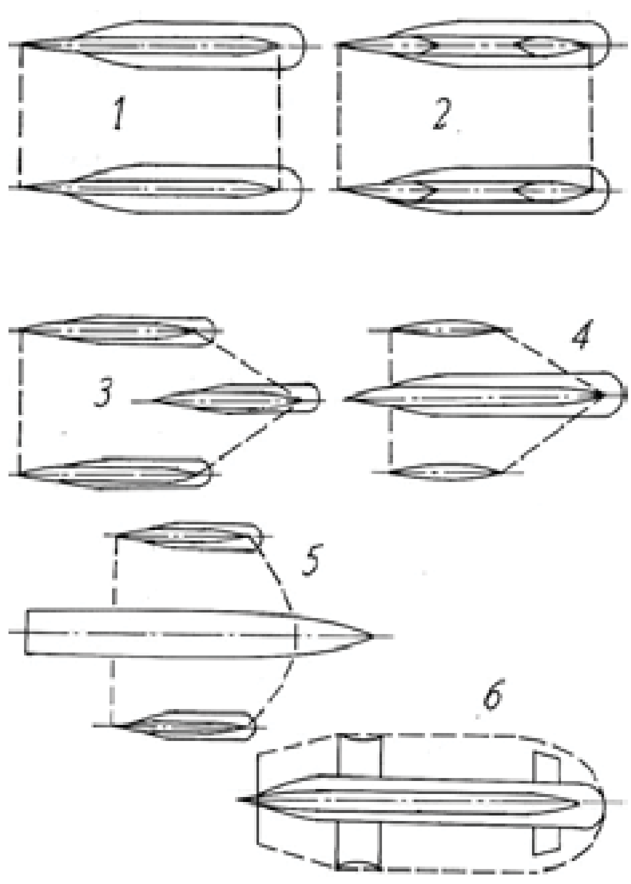


Figure 2 **Multi-hull ships with hulls of SWA:1 – duplus (two underwater gondolas, two long struts); 2 – trisec (two underwater gondolas, four short struts); 3 – tricore (three identical hulls); 4 – ship with an SWA main hull and two small side hulls of an arbitrary shape; 5 – ship with a conventional main hull and two conventional outriggers (the option of S. A. Rudenko); 6 – SWA mono-hull with foils**
Slika 2 **Višetrupci s trupovima male površine vodnih linija SWA**

An SWA hull usually consists of a main watertight underwater component (gondola), and one or more thin struts that intersect the water surface and connect the gondola with an above-water platform.

All the options shown here are of greater or lesser scientific or practical interest, and the author draws on his 50 years of experience in the following text.

2.1 Multi-hull ship characteristics

Specific features of multi-hull ships (MHS) compared to mono-hull ships:

- a great number of type and shape options with various characteristics;
- larger relative deck area;
- more or less higher seaworthiness;
- any needed initial stability without any restriction of the hull aspect ratio;
- large above-water watertight volume;
- possibility of wet deck slamming;
- a sufficient influence of transverse external loads on strength.

The relative **deck area** of multi-hull ships is larger than that of the comparable mono-hull craft, as follows:

- 2.4 – 4 times larger for a catamaran;
- 1.9 – 2.3 times larger for a twin-hull SWA ship (duplus and trisec);
- 1.6 – 2.3 times larger for an outrigger ship with a traditional main hull;
- 1.3 – 2.3 times larger for an outrigger ship with an SWA main hull.

The big advantages of the catamaran with regard to the deck area are evident, but other types of multi-hull ships have the advantage too.

For example, Figure 3 presents an option of an aircraft-carrier with two "fly-off-fly-on" complexes, the advantages of which are evident from the tactical point of view.

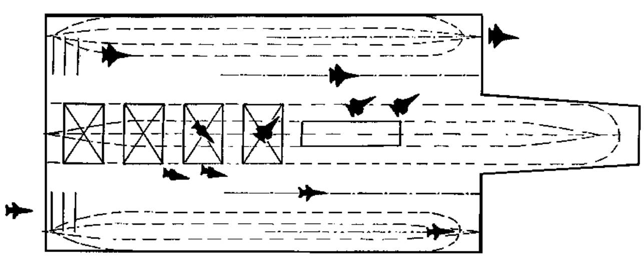


Figure 3 **A triple-hull aircraft-carrier with small water-plane area (for Sea State up to 9 inclusive)**
Slika 3 **Nosač zrakoplova s tri trupa male površine vodnih linija (za stanja mora do uključivo 9)**

It seems evident that no permissible mono-hull can ensure such aircraft deck width and such seaworthiness.

The **initial transverse stability** of multi-hulls is strongly dependent on the ship type, see Figure 4.

It must be noted that good stability does not mean rough roll due to side waves if the catamaran is designed correctly. So, the large transverse stability allows safety applications of a payload on the decks of some catamarans. In general, these two characteristics are the main, but not the only, reasons for the widespread application of catamarans.

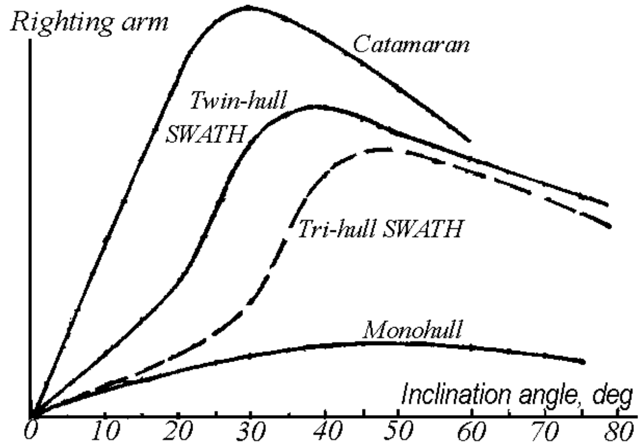


Figure 4 **Transverse stability comparison of some multi-hulls [2]**
Slika 4 **Usporedba poprečnog stabiliteta za neke višetrupce**

The initial transverse stability of a trisec or an outrigger ship, in contrast, is approximately the same as, or only slightly greater than, that of a comparable mono-hull craft. The initial transverse stability of a trisec can be compared with its longitudinal stability and they are both small enough (approximately as small as a mono-hull's transverse stability).

As it will be shown below, the decreased initial stability of SWA ships, both transverse and longitudinal, is one of the main reasons for the superior seakeeping qualities of such ships.

Transverse metacentric radii depend on the square of transverse clearance; SWA ships usually have to have a minimal water-plane area and relative increased transverse clearance.

It should be noted that the required outrigger dimensions of all ships with outriggers depend on the following two assumptions (for the same demands on transverse stability): the required moment of inertia of the water-plane area is ensured by either one or two outriggers. The existence of only one outrigger supposes damage caused by flooding. The latter case (two outriggers) corresponds to smaller dimensions of outriggers, i.e. smaller weight and own towing resistance, whereas the former corresponds to larger dimensions of outriggers, a larger transverse distance between outriggers or both.

In general, for all multi-hulls, there is no dispute about the relationship between initial transverse stability and performance: it is very important, especially at high speeds. Multi-hulls can be designed to have almost any required level of initial transverse stability, including one equal to the longitudinal stability value. Such a ship would contain hulls of a large enough aspect ratio to ensure a lower degree of towing resistance, especially at high speeds.

In correctly designed multi-hulls, a relatively larger size of the above-water watertight platform, whose volume and dimensions are not so strongly restricted by transverse stability (but, rather by weight), makes it simpler to ensure sufficiently higher damage stability and non-sinkability compared to mono-hulls. Of course, this platform must be divided by water-tight bulkheads for a full realisation of its safety capabilities.

Hydrostatic characteristics of multi-hulls (stability, non-sinkability) can be predicted using the usual calculation methods.

The majority of multi-hull ships with conventionally shaped hulls need no special stability restrictions, and the overall beam is selected based on other initial demands (for example, for a tug-catamaran, the needed heel restriction on the maximal side force of the towing rope). The initial transverse stability of an outrigger or SWA ship must be limited. For example, the US Navy standard is that the heel should be no more than 10 degrees from the side in wind speeds of 50 knots (in a restricted sailing area) or 100 knots (in an unrestricted sailing area) while the ship is at rest.

The multi-hull **towing resistance** characteristics can be defined by the counteraction of two tendencies: the larger relative wetted area per ton of displacement and smaller wave resistance (the main part of residual resistance) by the greater aspect ratio of single hulls and possible favourable interaction of wave systems generated by those hulls. (The disadvantage of a relatively larger wetted area declines with an increase in the comparison mono-hull's beam-to-draught ratio.) However, any straight comparison of wetted area and residual resistance is pointless, because a larger wetted area means a smaller residual resistance coefficient, even for the same absolute towing resistance of the model and vice versa in the contemporary method of towing resistance scaling.

The main source of high-quality performance in catamarans is the high aspect ratio of single hulls. Some statistical data comparing catamarans and mono-hulls are provided in Figure 5 [5].

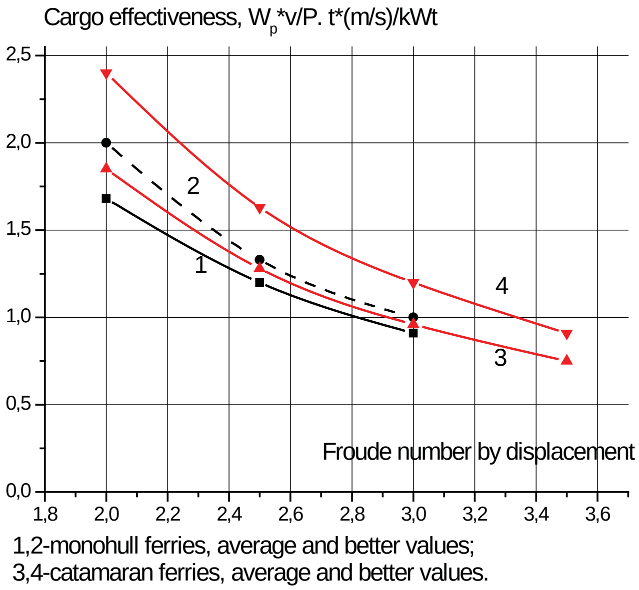


Figure 5 **Transport factors of catamarans and mono-hulls under a transient speed regime**
Slika 5 **Faktori transporta katamarana i jednotrupaca za prijelazni režim brzina**

In addition, the big enough interaction of the wave systems generated by the hulls – of lateral wave systems in the main– is possible in any type of multi-hull design. The interaction is the strongest in triple-hull ships, see Figure 6 [6]. Two staggered hulls of any shape (and identical or varied dimensions) differ too by sufficient possibility of favourable interaction (for Froude numbers for a hull length from 0.4 to 0.7).

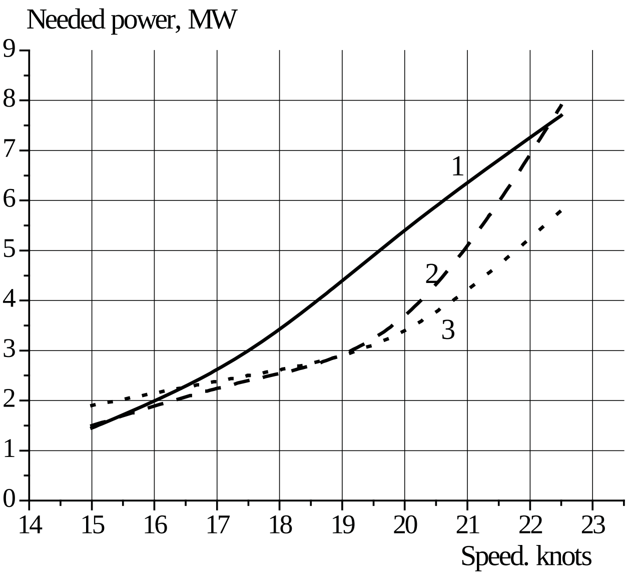


Figure 6 **The required power comparison of a catamaran and two trimarans of the same displacement of 500 t, 1 – catamaran, l_1 = 7.9; 2 – trimaran, l_1 =6.3; 3 – trimaran, l_1 = 7.4 (relative hull length of $l_1 = L_1/V_1^{1/3}$, where L_1- hull length, V_1 – single hull volume displacement)**
Slika 6 **Usporedba potrebne snage za katamaran i dva trimarana iste istisnine od 500 tona**

The evident advantage of trimarans results from the favourable interaction of the wave systems at the defined Froude numbers.

As with corresponding mono-hulls, **propulsors** can be applied for multi-hulls of any type with the same loading values. A transition from a mono-hull to a comparable catamaran means more or less growth of the propulsor hydraulic area, i.e. propulsion coefficient growth. In addition, in multi-hull ships a propulsor of is usually placed at each hull centre-plane. The viscous wake is then used by the propulsor to a greater degree, and the hull wake influence coefficient is then larger than is the case in mono-hulls. SWA ships usually have a larger design draught, which means a larger-diameter propulsors and a correspondingly higher propulsive coefficient.

Seaworthiness of multi-hull ships depends on the number, shape and mutual placements of the hulls. First, compared to mono-hulls, all multi-hull ships have various correlations between the forces of inertia and floating. This difference defines the value difference between the natural periods of motion, which is very important for seakeeping.

For example, the greater initial transverse stability of a catamaran acts more strongly than the difference between mass inertia moments of the catamaran in comparison with a mono-hull of the same displacement. As a result, the natural period of the catamaran's roll is usually by about two times smaller than that of the mono-hull, which means that the catamaran's roll resonance is in shorter waves of smaller length and inner energy. In the case of longer waves, the catamaran's roll is sufficiently far from the resonance conditions, i.e. it is sufficiently smaller than the mono-hull's roll in the same waves.

A practical example of the specificity is the successful sailing of the Soviet-built fishing catamarans, *Experiment* and *Experi-*

ment-2, having displacements of about 1000 t, in sea state 6. It is well known that even much bigger mono-hulls would not be able to sail in these wave conditions.

To decrease catamaran roll acceleration to the same level as that of a mono-hull, the catamaran dimensions must be selected correctly, since a badly designed catamaran will have higher roll acceleration than a mono-hull, even with smaller roll amplitudes.

The longitudinal motion (pitch and heave) of a catamaran is approximately the same as that of a comparable mono-hull, whereas that of a trimaran is slightly lower than that of a comparable catamaran.

The seakeeping advantages of SWA ships are a direct and indirect result of the small area of water-plane. Approximately the same transverse initial stability and the relatively larger overall beam (and mass inertia moment relative to the longitudinal axis) are the reasons that natural roll periods of these ships are double those of mono-hulls. However, their smaller degree of longitudinal stability and approximately the same mass moment inertia values relative to the transverse axis, are the reasons for their larger (by a factor of 1.5 or 2) natural pitch periods.

The disturbance forces and their moments are sufficiently small because of the small area of water-plane. As a result, large sized, low speed SWA ships and semi-submersibles can never sail in resonance motion. However, medium- and small-sized SWA ships can, but not in head waves, only in the following ones. Speed increase in waves results in better seakeeping characteristics of SWA ships. The very small additional resistance from the waves is also the result of the small water-plane area.

Usually, the resonance motion of an SWA ship has larger amplitudes than that of a mono-hull, but at a narrower range of frequencies. However, the disadvantage can be compensated for by the greater effectiveness of various types of motion stabilisation devices, as the forces and moments generated by them have the same order as disturbance forces and moments on a small water-plane area. Activation of air-water tanks can be recommended for motion stabilisation of slow-speed SWA ships and for motion mitigation at rest.

In general, a correctly designed SWA ship can have the same seakeeping level as a mono-hull ship at 5-15 times larger displacement.

A seakeeping comparison of various ship types carried out using a special method [2] demonstrates the advantage of small- and medium-sized SWA ships, which have an average achievable speed per year that is about 2 times greater than that in previously defined standards of seakeeping. The displacement of practically "all-weather" SWA ships can be about 5000 – 6000 t, see Figure 7. Here, the average operational index refers to part of a year, when all previously defined demands for seakeeping are fulfilled.

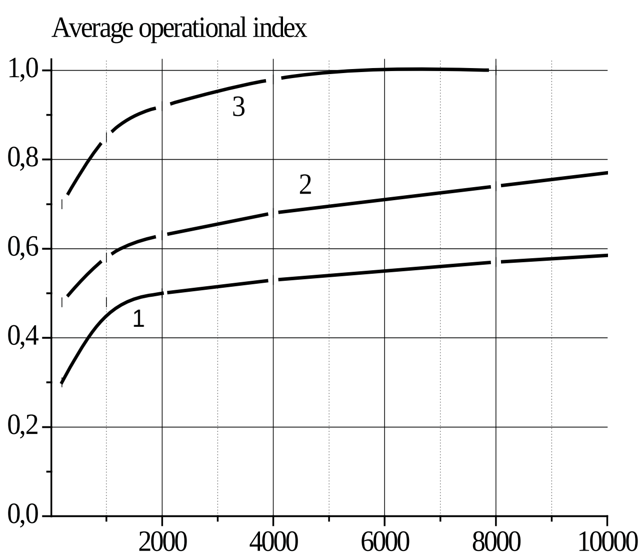
This means that their speed and any necessary heading relative to the wave direction will be ensured up to Sea State 6 (inclusive). The likelihood of more severe waves is usually less than 1 %.

At present, multi-hull seaworthiness cannot be predicted with a very high degree of exactness. Thus, seakeeping model tests are needed at an early stage of designing. Seakeeping characteristics can be predicted using calculations, but there is still no full understanding of the application limits and exactness of the proposed theoretical formulas.

Vertical clearance is a specific characteristic of multi-hull ships. Its selection is possible on the basis of calculation of motions and vertical displacement of the platform bottom, but today there are some recommendations based on the model tests and full-scale experiments [2], Figures 8, 9.

Figure 7 **Average operational indexes of combat SWATH and mono-hulls of various displacements [4] in the North Atlantic: 1 – mono-hulls with helicopters, 2 – the same ships without helicopters, 3 – SWA ships with helicopters**

Slika 7 **Prosječni radni indeksi za borbeni SWATH i jednotrupce različitih istisnina [4] u sjevernom Atlantiku**



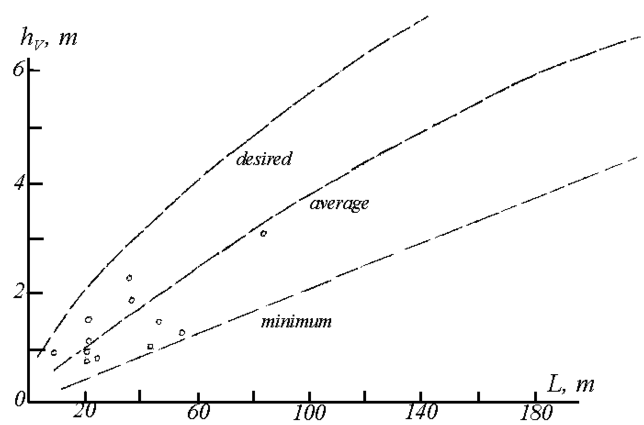


Figure 8 **Options of catamaran vertical clearance**

Slika 8 **Mogućnosti vertikalnih zračnosti katamarana**

The motion specificity of various types of multi-hull designs defines their **tactics of sailing** in waves. For example, if mono-hulls usually select head or following heading angles in waves, the practice has shown the possibility of catamarans sailing in side waves. Thus, all headings need to be taken into account for a full comparison of various levels of ship seakeeping and all ranges of achievable speeds in the method of seaworthiness comparison [2].

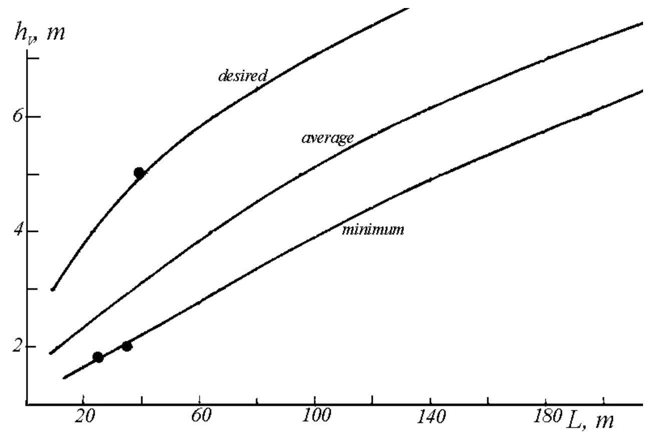


Figure 9 **Recommended options of vertical clearance of SWATH**
Slika 9 **Preporučene mogućnosti vertikalnih zračnosti SWATH plovila**

the same vertical flat surfaces as the above-water platform, struts (if there are any), and underwater components (gondolas).

Ensuring the longitudinal strength of trimarans and tricores requires longitudinal bulkheads supported by transverse bulkheads in the above-water platform.

Approximate analysis of the full-scale data shows that the metal hull weight of multi-hulls is smaller, by around 10-15%, than that of mono-hulls in relation to overall dimensions, see Figure 10.

Outrigger ships with SWA main hulls have a minimal relative weight of the metal structure: the transverse loads are small because the outrigger displacement is relatively small, whereas the longitudinal loads are small because of the small water-plane area of the main hull.

Systematic calculations show the possibility of approximate predictions of SWA hull weight using a database of the minimal platings of traditional mono-hulls.

The possibility of wet deck slamming is a disadvantage of MHS and the vertical clearance value must be a result of rational designing. A larger width is usually a disadvantage of MHS. A larger wetted area is also a disadvantage of MHS, because it means an increase in viscous drag and bigger mass of the hull plating.

The MHS disadvantages can be minimized by rational designing. The basic information for MHS designing are the deck area (or the inner above-water volume) relationships, Figure 11.

MHS are not convenient for ice. Generally, small-sized, high-speed, fast mono-hull vessels are not applicable too, because:

- they usually have too big aspect ratio of hulls;
- they have the hull shape that is not suitable for ice conditions;
- their local and general strength does not correspond to ice conditions.

It seems evident that various multi-hulls can ensure that new levels of the main technical characteristics are reached, and

The reasons for the higher level of **course stability** and the lower level of **controllability** in the majority of multi-hull ships, especially at high speeds, are the larger aspect ratios of the hulls and the greater or smaller distance between the hulls. Triple-hull ships and ships with stern outriggers are the most stable on course. The controllability of such ships compared to mono-hulls needs more attention from ship designers.

The manoeuvrability of SWA ships is strongly connected to their attitude (dynamic trim and average draught changing). Some slow-speed SWA ships were built without direction rudders; such ships can change course by changing their attitude using horizontally controlled foils. As with mono-hulls, additional devices are usually necessary to ensure multi-hull ship controllability.

In multi-hull ships, transverse **strength** (at low and medium speeds) is more important than, or equally important to, the longitudinal strength (particularly for high-speed ships with a traditional hull shape). Longitudinal strength is more important for triple-hull ships, however.

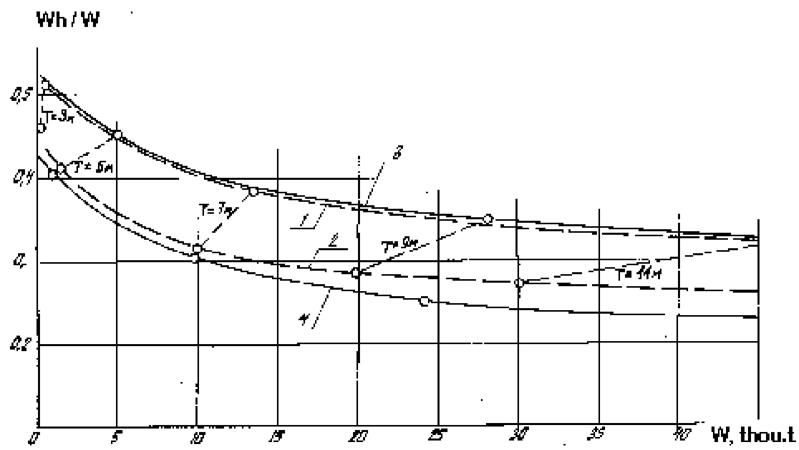


Figure 10 **Calculated data on metal hull weight of steel SWA ships (relative to full displacement): 1,2 – twin-hulls, L/D=24 and 9, correspondently; 3-triple-hull, identical hulls, L/D=15, advance 0.6; 4 – triple-hull, central hull L/D=24, outriggers L/D=9 (L-the hull length, D-gondola diameter)**
Slika 10 **Računski podaci za težine čeličnog trupa SWA plovila u odnosu na ukupnu istisninu**

Today it seems known that the main reason for transverse loads is horizontal velocity in waves. Therefore, the increase of transverse clearance rather than the increase of ship depth is the reason for a smaller increase of the transverse bending moments. It has been shown experimentally that transverse loads are linearly proportional to side hull displacement; which means that if outrigger ships have minimal transverse loads, then their transverse structure mass will be also minimal.

The longitudinal bending moments of SWA ships in head waves are proportional to the water-plane beam, i.e. the moments are smaller than the same ones of comparable mono-hulls. Besides, these moments decline with greater speed. Considering their large hull depth, this means that the longitudinal strength is a matter of secondary importance in SWA ships.

The transverse strength of all types of multi-hull ships is ensured by their transverse bulkheads with effective flanges as part of the board and deck plating. These bulkheads must be placed on

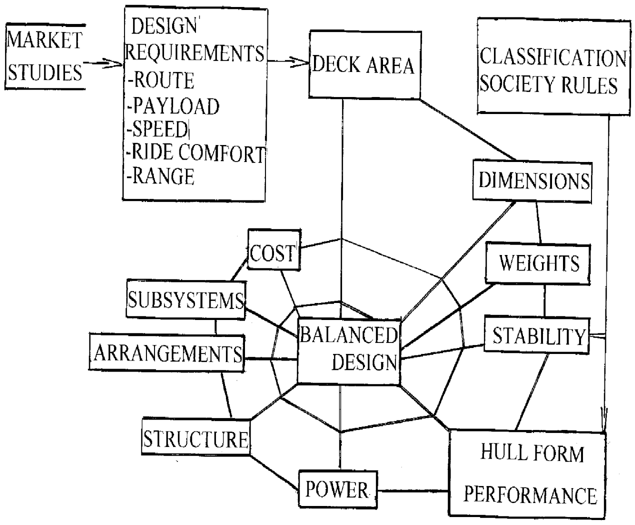


Figure 11 **Multi-hulls design algorithm**
Slika 11 **Postupak projektiranja višetrupnih plovila**

even perhaps new services, because of the individual specific characteristics of each multi-hull ship type.

3 Some examples

3.1 General overview

A general overview of multi-hull design options, as proposed by the author, is given in Figure 12.

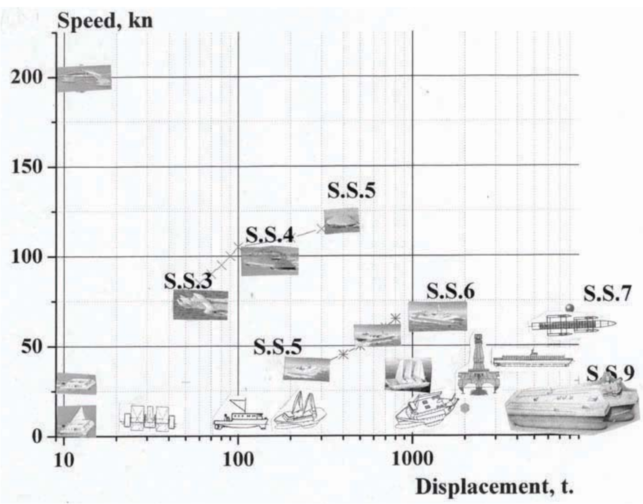


Figure 12 **Examples of new multi-hull ships, as proposed by the author (design sea states are shown on the figure field)**
Slika 12. **Primjeri autorovih prijedloga novih višetrupnih brodova (projektna stanja mora dana su na slici)**

At all ranges of shown displacements and speeds – from a self-stabilised racing boat capable of speeds up to 150 or 200 knots, to a 65,000-t aircraft-carrier with almost doubled fly-off-fly-on capacity and the ability to sail up to sea state 9 for larger ships – various multi-hulls for volume "cargoes" transportation can provide higher main technical characteristics or new functions. Some examples are presented in more detail in the text below.

3.2 'Wave-piercing' trimarans

Doubled speeds (in comparison with contemporary level), increased seaworthiness and **minimal wash** can be all ensured by the design of planing 'wave-piercing' trimarans (WPT) with sufficient air-borne unloading capacity [3]. For example, Figure 13 shows a proposed design for a 130-knot long-line ship for 200 passengers [8] that would allow a one-day trip between London and New York.

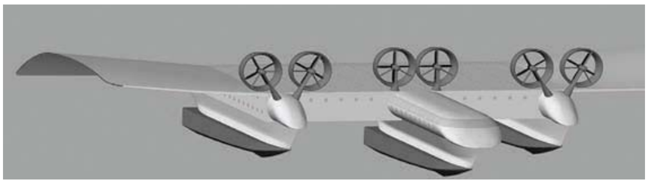


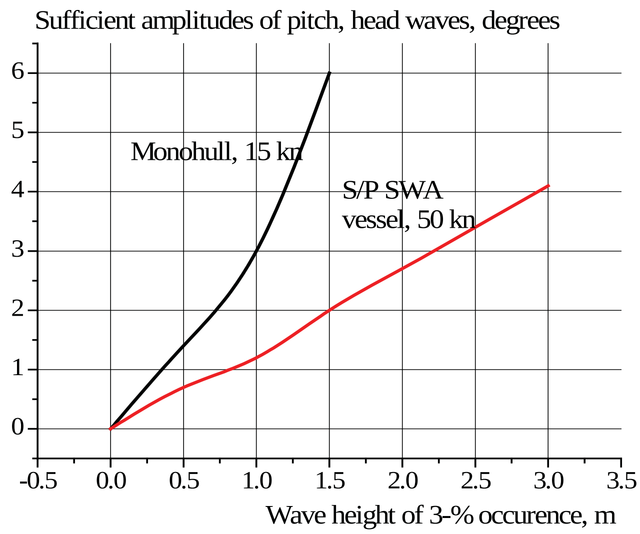
Figure 13 **'Wave-piercing' trimaran design for a super-fast long-line passenger ship**
Slika 13 **Trimaranski super brzi linijski putnički brod za prolaz kroz valove**

The proposed WPT line (Figure 13) is restricted at the top speeds only by the power capacity of existing gas turbines. No mono-hulls can ensure such speeds together at the required level of seakeeping.

3.3 Semi-planing SWA mono-hulls with foils

Unloading by under-water foils allows development of small-sized fast ferries. For example, a proposed mono-hull SWA vessel with foils has a passenger capacity of 150 persons and additional payload capacity of about 10 t. The ferry design

Figure 14 **Pitch amplitudes in head waves for a 150-t 'semi-planing' SWA mono-hull with unloading by foils**
Slika 14 **Amplitude posrtanja na valovima u pramac polu-planirajućeg 150-tonskog SWA jednotrupca s rasterećujućim krilcima**



features a displacement about 150-200 t, a design speed of 50 knots, a range of 500 nm at design speed, power of 10-12 MWt, and design seakeeping up to Sea State 5. The model-based data on pitch amplitudes and accelerations in head waves are shown in Figures 14 and 15.

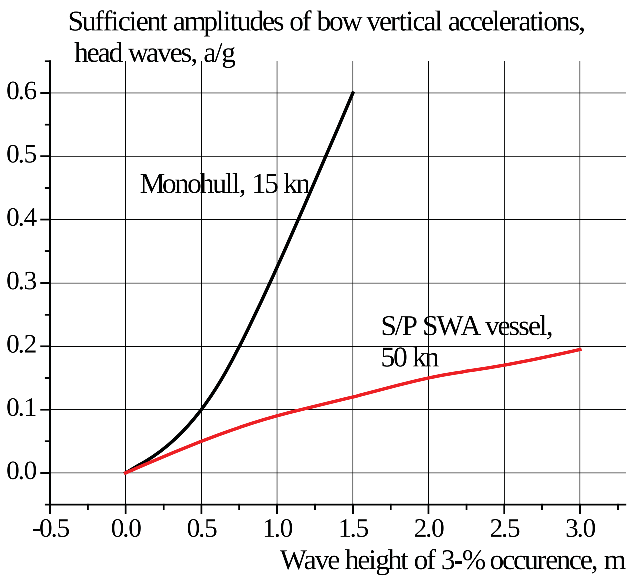


Figure 15 **Bow vertical acceleration in head waves of a150-t 'semi-planning' SWA mono-hull**
Slika 15 **Vertikalno ubrzanje pramca na valovima u pramac 150-tonskog polu-planirajućeg SWA jednotrupca**

It is evident from Figures 14 and 15 that the foiled SWA vessel is better from the seakeeping point of view than a 1000-t fast mono-hull vessel.

3.4 'Semi-planning' SWA vessels

A higher level of seakeeping and greater speeds in waves of fast ships is ensured by the proposed novel shape of an SWA ship gondola [9], Figure 16.

Figure 16 **Innovatively shaped SWA twin-hull corvette (55 knots, designed for Sea State 5)**
Slika 16 **Novi oblik dvotrupne SWA korvete (55 čvorova za projektirano stanje mora 5)**

The same hull shape can also be applied to foiled SWA corvettes, see Table 1.

The 'X-Craft' in this table refers to a built twin-hulled USNS with a decreased water-plane area [10].

Table 1 **Main dimensions and general characteristics of fast corvette options**
Tablica 1 **Glavne izmjere i opće značajke raznih izvedbi brze korvete**

Ship type	'X-Craft'	S/P SWATH	Foil-outrigger SWA
Design displacement (t)	1400	1500	1200
Overall length (m)	79.9	60	70
Overall beam (m)	22	28	25
Payload (t)	About 250		
Deadweight (t)	About 500		
Design speed (knots)	50	60	70
Total power (MW)	72	90-100	110-120
Sea State for full operability	4	5	6
Range at 20 knots, nm	4000	≅3500	≅3000

Figure 17 shows the speeds that the fast corvettes listed in Table 1 can achieve in head waves.

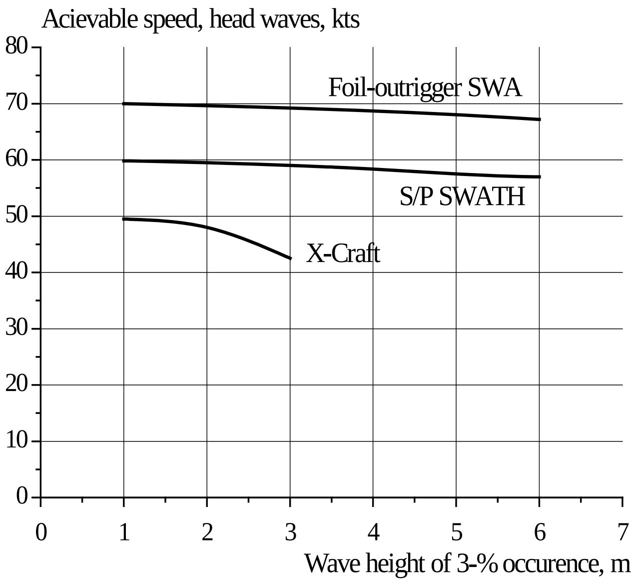


Figure 17 **Achievable speeds for considered corvette designs**
Slika 17 **Postizive brzine za razmatrane projekte korvete**

It seems evident that the alternative options of the 'X-Craft' offer higher speeds because of the smaller degree of speed loss in waves. No mono-hull designs can achieve comparable speeds in waves.

3.5 Container-carriers

Small design draught and a **high degree of seaworthiness** can be ensured by an outrigger SWA ship-platform as a feeder carrier of containers as presented in Figure 18.

The deadweight of this ship is about 3,000 t; its speed ranges between 15-20 knots; it has a design draft of 4.0 m at harbour and 6.0 m at sea, and it is designed for up to and including Sea State 6.

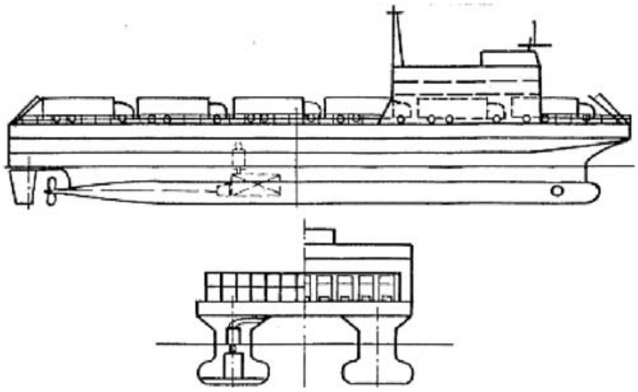
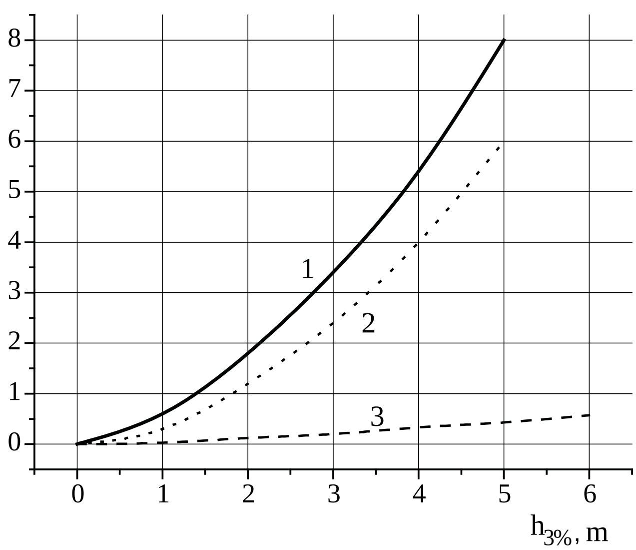


Figure 18 **Shallow-draught (at harbour) SWATH ship-platform**
Slika 18 **SWATH-brod-platforma plitkog gaza (uvjeti u luci)**

A comparison of motion prediction (Figure 19) and permissible levels allows the following assumption: without motion stabilizers, the ship rolling is permissible for wave heights up to 5 m and ship pitch is permissible for head wave heights up to 3.3 m. A wave height up to 4 m is permissible from the acceleration point of view in the ship's mass centre, which means Sea State 5 or slightly above. In Sea State 6, the speed and heading of the ship without stabilizers is restricted. But well-known desirable effect of the motion stabilizers promises a possibility of motion decrease in the next stages of designing.

Figure 19 **Motion characteristics of the carrier versus wave height: 1 – roll at rest, side waves, degrees; 2 – pitch, head waves, full speed, degrees; 3 – vertical acceleration, at mass centre, head waves, full speed, relative to gravity acceleration**
Slika 19 **Značajke gibanja kontejnerskog broda u ovisnosti o visini valova**



An all-weather 40-knot transatlantic container-carrier is shown in Figure 20 (payload 6,000 t).

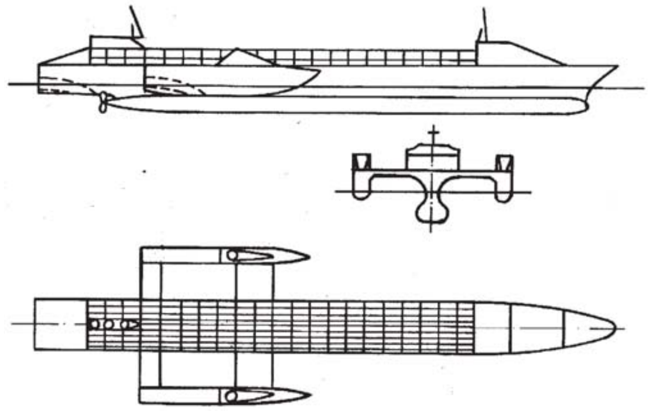


Figure 20 **Transatlantic container-carrier**
Slika 20 **Transatlantski brod za prijevoz kontejnera**

No mono-hull vessel can match this multi-hull container-carrier regarding such small loss of speed in waves.

3.6 Carriers for unmanned aircraft

Unmanned aircraft (UMA) have potential applications for surface monitoring in geology, oceanography, sailing, fishing, defence, and so on. The proposed carrier for UMA is intended to accommodate 10-12 UMA with a wing span of 6 m, 4-6 UMA with a wing span of 15 m, and a number of unmanned submersibles, Figure 21.

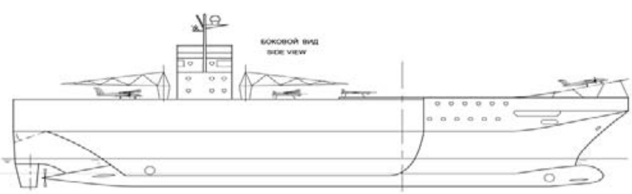


Figure 21 **Side view of a carrier for unmanned aircraft [11]**
Slika 21 **Pogled na nosač zrakoplova bez ljudske posade**

A small modification of the ship (the addition of two forked hangars and fuel-supply systems) would allow carrying 2-5 strike helicopters, instead of larger UMA, which could provide very effective defence capabilities against pirates, Figure 22. Unmanned aircraft can ensure permanent monitoring of a large sea region.

There is no mono-hull ship available that offers a comparably large deck area in combination with a high degree of seaworthiness and sufficiently small displacement.

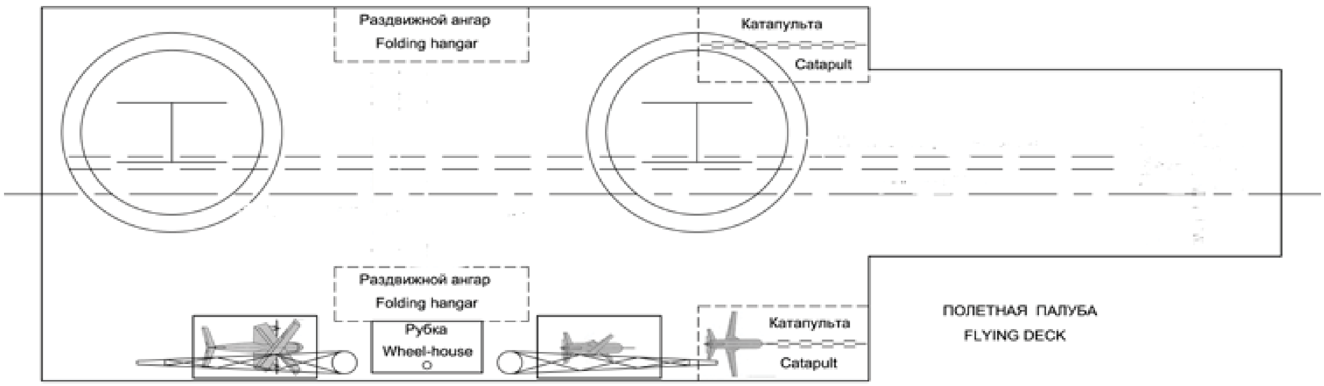


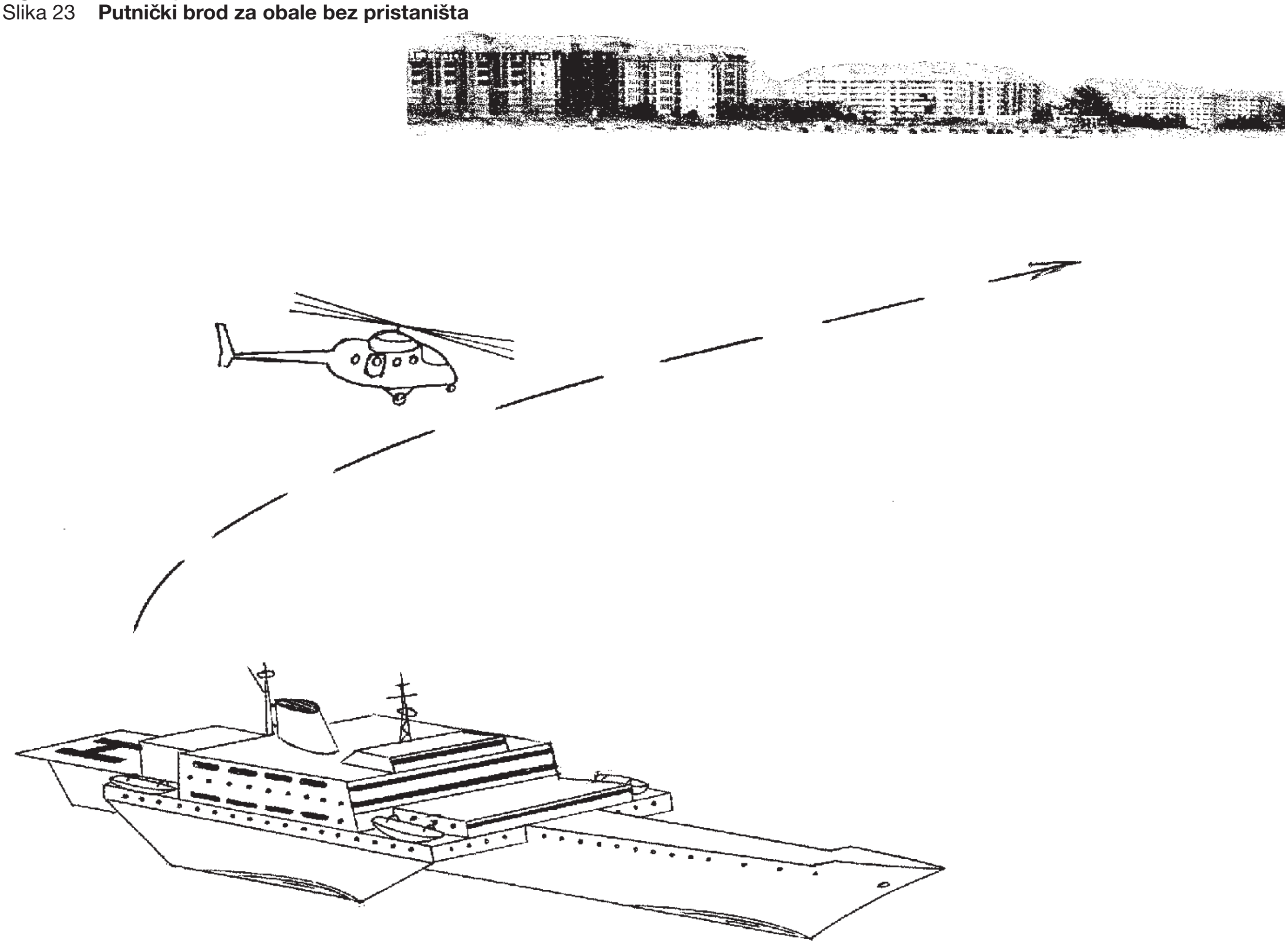
Figure 22 **Flying deck arrangement of the small-sized carrier for anti-pirate struggle**
Slika 22 **Oprema poletne palube malog nosača za borbu protiv gusarenja**

3.7 Passenger ships for coasts without harbours

The all-weather passenger SWA ship shown in Figure 23, carrying 1-2 helicopters, could be used to organise passenger traffic to and from the coast via helicopter, without the need for a harbour.

Such a helicopter service would be possible in conditions up to and including Sea State 6, with a full displacement of about 5,000 t, which no existing mono-hull ship can ensure**.**

Figure 23 **Passenger ship for coasts without harbours [12]**
Slika 23 **Putnički brod za obale bez pristaništa**



3.8 Cheap modification of small-sized passenger mono-hulls

The cheap modernisation of small sized passenger mono-hulls can be realised by the addition of outriggers to the existing hull with no need for docking. Figure 24 shows an option for the possible modernisation of a Chinese-built ship to increase its capacity and stability, ensuring thus a higher degree of safety.

Every year, we can read of accidents involving small sized mono-hull passenger ships, with the loss of many lives. Modernisation of these ships through the addition of outriggers could save many lives without great expense, because this modification can be carried out without docking.

Conclusion

It seems evident that a wider application of various designs of multi-hull ships in non-icy seas would ensure improved technical characteristics and/or new types of marine services. No existing mono-hulls offer comparable levels of technical capabilities.

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Figure 24 **Modernization scheme of a mono-hull ferry by adding two outriggers**
Slika 24 **Prikaz modernizacije monotrupnog trajekta dodavanjem dva izdanka**