Application and Development of Multi-Hulls

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ABSTRACT

A brief history of the expanded application of multi-hull ships and boats is shown. The possibilities of catamaran development are proposed. The first line of multi-hull development is the wider use of various types of multi-hulls. The second line of development is a special method of designing, including complex comparison of seaworthiness. The proposed method ensures the elimination of the disadvantages of multi-hulls, and the fullest realization of their advantages. Practical examples of the developments are shown.

KEY WORDS: *Multi-hull Ship; Small Water-plane Ship; Twin-hull Ship; Triple-hull Ship, Catamaran, Trimaran; Outrigger Ship; Proa; Duplus; Trisec; Semi-submerged Rig.*

NOMENCLATURE

API	American Petroleum Institute
ΔT	Temperature Difference in and out
F_T	Thermal Expansion
L_A	Anchor Length
ΔL	Expansion
F_P	Pressure Force
F_F	Friction Force
ε_{sd}	Design Compressive Strain
ε_c	Critical Strain

1.0 INTRODUCTION

The expanded use of twin-hull ships with identical hulls of usual shape, so-called catamarans, in the trade and auxiliary fleets began after World War II. Expanded scientific programs on multi-hulls in general began at the same time.
The building of semi-submersible rigs for drilling at sea also began at approximately the same time.
New ships, consisting of a central main hull and one or two added side hulls (outriggers), have been built since the last quarter of the last century.
Full-scale tests, wide research and practical applications of small water-plane ships also began in the last decades of the twentieth century.

A new stage of application was the building of battle multi-hulls, and their inclusion in the naval forces of various countries. For example, "wave-piercing" catamarans used as missile boats were built in China; a fast catamaran for use as a corvette, and (after building and testing of an experimental ship "Triton" in the UK) fast outrigger combat ships were built in the USA.

Today there is a large amount of full-scale, experimental and theoretical experience of research into various multi-hulls. This experience allows wider and more effective application of such ships for various purposes.

1.1 The Main Results of Practical Applications.

A large number of multi-hulls have been built since the middle of the twentieth century:

Thousands of small-sized ships and boats for uses including passenger, tourist, pleasure, and fishery roles;

- Hundreds of catamarans as fast passenger and car-passenger ferries (today about 70% of these ferries are catamarans);
- Hundreds of semi-submersible rigs for various purposes;
- Dozens of small water-plane area ships for full-scale tests and for practical applications;
- A number of ships with one or two outriggers, including a record sail racer.

Evidently, some types of multi-hulls are applied:

- The catamarans as are most spread type;
- The twin-hull ships with small water-plane area, so named "dupluses";
- Some ships with outriggers and usually shaped main hull.

A more detailed description of the history and state of the art of multi-hulls can be found in the monograph [1]. The science and practical results are contained in [2], [3]. The characteristics of the multi-hulls in use today are briefly examined below.

The relatively larger area of their decks, elimination of the transverse stability problem, reduced roll, the major provision of non-sinkability, and the large aspect ratio of the hulls, all ensure the effective application of catamarans as fast passenger and car-passenger ferries.

Today the special shape of the bow parts of the hulls and the above-water platform ensures the highest level of seakeeping in head waves in the so-called "wave-piercing" catamarans (WPC). Such catamarans are the most effective ferries in terms of contemporary capacity and speed, Fig. 1.

The high transverse stability and the large area of the upper decks are major advantages of catamarans used as a sea-going cranes or crane ships.

The simple modernization of any monohull by adding one or two outriggers allows a substantial increase of capacity (on the decks) and transverse stability, i.e., greater safety of ships employed for various purposes, such as passenger transport or fishery. This modernization can be carried out even without docking the initial ship.

The building of an outrigger battleship is the next important stage of naval fleet development. Such a ship differs from a comparable monohull in having a larger area upper deck, greater transverse stability, a larger aspect ratio of the main hull (with the usual shape), and smaller pitch at moderate speeds, Fig. 2.

Semi-submersible rigs, as floating objects with a small water-plane area, consist of two or three underwater pontoons that are connected with the above-water platform by a number of struts built in rectangular or circular sections (columns). The design draft is placed at about half of the column height, while the transport draft is placed near the top of the pontoons. Such rigs guarantee all-weather exploitation even in the worst wave and wind conditions.

A separate line of multi-hull development today is researching and building high-speed ships with a small water-plane area and twin hulls (SWATH - "ship with small water-plane, twin hull"). A lot of theoretical, full-scale and experimental data shows that the seaworthiness of a SWATH is approximately the same as that of a monohull with a bigger (5-15 times greater) displacement.

The other specificities of SWA ships are the same as those of other multi-hulls: increased area of decks, large volume of the above-water platform, lack of transverse stability problems.

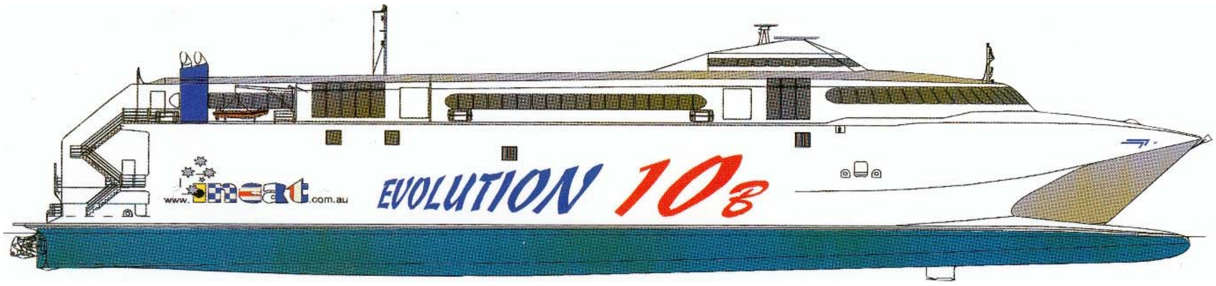

Figure 1: A typical "wave-piercing" catamaran.


Figure 2: The outrigger battle ship of US Navy.

2.0. BIG "FAMILY" OF MULTI-HULLS.

Today there are the theoretical and experimental data on the characteristics of a bigger, than applied, line of multi-hulls. For example, Fig. 3 shows the researched types of multi-hulls of usual shape of hulls.

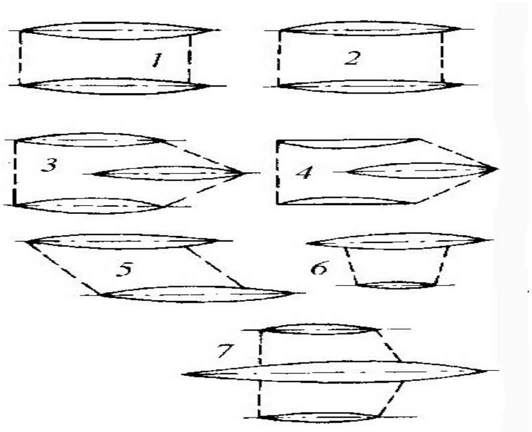

Figure 3: Some examined types of usually-shaped multi-hulls: 1, 2 – the catamarans with symmetrical and unsymmetrical hulls (the biggest transverse stability); 3,4 – the same trimarans (in Russian terminology), the biggest interaction of wave systems; 5 – a catamaran with shifted hulls (a sum of characteristics of a catamaran and a trimaran); 6 – proa (the minimal mass of the transverse structure); 7 – an outrigger ship (small enough mass of transverse structure).

Fig. 4 contains some types of ships with small water-plane area (SWA ships).

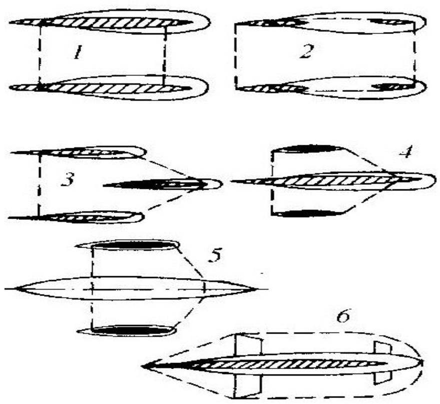

Figure 4: Some examined ships with small water-plane area:1 – a duplus (twin-hull ship with one long strut on each under-water volume, "gondola"), maximal transverse stability of SWA ships; 2 – a trisec (twin-hull ship, two short struts on each gondola) minimal area of water-plane; 3 – a tricore (triple-hull ship of small water-plane area), maximal interaction of wave systems of SWA ships; 4 – an outrigger SWA ship, small enough mass of the transverse structure; 5- a ship with usual main hull and SWA outriggers (option of S.Rudenko); 6 – foiled monohull SWA ship, for higher achievable speeds.

Table 1 shows the main difference of any multi-hulls^ relative bigger area of (upper) deck.

In general, the existing experience of multi-hull researching shows the following characteristics:

- increased area of decks (and corresponding possible growth of inner volume);
- better performance (at medium and high relative speeds) by reason of the high aspect ratio of the hulls;
- generally better seaworthiness (compared with monohulls with the same displacement);
- any required transverse stability without any restriction of the aspect ratio of hulls;
- increased above-water volume, which can be watertight and can be divided by watertight bulkheads;
- possibility of the design draft decreasing without loss of seakeeping.

In addition, SWA ships can have a minimal draft while in harbor, as well as greater draft at sea (for better seaworthiness) by means of relatively small water ballast.

- However, the same experience also shows the common disadvantages of multi-hulls:
- relatively larger wetted area, which means worse performance at low relative speeds;
- greater mass of hull structures relative to the displacement;
- a substantial possibility of wet deck slamming in head waves;
- increased overall width.

More detailed comparison of the monohull and some multi-hulls are shown by the Table 2.

It must be noted that several types of multi-hulls are currently being researched [1], [2], [3]; all of these differ from each other and from the monohulls in various stages. The application of other types of multi-hulls is the first line of development.

3.0. CATAMARAN DEVELOPMENTS

Unfortunately, the development of all the technical characteristics as a whole is impossible. Therefore, the previously shown features of ship types allow the development of the most important (for the required purpose) characteristics of a catamaran.

3.1. Increased Seaworthiness

This can be achieved by a transition from the catamaran to the duplus – if smaller transverse stability and lower achievable speed are permissible. Table 3 contains a comparison of the achievable (from the vertical acceleration point of view) speed in head waves of two ships with 100 t displacement and equal installed power, and no motion mitigation. The estimations are based on test results in the seakeeping basin of the Krylov Shipbuilding Research Centre, Russia.

The advantage of the small-sized duplus is clear: the corresponding catamaran can ensure a minimal speed only at Sea State 3.

Fig. 5 contains an example of the achievable speeds in head waves of two 1,000-t ships, for bow acceleration level a/g = 0.4.

Table 1: Relative deck area comparison, (here: L, L_1- length of the initial (combat) monohull and a hull of the comparable multi-hull; L_{OA}- overall length of a multi-hull, V – volume displacement of the monohull; B, B_1, B_{OA} – beam of the initial monohull, beam of a hull of comparable multi-hull, overall beam of a multi-hull; A_{UD}- upper deck area coefficient).

Ship type	Relative length of a hull	Most possible dimensions	Relative area of upper deck
Monohull	$l_{MON}=L/V^{1/3}$	L/B=8; A_{UD}~0.8	$0.1*L^2$
Catamaran	$l_1 = l_{MON}$	L_1=0.8*L; B_1=0.8*B; A_{UD}~0.9; B_{OA}=(4÷8)B_1	$(0.23÷0.46)*L^2$
Duplus or trisec	l_1=0.8*l_{MON}	L_1=0.64*L; B_{OA}=(0.3÷0.5)*L_1;A_{UD}~1.0	$(0.19÷0.32)*L^2$
Outriggered usual hull	l_1=1.2*l_{MON}	L_1/B_1=10; L_{OA}=(0.3÷0.4)*L_1; B_{OA}=(0.2÷0.3)*L_1;	$(0.17÷0.25)*L^2$
Outriggered SWA hull	l_1=0.8*l_{MON}	L_1=0.8*L; Lo=(0.3÷0.4)*L_1; B_{OA}=(0.3÷0.5)*L_1;	$(0.18÷0.3)*L^2$
Tricore	l_1=0.5*l_{MON}	L_1=0.35*L; L_{OA}=1.6*L_1; B_{OA}=(0.6÷0.8)*L_1;	$(0.08÷0.1)*L^2$
Trimaran (Russian understanding)	l_1 = 0.6*l_{MON}	L_1=0.42*L; L_{OA}=1.6*L_1; B_{OA}=(0.4÷0.5)*L_1;	$(0.09÷0.12)*L^2$

Table 2: The main advantages and disadvantages of different types of displacement ships.

Type	Advantages	Disadvantages
Monohull	Most comprehensively studied and most commonly used. Lowest building cost per ton of displacement. Minimal relative wetted area.	Limited initial stability for slender hulls. Speed or heading on rough seas is limited by roll and pitch motions, slamming, green water and longitudinal bending moment.
Catamaran	Lowest building cost per square meter of decks. No problems with initial stability and rolling. Vehicles can be conveniently placed far above WL. Lower wave resistance. Lower probability of bottom slamming.	Wide overall beam. Higher weight of metal structure per ton of displacement. Larger relative wetted area. Speed or heading on rough seas are limited by pitch, slamming of wet deck, and longitudinal bending moment.
SWATH	Wide and well elevated deck area for vehicles. Perfect initial stability, roll and pitch motions. Low longitudinal bending moment; it drops at higher speed in head seas. Low wave resistance. Low slamming probability. Low additional resistance in waves.	Wide overall beam, transverse bending moment is greater than for catamaran. Greater relative wetted area. Narrow struts and gondolas make it difficult to place and access the main engines. Greater relative wetted area.
Ship with conventional main hull and two outriggers	Wide and convenient cargo deck well above WL. Satisfactory initial transverse stability. Lower, than for monohull, wave resistance of main hull. Lower probability of bottom slamming. Transverse bending moment is less than that for catamaran and SWATH	Wider, than for monohull, overall beam, larger relative wetted area. Higher, than for monohull, longitudinal bending moment, which rises in higher seas. For stern outriggers – worse controllability, than that of a monohull,.
Ship with SWA main hull and two outriggers.	Wide and convenient cargo deck well above WL. Satisfactory initial transverse stability. Low transverse bending moment. Low wave resistance. Good motions and no slamming. Low additional resistance	Large overall beam. Wetted area is greater than for conventional main hull. For outriggers place aft, controllability is worse. The least apprehended yet and novel concept.

Table 3.The achievable speeds of two 100-t ships in head waves (the various vertical accelerations at bow, a/g).

Sea State	0	2	3	4	5	6
Catamaran, a/g = 0.25, knots	30	20	3	1	0	0
The same ship, a/g = 0.4	30	25	6.5	4	2	0
Duplus, a/g = 0.25, knots	28	27.5	27	15	7	3
The same ship, a/g = 0.4	28	27.5	27	25.5	13	6

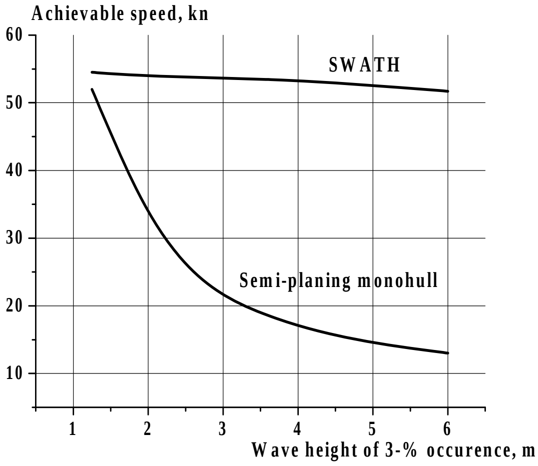

Figure 5: The achievable speeds in head waves, 1,000 t, a/g=0.4.

It must be noted that any motion mitigation is very effective for SWA ships, because they differ in their decreased disturbing forces and moments, compared with those generated by motion mitigation devices.

3.2. Better Performance at the Defined Range of Speeds

The favorable interaction of the wave systems which are generated by a trimaran (in the Russian sense: a triple-hull ship built with identical traditional hulls) is greatest at the Froude numbers for a hull length from 0.4 to 0.7, with the maximum near 0.5. This means a substantially better performance is possible if a catamaran is replaced by a trimaran (see Fig. 6).

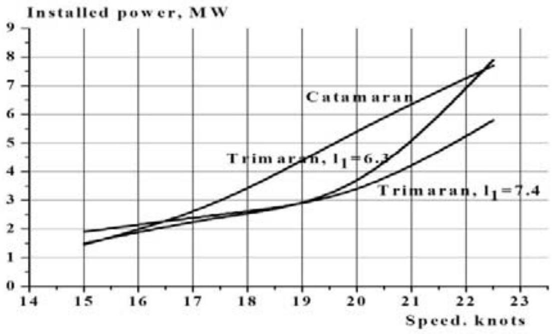

Figure 6: The power comparison of the catamaran and two trimaran options, displacement 500 t.

It is clear that the installed power of the better trimaran can be 30-35% less than that of the catamaran.

3.3. Decreased Hull Structure Mass

If the inner volume of the above-water platform is constant, the transition from a catamaran type to an outrigger type allows some reduction of the hull structure mass.

Moreover, in some cases, an outrigger ship has other advantages. For example, the pulling propellers ensure a minimal level of underwater noise for ships which require that characteristic. For example, Fig. 7 shows an external view of an outrigger seismic ship as an alternative to the catamaran used for the same purpose.

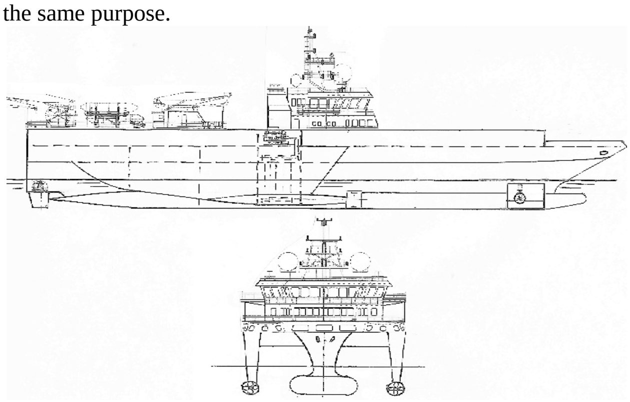

Figure 7: General arrangement of the seismic ship with a minimal level of under-water noise.

3.4. Growth of Achievable Speed

As noted previously, today's "wave-piercing" catamarans (WPCs) are the best fast vessels because of their good performance at high speeds, satisfactory seaworthiness and not so high cost of building. But most fast WPCs have a relative speed on the higher level of the transient speed regime. Their higher speed needs changing the shape of the hulls; instead of the lengthened smooth hulls of a catamaran, sharp hulls with a small aspect ratio are needed for the planning regime.

A new type of super-fast vessel has been proposed, called the "wave-piercing" trimaran (WPT). Fig. 8 shows a comparison of the installed power of two WPCs with two corresponding WPTs. The WPTs clearly perform better at approximately twice the speed of the WPCs.

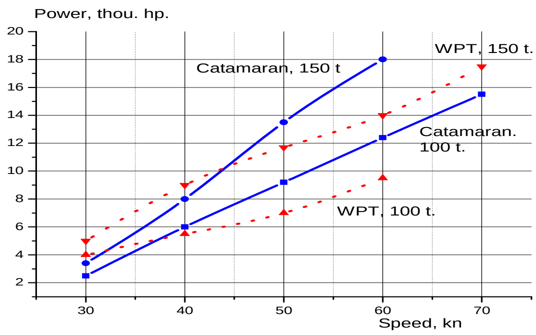

Figure 8: Power comparison of two WPCs and corresponding WPTs.

Tests on the models have shown the dynamic stability of a WPT in the vertical plane up to a relative speed (Froude number by hull displacement) of up to 7.5. In addition, the possibility of bottom slamming of sharp hulls is very low.Fig. 9 shows an example of the WPT as a passenger ferry (100 t, 100-150 passengers, up to 100 knots).

Figure 9: WPT as a ferry, up to 100 knots.

4.0 THE DEVELOPMENT OF AN OUTRIGGER SHIP.

The methods of outrigger ship development are defined by the needs of the owner and/or operator. The following aims and methods are possible:

- For improved seaworthiness – replacing the traditional main hull by a hull with a small water-plane area;
- For better performance at moderate speeds – replacing the outrigger ship with a triple-hull ship with identical (traditional or small-water plane) hulls.

5.0. THE DEVELOPMENT OF SWA SHIPS

Some methods of SWA ship development are described in [3]. For example, as for a catamaran, the better performance of a duplus can be ensured by the transition to a tricore (triple-hull SWA ship with the identical hulls), if the Froude number by a tricore hull length is near 0.5. A special shape of hull can ensure the achievable speed of a SWA ship near the planning regime of speed (a so-called "semi-submersible" SWA ship). Moreover, all SWA ships can have a smaller overall draft and greater damping of motions if the gondolas are designed with their height half that of the beam.

- For seaworthiness – replacing the traditional under-water volume (gondola) of circular frames by the gondolas of elliptical frames with its height is equal to half of its beam;
- For better performance at moderate speeds – replacing the outrigger ship with a triple-hull ship with identical (small-water plane area) hulls.

6.0 THE DEVELOPMENT OF THE DESIGN ALGORITHM.

A specially designed algorithm is the second method used in multi-hull development. The algorithm includes the following components compared with the usual design methods:

- The required area of the decks (or inner volume) is one of the main initial data for dimension selection;
- The main technical characteristics are defined by variant calculations (because the multi-hulls do not usually have any design prototypes);
- The hull mass is estimated on the basis of the preliminary series of calculations;
- The seakeeping comparison by only one number, which means the possibility of fulfilling the required seakeeping standards.

The proposed algorithm is shown in Fig. 10.

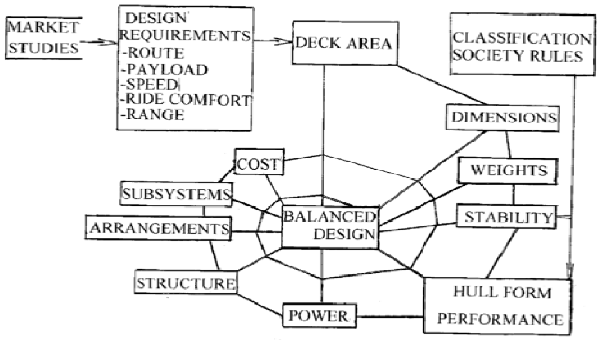

Figure 10: The specific algorithm for dimension selection.

Fig. 11 shows an example of the application of the proposed algorithm for designing a passenger outrigger ship.

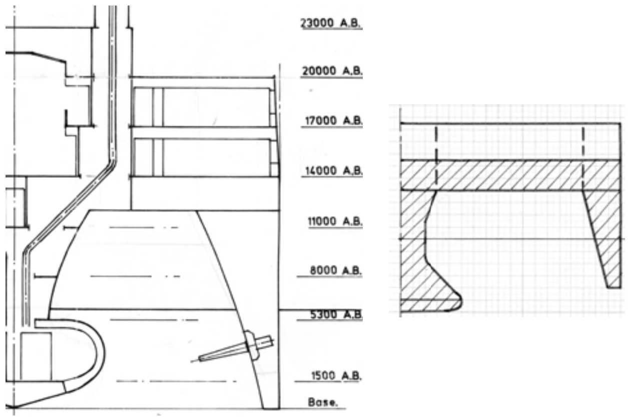

Figure 11: A comparison of the middles: left – dimensions selected by an "intuitive" method; final displacement 6,000 t; right – dimensions selected by the proposed method; final displacement 4,500 t.

The proposed method has been the main basis of many of the proposed conceptions of multi-hulls for various purposes. Fig. 12 gives examples of some of the proposed concepts.

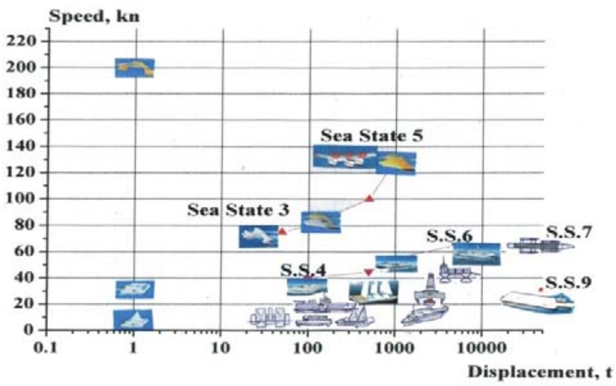

Figure12: Some new concepts of multi-hulls proposed by the author.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The brief history of multi-hulls since the middle of the twentieth century shows their expanded application for the transportation of volume – relatively light – "cargo", such as passengers in the cabins and saloons, wheeled vehicles, science laboratories, compartments for weapon systems, etc.

However, the big "family" of multi-hulls can ensure some essential developments of characteristics for various purposes. It is therefore recommended that there should be wider application of various types of multi-hulls, and the use of the special algorithm in their design.

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