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Slender Wave Superpositioning Monohull Ship

Preliminary communication

The paper presents a conceptual design displayed at the Concept Boat competition in 2004 at the Southampton Boat Show from10-19 September 2004. At the beginning the author gives a short review of the concepts of existing advanced forms, such as SWATH hull and Low Wake hull. Then he gives the main particulars of the proposed concept, and discusses the general arrangement, machinery, hull characteristics, general intact stability, boat trim, hull material, speed and weight. In the conclusion he discusses the issue of future development and improvements in ship's hydrodynamics.

Keywords: *SWATH ships, Low Wake hull form, monohulls, cruising boats.*

Vitki valno superpozicionirajući jednotrupni brod

Prethodno pripćenje

Članak opisuje idejni projekt predstavljen na natjecanju *Concept Boat 2004* na međunarodnom sajmu nautike *Southampton Boat Show* 10.-19. rujna 2004. Autor prvo kratko prikazuje koncepcije postojećih brodskih oblika, kao što su SWATH forme i Low Wake forme. U drugom dijelu autor navodi glavne značajke predloženog koncepta, daje njegov opći plan, te razmatra pogonski stroj, karakteristike trupa, opći stabilitet u neoštećenom stanju, trim, materijale trupa, brzinu i težinu. U zaključku razmatra budući razvoj i poboljšanja u brodskoj hidrodinamici.

Ključne riječi: *SWATH brodovi, Low Wake forma, jednotrupci, brodice za kružna putovanja.*

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Introduction

The study of different shapes of ship hull forms and their characteristics resulted in some interesting ideas how to adjust ship hull forms to certain conditions, and design in this way a boat that will have better hydrodynamic characteristics in certain sailing conditions.

The ship considered in this article was designed as a conceptual design made for the Concept Boat Competition 2004. It was displayed at the Concept Boat Stand at the Southampton Boat Show from 10-19 September 2004. The competition requirements were, among other things, reduced consumption, low emission and minimised effect of boating on the marine environment.

The proposed concept was developed by studying existing shapes, such as SWATH hull forms and Low Wake hull forms, natural shapes, and Bionic solutions. In the former hull forms the wave resistance of the hull form is successfully reduced by their shape.

The basic idea was to design the boat that will have good characteristics in heavier boating conditions but primarily in the speed ranges between 15 and 18 knots or in the range of the so-called "ideal" boating speed of around 18 knots. The latter speed range is interesting when designing small ships because current hull forms do not cover that range adequately at the moment. Thus, displacement hull forms cover the range below 11 knots (Froude number by hull length *Fn* about 0.4); planing hull forms are sensitive to an increase of weight and to mass centration, and they are usually efficient at the speeds greater than 20 knots (Froude numbers by length *Fn* between 0.75 and 0.9); and semi-displacement hull forms in the range below 15 knots (Froude numbers by length *Fn* between 0.4 and 0.75). The expression applicable for ship speed assessments is $v = F_n \cdot \sqrt{gL}$, where v is the ship speed in m/s, L is the hull length in m and g is the acceleration due to gravity in m/s^2.

In any case, the currently available designs of boats (small ships) make boating less and less pleasant as boating speed increases over 15 knots.

The concept described in this article is applicable to all kinds of boats, such as yachts, work boats, fishing boats, ferries and other passenger carrying vessels, suppliers etc. It provides the optimal cruising speed with less expensive machinery and fuel consumption.

The purpose of the presented concept as a cruising boat was chosen only as one variant to satisfy the competition requirements.

1 Known concepts in hull shapes

The principle of SWATH ship (Small-Waterplane-Area Twin-Hull) is that submerged hulls do not follow surface wave motion and struts supporting an above water platform have a small cross-section (waterplane) which results in longer natural periods and reduced buoyancy force changes [1]. The vessel length range of 18 – 20 m appears to be a threshold for achieving the full effectiveness of SWATH designs. Hull sizes less than this tend to become wave followers with reduced seakeeping. Weight sensitivity would be more pronounced, even intolerable. The total resistance of a twin-hull SWATH ship at moderately high speeds is roughly 50% frictional and 50% wavemaking plus form resistance [2]. SWATH ships are considerably shorter than a monohull or conventional catamaran of equal displacement tonnage. This is partly to minimise the weight penalty caused by the more deeply submerged hulls of a SWATH ship and the fact that smaller waterplane area makes it necessary to have wider hull spacing than on a conventional catamaran. Shorter length also minimises the frictional resistance penalty from the submerged hulls' considerably higher wetted area per foot of length. Lastly, twin-hull SWATH configurations often have relatively high wavemaking resistance because their smaller length and greater structural weight make them less slender than would be desirable. A SWATH ship has two sailing modes. The first sailing mode is characterised by small vertical motions when the ship rides over surface waves and is called platforming. The second sailing mode is called contouring and it is applied when wave heights exceed the amount of cross-structure clearance. SWATH ships are designed to have a sufficiently short heave period to provide inherent contouring behaviour at low speeds.

The use of wave superposition through combination of two different hull forms has proved successful in the Displacement Glider (DG) [3] which is designed for boating conditions in channels but also for the open sea. The intention was to design the boat that will not produce significant own waves, and thus to avoid the wave washing causing flushing and destroying of the shore and building foundations. The combination of the planing hull and deep wide keel provided two wave systems which interfere and cancel each other. The boat has good maritime characteristics and increased energy efficiency up to 30% because of reduced wave resistance.

The main characteristics of the Displacement Glider are:

- less total resistance than conventional hull design, particularly in the hump range;
- reduced installed power requirement and significant less fuel consumption;
- high directional stability and low leeway;
- lower rolling and slamming amplitudes resulting from damping influence of the keel higher stability from lower centre of gravity;
- higher obtainable speeds in rough sea than common planing boats; and
- enhanced manoeuvrability in rough seas.

2 Design proposal for the ship according to the new concept

In the text that follows the preliminary design considerations employing the idea of the new concept are presented.

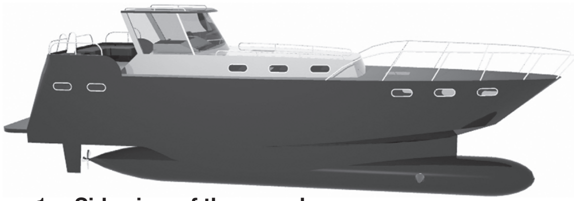
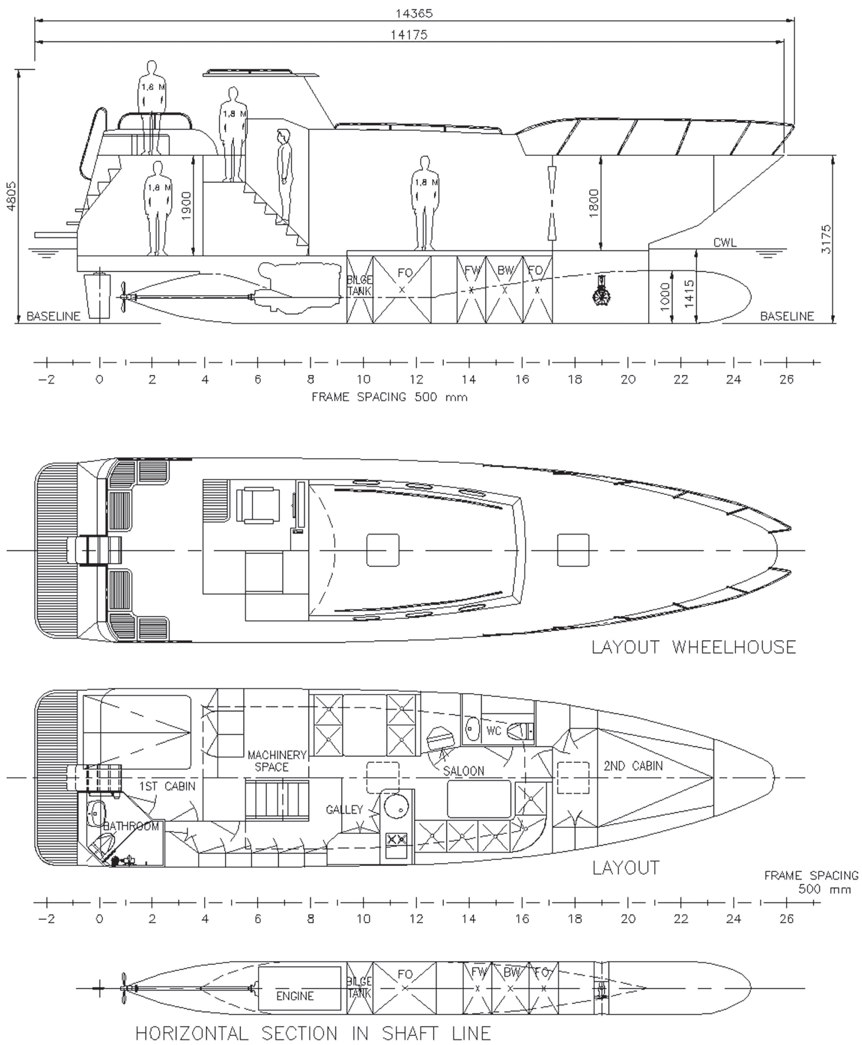


Figure 1 **Side view of the vessel**
Slika 1 **Bočni pogled na brod**

2.1 Main particulars of the new concept

- Length over all……………………........14.365 m
- Beam …………………………………. 3.5 m
- Draught ………………………………..1.415 m
- Displacement ………………………… 16 t
- Power ………………………………… 368 kW
- Max. speed …………………………… 20 knots
- Fuel ……………………...................... 1500 l
- Water …………………………………. 500 l
- Crew (passengers) ……………………. 6+2

Figure 2a **General arrangement**
Slika 2a **Opći plan**



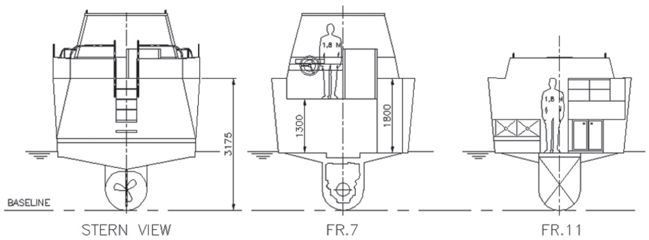


Figure 2b **Transversal sections**
Slika 2b **Poprečni presjeci**

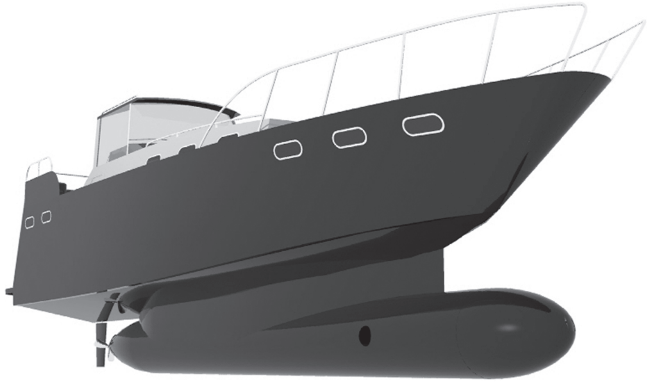
The inner space is divided into five main spaces: 1st cabin, 2nd cabin, saloon, galley and machinery space.

The engine, batteries and tanks are placed in the deep keel, which results in lowering vertical centre of gravity and more space in the upper hull. Because of a lower vertical centre of gravity, the superstructure of the vessel is higher and provides standing height in all spaces except machinery, which is placed below the wheelhouse and the stairs. Owing to the low position of the engine, construction of the shaft and propeller is simpler and less expensive. The 1st cabin is provided with a double bed and a bathroom with a shower and the 2nd cabin is provided with one double or two single beds. There is a toilet between the saloon and the 2nd cabin. The sitting and dining area is located opposite the gallery. The bench can be converted into a double bed, and so can the settee in the saloon. This provides enough space and offers comfort for eight persons.

2.2 Machinery

The vessel is equipped for example with a light duty operation MAN marine diesel engine for yachts (or with an engine of any other producer with similar characteristics and dimensions). Its characteristics are large operating range, low consumption and low emission values. The vessel is equipped with a bow thruster for better manoeuvring at low speed.

Figure 3a **Bow view**
Slika 3a **Pramčani pogled**



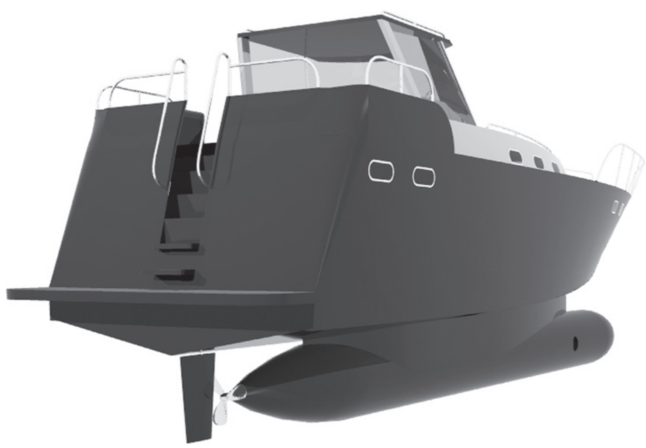


Figure 3b **Stern view**
Slika 3b **Krmeni pogled**

2.3 Hull characteristics

This concept combines two hull forms, i.e. a planing hull and a long "cylindrical displacement hull". The latter is designed in the shape of a torpedo or submarine having higher values of length-beam ratio, which has a direct influence on a reduction in hull form resistance (slender hull) [4], [5]. Most of the displacement occurs in the cylindrical displacement hull (approximately ¾ of displacement) and the rest of the displacement is placed in the planing hull. The cylindrical displacement hull is submerged deeply in the water to have minimal wave resistance. The planing hull is in the semi-planing position in all speed ranges. In comparison with a SWATH ship, which has a small and narrow waterline area, this ship has a wide waterline just like classical planing boats (Figure 4). Owing to this, its hull form has good stability characteristics as illustrated in the diagram of righting arms (Figure 7).

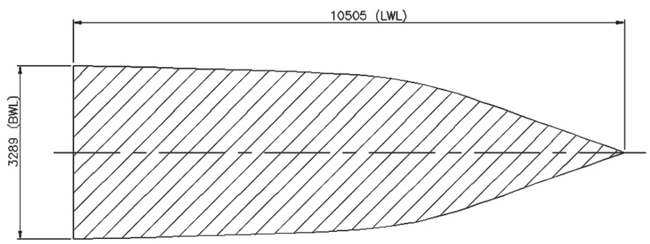


Figure 4 **Appearance of design waterline (dimensions in mm)**
Slika 4 **Izgled konstrukcijske vodne linije (dimenzije u mm)**

Because of its deep keel, this vessel will have good seekeeping characteristics in calm water and in waves too. In comparison with displacement hulls this vessel has a lower wave resistance. If compared to planing hulls with deep V-form, this form has a reduced angle of the bottom resulting in increased power efficiency when cruising in the semi-displacement range of speeds.

The idea of combining two different hull forms is not new, and it has been already used to improve the characteristics of the combined ship hull. In the considered case, this idea is aimed at the following:

- Lowering the total wave resistance by placing greater part of displacement in the zone of smaller wave influence;

- Lowering the remaining wave resistance by interfering two oppositely directed wave profiles that cancel each other, which results in a smaller wave amplitude;
- Drag reduction through a high length to beam ratio;
- Better flow characteristics because of bow bulb; and
- Wave piercing.

Theoretically, with proper selection of these hull forms and their mutual position, waves will interfere to zero and the vessel will not produce any waves. In this way the appearance of humps on the resistance diagram is avoided, wave resistance at speeds higher than 11 knots lowered, effectiveness increased and consumption reduced, i.e. speed can be increased significantly with no increase in fuel consumption.

Besides this, a long bulb on the bow additionally improves the hull form characteristics but it also reduces manoeuvrability. Because of this, the vessel is equipped with a bow thruster which, except providing help at manoeuvre in ports, marinas, etc., it generates a side force on the bow, which reduces radii of vessel turn.

Considering the keel depth, the ship is expected to exhibit the following characteristics: (1) high directional stability and low leeway, (2) lower rolling and pitching, (3) reduced slamming resulting from the influence of the keel, (4) higher speeds in rough sea than common planing boats, and (5) enhanced manoeuvrability in rough seas (high waves, strong wind etc) [3].

Lately, careful consideration has been given to environmental protection. Accordingly, efforts are being made to protect shores and buildings from flushing and washing out by boat produced waves. Thus the boats exerting reduced influence on shores and the environment are more ecologically acceptable.

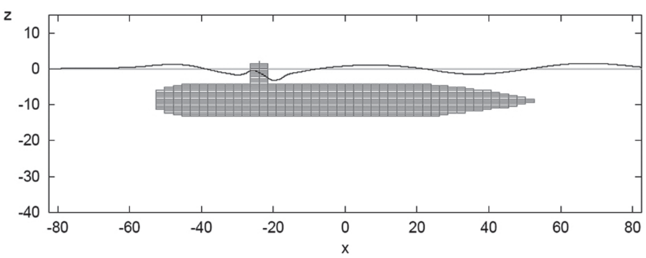
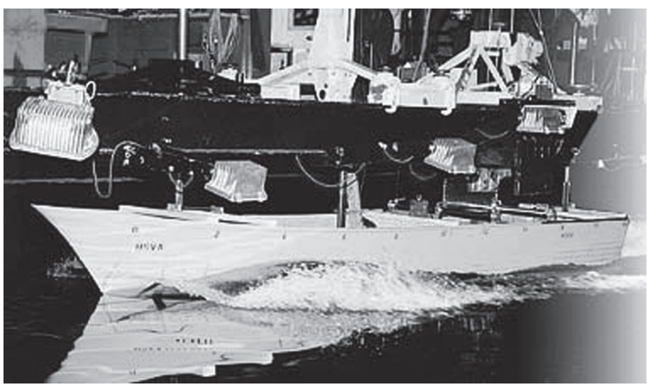


Figure 5 **Wave system of a submarine travelling at 20 knots near the surface [6], [7] (dimensions in metres)**
Slika 5 **Sustav valova podmornice koja plovi brzinom 20 čvorova blizu površine [6], [7] (dimenzije u metrima)**

Figure 6 **Example of ship's own wave system of a semi-displacement ship [8]**
Slika 6 **Primjer vlastitih valova poludeplasmanskog broda [8]**



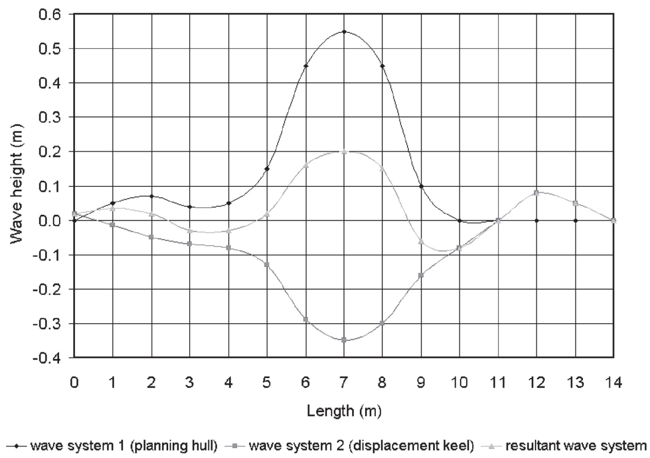


Figure 7 **Example of wave superposition**
Slika 7 **Primjer superpozicije valova**

Figures 5 and 6 are given just to illustrate the idea of wave superposition. These examples show the typical wave systems of a semi-displacement hull and submerged submarine travelling near the surface and they do not exactly correspond to the wave systems of the considered wave superpositioning hull form at the design speed. Actual wave systems can be defined only after carrying out the CFD analysis and model testing.

General idea of such analysis is to observe and examine the complete hull form without dividing on elementary parts, because when those parts interact, their wave shapes will pass through mutual changes resulting in a new wave system. Elementary parts analysis can only give the initial shape of those elementary parts of the hull and their initial longitudinal shift.

An example of possible wave superposition of an optimised hull form is shown in Figure 7.

2.4 General intact stability criteria [9]

According to the Rules and Regulations for classification of the Special Service Craft:

- Area under righting lever curve (*A1*) up to Θ = 30° angle of heel:
  $A1 \geq 0.055$ metre-radians
  $A1 = 0.084$ metre-radians
- Area under righting lever curve (*A2*) up to Θ = 40° angle of heel or the angle of flooding:
  $A2 \geq 0.09$ metre-radians
  $A2 = 0.13$ metre-radians
- Area under righting lever curve (*A3*) between the angles of heel 30° and 40°:
  $A3 \geq 0.03$ metre-radians
  $A3 = 0.046$ metre-radians
- The righting lever *GZ* is to be at least 0.2 m at an angle of heel equal to or greater than 30°.
  $GZ = 0.22$ m
- The maximum righting arm is to occur at an angle of heel preferably exceeding 30° but not less than 25°.
- The initial metacentre height *GM0* is not to be less than 0.15 m.
  $GM_0 = 0.842$ m

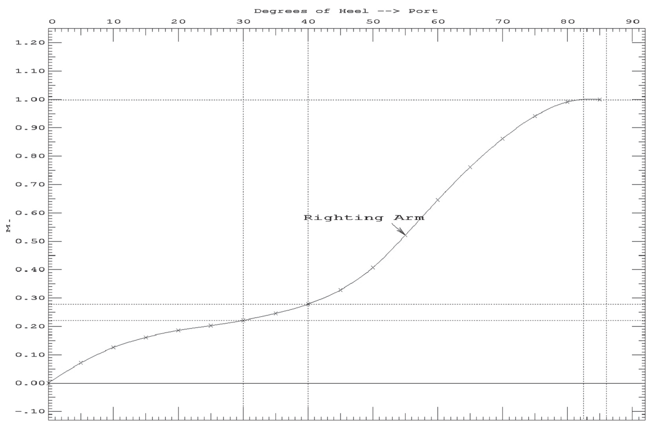


Figure 8 **Diagram of righting arms at design draft (Weight 16 t, LCG = 5.3 m, VCG = 1.250 m)**
Slika 8 **Dijagram poluga stabiliteta na konstrukcijskom gazu (Težina 16 t, LCG = 5,3 m, VCG = 1,250 m)**

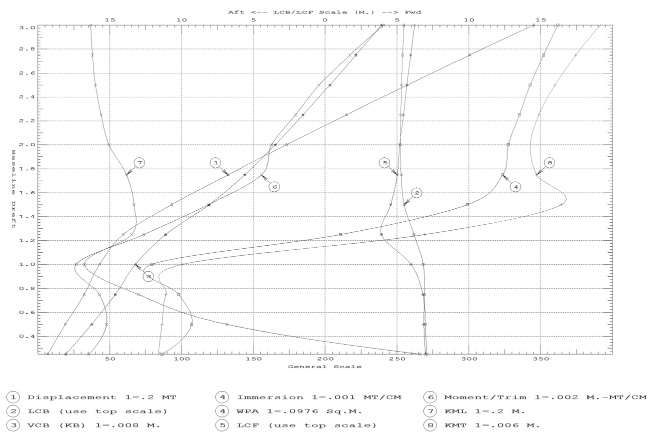
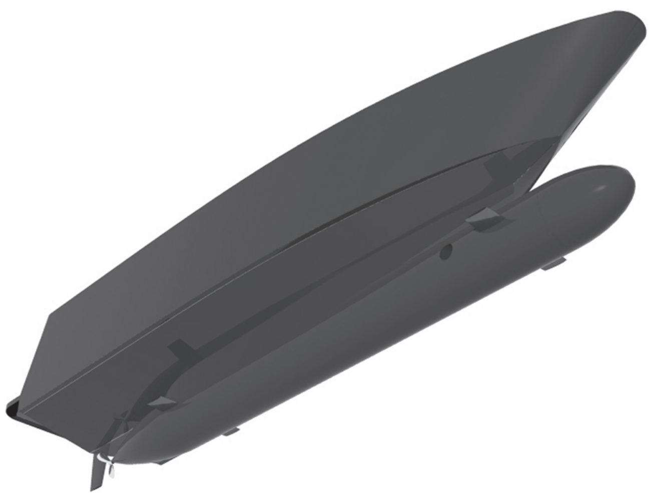


Figure 9 **Hydrostatic properties at design draft**
Slika 9 **Hidrostatske značajke na konstrukcijskom gazu**

Figure 10 **Example of a hull with hull fins**
Slika 10 **Primjer trupa s krilcima**



2.5 Boat trim

There are two possible ways to achieve an appropriate boat trim. One is an Active Ship Trimming with ballast water placed in tanks in the bow and stern of the ship. Since a minimum wave resistance in a definite range of speeds is required, an appropriate trim for every speed in this range should be provided. For this reason, the trimming system is to be controlled automatically, preferably by computer-controlled sensing and servo devices. The other solution is a trimming system with hull fins on the submerged hull similar to the one used on some SWATH ships.

2.6 Material

In order to place the main engine, systems and tanks in a deep cylindrical keel, the transversal section of the keel has to be wide enough. Additionally, the keel displacement is significant too. This is why the ship's weight has to be sufficient to place the displacement under the ship and get a proper draught. In the case of the presented conceptual design steel was used as the weight of steel is an advantage in relation to the light composite materials and aluminium, which are usually used for building small ships. Thus, steel seems to be an "ideal" boat material, thanks to its characteristics and weight in particular, and is therefore ranked first in the selection of materials. Additionally, it completely satisfies design requirements.

Prior to the calculation of the thickness of plates to be used for shell plating, and those of bulkheads and structure dimensions, a comparison between steel (7.85 t/ m^3) and aluminium (2.7 t/m^3) was made whereby aluminium is considered to be much lighter than steel (approximately 3 times). However, based on the exact calculations of plate thickness and stiffener dimensions the conclusions are different. In principle, the structure made of aluminium is 50 to 100% thicker than that made of steel because of lower mechanical strength of aluminium. Thus, in the end the relation between steel and aluminium hull is such that the steel hull is approximately 1.5 times heavier than the aluminium hull. In fast planing boats any savings in hull weight implies the savings in engine power and engine weight, weight of the auxiliary systems, fuel consumption, tank size etc. However, in case of displacement and semi-displacement boats criteria are a little different. These boats are less sensitive to weight increase (especially displacement boats) than the planing boats, and here the criteria for material selection can be different if material costs, technology, hull processing and production costs, corrosion protection, etc. are compared.

A main shortcoming of composite materials is the fact that, due to the technology used for their production, they are not cost-effective unless several boats are built using the same mould, and the production price of a single hull is high. The small specific weight of composite materials is a very unfavourable characteristic in the selection of the hull material intended for this concept.

Structure faults inside the composite structure such as cracks and delamination are hardly noticeable or not noticeable at all compared to the faults in the metal structure. The bonding of structure elements and equipment is easier on metallic boats because of the possibility of joining by welding. On the other hand, steel is environmentally more acceptable material. It is corrosive but, unlike composites, it can be recycled and reused.

In comparison with aluminium, steel production requires lower energy consumption, which is why aluminium production costs are twice as high as those of steel.

The design of the boat described in this article makes it possible to use either aluminium or composite materials, or a combination of these materials. Hybrid steel boats with fibreglass or aluminium decks and superstructures make good use of both materials [10].

The deck, wheelhouse floor and stern platform of the considered boat are covered with teak. The inner space and the cabins are covered with cherry wood.

2.7 Speed

Maximum anticipated speed of this boat is approximately 20 knots, but economical cruising speed is in the range between 15 and 18 knots.

The boat will probably have a slightly higher resistance in the speed range up to approximately 9 knots in comparison with a displacement vessel.

Engine power of 368 kW (500 KS) was chosen according to the boats with similar dimensions and displacement but it was enlarged with a certain reserve [10 -12]. Because of the specific hull form, the actual values of resistance and propulsion power can be defined only after the CFD analysis and model testing are carried out. However, these values are expected to be lower than the specified ones considering the designed characteristics of the described hull form.

A comparison between effective power of a typical planing hull form (L_{oa}= 14 m, displacement 15 t) and this new design - Slender Wave Superpositioning Hull (SWSH) form (L_{oa}= 14.365 m, displacement 16 t) is shown in Figure 11. This preliminary calculation of effective power for the SWSH is done using Michlet software [13].

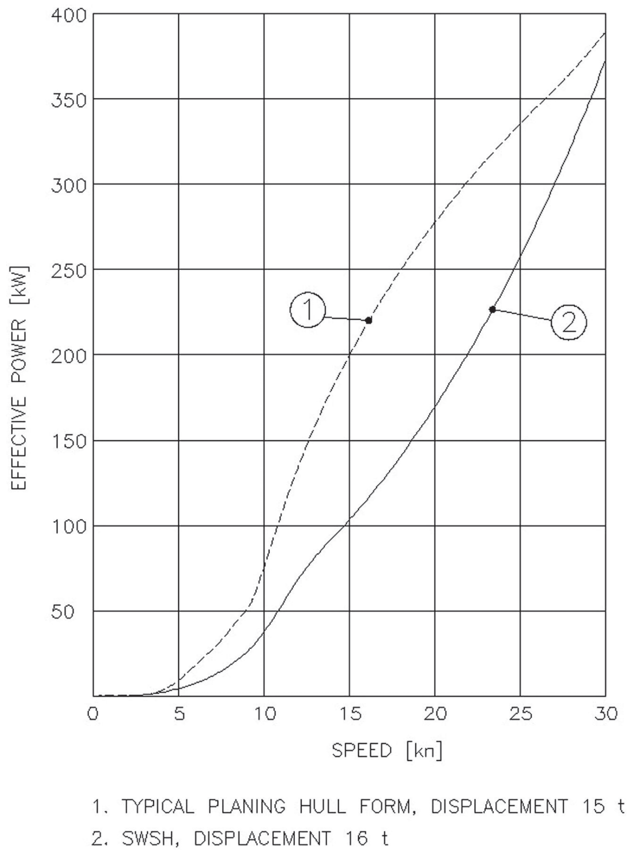


Figure 11 **Comparison of effective power between typical planing hull form and SWSH form**

Slika 11 **Usporedba snage otpora tipične gliserske forme i SWSH forme**

Table 1 **Main particulars of conventional boats with similar dimensions**

Tablica 1 **Glavne značajke konvencionalnih brodova sličnih dimenzija**

Boat No.	TYPE OF BOAT	L_{oa} [m]	B [m]	T [m]	DRY WEIGHT [kg]	POWER [kW]	SPEED max. [knots]	SPEED optimal [knots]	CONSUMP max. [l]
1	DISPLACEMENT	13.31	4.34	1.30	15195	89.4	8.8	7.2	28.0
2	DISPLACEMENT	14.30	4.45	1.36	24000	216.05	9	7	/
3	DISPLACEMENT	16.15	5.28	1.52	25424	167.625	9.6	7.7	41.6
4	SEMI-DISPLACEMENT	11.94	3.96	1.22	9534	245.85	17.7	12.5	49.6
5	SEMI-DISPLACEMENT	13.46	4.22	1.32	13166	335.25	18	14	at 9.0 knots under 11.4 l
6	SEMI-DISPLACEMENT	17.32	5.13	1.47	26786	685.4	19	13.3	187.0
7	PLANING	13.13	4.11	1.07	10896	715.2	34.6	22.3	193.8
8	PLANING	13.16	3.84	1.07	8748	551.3	30.5	25.8	155.2
9	PLANING	13.26	4.27	0.97	12258	715.2	29.7	22.3	98.0
10	PLANING	13.41	4.34	1.07	9988	664.54	29.5	14.7	187.4
11	PLANING	13.72	4.29	0.99	14391	715.2	31.5	20.6	205.9

2.8 Weight

Compared to modern plastic yachts, this vessel has a slightly greater lightweight because it is to be made of steel. Somewhat higher weight is necessary to achieve the design draught at which the vessel has its best hydrostatic and hydrodynamic characteristics.

According to the preliminary weight calculation, the weight values are as follows:

Lightweight mass ………… 12.50 t
Fuel ………………………. 1.50 t
Water ……………………... 0.50 t
8 persons (x75 kg) ………… 0.60 t
Stores ……………………… 0.90 t
Fully loaded mass …………. 16.0 t

The weight of ballast was not taken into account in the weight calculation because the vessel has ballast tanks that insure sufficient draught regardless of the amount of fuel, water and provision supply. The biggest tank with a capacity of minimum 0.7 m^3 is placed forward to provide suitable trim and draught when water and fuel tanks located forward are not fully loaded or empty.

Conclusion

As a result of careful consideration of the subject, a new ship hull form was developed. The new form resembles that of a SWATH hull form but it works on different principles. It has a slender displacement submerged hull (Figure 1), and wave resistance is reduced through wave superposition of two different parts of the hull form.

Future development of this hull form is expected to result in the creation of a new generation of the so called Smart Ship Hulls (SSH). In the future, these SSHs will enable designers to make an important step forward in conceiving and designing ships by using new alloys, composite materials and computer technology, and to lift the stiffened shell of the ship's hull to the level of sensitively-adaptive artificial life form which actively corrects unwanted flow effects in boating conditions. For example special titanium alloys which are successfully used for production of airplane wings but also for “smart ship ducts” [14], coatings which imitate dolphin's skin etc. [15]. Thus, just as penguins and dolphins, feeling undesirable flows through feather flickering or skin wrinkling, change the position and shape of their bodies to correct undesirable turbulences and water flow, so do ship's hull forms change their shape and position “sensing” undesirable flows using an automated artificial nerve system.

The idea of changeability and adaptation of the hull offers itself as a logical solution in different conditions of boating. If the planing hull is observed in the whole range of its speeds it can be seen that it passes through several different conditions of boating or water flow. Nevertheless the hull form is a rigid shell which is just exactly the same in all those conditions and thus hydrodynamic effects are manifested by forcing the water to adapt to more or less well-shaped hull form which is in fact a foreign body with completely different properties and physical laws than water.

The concept presented in this article is only one of many ways to improve hydrodynamic characteristics of a ship. In order that this idea may result in designers' different conception of a ship, it needs to be further developed and worked out.

Possibilities are endless as for development of hull forms, automation, or usage of new materials.

On one hand new technologies are thought to be expensive and not cost-effective. On the other hand, the impression is that designers of small and medium motor vessels do not give a high priority to fuel consumption and energy efficiency or, maybe, they try to compensate for inferior hull forms by providing sufficient horsepower, which results in high consumption.

Today, when oil prices are increasing rapidly and oil supplies are ever more limited, the issue of fuel consumption has to be tackled head-on because *navigare necesse est*.

References

[1] DINSMORE, R.: "Small SWATH Research Vessels" http://www.unols.org/publications/manuals/SBCompendium/11SWATH.pdf
[2] …:”The SWATH Ship Concept”, June 24th,1999; http://www.swath.com
[3] …:”Displacement Glider, DG Factsheet” E 1.3 –10/2002; http://www.alsphere.at
[4] VUČINIĆ, A.: “Hidrodinamika plovnih objekata (Otpor i propulzija broda)”, Sveučilište u Rijeci, Tehnički fakultet, Rijeka, 1997.
[5] MARCHAY, C.A.: "Aero-Hydrodynamics of Sailing" (Third Edition),Tiller Pub, November, 2000.
[6] TUCK, E.O., SCULLEN, D.C., LAZAUSKAS, L.: "Sea Wave Pattern Evaluation" (Submarine portfolio), Applied Mathematics Department, The University of Adelaide, 5 August 2000; http://www.cyberaid.net
[7] TUCK, E.O., SCULLEN, D.C., LAZAUSKAS, L.: "Wave Patterns and Minimum Wave Resistance for High-Speed Vessels", The University of Adelaide, Australia, 24th Symposium on Naval Hydrodynamics, Fukuoka, Japan, 8-13 July 2002; http://www.cyberaid.net
[8] …: "The Hamburg Ship Model Basin"; http://www.hsva.de
[9] …: Lloyd's Register: "Rules and Regulations for the Classification of Special Service Craft", July 2002.
[10] SORENSEN, E.: "Sorenson's Guide to Powerboats, How to Evaluate Design, Construction and Performance", International Marine/Ragged Mountain Press, June 14, 2002.
[11] http://www.boattest.com
[12] http://www.powerandmotoryacht.com/boattests
[13] http://www.cyberaid.net
[14] QUACKENBUSH, T.R., USAB, W.J. Jr., CARPENTER, B.F.: "Ducted Propulsors With Steerable Outflow Using Smart Materials Technology", Continuum Dynamics, Inc, USA; B&B Consultants, USA, http://www.continuum- dynamics.com/research/topics/variable_geometry_ducted_prop/
[15] THOMAS, R.H., CHOUDHARI, M.M., JOSLIN, R.D.: "Flow and Noise Control: Review and Assessment of Future Directions", NASA Langley Research Center Hampton, Virginia, April 2002.
[16] NIGEL IRENS : "The Application of Slender Hull Technology in Powered Yachts and Small Commercial Craft", Proceedings of the 18th International HISWA Symposium on Yacht Design and Yacht Construction, Amsterdam, Netherlands, 2004.
[17] NACHTIGALL, W., BLÜCHELL, K.G.: „Das Große Buch der Bionik, Neue Technologien nach dem Vorbild der Natur“, Deuche Verlags-Anstalt, Stuttgart-München 2000.