Journal of Ocean, Mechanical and Aerospace
-Science and Engineering-, Vol.2

December 20, 2013

The Minimal - Sized Ships with a Small Water-Plane Area

Victor A. Dubrovsky,[a,*]

[a)]*BaltTechnoProm Ltd., Russian Federation*

*Corresponding author: Multi-hulls@yandex.ru

Paper History

Received: 10-December-2013
Received in revised form: 11-December-2013
Accepted: 16-December-2013

ABSTRACT

In theory, a small water-plane area results in a larger than usual immersion of the main displacement volume of a ship's hull(s). Although practical realization of this theory typically involves an unusually large draft, small vessels tend to have small enough drafts. This contradiction demonstrates the problem associated with a minimal-sized ship with a small water-plane area (SWA ships). Here restrictions in terms of possible displacement and dimensions are described, with the range of minimal displacement and dimensions of an SWA ship estimated and alternative options outlined on the base of [1], [2],, [3], [4]. (A SWA hull consists of an under-water gondola as the main displacement volume, together with one or more struts connecting the gondola to the above-water platform. Evidently, the struts intersect the water surface at design draft.).

KEY WORDS: *Ships with Small Water-Plane Area; Strut; Gondola.*

NOMENCLATURE

L_1	water-plane length of a hull ,
V_1	volume displacement of a hull.
$l_1 = L_1 / V_1^{1/}3$	relative length of a hull.

1.0 INTRODUCTION

The most convenient arrangement for the engine rooms of a small water-plane area ship is the under-water gondola(s). However, if the ship's draft is significantly restricted, such an arrangement may not be permissible because the engine height may be larger than the required draft. This means that the sum of the engine width and two side passages at the level of the water-plane will be too wide for the needed width of the strut, i.e. the water-plane area will not be small enough.

The alternative option for engine room arrangement is the above-water platform. However, this usually means an increase in the mass centre height, as well as the added problem of power transmission from the main engines to the propulsors.

A compromise does exist in the form of the so-called "semi-SWATH" shape. A semi-SWATH comprises a traditionally-shaped hull middle and stern, together with a more or less strongly bulbed bow. Ships known as "quarter-SWATHs" are even further from the typical SWATH shape. Amongst the most well-known examples of these two shapes are the semi-SWATH fast car-passenger ferries built for Stena Line, and the US Navy "Sea Fighter", a fast littoral combat corvette which possesses an almost conventional (i.e. quarter-SWATH) under-water shape.

The two above-mentioned options for small-sized typical (i.e. not a combination of shapes such as a semi- or quarter-SWATH) SWA ships are presented and discussed below.

2.0 THE SIMPLIEST OPTION

It seems evident that the simplest option for the lower arrangement of engines is a conventional hull shape, positioned at the engine room(s) as a minimum. The shape of the stern is also conventional, with the bow part (from engine room to bow) more or less bulbed. However, it is thus also apparent that a significantly large water-plane area results in a reduction in seaworthiness. Minimal-sized SWA vessels can therefore be semi- or quarter-SWATH in shape only in those cases where a lower level of seakeeping is required.

3.0 THE MAIN DIESELS IN THE GONDOLAS

Naturally, the beam and height of the hull part (which contains the engine room) are defined by the engine dimensions and by the required minimal passages and frame height. The room length is defined by the engine length, the required passages and the required space for auxiliary equipment.

The strut beam is defined by the engine width and frame height, as well as some minimal gaps between the engine and frames during engine installing and extracting.

The minimal length of the ends is defined by the possible angles of flow inclination, which ensure the absence of flow separation. Usually the value of this angle is around 10 degrees.

Two end-shape options are available for minimal-sized SWA gondolas: flat in the vertical (bow) or horizontal (stern) planes, or conical. Concave ends of a gondola are supposed as not permissible ones. The struts are assumed with the same waterline angle for both ends on all strut heights, with the angles of inclination the same.

We can now define the minimal dimensions and displacements of minimal-sized SWA ships with respect to main engine power, i.e., engine dimensions. The initial assumptions are as follows: side passage plus frame height of around 1 m; distance between the gondola top and water surface at design draft of no less than 1 m; side inner gap in the strut plus frame height 0.25 m; height of double bottom 0.75 m.

The corresponding data for minimal-sized SWA hulls (twin-hulls) and achievable speeds versus engine power are shown in Table 1.

Table 1: The minimal-sized swa ships with engine rooms in the gondolas.

Single gondola power, MW	0.1	1	5
Engine height*length*beam, m	0.975*0.925*0.76	1.76*2.6*1.64	2.94*5.31*1.66
Design draft, m	2.7	3.5	4.65
Engine room length, m	4	5.5	8.3
Engine room volume including strut, cu m	14.7 + 5 = 19.7	39.3 + 11.8 = 50.6	87 + 18.3=105.3
End Length, m	2*8.1	2*10.7	2*10.8
Flat gondolas, strut displacement, cu m	2*(19.7+40)= 119.4	2*(51.1+99)= 300.2	2*(104.4+135)= 478.8
Conical gondolas, struts, cu m	2*45=90	2*112= 224	2*184= 368
Water-plane length (strut length on the water-plane), m	20.2	26.9	30
Achievable speed, kn	10.5/11	14.5/17	27/31
Relative length of a hull, l_1	5.16/5.68	5.06/5.58	4.8/5.26

Evidently, the minimal designed draft of an SWA ship with diesels located in the gondolas is around 2.5-2.7 m, the minimal displacement around 90-120 t and the achievable speed around 10-11 knots. (The achievable speeds were estimated by the SWA hull model series, [1].)

It must be noted that conical ends result in higher achievable speeds but lower damping of motion, the latter being undesirable from a seakeeping point of view.

Employing gas turbines as the main engines requires both smaller transverse gondola dimensions and a significantly large cross-section for the exit gases. As a result, the minimal design options for gas turbine-driven SWA ships will have the same displacement, but the achievable speeds will be bigger significantly, Fig. 3.

It seems evident, the minimal displacement of the twin-hull SWA ships of the main engines in the under-water gondolas is restricted exactly enough by the power and type of engines. It means the corresponded restriction of the achievable speeds too.

On the contrary, there is no such restriction, if the main engines are placed in the above-water platform.

Therefore, the displacements of such SWA ships are defined by bigger list of conditions, i.e. can`t be defined previously, without examination of these conditions, see below

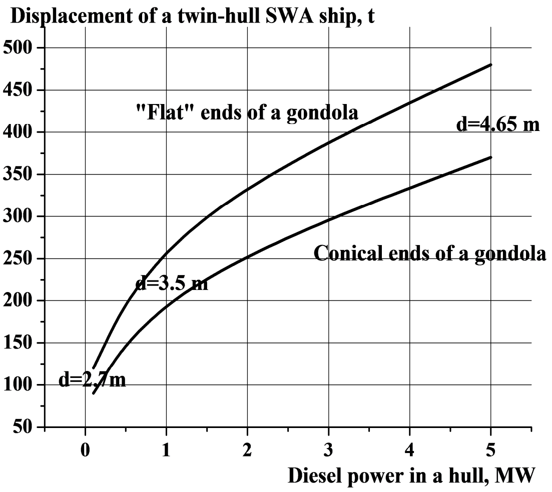

Figure 1: Minimal displacement of a twin-hull SWA ship with main diesels located in the gondolas.

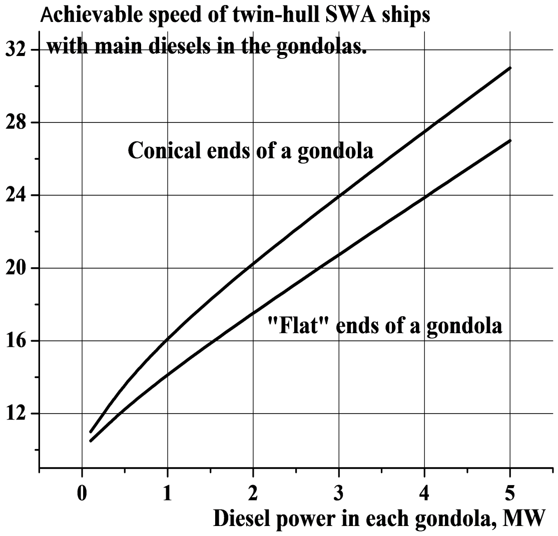

Figure 2: Achievable speeds of twin-hull SWA ships of main diesels located in the gondolas.

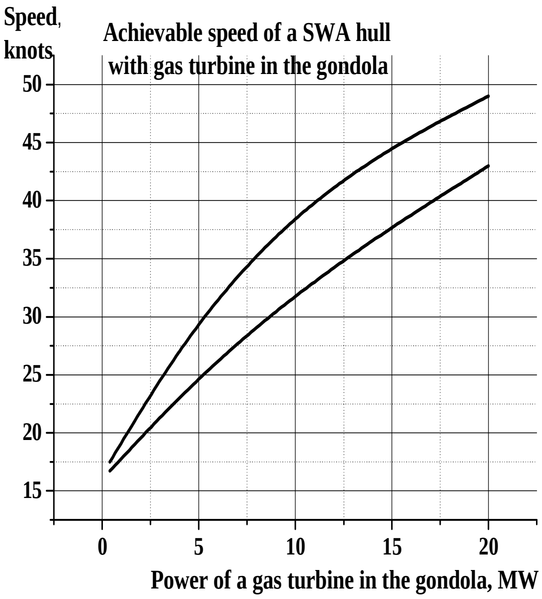

Figure 3: The achievable speeds of the minimal SWA ship hulls of gas turbines in the hulls.

4.0 THE MAIN ENGINES IN THE ABOVE-WATER PLATFORM

Although this arrangement eliminates all design draft restrictions, the need for immersion of the main displaced volume is critical for the dimension selection too. Various types of power transmission can be applied, including mechanical, electrical, hydrodynamic and pneumatic.

The simplest and cheapest – but also the most inconvenient – design is the long inclined shaft. The most significant disadvantages associated with this method include strong vibration, large weight and large occupied space. Mechanical gears can be designed for a practically unrestricted range of power. However, such an individual transmission design often means an increase in price. Electrical transmission is the most convenient method in terms of exploitation, but results in a three-fold increase in main power plant mass. Therefore, fast vessels with a high power per ton of displacement cannot use regular electrical transmission designs, while super-conducted electrical equipment is often too expensive for the majority of commercial shipping. A hydraulic transmission is thus often employed by small vessels and must be specifically designed for each.

Smaller vessels have high relative rather than absolute speeds. Fast small-sized vessels thus generally sail in the transient or planing speed modes.

It must be noted that all SWA shapes are not effective for transient and planing modes of sailing because of their principally larger relative wetted area. However, a specially-designed shape for fast SWA ships is here proposed and tested, entitled the “semi-planing” SWA ship. A relative achievable speed corresponding to a Froude number of around 3.0 – 3.1 was obtained via model tests. This speed represents the beginning of planing speed mode.

Unfortunately, such a shape is not stable under dynamic trimming and thus an automatic active trim control system is required. The proposed minimal “semi-planing” SWATH is shown in Fig. 4 [1].

Figure 4: Semi-planing SWATH as a mini-ferry or motor yacht.

The designed “semi-planing” SWATH ship can be employed, for example, as a passenger ferry for 40-50 persons or a sea-going motor yacht for 4-6 persons. The overall dimensions are ca. 15 x 7 x 4.2 m, with full displacement around 17 t, deadweight around 5-6 t for light alloy hull structures and draft around 1.2 m. The power of 2 x 0.5 MW ensures speeds of up to 30 knots in Sea States up to 3 inclusive, with a range at full speed of around 300 NM.

An alternative small-sized SWA ship design for Sea State 4 conditions is shown below (Fig. 5).

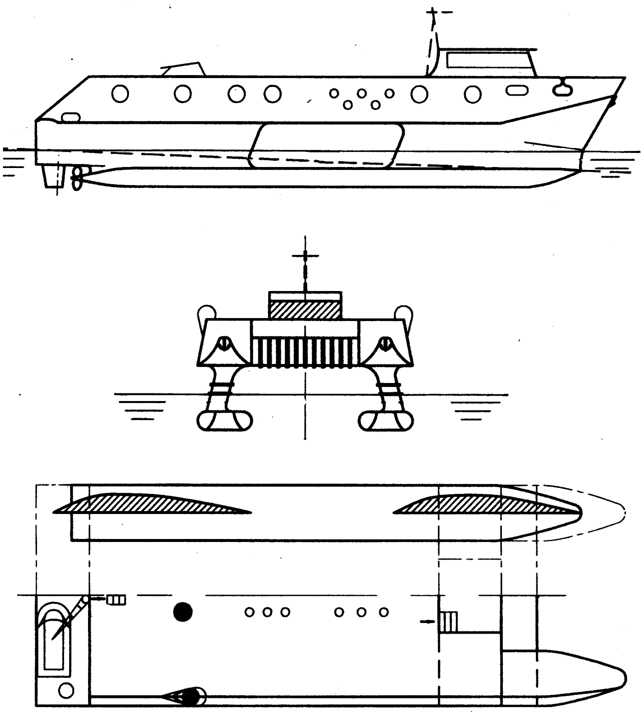

Figure 5: Motor yacht for 6 passengers: ca. 125 t, 25 knots at 2 x 0.5 MW, Sea State 4 design (the main diesels are in the above-water platform)

Even small SWA vessels have significant advantages from a seakeeping point of view. As an example, Fig. 5 displays the achievable speeds in head waves of two 100-t 30 m vessels: a duplus (a twin-hull SWA ship with one long strut at each gondola) and an usual catamaran (a monohull of the same length and displacement exhibits approximately the same longitudinal motions as an usual catamaran).

The design draft of the duplus is around 1.5 times larger than that of a standard catamaran, and the duplus has about 3 times smaller the relative water-plane area. In the graph below, the displayed achievable speed is not connected with main engine power but is defined only with respect to seakeeping.

As a rule, the achievable (seakeeping) speed in head waves is restricted by vertical acceleration at the bow. Here we selected acceleration values (relative to "g") of 0.25 and 0.4 in order to determine the possible speed during seakeeping tests, with seakeeping characteristics calculated for a random sea.

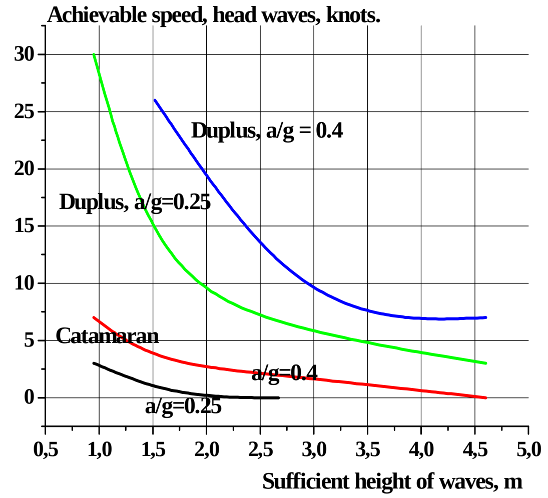

Figure 6: Comparison of the achievable (in terms of seaworthiness) speeds of two vessels (30 m, 100 t) in head waves based on model tests (without motion mitigation) [1].

Analysis of Fig. 6 reveals that the speed of a small-sized catamaran is severely restricted in head waves for the selected bow acceleration values. Furthermore, increasing the catamaran's main engine power would have no effect on its speed in waves. An engine power of 2 x 1 MWt results in the following achievable speeds for the two vessels in smooth water: catamaran – around 28 knots; duplus – around 26 knots.

5.0 A SPECIFICITY OF HULL STRUCTURE

The hulls of small-sized SWA vessels are typically connected to the above-water platform by no less than two decks, i.e., by a volume structure. This structure usually includes a third deck which provides a "double bottom" between the hulls, as shown in Fig. 7.

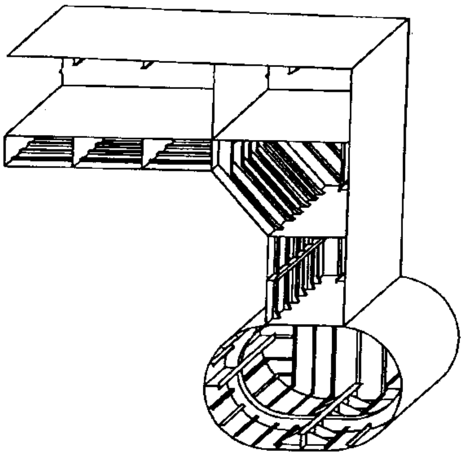

Figure 7: Usual structure of an above-water platform.

However, the inner volume of the platform must also be divided by transverse bulkheads in order to increase ship un-sinkability. The wet deck plating is thus supported by bulkheads, with the longitudinal distance between them smaller than the platform width, producing the new platform structure shown in Fig. 8 [2].

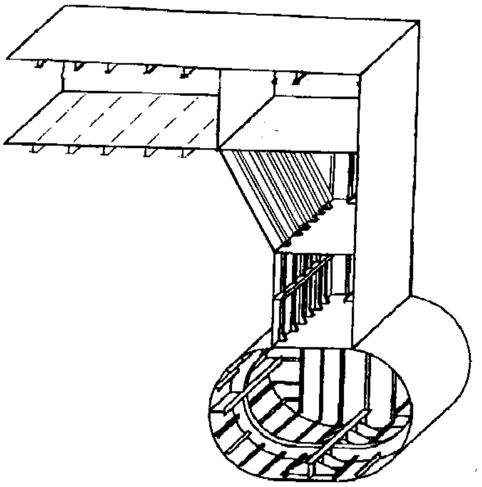

Figure 8: Proposed structure of the above-water platform (including longitudinal stiffeners below the wet deck).

This proposed structure allows both a decrease in platform structure weight and a reduction in wave slam shock. The transverse bulkheads inside the platform, which ensure the cross-sectional strength of the vessel, must be connected to the bulkheads in the struts and gondolas. The structure is presented by Fig. 9 [5].

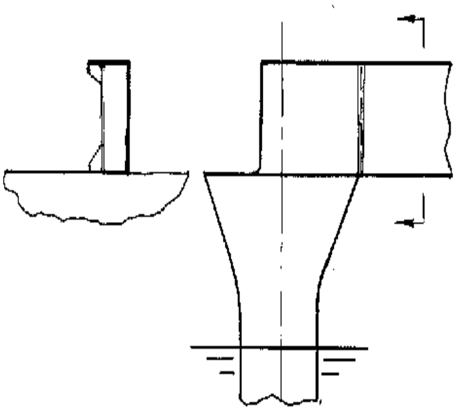

Figure 9: Platform structure of a very small-sized twin-hull SWA ship.

The two above-described design decisions ensure the minimal weight of small-sized SWA vessels with the main engines in the above-water platform.

6.0 CONCLUSION

1. The achievable minimal draft and displacement of SWA vessels depends on the main engine arrangement.
2. For ships with the main diesels in the gondolas, a minimal draft of around 2.5 m and a corresponding displacement of around 100 t can be achieved. Such vessels can reach an achievable speed of around 10 knots.
3. If the main engines are placed in the above-water platform, the SWA vessel can achieve a minimal water-plane area, thus ensuring maximal seaworthiness. And the ship displacement is not restricted practically. Some specific design options for such ships were shown.
4. A specific structure for the above-water platform was proposed with which to both minimize the weight of the SWA vessel and to decrease wave slam shock.

REFERENCE

1. Dubrovsky V.A., Lyakhovitsky, A.G. (2001), *Multi-Hull Ships*, Backbone Publishing Co.
2. Dubrovsky, V. (2001), *Multi-hulls: new options and scientific developments*, Ship & Offshore Structures, 2010, vol. 5, issue 1, pp.81-92
3. Dubrovsky,V. (2008), *A carrier for unmanned aircrafts*, The Naval Architect, pp.87,88.
4. Dubrovsky, V. (2000), *A Concept of the Triple-Hull Frigate*, Marine Technology and SNAME News, vol. 37, # 3, pp.141-142.
5. Dubrovsky, V., Matveev, K., Sutulo S. (2007), *Ships with Small Water-Plane Area*, Backbone Publishing Co.