PASSENGER VESSELS FOR THE NEW MILLENNIUM
Joint Meeting of the Pacific Region Sections
May 13 and 14, 2005
California Maritime Academy, Vallejo, California

New Types of Sea-Going Multi-Hull Ships with Superior Comfort Level and Safety

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Abstract

Multi-hull vessels of various types have inherently larger deck area, higher safety, and better seaworthiness than conventional monohulls. Multi-hulls are very well suited for passenger transportation and are a dominant force on the fast ferry market. Several advanced concepts of multi-hulls with small water-plane area hulls are considered in this paper. New relatively small ship types could expand fast marine passenger transportation to regions with statistically high sea states. Alternatives to existing large sea-going cruising ships are also proposed. Another concept, the wave-piercing trimaran with aerodynamic unloading, is considered as a natural development of modern wave-piercing catamarans into higher speed range. A large volume of technical knowledge is already available on all these concepts and no new or expensive construction technology is needed for their realization.

Introduction

The large deck area and good seaworthiness characterize the comfort level on sea-going passenger vessels. In addition, small passenger ferries must operate at high Froude numbers to keep up with the speed of large ships.

Multi-hull vessels of various types have inherently larger deck area than conventional monohulls as illustrated in Table 1. The relative hull length (length over a cubic root of displacement) is usually similar for monohulls and catamarans and somewhat smaller for ships with small water-plane area (SWA). The deck area of a catamaran and a SWA-ship can be up to 4 and 2 times, respectively, larger than the deck area of a monohull. The advantage of having an increased deck area on passenger ships comes at the cost of wider beam. This can be a problem in construction and docking and result in greater structural weight per ton of displacement.

Multi-hulls have higher intact and damage stability (Fig. 1). A large volume of the above-water platform can ensure extra reserve buoyancy, and therefore, increased safety against damage or flooding. Internal subdivision of inner volumes of hulls into two or three parts can further improve the damage stability characteristics.

A greater variety of possible general arrangements on multi-hulls allows us to design vessels suited for specific operational requirements. For example, a sufficiently high placement of the car hangar relative to the design water line means higher level of protection of this area from an accidental flooding through the hangar doors (Table 2).

Smaller roll angles on SWA ships creates an opportunity for an unusual arrangement of wheeled cargo: instead of the longitudinal placement, the lateral direction can be utilized (Fig. 2). The lateral-

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path option provides much faster loading. Solid bulkheads could be installed that effectively counteract the transverse bending moment.

Although multi-hull ships have larger relative wetted area than monohulls, this can be compensated by higher aspect ratio hulls that reduce wave resistance. As a result, the total towing resistance of a multi-hull ship is less than the resistance of a monohull with the same deck area at sufficiently high speeds.

A characteristic dependence of admiral coefficients on the length Froude number is shown in Fig. 3. The curves indicate the upper level of performance achieved by various ship types. For the length Froude number over 0.5, multi-hulls usually demonstrate better performance in comparison with monohulls. Some interpretation of these general data is presented in Figs. 4 and 5, where residual resistance coefficients and installed power are plotted against speed for three ship types having similar displacements (100 t) and length (35 m).

Frictional resistance of multi-hulls (and especially SWA ships) with large underwater hull surfaces may be reduced by using air lubrication technology (Matveev 2005). A thin air cavity is formed on the hull surface, decreasing the hull wetted area and therefore frictional resistance. For both monohulls and multi-hulls, 15-30% drag reduction is achievable at a small power expense for air injection, usually less than 3% of the total propulsive power.

Multi-hull vessels generally have better seakeeping characteristics than monohulls. For example, a properly designed catamaran has smaller roll amplitudes and similar roll accelerations as a comparable monohull. SWA ships have the best seakeeping characteristics among all ship types in displacement and transitional speed regimes. The full-scale tests of the USN SWATH *Kaimalino*, with displacement about 200 tons, demonstrated seaworthiness better than that of a 3,000-ton monohull frigate (Kennel 1992).

Larger relative deck area, higher initial stability, better safety, and potentially better speed-power performance are all reasons for using multi-hulls for transporting volumetric cargo and carrying passengers in a broad range of sea states.

General considerations

Currently, catamarans are the fastest growing ship type for passenger transportation. SWA ships are also very attractive for passenger transportation because of their excellent seakeeping, small speed loss in high seas, relatively large area of decks, and moderate construction costs. Other types of advanced multi-hull concepts can find their niche too. The service range, passenger profile, and passenger traffic volume determine the main conceptual design characteristics. Various routes that can be served by new types of multi-hulls are considered below. More details on suitable ship designs are available in the books by Dubrovsky and Lyakhovitsky (2001) and Dubrovsky (2004).

Business passengers, long routes. Currently, ships are unable to compete with aircraft as fast passenger transportation means on long routes. Only special semi-WIG multi-hull concepts, having speeds of 150-200 kts, could compete with aircraft in the future. If commercial aircraft remain a potential terrorist target, these innovative ship designs will become more attractive.

Business passengers, short routes. Under some conditions, multi-hull ships could be competitive with air and ground transportation already available on the route. For example, at a speed of about 85 kts, a sea trip between downtowns of St. Petersburg and Helsinki (225 nautical miles) could take only 3 hours with much higher comfort level as compared with airplane or bus/car (Dubrovsky 1995).

Long cruise lines, vacationing passengers. Large deck areas and excellent seaworthiness provide advantages for SWA ships on such routes. The world-first “sailing hotel” *Radisson Diamond* was built in Finland and operates in the Caribbean and Mediterranean. She is a slow-speed SWATH with horizontal foils applied as motion moderators. A possible alternative, a SWA ship with outriggers, is outlined in the next section.

Short cruise routes, sightseeing passengers. These routes have been served by ships usually designed for passenger transportation on regular routes. However, excessive speed (and power) and crowded passenger spaces are not the best solution for this application. A sail-motor SWATH with steel hull and low speed and power could be more convenient for such a service and inexpensive in construction and operation.

Fast cruise routes. In a coastal area with developed recreational infrastructure, a new type of cruise lines may be effective: staying at nights in coastal hotels and traveling fast between points of attraction. SWATH vessels could provide fast and comfortable all-weather transfer.
Yachts. Due to their inherently high safety and comfort, small SWATH vessels make attractive and safe motor yachts.
Car-passenger ferries. This is currently the most developed and growing type of marine passenger transportation. SWA ships can provide much better seakeeping and increase passenger safety. However, these ships have higher resistance in calm water than conventional catamarans.
Routes along unequipped coasts. An example of an outrigger SWA mini-liner with helicopters aboard is discussed below. Her excellent seakeeping characteristics would permit safe and efficient helicopter transfer of passengers on and off the ship without a reduction in ship speed. Such a service cannot be offered by a ship of any other type with comparable dimensions.
Existing routes of passenger-only ferries. Relatively small ships that demonstrate high speed in calm water often serve passenger-only routes. However, these ships are unable to maintain their high speed in high sea states while maintaining passenger comfort. As a result, they often experience problems in maintaining the schedule. Two new groups of relatively small multi-hull ships, discussed later in this paper, could be developed to improve the service reliability and passenger comfort in regions that frequently experience high seas. One group includes ships for scheduled lines capable of providing high speeds in rough seas. The second group includes inexpensive slow-to-moderate-speed recreational vessels with large deck areas. The first group would be more expensive in construction (with powerful engines and light-weight hulls) and could operate in seas up to sea state 5 inclusive. The second group of ships includes vessels with even better seakeeping, but with lower design speed in calm water.

Large sea-going ships

An alternative to the existing SWATH *Radisson Diamond* could be an outrigger ship with a small water-plane area main hull, as shown in Fig. 6. Her characteristics are listed in Table 3. The proposed outrigger option with an oval-shaped underwater gondola of the main hull can have smaller displacement than that of *Radisson Diamond*. The struts and outriggers will be positioned for the most favorable wave interaction. As a result, considerably lower propulsion power will be needed. The cost of construction is estimated to be lower by 15-20%. It would also provide better safety because of higher design speed and have the same deck area and seakeeping.

Many coasts in the world do not have harbors. This creates significant problems and even danger for passenger transportation along such coasts. A newly proposed type of SWA ship shown in Fig. 7 with specifications given in Table 3 could open a new market for marine transportation. This sea-going ship has two helicopters onboard to pick up and deliver passengers to/from the coast in virtually any sea states without entering harbors, mooring, or even altering the course or speed of the ship. A large deck area makes it convenient to use helicopters.

Ferries with improved seaworthiness

A line of traditional SWATH is proposed as passenger-only and car-passenger ferries with two drafts. Smaller draft ensures higher speed in calm sea, but deeper draft provides better seakeeping in waves. All these ferries exhibit minimal speed losses in waves as no other type of fast ships does; excluding vessels with automatically controlled hydrofoils. However, hydrofoil boats are not effective at large displacements and can be more expensive to build and maintain than SWA ships.

Besides SWATH ships for moderate speeds, a new type of semi-planing hydrofoil-assisted SWA ship is proposed for relative speeds up to displacement Froude numbers 3. New hull forms provide faster SWATH with minimal losses of their seakeeping in comparison to the traditional SWATH hull form. The largest displacement of these passenger and car-passenger ferries would be restricted only by the power of available gas turbines (Table 5). An artist's impression of a semi-planing SWATH as a mini-ferry (or a mini-yacht) is shown in Fig. 8. It should be noted that these ships will operate at length Froude numbers over 0.6, i.e. they are super-critical vessels for shallow-water conditions. Therefore, these ferries would have minimal loss of speed in shallow waters and minimal wash waves. Hydrofoil systems can be applied on semi-planing SWATH, supporting the ship weight, ensuring optimal trim and draft, and further improving seaworthiness.

Ferries with doubled speed

Contemporary 150-250 t fast ferries achieve maximum speeds of about 45-50 kts in calm water; 1,000 t ferries can achieve speeds up to 60 kts. Today one of the most popular types of fast ferries is a wave-piercing catamaran, because of moderate construction costs, high performance, large deck area, and reasonable seaworthiness. However, this ship type does not have a significant reserve for the speed growth, because the high aspect ratio catamaran hulls are not optimal for the planing speed regime. A new type of super-fast vessels has been proposed (Dubrovsky 1995): the wave-piercing trimarans, or WPT, that represent a combination of planing hulls with a large wing-shape above-water platform. The towing tests showed a possibility of achieving speeds corresponding to displacement Froude numbers up to 7.5 without experiencing motion instability. In seakeeping tests, hull slamming was absent up to displacement Froude numbers of 4.5 (higher speeds were not studied). The main dimensions and general characteristics of a line of WPT as ferries are given in Table 6. Artist's impressions of smallest and largest WPT are presented in Figs. 9 and 10. A general comparison of achievable speeds with other ship types is shown in Fig. 11.

As seen in Fig. 11, WPT speeds could be double these of current ferry designs. It should be noted that all WPT hulls operate in the planing regime, producing a minimal wash wake. Besides, WPT have better seaworthiness in comparison with usual planing vessels at the same speeds. A financial estimation (Dubrovsky 2003) indicates that WPT will provide a significantly faster return on investment than that by conventional fast ferries.

Conclusions

Inherent advantages of multi-hull ships in the deck area, speed/power performance, seaworthiness, and safety can provide reliable fast passenger transportation in regions characterized by high sea states and austere harbors. New concepts, such as small water-plane area ships with outriggers and wave-piercing trimarans with aerodynamic unloading, can offer a step change in the capabilities of marine vehicles and are economically more efficient than contemporary ships.

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Ship type	Monohull	Catamaran	SWA ship
Relative hull length $l = L/V_{hull}^{1/3}$	l_{mon}	$l_{cat}=l_{mon}$	$l_{swa}=0.8*l_{mon}$
Main dimensions	$L_{mon}/B_{mon}=8$ $A_d \sim 0.8$	$L_{cat}=0.8*L_{mon}$ $B_{hull}=0.8*B_{mon}$ $B_{cat}=(3\text{-}5)*B_{hull}$ $A_d \sim 0.95$	$L_{swa}=0.64*L_{mon}$ $B_{swa}=(0.3\text{-}0.5)*L_{swa}$ $A_d \sim 1.0$
Deck area	$L_{mon}*(L_{mon}/8)*A_d \approx$ $\mathbf{0.1*L_{mon}^2}$	$0.8*L_{mon}*$ $(3\text{-}5)*0.8*(L_{mon}/8)*A_d \approx$ $\mathbf{(0.2\text{-}0.4)*L_{mon}^2}$	$0.64*L_{mon}*(0.3\text{-}0.5)*$ $0.64*L_{swa}*A_d \approx$ $\mathbf{(0.1\text{-}0.2)*L_{mon}^2}$

Table 1. Typical dimension correlations and deck areas for different ship types with the same displacement. Here, L, B, and V are the length, beam, and volumetric displacement respectively; A_d is the ratio of the deck area to L*B; and subscript *hull* stands for one hull in multi-hull configurations.

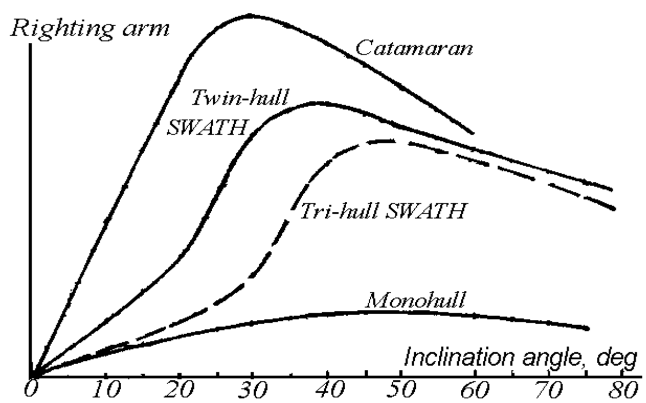

Fig. 1. Intact lateral stability comparison.

Ship type	Monohull	Catamaran	SWATH
Relative free board	*h*	*h*	1.5**h*
Height of hangar deck from water-plane, m	1-2	5-7	7.5-9.5
Relative probability of accidental flooding	p	(0.005-0.03)*p	(0.0005-0.008)*p

Table 2. Estimation of relative probability of accidental flooding through hangar doors for different types of large car ferries (L=100-150 m).

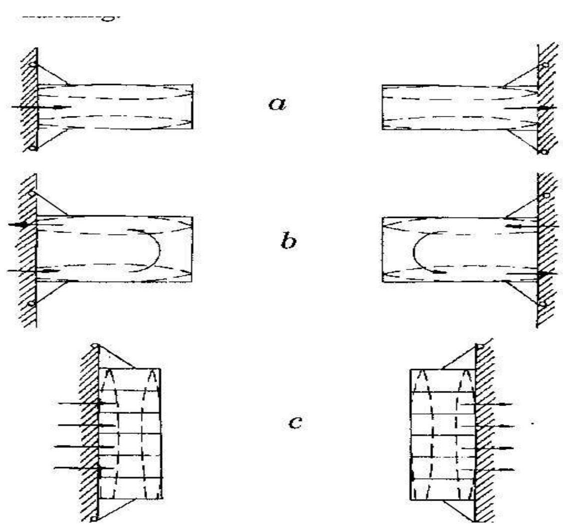

Fig.2. Possible variants of the wheeled cargo arrangement on a deck of a multi-hull car ferry: a, two doors, longitudinal path of loading-unloading; b, one door, reversing path; c, side doors, lateral path on a deck.

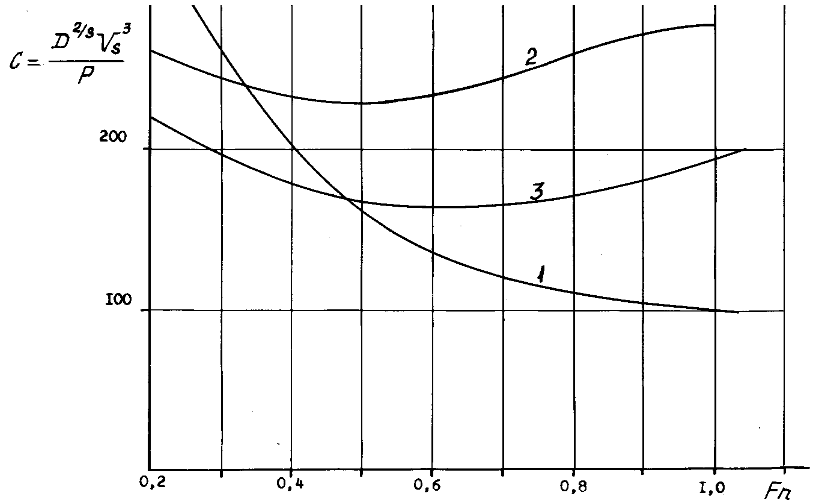

Fig. 3. Comparison of admiral coefficients: 1, monohulls; 2, catamarans; 3, SWATH. Here, D is the displacement, tons; P is the installed power, hp; V_S is the speed, knots; Fn is the length Froude number.

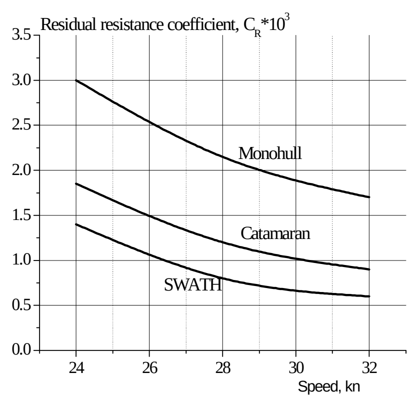

Fig. 4. Comparison of residual resistance coefficients (same displacement and length).

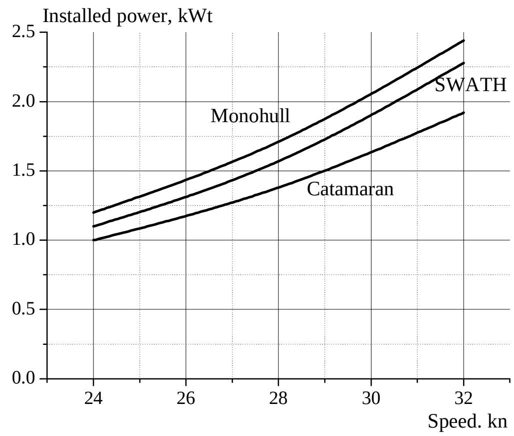

Fig.5. Comparison of installed power (same displacement and length).

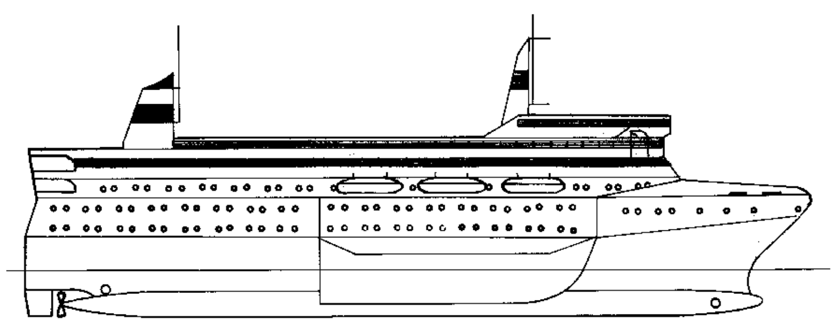

Fig. 6. Side view of a cruise outrigger ship with SWA main hull.

Purpose	Cruise ship	Mini-liner with helicopter(s)
Passenger capacity, persons	350	200
Number of cabins	175	100
Overall dimensions, m	130x42x14	140x40x14
Power plant, type and power, kW	Diesels, 8,000	Gas turbines, 40,000
Full speed, kts	16	30
Range, nm	3,000	3,000

Table 3. Dimensions and main characteristics of passenger SWA ships with outriggers.

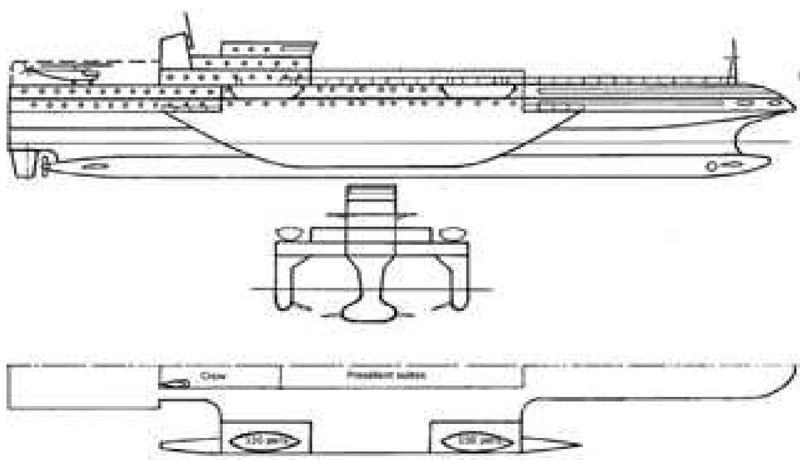

Fig. 7. External view on a passenger ship with helicopter transportation along to the coast without harbors.

Overall length and beam, m	32 x 12	40 x 14	45 x 16	50 x 16
Minimum draft, m	1.5	2.0	2.5	3.0
Maximum draft, m	2.5	3.0	3.5	4.0
Passenger capacity	150	250	350	300 +24 cars
Small draft deadweight, t	22	45	60	80
Large draft deadweight, t	50	100	120	175
Design significant height of wave, small draft, m	0.8	1.0	1.1	1.2
Design significant height of wave, large draft, m	2.0	2.5	2.7	3.0
Design speed at small draft, kts	26	33	35	33
Design speed at large draft, kts	21	30	32	30
Power plant, hp	2 x 1,000	2 x 3,500	2 x 5,000	2 x 5,000

Table 4. Main dimensions and characteristics of two-draft ferries.

Passenger/car capacity	50	1,000/100	2,000/200
Full displacement, t	25	1,200	2,500
Installed power, KW	2x400	2x30,000	4x35,000
Design speed, kts	30	50	60
Plan overall dimensions, m	15 x 7	60 x 22	80 x 28
Design significant wave height, m	1.0	2.6	4.5

Table 5. Main dimensions and general characteristics of some semi-planing SWATH.

Fig.8. Semi-planing SWATH as a mini-ferry, 50 passengers, 30 kts.

Full displacement, t	20	100	900
Overall dimensions, m	20 x 10 x 4.4	35 x 16 x 5.5	70 x 32 x 9.5
Deadweight, t	7	35	350
Useful area of decks, sq m	60	400	1,500
Passenger capacity	50	250	600
Car capacity	-	-	100
Installed power, KW	2x1,100	2x7,500	3x50,000
Speed in smooth water, kts	75	90	120
Design significant height of waves, m	0.9	1.5	2.6
Speed in this sea state, kts	45	52	60
Range in full speed, nm	400	450	500

Table 6. Main dimensions and general characteristics of a proposed family of WPT ferries.

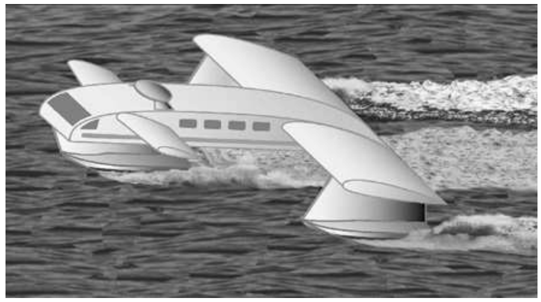

Fig. 9. WPT as a small patrol vessel.

Fig. 10. Largest WPT as a car-passenger ferry.

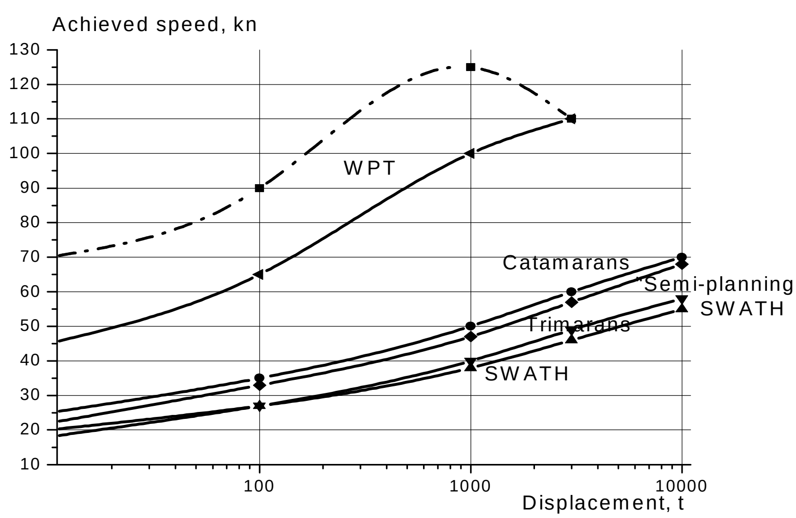

Fig. 11. Achievable speeds of various types of multi-hull ships. Upper (dash-dotted) curve for WPT is the restriction by currently available power systems; lower (solid) line for WPT is the boundary between adverse and favorable hull interactions.