

Attractive Alternatives of “X-Craft”

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Abstract

USNS “X-Craft” built as a catamaran with decreased water-plane area shows some practical advantages as multi-hull combatants. It comprises of a large deck area per tonne of displacement, wide (and free from superstructure) upper deck, high performance in terms of high-speed and enhanced seaworthiness. In this paper two alternatives have been proposed based on the concept of vessels with small water-plane area, which would allow for similar payload, useful deck area but sufficiently better seaworthiness at higher speeds. Resistance and seakeeping characteristics based on test results of the conceptual hull shapes have been illustrated. The new hull shapes of small water-plane area (SWA) ship with additional hydrodynamic lift from foils would ensure higher achievable speeds and better seaworthiness at corresponding displacement.

1. Introduction

A principally new type of fast combatants, so called “X-Craft”, was built for US Navy (Dudson, 2005). The ship with a design displacement of 1400 tonnes is a catamaran with reduced water-plane area in the bow region of the hull. This type of hull shape could be appropriately termed as “semi-SWATH”, which is a well-known hull form employed extensively in the high-speed ferry industry.

The combatant has containerized (changeable) armament, which requires large inner above-water volume (and deck area), two helipads on upper deck, movable stern ramp for boats or wheeled vehicles. The combatant has a design speed of 50 knots, unlimited operations in sea state 4 but restricted speed and heading in sea state 5. The proposed next generation of combatants demonstrates all the advantages of a multi-hull configuration namely, relative ~~big~~ large inner volume and deck area per tonne of displacement, wide (and free from the superstructure) upper deck, high performance in terms of achievable speeds and enhanced seaworthiness. These advantages have been amply demonstrated by practical application of commercial multi-hulls in the fast passenger and car-passenger ferry industry. The research publications of the last few decades in theoretical and experimental investigations coupled with the present scientific knowledge has provided a good foundation to achieve sufficiently better hydrodynamic characteristics, above all – the seaworthiness. The two alternative concepts have been described and explained below.

2. Innovative Base of Alternative Designs

The development of power plants for high-speed vessels has shown tremendous growth and does not appear to be a constraint when powering a vessel is concerned. However there are two significant factors which influence the speed of the vessel in a seaway, namely: (a) increased resistance at higher speed with a corresponding drop in propulsive coefficient due to propulsor loading and (b) unavoidable course changing in order to have better seakeeping characteristics. The change in course implies that the vessel has to traverse a longer distance between two given ports thereby decreasing the average speed. Therefore, there are three criteria to be fulfilled so that a vessel has enhanced seaworthiness: (a) reduction of added resistance (b) reduction in amplitudes of motion and acceleration and (c) reduction in slamming intensity at any heading angle relative to wave front.

There are two types of vessels which can be characterized as having significant seaworthiness: vessels with deep submerged foils and vessels with small water-plane area (SWA ships). A SWA ship can be briefly defined as having an above-water platform with payload and underwater gondolas connected

by thin struts. The displacement and the speed of foiled vessels are restricted primarily by the relative increase in foil size and hence weight at higher displacements and the cavitations phenomenon that sets in at higher speeds for foils.

In the present day scenario the maximum achievable speed for a vessel with foils is estimated to be around 70 knots with a permissible displacement of 500 tonnes. Moreover, the permissible height of waves is restricted by the clearance between the bottom of the ship's foils and wave surface. On the other hand indications from full scale trials indicate that the seaworthiness level of a SWA ship could be similar to a monohull at a displacement which could be 10-15 times larger than that of a monohull. But conventional SWA ships (with circular frames of gondolas) are not exactly suitable for high-speed operation due to the nature of their hull form. An increase in dynamic trim at high-speed and bow emerging leads to a higher than usual resistance, increased longitudinal bending moment in waves and increase motion and acceleration amplitudes for vessels with small water-plane area. In light of above facts it was envisaged that there is a need for further investigations in SWA vessels which could achieve higher speeds and have better seakeeping qualities.

3. New Hull Shapes

The new shape of a SWA ship gondola has been defined by Dubrovsky and Lyakhovitsky (2001) where the main hull is characterized by a vertical bow instead of an elliptical or semi-round bow and "flat" stern of the gondola. Moreover, the optimal dynamic trim and average draft is ensured by two pair foils at the transom end of the main hull. The proposed shape is shown by Fig. 1.

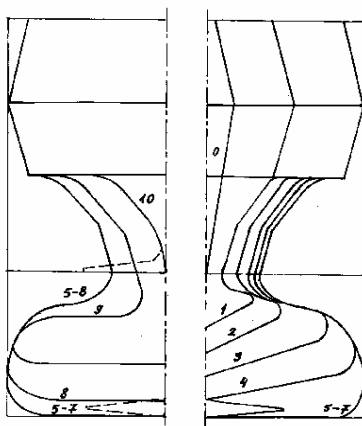


Figure 1: SWA ship with optimal trimming by foils.

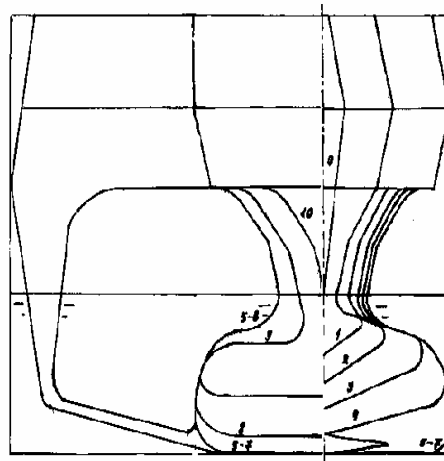


Figure 2: SWA ship with sufficient lift by foils.

The result of such changes is to avoid the disadvantage associated with bow emergence and ensures decreased wetted surface area, i.e. ensures reduction in viscous resistance at high speeds. This particular configuration, which includes foils, also prescribes an optimal attitude. If the foils generate sufficient lift force then at 25-30 % of the same vertical force motion mitigation at full speed could be achieved. It leads to the second proposed shape of fast SWA ship, illustrated in Figure 2, which is essentially a monohull SWA ship with outriggers and foils.

The large lift forces used for motion mitigation provide a possibility of a vessel traversing in larger waves within permissible levels of motions and accelerations. The proposed new conceptual hull forms eliminates wet deck slamming at high speeds as a result of increased hull clearance, (the distance between wet deck and design water-plane).

4. Towing Test Results

A twin-hull form model as previously illustrated in Figure 1 was tested in the towing tank of Krylov Shipbuilding Research Institute, St. Petersburg, Russia towards the end of 1980s. The model particulars are shown in Table 1. The towing speed and resistance were measured to an accuracy level of 0.5%.

Table 1: Model particulars relevant to Hull Form shown in Figure 1

Model Data	Dimensions
Length of waterline	3.6 m
Beam (overall)	1.6 m
Draught at rest	0.30 m
Displacement	380 kg
Foil Area (4 pairs)	0.072 m ²

The tests have clearly demonstrated that there is a possibility of dynamic attitude optimization with minimum wetted area. Figure 3 depicts a comparison of dynamic trim for various SWATH hull forms. It is evident that the decreased longitudinal stability of the tested model allows selection of the dynamic trim in the required ranges and avoidance of negative values of trim at the intermediate speeds.

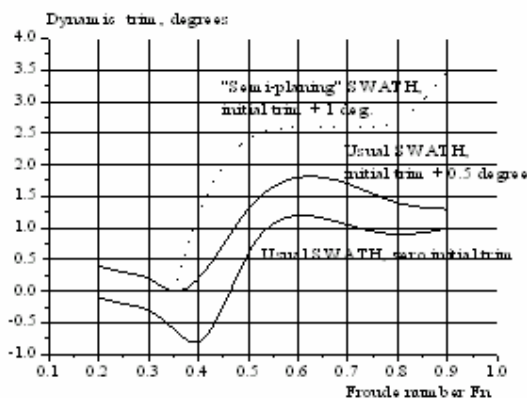


Figure 3: Dynamic trim comparison for SWATH configurations.

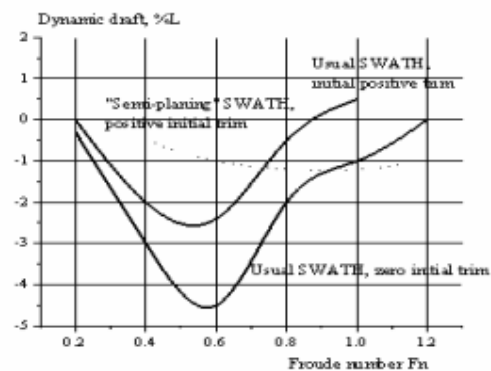


Figure 4: Dynamic draft comparison.

Figure 4 demonstrates a possibility of average dynamic draft decreasing at any speed as a consequence of decreasing part of the dynamic wetted area.

The residual resistance coefficients were defined using the constant wetted area of the model. The evident drop of the coefficient at highest speeds means the real wetted area is smaller, than the corresponding wetted surface area at rest. Thus the problem of wetted area increase has been avoided at high speeds by the proposed shape of the gondolas. Residual resistance coefficients of the first model (two drafts) are depicted in Figure 5. The residual resistance coefficient comparison shows the sufficient advantage (about two times) of the proposed hull shape. The achieved level of speed corresponds to lower limit of planing regime. Volumetric Froude number (F_{nV}) of about 3.0 is taken as the begin of planing regime for usual boats. S/P SWATH can achieve such speed, as shown by

tests. Thus the vessel can be termed as “semi-planing”, since complete planing regime corresponds to higher values of volumetric Froude numbers.

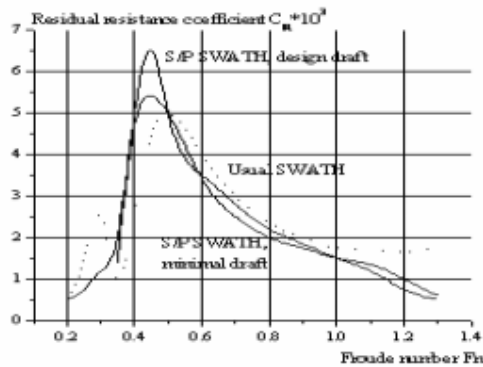


Figure 5: Residual resistance coefficients of the first shown model.

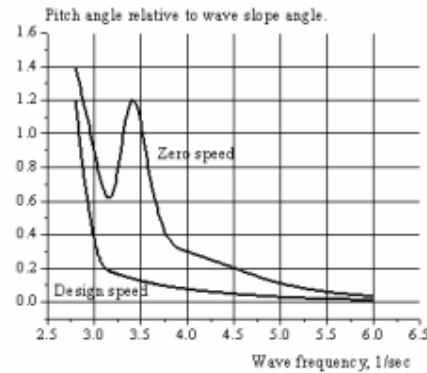


Figure 6: Pitch RAO of “semi-planing” SWATH

5. Seakeeping Test Results

The model as illustrated in Table 1 was tested in regular head waves with optimal (for ~~towing~~ resistance) angle of attack for foils. The pitch RAO is shown in Figure 6.

It is quite evident, as all SWA ships, that the “semi-planing” one has a sufficient resonant peak, and small enough pitch amplitudes on higher frequencies. It implies that there is a possibility of sufficient pitch mitigation as a result of pitch damping at resonance frequencies. The heave RAO of the same model is shown in Figure 7.

As pitch and heave motions have sufficient peak at low-frequency ranges at design speed and small enough amplitudes at the other frequencies, then resonance mitigation means there is a significant reduction in motions over a wide range of frequencies.

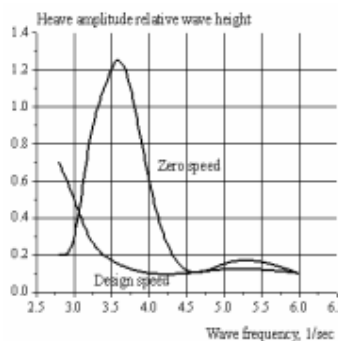


Fig.7. Heave RAO of “semi-planing” SWATH.

6. Alternative Ship Characteristics

The alternative proposals were designed to the pre-contract stage for the same payload and useful deck area, identical to the built X-craft. The hull material was of light alloy, so that the achievable

speed could be maximized. Hull structure design and scantlings were estimated as per ABS (1999). The total resistance of the first proposed vessel was estimated on the basis of previously conducted resistance tests compiled for the bigger draft. The total resistance of the second proposed vessel was estimated for minimal draft from the same test data as shown in Figure 5. The difference between the displacements at rest and at the minimal draft on full speed will be compensated by titanium foils of hydrodynamic quantity of lift to drag ration of $L/R=10$ (L – foil lift force in tonnes, R – foil resistance in tonnes). The achievable speed SWA monohull fitted with a foil corresponds to a volumetric Froude number of approximately 3.5. The results of the proposed designs against X-craft are shown in Table 2.

Table 2: Main dimensions and general characteristics of fast corvette options

Ship type	“X-Craft”	S/P SWATH	Foil-outrigger SWA
Design displacement (tonne)	1,400	1,500	1,200
Overall length (m)	79.9	60	70
Overall beam (m)	22	28	25
Payload (tonne)	About 250		
Deadweight (tonne)	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	4,000	≈3,700	≈3,500

The results clearly exhibit that the new hull forms would ensure higher achievable speeds with slightly smaller range at the economical speed of 20 knots. Moreover the shape and lift forces generated by foils would enhance the seakeeping characteristics of the vessels at a higher sea state as shown in Figure 8 whereas Figure 9 shows the achievable speed for the three crafts against wave height.

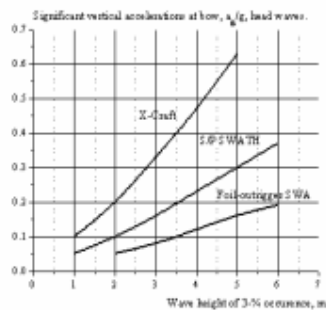


Figure 8: Vertical accelerations at bow, head waves, full speed.

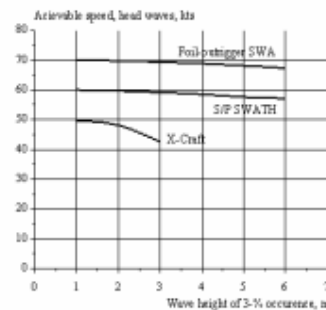


Figure 9: Achievable speed versus wave height, head waves.

The test data thus presented could be further corrected and amended during the process of detailed design. An artist's impression of a twin-hull “semi-planing” corvette is shown in Figure 10.



Figure 10: An artist impression of twin-hull fast corvette with the new hull form.

7. Conclusions

It is apparent that some quite interesting results have been derived from the above investigation. The following conclusions can be drawn:

- The proposed hull form could ensure higher achievable speed. The “X-Craft” has a maximum speed of 50 knots but a better range at the economical speed of 20 knots. Both the proposed hull forms have higher achievable speed than “X-Craft”.
- The proposed hull forms have enhanced seaworthiness when compared against “X-Craft”.

8. References

1. Dudson, E. (2005): “The X-Craft – A 73 m Experimental Platform for The US Navy”, *High-Speed/High Performance Ship and Craft Symposium, ASNE, Everett, WA, USA*.
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