Scientia Iranica B (2012) 19 (3), 463–471

Sharif University of Technology
Scientia Iranica
Transactions B: Mechanical Engineering
www.sciencedirect.com

Parametric study of a low wake-wash inland waterways catamaran

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Received 9 September 2011; revised 19 February 2012; accepted 9 April 2012

KEYWORDS
Wake wash;
Catamaran;
CFD;
Model experiment;
Wave profile.

Abstract The wake wash from passing ships can cause environmental damage. The wake wash is an important issue for naval architects and shipbuilders in concentrating on more environmentally friendly designs. This paper presents results of a parametric study of catamaran hull form to obtain low wake wash hull form configurations or low speed inland waterway boats. The study uses a Computational Fluid Dynamics (CFD) simulation, and model experiments were carried out for validation of the CFD software set-up. The study concentrates on the asymmetric catamaran hull form. The investigation is conducted on two configurations of hull form; Flat Side Inward (FSI) and Flat Side Outward (FSO) configurations. The investigation is conducted on a hull form with a Length to Beam (L/B) ratio of 12.2, 15.2 and 18.3 and a Separation to Length (S/L) ratio of 0.2, 0.3 and 0.4. The results based on wave height criteria at various longitudinal cuts have shown that the FSO configuration has a lower wake wash compared with the FSI configuration. Considering L/B and S/L ratios, hull forms with a larger separation or higher L/B ratios produce lower wave heights.
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1. Introduction

Over the past few decades, there has been considerable interest and subsequent research into a number of problems associated with ship-generated waves [1,2]. In addition to bank erosion, waves produced by ship or boat wakes are a nuisance to other users causing rubbing damage to boats berthed in marinas, as well as disturbance to swimmers, personal watercraft and water skiers.

Much work has been carried out in developing low wake wash boats but they are mainly concerned with ferries and other high-speed marine craft. There is not so much work being done in the field of smaller, slower speed craft for inland waterway applications, despite the fact that bank erosion is more critical in rivers and lakes compared to the sea.

Several things can be done to reduce wake wash or the effects of wake wash. One is designing ships for low wake. In designing catamarans, the main design characteristics to be taken into consideration are asymmetric demihulls, choosing suitable displacement distributions, increasing hull separation, and fitting hulls with bulbous bows [3–6]. Efforts in this aspect are described in [7–10].

There are many rules that can be followed in order to minimize wake wash, and these are fairly well understood. Long skinny lightweight hulls with a fine entrance, rounded bottoms, and smooth transition to the stern profile are likely to produce low wash characteristics as opposed to heavy, blunt bowed, broad beamed, flat bottom vessels [11].

2. Methodology

2.1. General

There are various methods of studying wake-wash phenomena. Ref. [1] describes an example of a full-scale study that is very costly and time consuming, while Ref. [8] presents results of laboratory experimental investigations. Some others, such as Refs. [4,5,9] use both numerical and experimental methods. On the other hand, Refs. [2,3,12] rely mainly on numerical and CFD simulation. This study puts emphasis on the use of CFD

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doi:10.1016/j.scient.2012.04.014

Table 1: Main particulars of basis ship.

Length overall (LOA)	5.10 M
Length waterline (LWL)	5.02 M
Breadth moulded of demihull	0.33 M
Beam overall	2.65 m
Draught	0.50 m
Passengers	4 persons
Crew	1 person
Service speed	3 knots
Maximum speed	6 knots

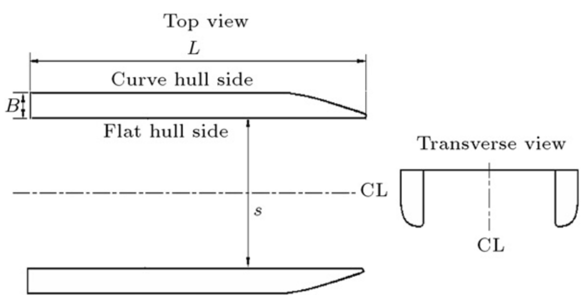


Figure 1: Basis hull form configuration.

simulation. A model experiment was used for validation in determination of the simulation setup. The early step in this study is the catamaran hull form selection. The selected asymmetric catamaran hull form was determined as a basis hull form. The parametric study was conducted on variant hull forms, which were generated from the basis hull form. The parametric study used CFD simulation for wake wash generation, while a wake profile criterion was used for low wake wash assessment.

2.2. Basis hull form

The basis hull form was created from the original hull form taken from [13] i.e. a flat bottom shaped, asymmetric catamaran, with the flat side of the hull faced inward. In order to obtain better wash characteristics, the hull form was modified based on the assumption that a hull form with a rounded bottom and smooth transition to the stern profile will produce a lower wash compared to a flat bottom vessel [12]. The main particulars of this basis hull form are given in Table 1.

The basis hull form configuration is shown in Figure 1. It is designated as a FSI configuration in which the flat hull side is placed at the inner side of the asymmetric catamaran and the curved hull side is placed at the outer side of the asymmetric catamaran. The value of the L/B ratio for the basis hull form is 15.2.

3. Wake wash assessment

This study concentrates on the use of wave height criterion for the wake wash assessment. The assessment of wake wash using this criterion is based on comparison of the longitudinal cut of the wave profile at several transverse locations. Figure 2 shows an example of the location of a longitudinal wave, cut at a distance, y, from the outer side of the demihull.

3.1. Simulation

The aim of the simulation is to investigate the wake wash generated by the asymmetric catamaran hull form. The hull form of the asymmetric catamaran was designed with Computer Aided Design ship design software, PROSURF 3. It was

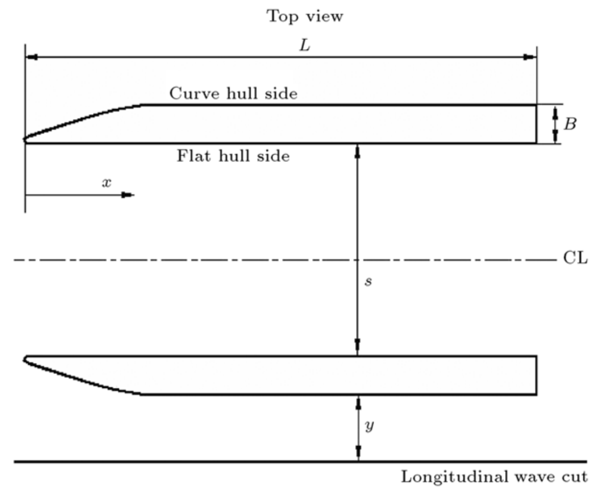


Figure 2: Location of the longitudinal wave cut from outer side of the demihull.

developed by New Wave Systems, Inc. USA. The 3-dimensional design of the asymmetric catamaran hull form produced by PROSURF 3 was then transferred to Computer Aided Design software, AutoCAD 2000 to get a complete set of offset data for the simulation process. The offset data of the asymmetric catamaran obtained from AutoCAD contains 100 stations with around 27 points each.

The simulation program used in this study was a commercial package of CFD software, SHIPFLOW [14] version 2.8. The software developed by Flowtech International AB and Chalmers University of Technology is a special purpose software for investigating the hydrodynamic properties of ships and other marine vessels. It makes use of three different methods to compute the resistance of a ship; a potential flow method, a boundary layer method and Reynolds Average Navier–Stokes equations (RANS). Amongst the many capabilities of this software is prediction of the wave profile.

3.1.1. Simulation set-up

The accuracy of the simulation results depends on its setup. The setup conditions in this simulation cover the number of points in development of the hull form, the number of elements used for the division of the hull form and the free surface area, and the calculation method of the fluid.

In order to obtain the desired shape of the hull form for simulation purposes, 5400 points were defined at each demihull of the catamaran hull form, covering 100 stations and 54 points at each station.

In terms of the division of elements, the hull form of the catamaran demihull is divided by 31 stations. Each station was divided by 14 points; seven points at portside and seven points at the starboard side. The free surface was divided into two areas, the first was the area near the hull form and the second was far from the hull form or, so called, the far field area. The near area was divided by 48 elements in breadth and 53 elements in length, and the far field area was divided by 81 elements in breadth and 61 elements in length. The total area of free surface was five times the ship length in breadth, and the length of the free surface area was as far as eight times the ship length. Figures 3 and 4 describe the hull form elements and the free surface elements division methods, respectively.

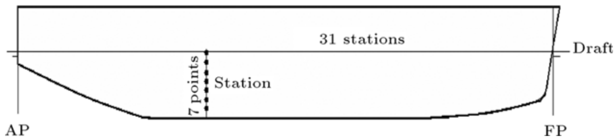


Figure 3: Element division of the hull form.

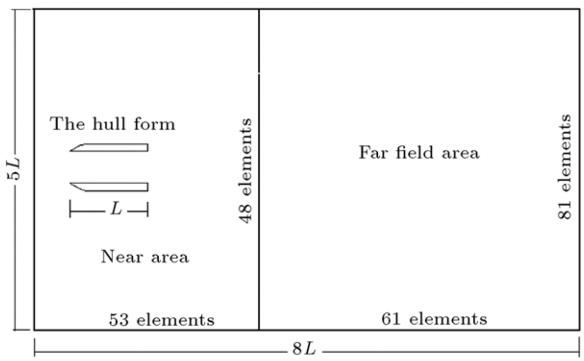


Figure 4: Element division of free surface.

Table 2: Main particulars of ship model.

Length overall (LOA)	2.04 m
Length waterline (LWL)	2.00 m
Breadth moulded of demihull	0.13 m
Beam	1.06 m
Draught	0.20 m
Displacement	80.64 kg

The simulation set-up was limited to potential flow and boundary layer calculation. This complies with the SHIPFLOW limitation for a multihull case [15].

3.2. Hull form configuration and wave cut location

For validation purposes, the basis hull form of an asymmetric catamaran, with L/B ratio of hull form 15.2 and S/L ratio of 0.3, is used. Froude Number (F_n) of 0.3 was used for the validation.

In order to carry out the assessment of wake wash criteria, the wave profiles are taken at two longitudinal wave cut locations (y/L). The locations are the Centreline (CL) of the asymmetric catamaran and the outer side of the demihull of the asymmetric catamaran i.e. y/L ratio of 0.2. The hull form configuration and location of the longitudinal wave cut of the wave profile can be seen in Figure 2.

4. Experimental validation of CFD software

In order to validate CFD simulation results, a model experiment was conducted in the towing tank of the Marine Technology Laboratory (Figure 5).

The tank is 120 m long by 4 m wide, with a water depth of 2.5 m. For model experiment dimensions, the asymmetric basis hull-form was scaled down using a scale of 1:2.5, giving a 2 m long model, and weighing 80.64 kg in weight. The detailed particulars of the model can be seen in Table 2.

The investigation was conducted on the basis hull form configuration, which is the FSI configuration with L/B ratio of the hull being 15.2. The investigation was conducted with $F_n = 0.3$, which corresponds to a speed of 3 knots. At each run, wave heights are measured at three points using resistance-type wave probes. Two wave probes are placed 40 cm distance from the outer side of the asymmetric catamaran hull form model, corresponding to y/L ratio of 0.2. Another wave probe was placed at the centre line of the catamaran. The longitudinal locations of the wave probes were varied along the length of the boat at every experimental run.

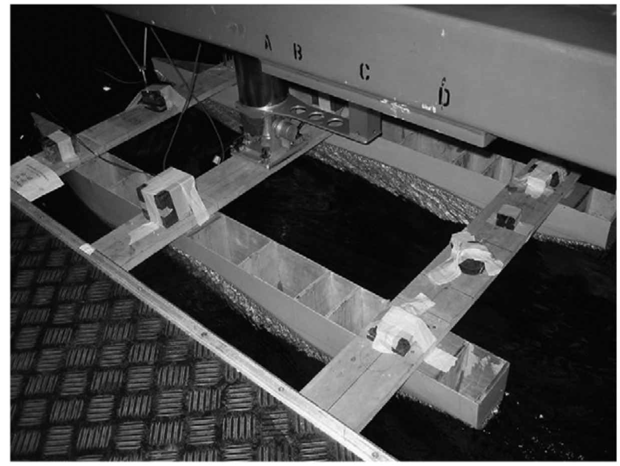


Figure 5: Model test in Marine Technology Laboratory.

The validation was made based on a comparison of the wave generated by the asymmetric catamaran from simulation and the model experiment. The comparison covers the asymmetric catamaran generated wave in a three-dimensional view, and the graphs presented the wave profile at specified longitudinal wave cuts. The wave profile was presented as the ratio of the distance and ship length (x/L) versus the ratio of wave height and ship length (h/L).

4.1. Validation results discussion

The comparison of wave profile results at longitudinal wave cut locations along the Centerline (CL) and $y/L = 0.2$ are given in Figures 6 and 7 respectively. Figures 6 and 7 show that the simulation results are very closely correlated to the model experiment results. For y/L of 0.2, the correlation is very good except for a slight phase shift. The comparison at the CL is not as good, but SHIPFLOW results are not too far out from the experimental data, particularly in order of magnitude. The covariance between the datasets is positive and the correlation coefficients for $y/L = 0.2$ and the Centerline are found to be 0.76 and 0.68, respectively.

The experimental work carried out has validated the CFD software set-up. The comparison of wave profiles from the model experiments with CFD results has indicated a good correlation. Although the phase relationship was not very good, the order of magnitude is comparable. This should be sufficient for parametric study purposes because in parametric study, the comparison will be made in terms of the order of magnitude of the wave heights. Hence, SHIPFLOW CFD software can be used in the parametric study based on the set-up described in this work.

5. Parametric study

The parametric study of the asymmetric catamaran hull form in this study covers the hull form configuration, the

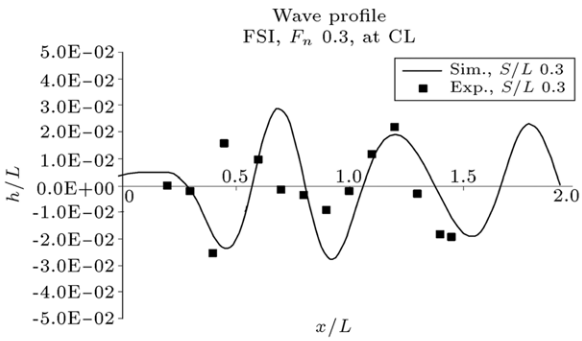


Figure 6: Wave profile comparison between simulation and model experiment results at longitudinal wave cut of the *CL* for basis hull.

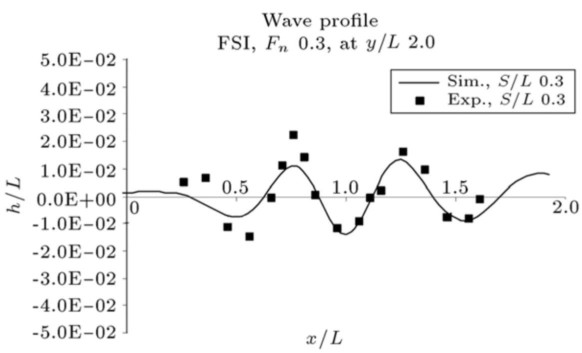


Figure 7: Wave profile comparison between simulation and model experiment result at longitudinal wave cut (y/L) of 0.2.

variation of S/L ratio, and the variation of L/B. The flow chart for the parametric study of low wake catamaran hull form was presented in Figure 8. Two variations of hull form with different L/B ratio are generated from the basis hull form, as shown in Table 1.

The wake wash of the variants was predicted using CFD software. The assessment of low wake wash was conducted using the wave height criterion. Variation was also made in S/L ratio.

The hull form configurations investigated are related to the placement of the flat hull side of the asymmetric catamaran hull form. The configurations are FSI and FSO, where FSI is the flat hull side of the asymmetric catamaran placed at the inner side of the asymmetric catamaran, and FSO is the flat hull side of the asymmetric catamaran placed at the outer side of the asymmetric catamaran.

Concerning the S/L ratio and L/B *ratio* variations, the variations of S/L ratio are 0.2, 0.3, and 0.4 and the variations of L/B ratio are 12.2, 15.2, and 18.3. Figure 9(a) and (b) show the configurations, S/L, and L/B ratio of the asymmetric catamaran hull form. A summary of the parametric study of the asymmetric catamaran hull form, with F_n of 0.1, 0.2 and 0.3 is given in Table 3.

5.1. Wave cut location

The wave profile investigation in the parametric study was conducted at three locations of longitudinal wave cut as shown in Figure 9. The locations are the centerline of the asymmetric catamaran, y/L of 0.2, and y/L of 2.0.

The centerline wave profile was taken to determine the interaction of the wave generated by the demihulls near the tunnel of the asymmetric catamaran, while the longitudinal wave cut (y/L) of 0.2 was the wave cut near the outer side of the asymmetric catamaran to investigate the initial wave generated by the asymmetric catamaran. Then, the longitudinal wave cut (y/L) of 2.0 was taken with the assumption that it was a wave cut far from the asymmetric catamaran, i.e. the wave near the shore or river bank.

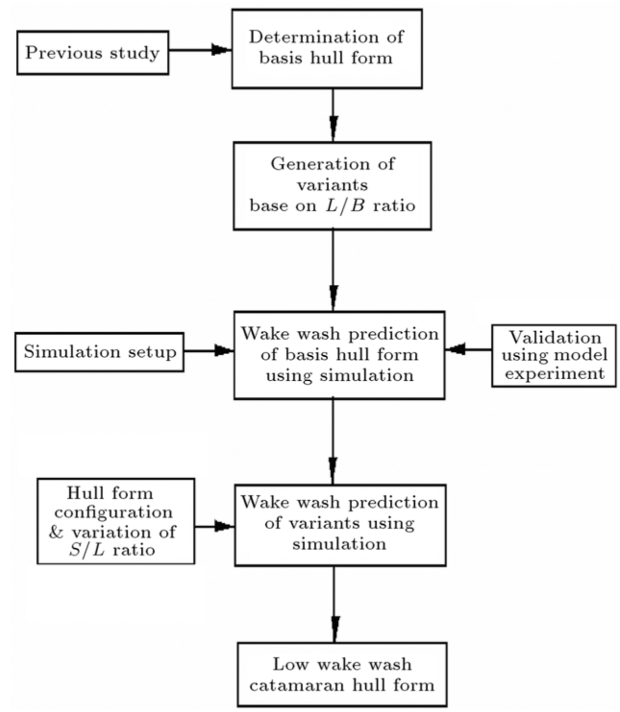


Figure 8: Flow chart of parametric study.

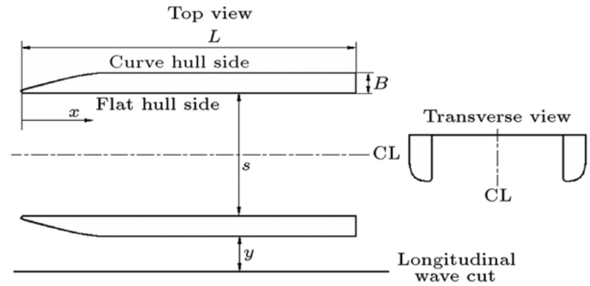
Table 3: Parametric study of asymmetric catamaran hull form.

Hull form configuration (FSI or FSO)								
L/B	S/L	F_n	L/B	S/L	F_n	L/B	S/L	F_n
		0.1			0.1			0.1
	0.2	0.2		0.2	0.2		0.2	0.2
		0.3			0.3			0.3
12.2		0.1	15.2		0.1	18.3		0.1
	0.3	0.2		0.3	0.2		0.3	0.2
		0.3			0.3			0.3
		0.1			0.1			0.1
	0.4	0.2		0.4	0.2		0.4	0.2
		0.3			0.3			0.3

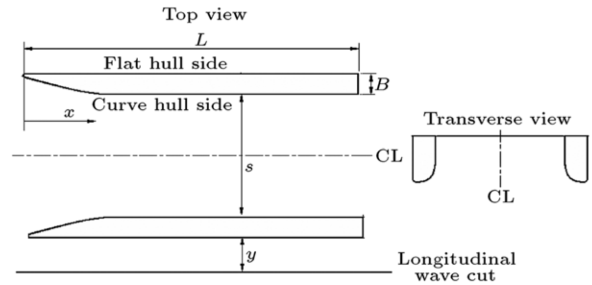
5.2. Hull form configuration effect on wave profile

As described in the previous section, the first step in the parametric study was the investigation on the hull form configurations. The investigation was conducted on the FSI and FSO hull form configurations. The L/B ratio of 15.2 and S/L ratio of 0.4 for the basis hull form are used. Based on the result of the hull form investigation, the next parametric study was conducted on one of the two hullform configurations, which produces low wake wash i.e. wave height.

Figures 10 and 11 show the wave contours of FSI and FSO configurations, respectively, while Figures 12–14 show the comparison of wave profiles of FSI and FSO configurations with



(a) Flat Side Inward (FSI) configuration.



(b) Flat Side Ourward (FSO) configuration.

Figure 9: Asymmetric catamaran hull form configuration, S/L and L/B ratio.

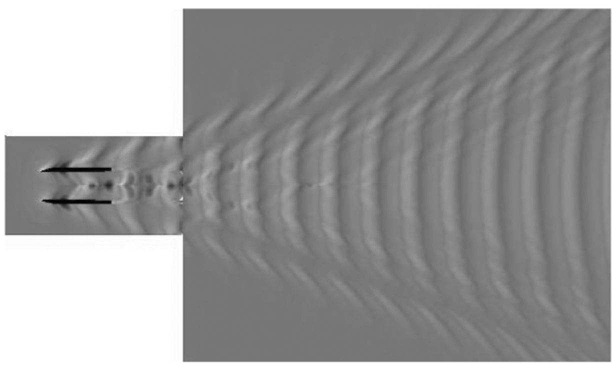


Figure 10: Wave contour of FSI configuration, L/B of 15.2, S/L of 0.4 and F_n of 0.3.

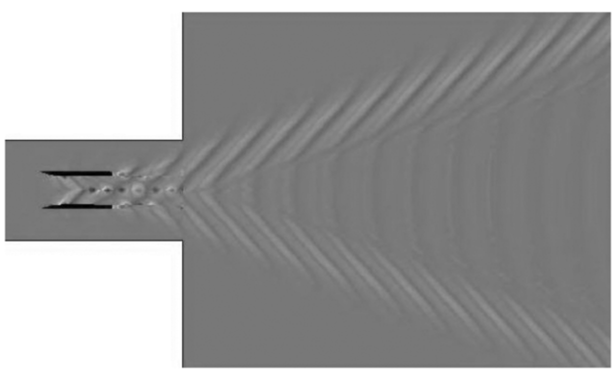


Figure 11: Wave contour of FSO configuration, L/B of 15.2, S/L of 0.4 and F_n of 0.3.

the longitudinal wave cut location at the *CL*, y/L of 0.2, and y/L of 2.0, respectively. FSI configuration is presented with a dashed line and FSO configuration is presented with a continuous line.

Results of the comparisons above clearly show that FSO configuration has the lower wave height at any longitudinal wave cut locations. Therefore, based on the results above, the parametric studies according to S/L and L/B ratios are conducted only on FSO configuration as described in the next sections.

5.3. The effect of S/L ratio on wave profile

Based on the results of the wave profile comparison between FSI and FSO configurations in the previous section, the study on S/L ratio variations was carried out only on FSO configuration; the configuration that generates a lower wave wash.

Three variations of S/L ratio were used, viz., 0.2, 0.3 and 0.4, while the wave profiles were taken at three locations of

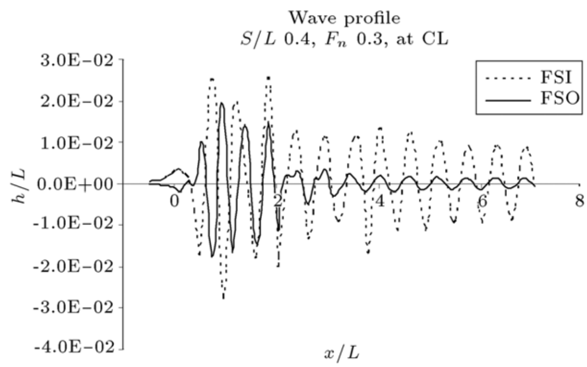


Figure 12: Wave profile comparison between FSI and FSO configuration with L/B of 15.2, S/L of 0.4 and F_n of 0.3 at the *CL*.

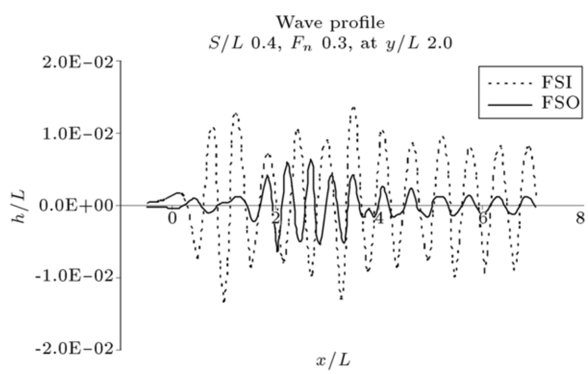


Figure 13: Wave profile comparison between FSI and FSO configuration with L/B of 15.2, S/L of 0.4 and F_n of 0.3 at longitudinal wave cut (y/L) of 0.2.

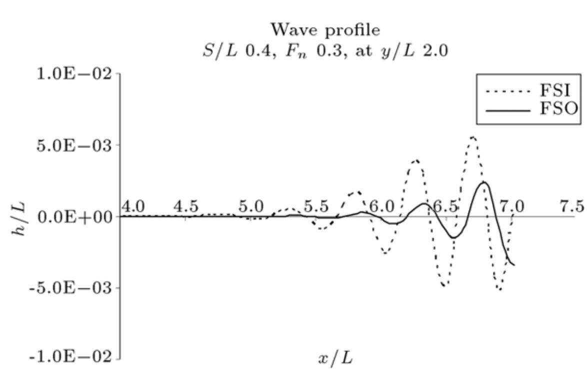


Figure 14: Wave profile comparison between FSI and FSO configuration with L/B of 15.2, S/L of 0.4 and F_n of 0.3 at longitudinal wave cut (y/L) of 2.0.

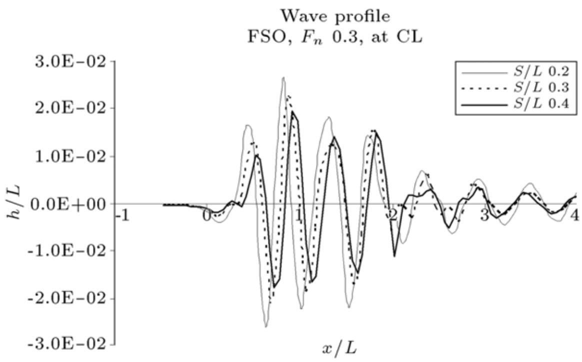


Figure 15: Wave profile comparison on S/L of 0.2, 0.3 and 0.4 with FSO configuration, L/B of 15.2, and F_n of 0.3 at the *CL*.

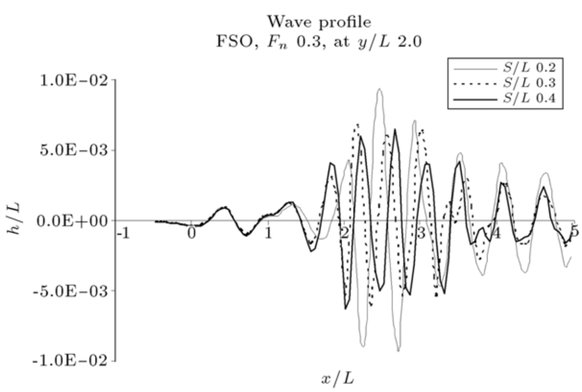


Figure 16: Wave profile comparison on S/L 0.2, 0.3, and 0.4 with FSO configuration, L/B of 15.2, and F_n of 0.3 at longitudinal wave cut (y/L) of 0.2.

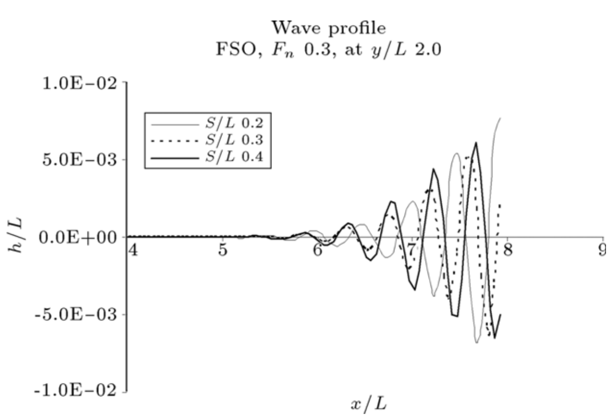


Figure 17: Wave profile comparison on S/L 0.2, 0.3, and 0.4 with FSO configuration, L/B of 15.2, and F_n of 0.3 at longitudinal wave cut (y/L) of 2.0.

longitudinal wave cuts, i.e. the centerline, y/L of 0.2, and y/L of 2.0. The three L/B ratios used were 15.2 for the basis hull, and a further two L/B ratios at 12.2 and 18.3. The study was carried out at Froude Numbers (F_n) of 0.1, 0.2, and 0.3.

5.3.1. S/L ratio effect at various L/B ratios

Figures 15–17 show the wave profile comparisons resulting from S/L ratio variations with L/B ratio of 15.2 and F_n of 0.3. The longitudinal wave cuts shown are at the *CL*, y/L of 0.2, and y/L of 2.0, respectively. Figures 18–20 show the corresponding profiles for the L/B ratio of 12.2, while Figures 21–23 show the corresponding profiles for the L/B ratio of 18.3.

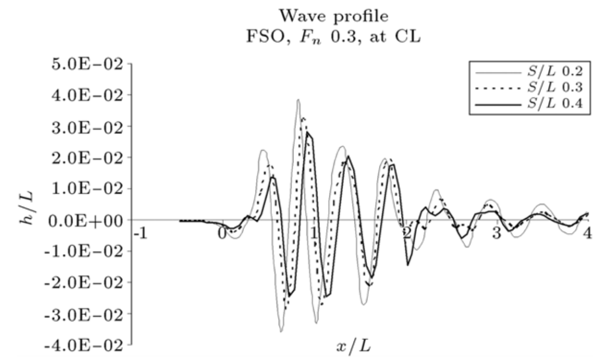


Figure 18: Wave profile comparison on S/L of 0.2, 0.3, and 0.4 with FSO configuration, L/B of 12.2, and F_n of 0.3 at the *CL*.

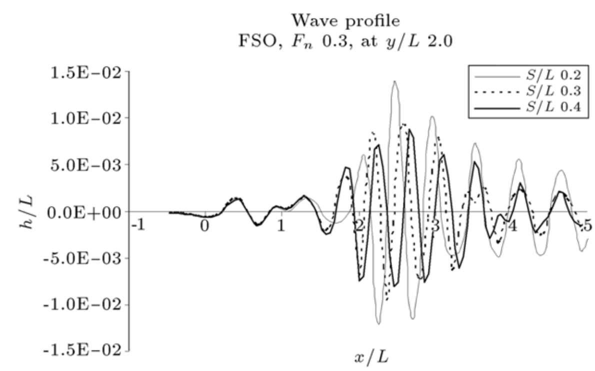


Figure 19: Wave profile comparison on S/L 0.2, 0.3, and 0.4 with FSO configuration, L/B of 12.2, and F_n of 0.3 at longitudinal wave cut (y/L) of 0.2.

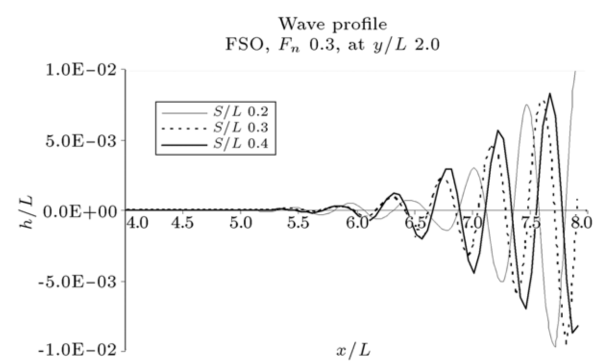


Figure 20: Wave profile comparison on S/L 0.2, 0.3 and 0.4 with FSO configuration, L/B of 12.2, and F_n of 0.3 at longitudinal wave cut (y/L) of 2.0.

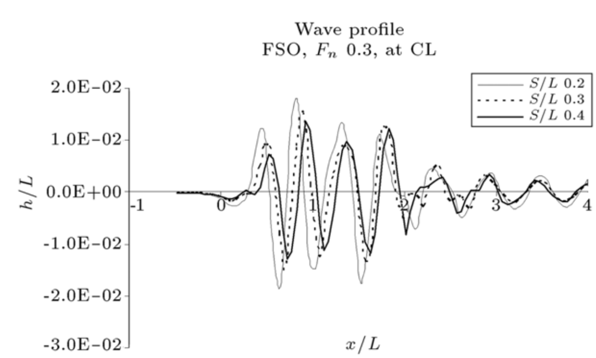


Figure 21: Wave profile comparison on S/L of 0.2, 0.3 and 0.4 with FSO configuration, L/B of 18.3 and F_n of 0.3 at the *CL*.

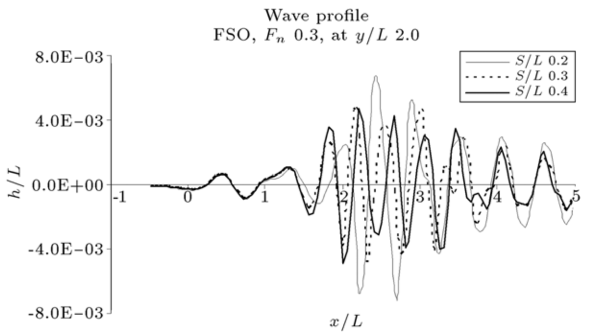


Figure 22: Wave profile comparison on S/L 0.2, 0.3 and 0.4 with FSO configuration, L/B of 18.3 and F_n of 0.3 at longitudinal wave cut (y/L) of 0.2.

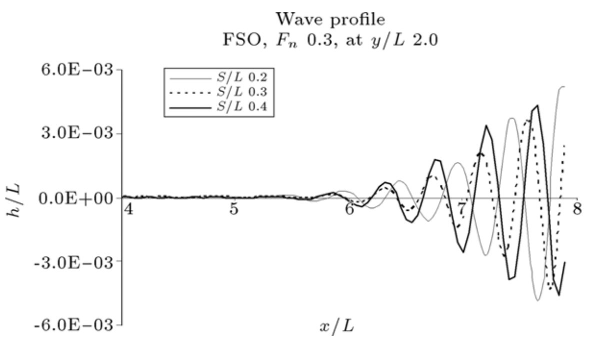


Figure 23: Wave profile comparison on S/L 0.2, 0.3 and 0.4 with FSO configuration, L/B of 18.3, and F_n of 0.3 at longitudinal wave cut (y/L) of 2.0.

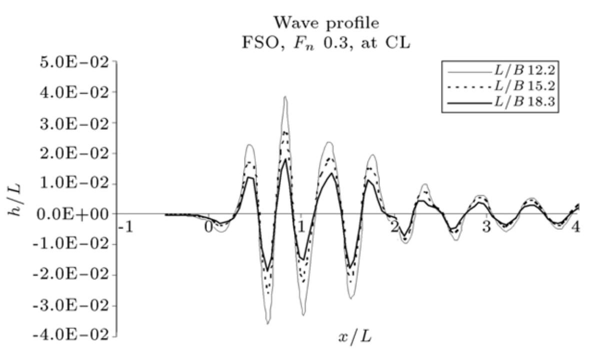


Figure 24: Wave profile comparison on L/B 12.2, 15.2, and 18.3 with FSO configuration, S/L of 0.2 and F_n of 0.3 at the *CL*.

The results in Figures 15–17 have shown that regardless of the transverse positions of longitudinal cuts, the higher separation to length ratio, the smaller is the wave height of wave profiles produced by the FSO configuration. Although not shown here, the results are also similar on F_n of 0.1 and 0.2, i.e., the higher separation to length ratio, the smaller is the wave height of wave profiles. Results across the other two L/B ratios are also similar.

5.4. The effect of L/B ratio on wave profile

Besides hull-form configuration and S/L ratio, the wave profiles produced by the hull-form also depend on the value of the L/B ratio for the demihull. Figures 24–32 show the comparison of the wave profile with L/B ratio variations of 12.2, 15.2 and 18.3 at F_n of 0.3. The wave cut profiles are given at the centerline, y/L of 0.2, and y/L of 2.0.

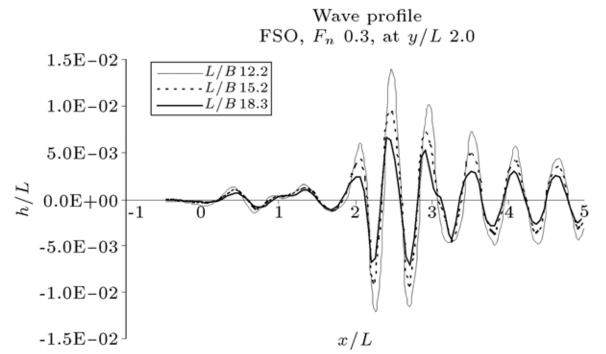


Figure 25: Wave profile comparison on L/B 12.2, 15.2 and 18.3 with FSO configuration, S/L of 0.2, and F_n of 0.3 at longitudinal wave cut (y/L) of 0.2.

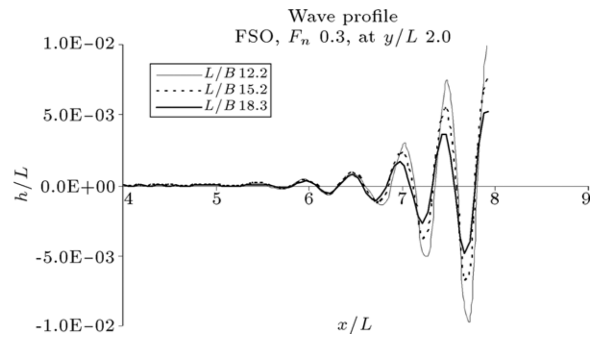


Figure 26: Wave profile comparison on L/B 12.2, 15.2 and 18.3 with FSO configuration, S/L of 0.2, and F_n of 0.3 at longitudinal wave cut (y/L) of 2.0.

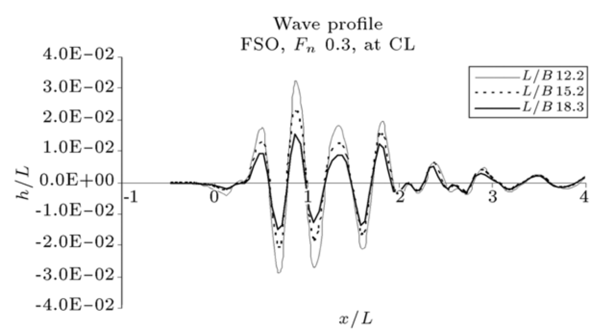


Figure 27: Wave profile comparison on L/B 12.2, 15.2 and 18.3 with FSO configuration, S/L of 0.3 and F_n of 0.3 at the *CL*.

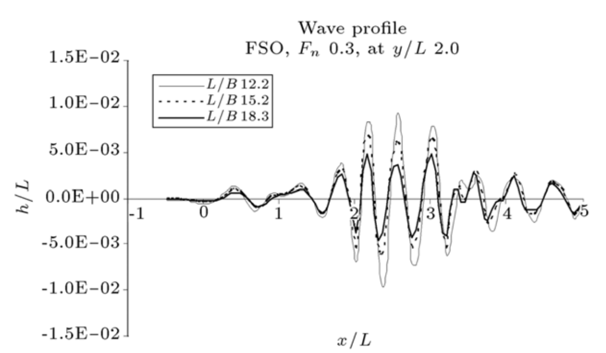


Figure 28: Wave profile comparison on L/B 12.2, 15.2 and 18.3 with FSO configuration, S/L of 0.3 and F_n of 0.3 at longitudinal wave cut (y/L) of 0.2.

Figures 24–32 show that higher L/B ratios give rise to lower wave profiles. The results are similar for different S/L and also for other Froude numbers.

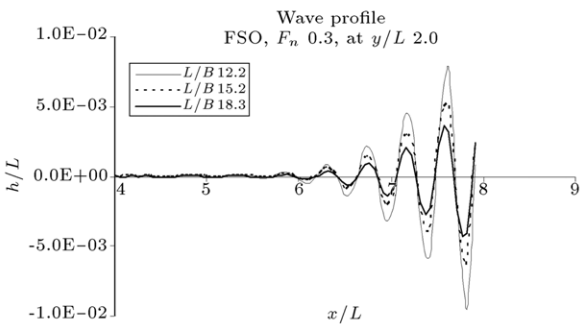


Figure 29: Wave profile comparison on L/B 12.2, 15.2 and 18.3 with FSO configuration, S/L of 0.3 and F_n of 0.3 at longitudinal wave cut (y/L) of 2.0.

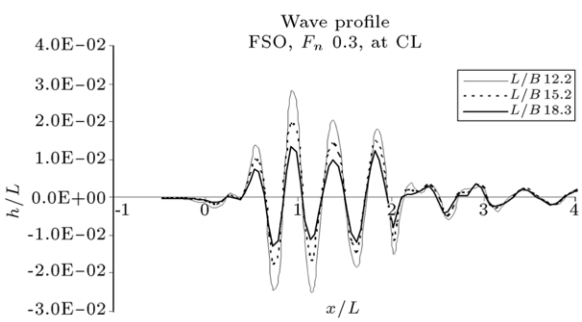


Figure 30: Wave profile comparison on L/B 12.2, 15.2 and 18.3 with FSO configuration, S/L of 0.4 and F_n of 0.3 at the *CL*.

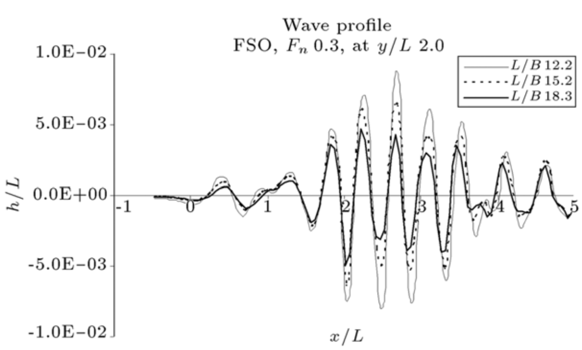


Figure 31: Wave profile comparison on L/B 12.2, 15.2 and 18.3 with FSO configuration, S/L of 0.4 and F_n of 0.3 at longitudinal wave cut (y/L) of 0.2.

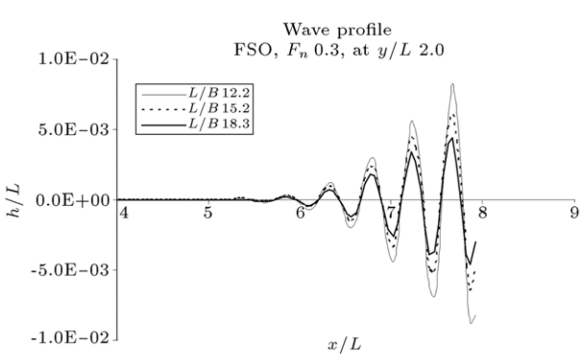


Figure 32: Wave profile comparison on L/B 12.2, 15.2 and 18.3 with FSO configuration, S/L of 0.4 and F_n of 0.3 at longitudinal wave cut (y/L) of 2.0.

6. Discussions

According to the parametric study on the hull form configuration, it is shown that the FSO configuration produces a lower wake wash compared with FSI configuration. This agrees with the prediction of the proponent of this configuration, i.e., the flat hull side of the asymmetric catamaran produced a low wave height [5].

Considering the S/L ratio, the results have shown that the farther separation of hull form produces a lower wave height. This indicates that the interference of the wave generated by demihulls was weaker, with the farther separation distance. This condition also occurred at L/B ratio of 15.2 (Basis Hull Form), L/B ratio of 12.2 (Variant 1), and also L/B ratio of 18.3 (Variant 2).

Considering L/B ratios, the results have shown that the longer length of hull form produces a lower wave height. This indicates that long skinny hull form produces a low wake wash [12].

The wave profile investigation in the parametric study was conducted at the centerline of the asymmetric catamaran, y/L of 0.2, and y/L of 2.0. The centerline wave profile was taken to determine the interaction of the wave generated by the demihull near the tunnel of the asymmetric catamaran, while the longitudinal wave cut (y/L) of 0.2 was the wave cut near the outer side of the asymmetric catamaran. It was taken with the purpose of investigating the initial wave generated by the asymmetric catamaran. Then, the longitudinal wave cut (y/L) of 2.0 was taken, with the assumption that it was a wave cut far from the asymmetric catamaran, i.e., the wave near the shore or river bank.

7. Conclusions and future work

The study has revealed a number of significant findings in the quest for a lower wake wash for slow speed, inland waterway catamarans. The hull form configuration, S/L ratio, and L/B ratio significantly affect the wake wash generated by the catamaran. FSO configuration generates a lower wake wash than FSI configuration of the asymmetric catamaran, while the well-separated demihulls separation and longer length produce a lower wake wash. The wave height criterion used for the wake wash assessment in this study has the great advantage of simplicity and ease of understanding.

There are limitations in this study. The wake wash measurement, using the model experiment, was conducted near the hull form (near field), i.e., y/L of 0.2. The measurement of the far field was also needed to validate the investigation of the wake wash effect on the shore or river bank. The other wake wash assessment methods, such as Wave Energy Criterion, Wave Energy Flux Criterion, and Wave Height Decay Criterion, may be considered in future studies.

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