Transactions of the TSME (2019) Vol. 7, No. 1, 23-32
Journal of Research and Applications in Mechanical Engineering

ISSN 2229-2152 print
DOI: 10.14456/jrame.2019.3

Research Article

BLOCKAGE EFFECTS ON RESISTANCE PREDICTION OF HIGH-SPEED CATAMARANS

S. Srinakaew[1,*]
D. J. Taunton[2]
D. A. Hudson[2]
[1] *Department of Marine Engineering, Royal Thai Naval Academy, 204 Sukhumvit Road, Paknam, Samut Prakan, Thailand, 10270*
[2] *Fluid-Structure Interaction Group, University of Southampton, Burgess Road, Southampton, SO16 7QF, UK*

Received 25 February 2019
Revised 2 May 2019
Accepted 7 May 2019

ABSTRACT:
Model experiment is the most reliable method to estimate ship resistance; however, price and complexities are the most disadvantage factors. Another aspect that affects the precision of the results are blockage effects due to tank dimension and model size. Some correction procedures introduced by ITTC are widely used. However only resistance components that can be corrected while flow field and wave elevation cannot be justified using the blockage correction procedures. To demonstrate how the blockage affects the flow around catamaran, this study focuses on resistance prediction and flow characteristics around high-speed catamarans using CFD code with RANS equations. Two Southampton University towing tanks – Solent and Boldrewood – are compared. The NPL 5b model is used as it is widely investigated and used in the commercial applications. Four Froude numbers (Fn = 0.273, 0.433, 0.70 and 0.90) are investigated. CFD results show that resistance components measured from the higher blockage towing tank are higher than the bigger tank. Wave contour plots and wave cut show that the higher blockage towing tank causes the higher wave elevation due to the reflection of the wall which results in differences for the wave resistance prediction between the two towing tanks.

Keywords: *Blockage effects, CFD, NPL 5b, Flow field*

1. INTRODUCTION

High-speed catamarans have been developed in past decades and widely used as seen in the passenger and car ferries. Mostly, the catamarans are operated in the high-speed regime. To ensure that catamaran can achieve the design speed, the resistance prediction procedure is required to apply precisely. The classic and reliable method to estimate resistance components is the experiment; however, it is expensive and time consuming. Another key factor is that catamaran experiment requires more space to run the model compared with monohull models. Hence, the blockage correction is highly recommended for the catamaran experiment. The ITTC recommended procedures and guidelines summarizes the blockage correction procedures for the model experiment. For example, the Schuster, Scott and Tamura are recommended.

The experimental works into the blockage effect and correction were investigated by many researchers. For example, Schuster investigated the blockage effect and proposed the blockage correction which is now being used and recommended by ITTC [1]. Hughes also conducted the experiment into the effect of model and tank size [2]. Taniguchi and Tamura reported the experimental results of the tank boundary effect on model resistance and the blockage effects, [3] and [4]. In 1970, Scott reported the experimental outcome for the smooth ship resistance by

* Corresponding author: S. Srinakaew
E-mail address: s.srinakaew@gmail.com

focusing on the blockage effects and correction [5]. The work also proposed the blockage correction formula for the experiment which later is recommended by ITTC. Another series of experiment of the blockage effects and correction is found in [6]. The work was to focus on finding the applicable correction for model experiment by applying various blockage corrections

The numerical investigation is another approach that now has capabilities to estimate resistance for marine application as seen in many published works. The investigation into the blockage effect due to finite water depth for the numerical domain using CFD is done by Haase et al. [7]. The model test data and full-scale measurements were used to verify the numerical study. Both steady and unsteady simulation were compared. Two Froude number (Fn = 0.37 and 0.45) were focused as these numbers are considered as the intermediate speed where the hump peak of the resistance is found and dominated by wave making resistance. The results showed that the blockage effects result in the increasing of the resistance prediction which leads to the overprediction for the full-scale catamaran using the extrapolation procedure.

To further understanding of the blockage effects on resistance prediction for the high-speed regime using CFD with Reynolds-Averaged Navier-Stokes Equations (RANS), this paper presents the study on how the blockage effects result in resistance prediction, form factor and flow filed.

2. Blockage Effects

The precision of the resistance prediction is significantly affected by the blockage effects due to the model size to tank size for experiment and numerical domain dimension for numerical estimation methods. To correct the error due to the blockage effects, some formulae are proposed as recommended by ITTC 2011 procedures and guidelines. Those formulae consider the blockage parameters (m) and Froude depth number as the key aspects. The first blockage correction is known as Schuster corrector, which is highly recommended for the experiment in the finite water depth or shallow water. However, the limitation for the Schuster blockage corrector is that the maximum Froude number which can be used is 0.30. The Scott's blockage corrector is another procedure that relates Froude number. It is highly recommended by ITTC for the practical and general use. This blockage correction procedure can be used for the tank breadth to depth approximately 2:1 with the model length between 3.5 and 9.0 meters. The range of Froude numbers that the Scott blockage corrector can be used is approximately between 0.08 and 0.4. Another blockage correction procedure is the Tamura corrector which is like Scott's – water depth is also considered. The model length (L) and breadth (B) are taken into the consideration which is the key parameter that can differentiate between Tamura's and Scott's.

The model used in this study is the key factor that minimizes the objectives – the model particulars presented in section 3.1. Hence, the Schuster and Tamura blockage correction procedures are implemented and used. The expression for those two correctors are presented in equations (1) and (2).

- ***Schuster Blockage Correction***

$$\frac{\Delta V}{V} = \frac{m}{1 - m - Fn_h^2} + \frac{2}{3} * \left(1 - \frac{C_V}{C_T}\right) * Fn_h^{10} \tag{1}$$

- ***Tamura Blockage Correction***

$$\frac{\Delta V}{V} = 0.67 * m * \left(\frac{L}{B}\right)^{0.75} * \frac{1}{(1 - Fn_h^2)} \tag{2}$$

Where $m = {A_{model}}/{A}$,

A_{model} and A is model cross-section and tank cross-section area.
L is the model length and B is the model breadth.
C_V is viscous resistance coefficient
C_T is total resistance coefficient.

3. Hull Geometry, Numerical Domain And Grid Generation

3.1 Hull Geometry and Numerical Domain

NPL 5b model is used as it is one among the good representation for the high-speed catamarans. The hull geometry details and plan view are shown in Table 1 and Fig. 1 respectively. To demonstrate the blockage effects due to the model size corresponding to the numerical domain dimensions, the two Southampton University towing tanks are compared. Those two tanks are called Southampton Solent and Boldrewood respectively, see Table 2. The Solent tank is considered as the data used for the validations were retrieved from Insel's experiment [8]. As can be seen in Table 3, the half of the towing tank width to model length for the larger towing tank is approximately 60% greater than the smaller one. In term of the blockage percentage, the Solent towing tank has the blockage approximately 3 times larger than the Boldrewood towing tank. The separation to model length ratio (S/L) used in the simulation is 0.3 which is particular the good hull configuration to represent the catamaran application.

Table 1: NPL 5b hull particulars

Model	NPL 5b
L, *m*	1.60
L/B	11.00
B/T	2.00
$L/\nabla^{1/3}$	8.479
C_B	0.397
C_P	0.693
C_M	0.565
WS, m^2	0.276

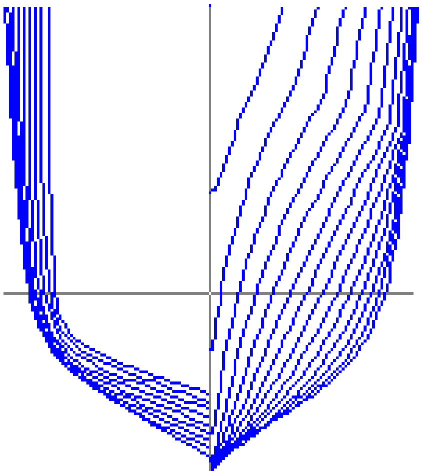


Fig. 1. NPL 5b bodyplan [9]

Table 2: Towing tank dimension comparison

	Solent Towing Tank	Boldrewood Towing Tank
Length, m	60	138
Width, m	3.70	6.0
Depth, m	1.80	3.50

Table 3: Comparison of blockage for different towing tank

Model	S/L	Tank	$0.5W_{Tank}/L$	Blockage %
1.6 m	0.3	Solent	1.16	0.10
1.6 m	0.3	Boldrewood	1.88	0.03

3.2 Grid Generation

The total number of cells for the Solent towing tank is approximately 5 – 6.5 million cells. Number of cells increase to 6 – 7.5M as the domain dimensions to represent the Boldrewood towing tank is larger than the Solent towing tank. According to the STAR CCM+ tutorial and [10], total number of cells per wave is approximately between 20 and 30 cells. To capture the flow field around demihulls, the refinement techniques are used. The techniques add different blocks into the area where the waves propagate. The first block is placed behind transom stern with a very dense mesh and another larger refinement block is located further around catamaran and far field area as shown in Figs. 2 and 3. The last refinement block is placed between demihulls to capture wave elevation, see Fig. 4.

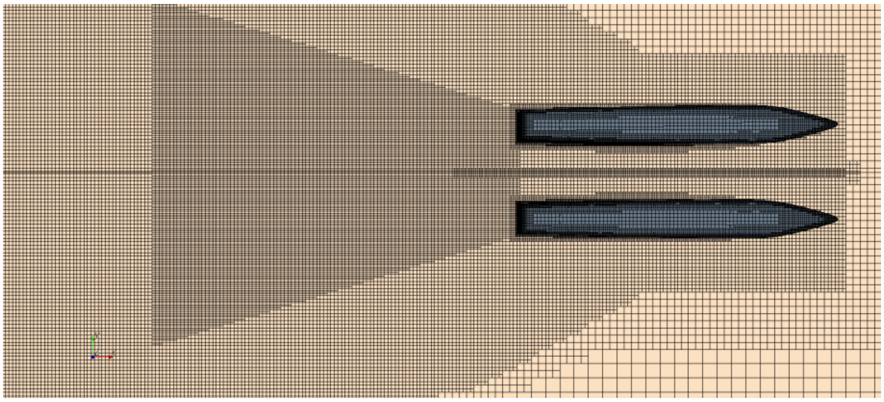


Fig. 2. Top view mesh

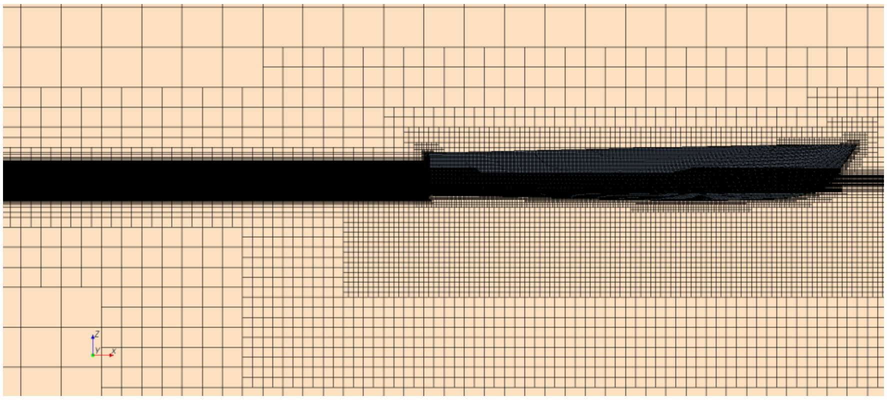


Fig. 3. Side view mesh

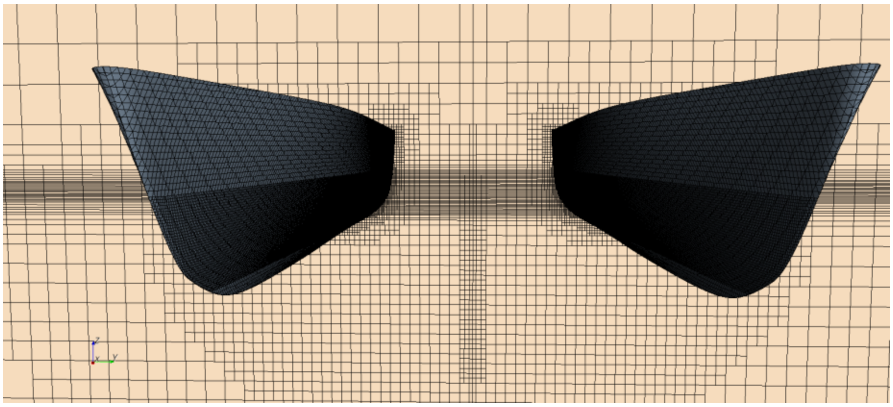


Fig. 4. Free surface mesh

4. RESULTS

4.1 Blockage Effects

The CFD results for the resistance components against the depth Froude Number (Fn_h) and Froude number (Fn) are shown in Figs. 5, 6 and 7 respectively. The CFD results including total resistance (C_T), skin friction (C_F), viscous resistance (C_V), residual resistance (C_R) and wave resistance (C_W) are validated against the experimental results [8]. The results show that the resistance components estimated in the low blockage percentage tank – Boldrewood – are significantly lower than in the higher blockage tank – Solent. The CFD results for the Solent towing tank show a good agreement with the experimental results for all resistance components while the CFD results for Boldrewood towing tank are slightly under prediction.

Figure 8 shows the blockage effects using the Schuster's correction procedure for the different Froude numbers. The results show that the blockage effects increase with speed (Fn). As can be seen, the smaller domain has a higher blockage. The average CFD and experimental blockages for Solent tank show nearly the same values which are 1.185 x 10^{-3} and 1.184 x 10^{-3} respectively. The average CFD blockage for the Boldrewood towing tank is 0.393 x 10^{-3} which is approximately 3 times smaller compared with the Solent towing tank. Table 4 shows the comparison for the Schuster and Tamura correctors. As can be seen, the blockage calculated using Tamura are much higher than the Schuster correctors. The comparison also shows that the blockage increases with speed (Fn).

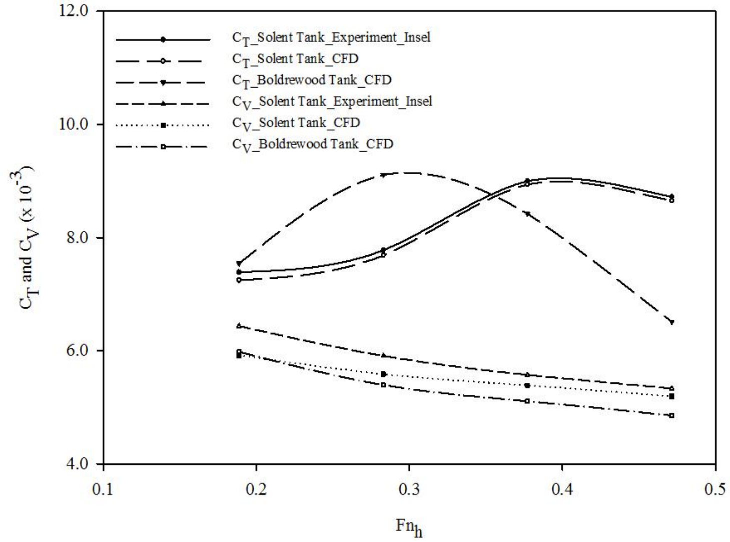


Fig. 5. Resistance components for different depth Froude numbers

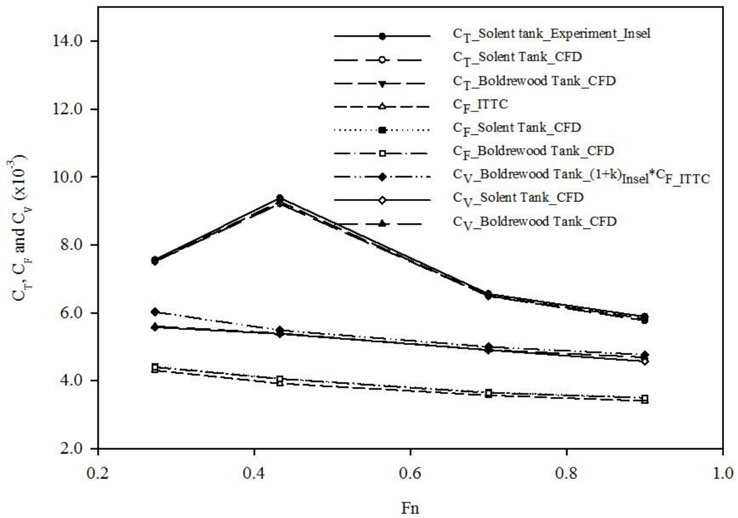


Fig. 6. Comparison of blockage effect on C_T, C_F and C_V

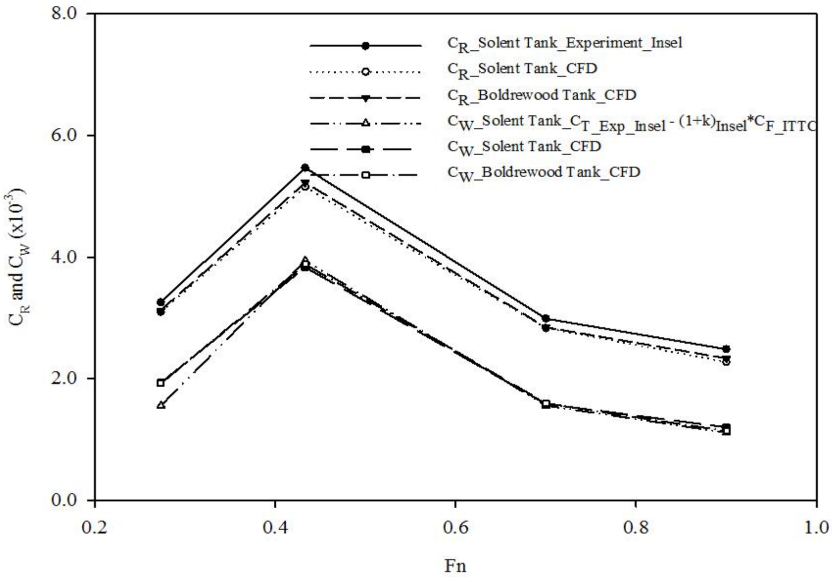


Fig. 7. Comparison of blockage effect on C_R and C_W

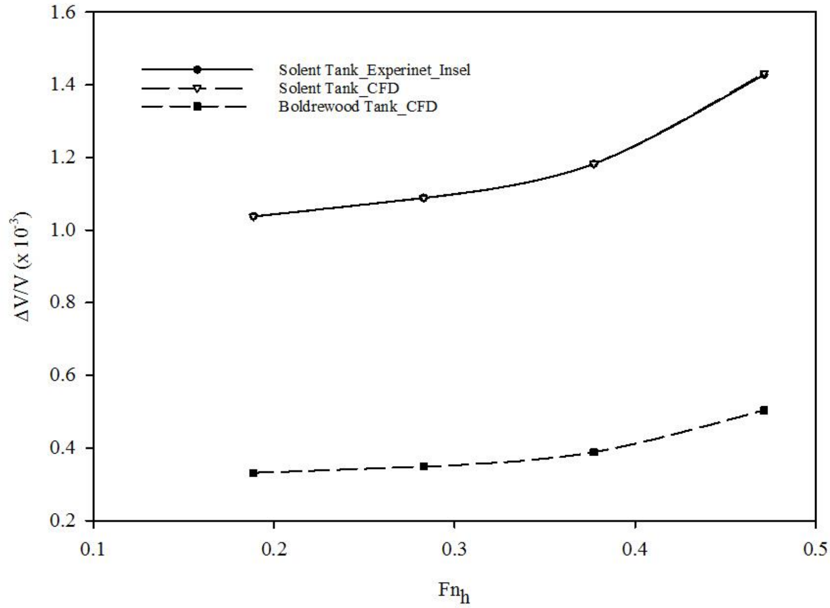


Fig. 8. Comparison of blockage correction using Schuster's correction procedure

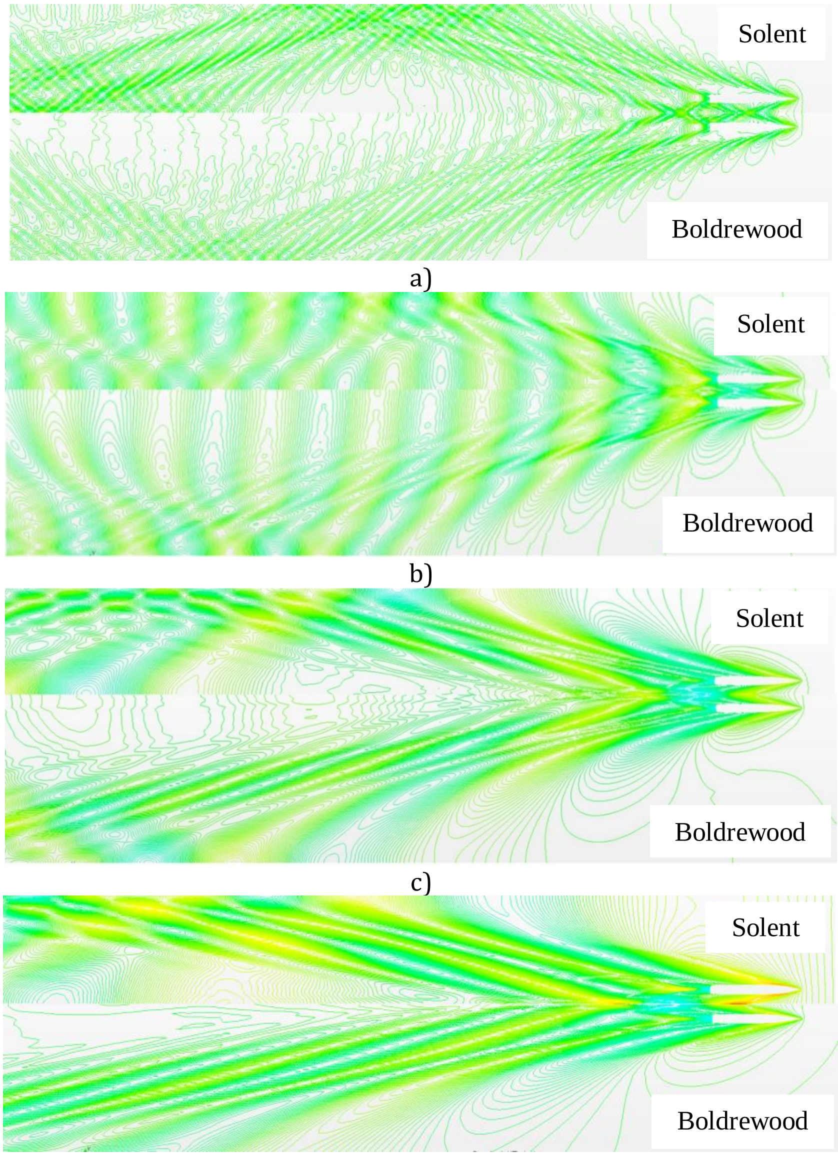
Table 4: Comparison of blockage for different correction procedures

Fn_h	$\Delta V/V$ (x 10^{-3})			
	Solent Tank		Boldrewood Tank	
	Schuster	Tamura	Schuster	Tamura
0.189	1.038	4.196	0.332	1.343
0.283	1.089	4.399	0.349	1.408
0.377	1.182	4.718	0.388	1.510
0.471	1.428	5.203	0.504	1.665

4.2 Wave Elevation

The contour plots of wave elevation around catamarans for all different Froude numbers are shown in Figs. 9a) – 9d). It can be seen that for high Froude numbers (Fn = 0.7 and 0.9) surface colour shows brighter scheme (more orange and redder) which represents the higher wave elevation. The wave cuts are performed in the y-direction parallel to the domain centerline at the y/L = 0.5 and the original point for x-direction is parallel to the forwards perpendicular point.

Figs. 10 – 13 show the wave elevation for the different Froude numbers. Wave elevation measurement for the lowest Froude number, Fn = 0.273, shows similar in term of both amplitude and wavelength up to x/L ~ 4.5 for all numerical domains before the reflection off the wall occurs. For Fn = 0.433, wave pattern is similar for all numerical domains for x/L < 4.0, which shows similarity of both wave weight and wavelength. The similar wave pattern is also seen for x/L < 4.0 for Fn = 0.70, however, wave height for the Boldrewood towing tank is slightly lower before the wall reflection. This phenomenon is also seen for the highest Froude number, Fn = 0.90. Due to the disturbance of the wall distance, the model running in the Solent towing tank creates a very high wave elevation throughout the numerical domain.



d)

Fig. 9. Wave contour at a) Fn = 0.273, b) Fn = 0.433, c) Fn = 0.70 and d) Fn =0.90

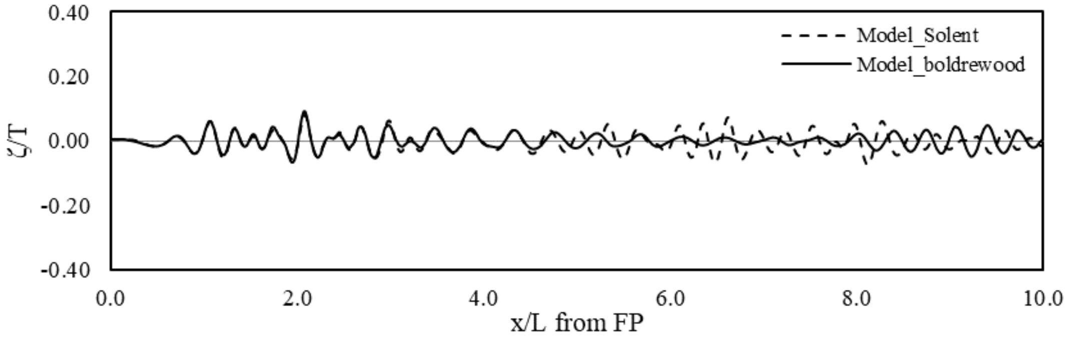


Fig. 10. Wave cut at Fn = 0.273

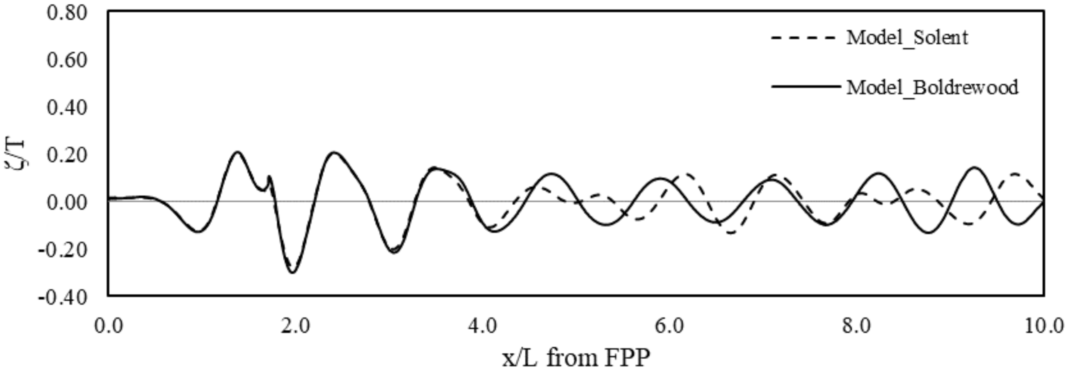


Fig. 11. Wave cut at Fn = 0.433

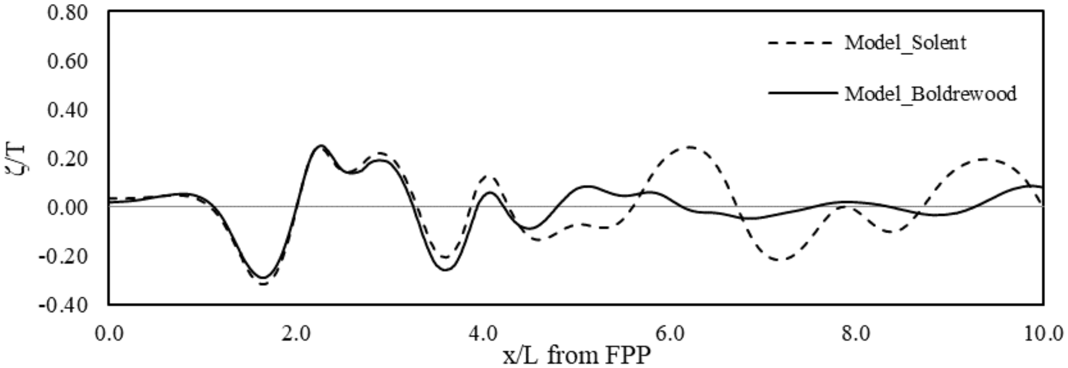


Fig. 12. Wave cut at Fn = 0.70

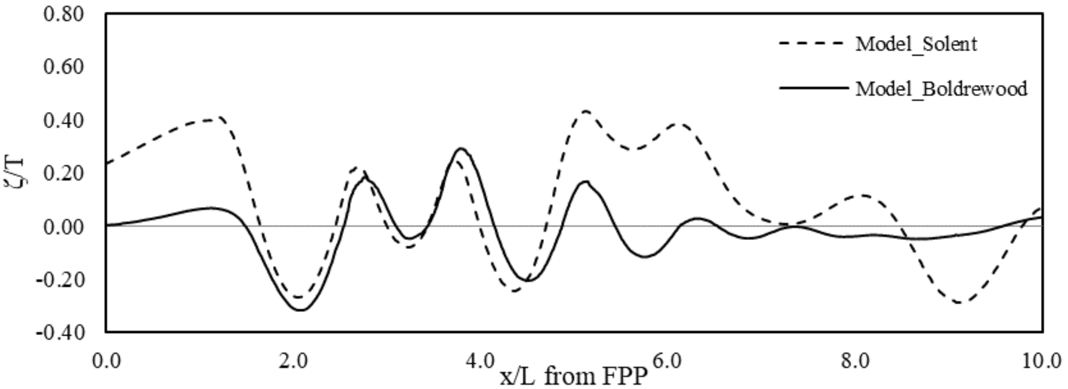


Fig. 13. Wave cut at Fn = 0.90

5. Discussion And Conclusion

Two blockage correction formulae are used as the assessment tools to investigate the influence of the tank blockage effects using CFD code. Those correction formulae are Schuster and Tamura blockage corrections. Two towing tanks located in the University of Southampton facilities including Solent and Boldrewood towing tanks. Four Froude numbers are assessed including Fn 0.273, 0.433, 0.70 and 0.90 respectively. It is found that the blockage effects increase significantly with speed (Fn). Resistance components measured from the higher blockage percentage towing tank are slightly higher than the bigger towing tank for all Froude numbers. Wave contour plots are measured and shown. Wave elevation shown that for the low Froude numbers the differences are not clearly visible while at higher Froude numbers (Fn = 0.70 and 0.90) wave elevation increase significantly for the higher blockage percentage towing tank.

The works done in this investigation is steady simulations which dynamic sinkage and trim are fixed with the experiment retrieved from Insel, hence wave elevation measurement might be affected. The future works which are highly recommended are to run the simulation with free motion so allow the catamarans to move freely.

Nomenclature

B	Hull breadth *(m)*
C_B	Block coefficient (-)
C_F	Frictional resistance coefficient *(-)*
C_R	Residuary resistance coefficient *(-)*
C_T	Total resistance coefficient *(-)*
C_V	Viscous resistance coefficient *(-)*
C_W	Wave resistance coefficient *(-)*
Fn	Froude number *(-)*
Fn_h	Depth Froude number *(-)*
g	Acceleration due to gravity *(m/s^2)*
L	Hull length *(m)*
Re	Reynolds' number *(-)*
S	Separation distance between the centerlines of demihulls *(m)*
T	Hull draught *(m)*
ζ	Wave Elevation (*m*)
∇	Displacement volume *(m^3)*

References

[1] Schuster, S. Beitrag zur Frage der Kanalkorrektur bei Modellversuchen, Schiffstechnik, 1955.
[2] Hughes, G. The effect of model and tank size in two series of resistance tests, T.I.N.A., 1957.
[3] Taniguchi, K. and Tamura, K. Study of the tank boundary effect on model resistance (in Japanese), Journal of S.N.A. of West Japan, No. 9, 1955.
[4] Taniguchi, K. and Tamura, K. On the blockage effect, experimental tank, Mitsubishi shipbuilding and engineering Co., Report No. 307, 1958.
[5] Scott, J.R. On blockage correction and extrapolation to smooth ship resistance, T.I.N.A., 1970.
[6] Tamura, K. Study on the blockage correction, Journal of the Society of Naval Architects of Japan, No.131, 1972, pp. 17-28.
[7] Haase, M., Zurcher, K., Davidson, G., Binns, J.R., Thomas, G. and Bose, N. Novel CFD-based full-scale resistance prediction for large medium-speed catamarans, Ocean Engineering, Vol. 111, 2016, pp. 198-208.
[8] Insel, M. An investigation into the resistance components of high-speed displacement catamarans. PhD Thesis, 1990, University of Southampton, Southampton.
[9] Molland, A.F., Wellicome, J.F. and Couser, P.R. Resistance experiment on a systematic series of high-speed displacement catamaran froms: Varian of length-displacement ratio and breadth-draught ratio. Ship Science Report 71, Southampton: University of Southampton, 1996.

[10] Srinakaew, S., Taunton, D.J. and Hudson, D.A. A study of resistance of high-speed catamarans and scale effects on form factor, paper presented in Proceeding of the 19th Numerical Towing Tank Symposium (NUTTS'16), 2016, St Pierre d'Oleron, France.