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Geometric Effect of Bulbous Bows to the Hydrodynamic and the Probability of Slamming on Catamaran

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ABSTRACT

Achieving optimal efficiency, good performance, and cost-effectiveness is the main challenge in ship design. Using a bulbous bow is part of attaining an excellent design to reduce drag and dynamic load caused by waves and slamming. The design of the bulbous bow is commonly determined by shape geometric based on laboratory testing or computer optimization. This article compares the probability of slamming into a catamaran NPL hull without a bulbous bow and with a bulbous bow. Variation of the geometric bulbous bow and its effect on hydrodynamics and slamming was investigated. This study uses a numerical method by CFD software and applies secondary data of model testing on the same object as another researcher. The adjustment of the bulbous bow led to a 15.22–17.07% reduction in wave drag. According to the bulbous bow variant, increasing the linear parameter of the length of the bulbous bow reduces the wave drag and the probability of slamming to 2,9% In the motion analysis of a catamaran without a bulbous bow, the heaving and pitching are more significant than a catamaran with a bulbous bow.

1. Introduction

The increase in commercial multi-hulls, especially catamarans, is a concern in marine transportation related to safety and speed factors. The development of a catamaran hull based on design criteria provides advantages over monohulls, offering less drag, better stability, and a more expansive deck. Catamaran design has developed quite rapidly in the last few years to improve hydrodynamic performance [1-4]. Modifications to the hull, configuration, and bulbous bow of the catamaran can offer a solution to increase the ship's power by reducing drag. Reducing drag means reducing horsepower (energy power) and fuel consumption savings. And many efforts have been made to reduce energy or to produce new and renewable energy [5-8]. Several studies on the geometric effect of the bulbous bow on catamarans can affect drag and as an anti-slamming so that it can improve seakeeping performance. Chrismianto and Aditya [9] found that the geometric effect of the bulbous bow on catamarans can reduce drag by 11-13%. A bulbous bow can lessen the frequency of slamming in catamarans where the heaving and pitching arc motions occur. Atlar *et*

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al.,[10] and Abdul Ghani and Wilson [11] have revealed how the geometric change of the bulbous bow affects hydrodynamics and the probability of slamming.

The main objective of this work is to modify a catamaran NPL form by adding bulbous bows to analyze the geometric alterations of bulbous bows concerning drag and the possibility of slamming [12]. The technique involves altering the bulbous bow form of the nabla type and analyzing the hydrodynamics, seakeeping factor and probability of slamming for each shape variation based on the guidelines established by Nielsen [13]. Catamaran modelling were designed utilizing Maxsurf Modeler Advance software [14]. The initial catamaran with a symmetrical hull shape with the main dimension is 25.25 m in length, 2.6 m in breadth, and 1.4 m from keel to draft, as shown in Table 1 and the body plan in Figure 1. The catamaran configuration, the distance of the hulls to the ship length (s/L) is 0.3.

Table 1
The dimension of initial catamaran based on Sidik *et al.,* [8]

Parameter		
Length per pendicular (L_{PP})	25.25	m
Length overall (L_{OA})	25.80	m
Breadth of a demihull (B_{hull})	2.6	m
Breadth overall (B_{OA})	10.18	m
Draft (T)	1.4	m
Block coefficient of a demihull (C_B)	0.39	-
Wetted surface area (WSA)	160	m²

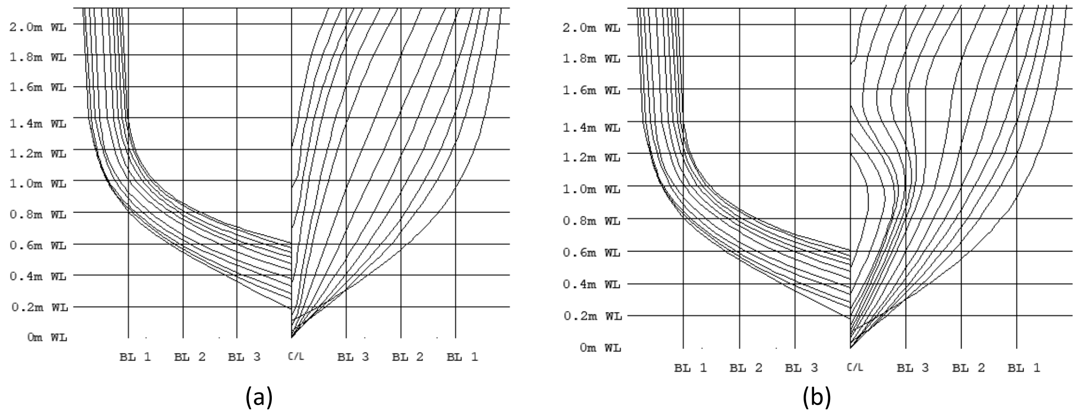


Fig. 1. The body plan catamaran NPL with a symmetrical hull (a) Initial hull without bulbous bow (b) Modification hull with bulbous bow

The ship's overall proportions remain the same, but the bow has been altered to have a bulbous bow. The catamaran types with different bulbous bow shapes are B-1.5, B-3, B-4.5, and B-6. In comparison to the original model, the improved form of the bulbous bow raised WSA (Wetted Surface Area) by 6.3%, 6.7%, 7.8%, and 8.3%, respectively. Table 2 and Figure 2 display the dimensions and variants of the redesigned bulbous bow. Changes were made to the bulbous bow's length to ship length ratio (C_{LPR}), but the criteria for breadth and depth remained the same.

Table 2
Variation modification of bulbous bow

Linear parameter		Model				
		B-0	B-1.5	B-3	B-4.5	B-6
Length (L_{PR})	m	0.000	0.375	0.750	1.125	1.500
Breadth (B_B)	m	0.000	0.547	0.547	0.547	0.547
Depth (Z_B)	m	0.000	0.825	0.825	0.825	0.825
Length coefficient (C_{LPR})	-	0.000	0.015	0.030	0.045	0.060

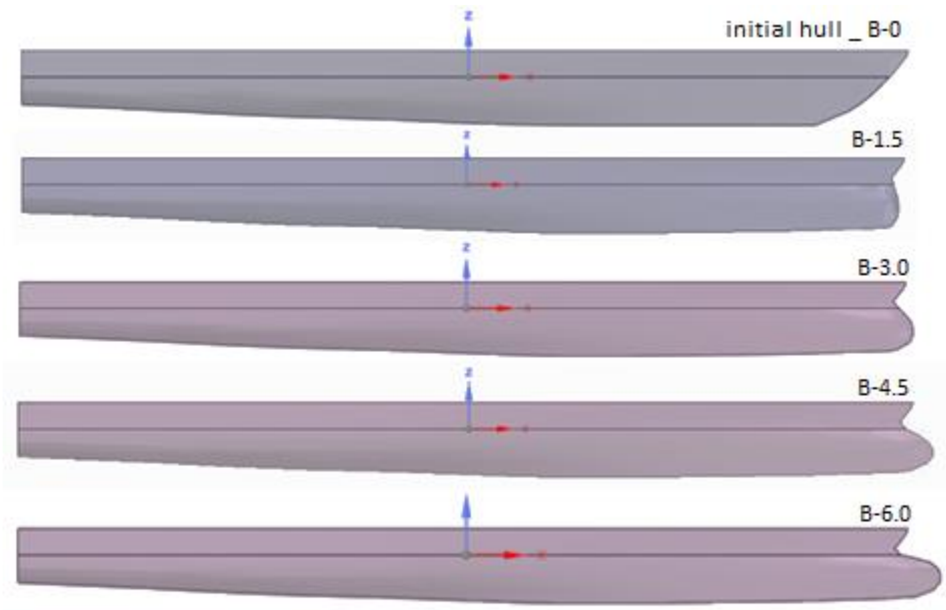


Fig. 2. The profile view of catamaran with different bulbous bow

2. CFD Simulation

Hydrodynamic investigation of the drags component of the bulbous bow variation using CFD (Computational Fluid Dynamics) simulation, Ansys CFX [15]. Additionally, determine the probability of slamming on the bow and the reaction amplitude caused by movement by Ansys AQWA [16] .

2.1 Ship Drag

The two parts that make up the total drag (R_T) are the viscous drag (R_V), which is energy lost in the wake, and the wave drag (R_W), which is energy in the form of water waves.

$$R_T = R_V + R_W \quad (1)$$

$$R_T = R_F(k + 1) + R_W \quad (2)$$

In CFX-Post, friction drag (RF) is computed by executing a count in an area integral to the wall shear in the x-direction. And based on the Prohaska approach, a low-speed simulation was used to establish the model's form factor (k+1). Then the nondimensionalized measurements of total drag coefficient (CT), frictional coefficient (CF), and wave coefficient (CW) are as follows:

$$C_T = R_T/(0{,}5 \times \rho \times S \times v^2);\ C_F = R_F/(0{,}5 \times \rho \times S \times v^2);\ C_W = R_W/(0{,}5 \times \rho \times S \times v^2) \quad (3)$$

Following ITTC guidelines [17], the simulation for calculating ship drags used commercial CFD ANSYS 2021. The meshing and domain of the model were constructed repeatedly in ICEM-CFD. The following factors determine the domain size utilised in boundary conditions: 1 L_{PP} (Length of Perpendicular) from the bow, 2 L_{PP} or so downstream from the stern, 1 L_{PP} from the plane of symmetry to the side, and 0.5 L_{PP} from the top as shown in Figure 3. A mixture of prismatic and tetrahedral cells has been subjected to meshing with unstructured parts. In six mesh processing rounds, various element sizes, 0.11 to 0.07, were used to analyse the convergency number of meshing elements and uncertainties. The meshing procedure considered the value of Y+ when determining the mesh's overall size and many components. Initial component output from the mesh was 27 million, eventually reaching 40 million.

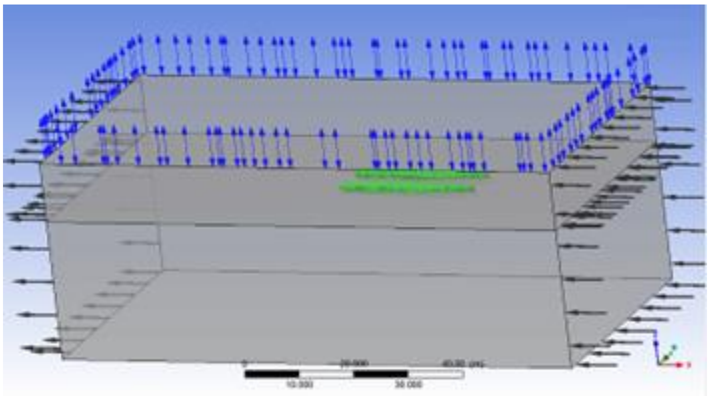


Fig. 3. CFD domain of catamaran NPL form

The average residuals are assumed by recurrent convergence via the residual Root Mean Square (RMS) in 10-4. And the simulations employed the Shear Stress Transport (SST), a turbulence model typically used in ship hydrodynamic assessments. SST was made up of a number of turbulence models, including k-ω models in the inner boundary layer and k-ε models in the outer boundary layer and the free stream. k-ω were suggested for ship flows and, in many circumstances, produce greater agreement with trials; nevertheless, they are more susceptible to grid quality [18].

2.2 Ship Response and Slamming Probability

The ship's global movement generates a response amplitude operator vector (RAO), the ratio of the amplitude of the ship motions (Z_0) to the wave amplitude (ζ_0) at various frequencies [19].

$$\mathrm{RAO} = \frac{Z_0}{\zeta_0} \tag{4}$$

The sea state is represented by the wave spectrum, which is a mathematical approximation of the real properties of ocean waves. The ship's reaction to regular waves is represented by the RAO, therefore to get the precise response (($S_{\zeta r}$), the RAO is squared and multiplied by the wave spectrum (S_{ζ}). It can be described that spectrum is defined as a representation of the distribution of the amplitude, and the RAO. Spectrum equations based on ITTC [20].

$$S(\omega) = \frac{A}{\omega^5} e^{-B/\omega^4} \tag{5}$$

where A equals $0.0081g^2$, B equals $3.11/H_S^2$, g is the gravitaional acceleration, H^S is the significant wave height, and ω is the wave frequency. The response spectrum value is used to obtain the density of relative bow motion (m0s) and relative vertical velocity spectrum (m2s) and to calculate the slamming probability. The probability of slamming $P\{slam\}$can be obtained by:

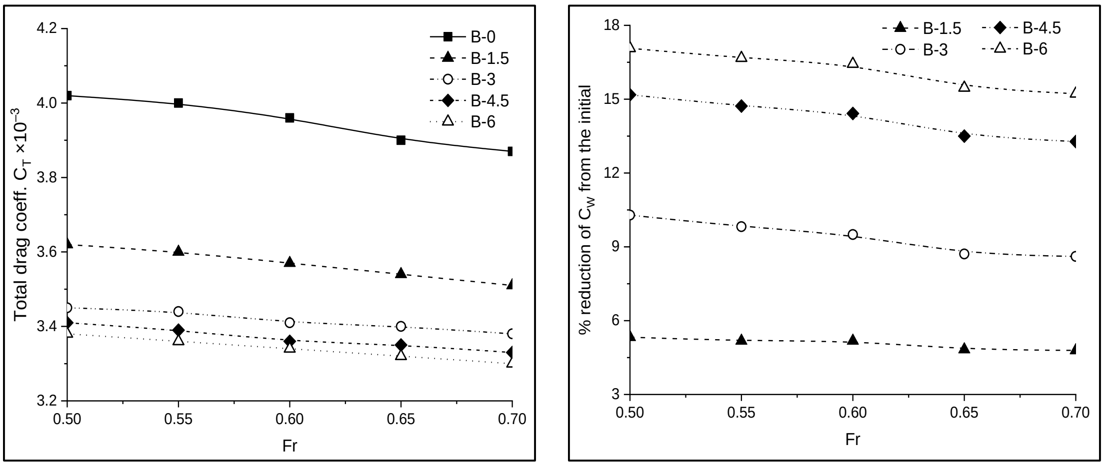
$$P\{slam\} = \exp^{-(\frac{T_b{}^2}{2m_{0s}}+\frac{V_{th}{}^2}{2m_{2s}})} \quad (6)$$

where T_b is ship's draft in the bow, V_{th} is treshold velocity obtained by square root of 0.093gL.

3. Results and Discussion

3.1 Drag Investigation

Figure 4 displays the result findings on the drag coefficient of the five different bulbous bow variants. It shows the modified catamarans have lower values of CW. It also shows the catamaran model with a high bulbous bow's length coefficient has the lowest ship's drag. These results are consistent with those reported by Abdul Ghani and Wilson [11].



(a) (b)

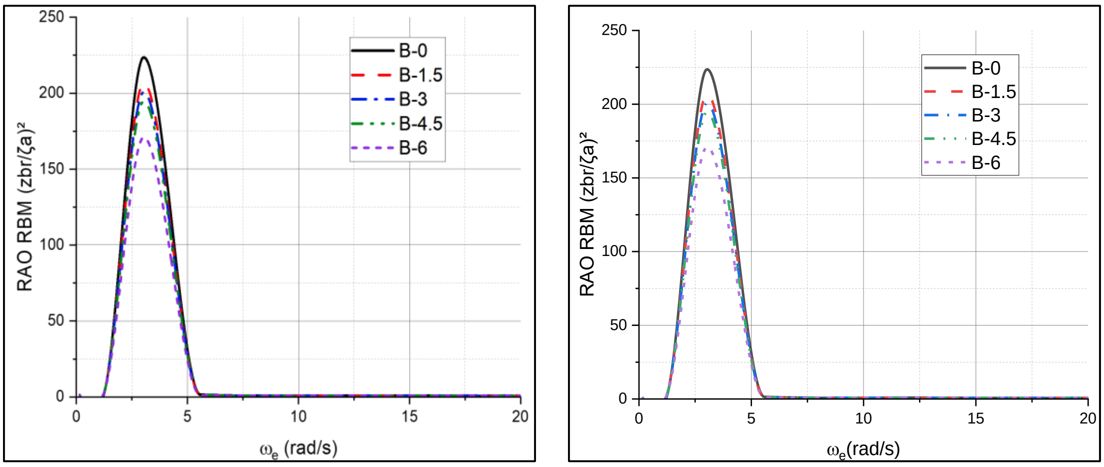
Fig. 4. Comparison results on (a) Total drag coefficient (C_T) (b) Percentage wave-making coefficient (C_W) reduction

The comparison between the initial catamaran and variation modification bulbous bow brought the most significant reduction in wave-making coefficient (C_W): B-1.5 by 2.74%, B-3 by 7.83%, B-4.5 by 12.85%, and B-6 by 14.79 %.

3.2 Relative Bow Motions

Determination of the relative vertical motion of the bow (zbr) requires the parameters of the distance of the center of gravity (CoG) to the bow of the ship on the x-axis (ξ), wave amplitude (ζa), and wavelength (LW) obtained by dividing the speed of the ship by the frequency of the waves.

The calculation results of relative bow motion (RBM) indicate the RAO relative bow motion and response spectrum. Figure 5 to Figure 6 depict the RAOs of the ship models' RBMs peak point at the same low frequency. For each significant wave height, the findings reveal that model B-6 has the lowest RAOs of RBM and model B-0 has the highest RAOs of RBM.



(a) (b)

Fig. 5. Comparison of The RAOs of relative bow motions on variation bulbous bow (a) RBM at wave height = 0.6m (b) b) RBM at wave height = 1.2 m

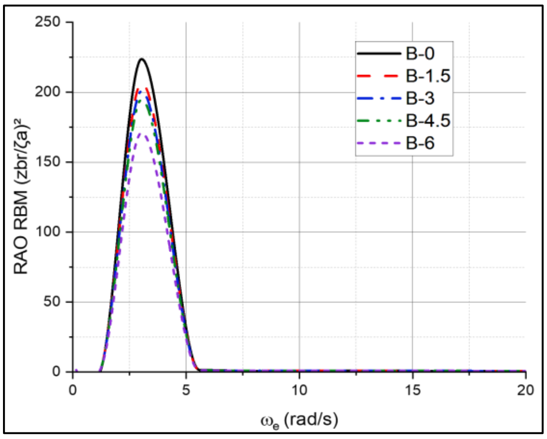
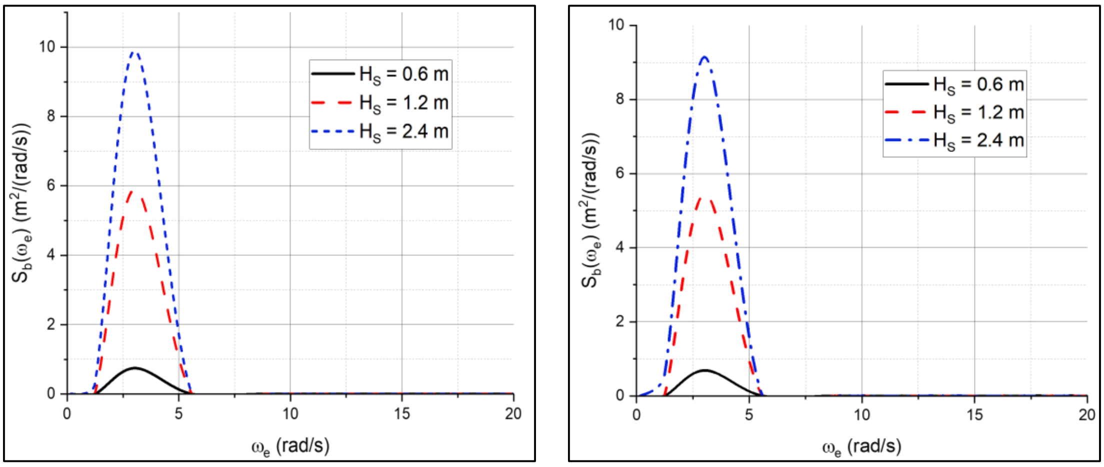


Fig. 6. Comparison of The RAOs of relative bow motions at wave height = 2.4 m

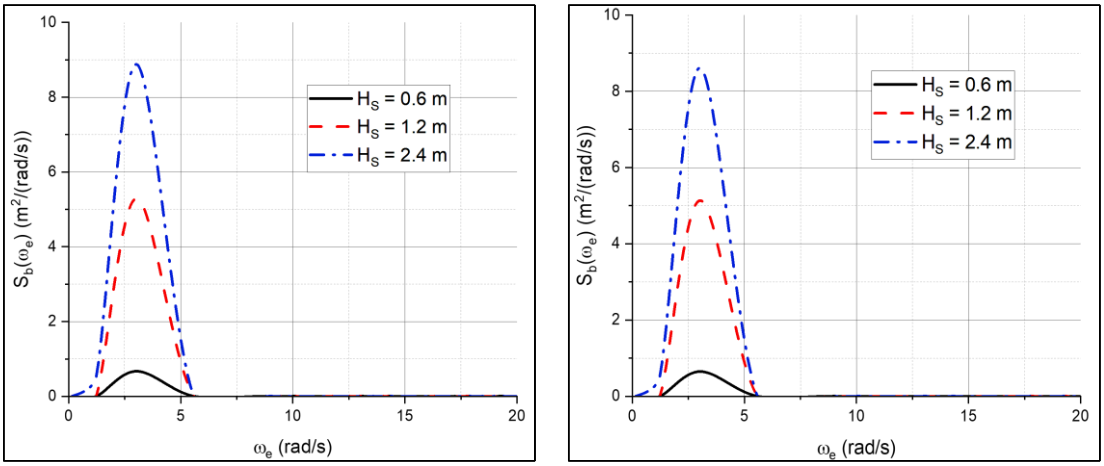
3.3 Response Spectrum

The response spectrum of the relative motion of the bow (Sb(ωe)) according to Bhattacharyya [19] is shown in Figure 7, Figure 8, and Figure 9. In results showed model B-0 has the highest response spectrum for each significant wave height, while model B-6 has the lowest spectrum value. The reason is that RAOs of relative bow motion for the B-0 model are higher than the modified models.



(a) (b)

Fig. 7. The response spectra of RBM at wave height (H_S): 0.6 m, 1.2 m, and 2.4 m on (a) B-0 (b) B-1.5



(a) (b)

Fig. 8. The response spectra of RBM at wave height (H_S): 0.6 m, 1.2 m, and 2.4 m on (a) B-3 (b) B-4.5

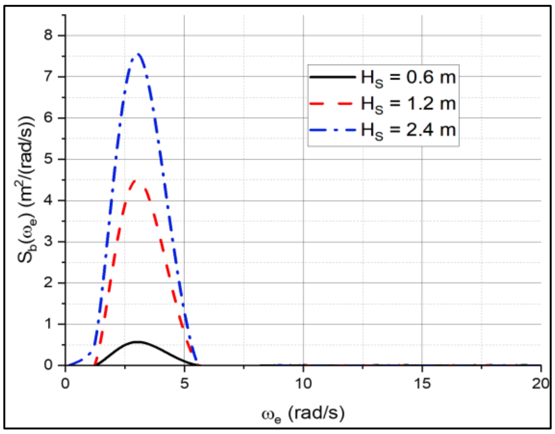


Fig. 9. The response spectra of RBM of B-6 at wave height (H_S): 0.6 m,1.2 m, and 2.4 m.

3.4 Probability of Slamming

Slamming is simulated to occur at significant wave heights (HS) = 0.6 m, 1.2 m, and 2.4 m at a threshold speed of 1.4637 m/s. At a ship speed of 9.44 m/s (Fn 0.6) at a wave height of 0.6 m, the highest slamming probability value occurs in B-0 of 0.029 (2.9%), followed by B-1.5 by 0.022 (2.2%), B-3 by 0.019 (1.9%), B-4.5 by 0.017 (1.7%), and B-6 by 0.010 (1.0%) . As the wave height increases, the probability of slamming increases as shown in Figure 10.

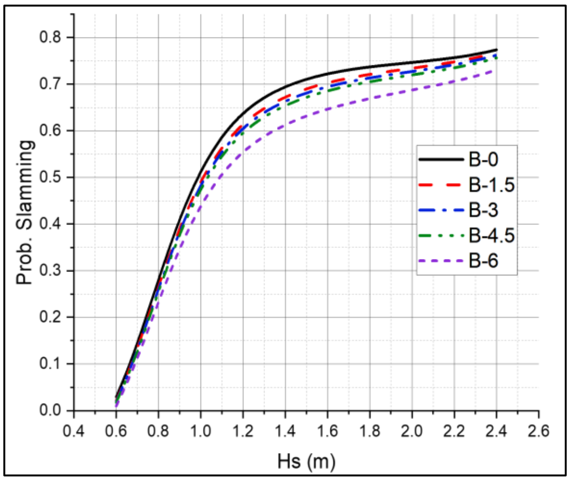


Fig. 10. The slamming probability at speed 9.44 m/s and wave heights 0.6 m, 1.2 m, and 2.4 m

As reported by Nielsen [13], the standard seakeeping criteria for fast boats are small, and the chance of slamming need not exceed 0.03. The analysis results on the catamaran have a slamming probability of less than 0.03 at a significant wave height of 0.6 m. At wave heights of 1.2 m and 2.4 m, the probability of a slam is higher than the standard criteria. This result is underreported by Suastika *et al.,* [4].

4. Conclusions

The modified catamaran adds the bulbous bow in geometric variation to know the effect on the slamming probability. This bows modification is based on the bulbous bow's linear parameters. Investigation of drags by CFD simulations to ensure the bulbous bows can reduce the ship's drag. The results reveal that catamarans with bulbous bows minimize wave-making drag more than those without. Furthermore, an examination of the slamming probability showed that at a speed of 9.44 m/s and a significant wave height of 0.6 m, the initial catamaran (without a bulbous bow) has the most excellent slamming probability value of 2.9%. While on the catamaran with a bulbous bow with length coefficient: B-1.5, B-3, B-4.5, and B-6 decrease the slamming probability of 2.2%, 1.9%, 1.7%, and 1.0%, respectively. The probability of slamming was lowered by 25.93-66.24%, 3.66-13.00 %, and 0.73-5.60 % at significant wave heights of 0.6 m, 1.2 m, and 2.4 m, respectively. A check of the NORDFORSK seakeeping criteria for fast, small crafts shows that the catamaran can operate safely in the significant wave height of 0.6 m. However, due to the ship's relatively fast speed, it cannot meet the requirements in the considerable wave heights of 1.2 m and 2.4 m.

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