Comparison of shallow water effect on a monohull and chine catamaran

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Abstract. Many modifications to the hull shape have been made to obtain the optimum hull to reduce resistance. Various modifications of hull shape, as well as with the addition of the number of hulls, become multihulls. This study conducted a comparative study of monohull rounded and chine catamarans on the squat factor by varying the water depth ratio h/T 1.2, 1.3, and 1.5. The analysis is also carried out on the sinkage and trim factors by varying the ship's trim with changes in LCG points and variations in speed. The simulation results on the effect of depth ratio show that chine catamaran has a squat effect lower than monohull at Fr 0.5. The depth ratio h/T 1.2 of 9.83%, h/T 1.3 of 18.3%, and the h/T 1.5 of 20.69%. At a lower speed Fr<0.3, the monohull has a lower squat effect than chine catamaran. For the effect of 10% LCG trim by stern on the sinkage factor, chine catamaran has a lower value than monohull at Fr 0.5. The analysis results show that chine catamaran has a sinkage effect of up to 40.4% lower than monohull at a ratio of h/T 1.3. In trim by bow conditions, chine catamaran had a lower sinkage effect than monohull at Fr 0.5 with the most significant deviation of 34.21% at a ratio of h/T 1.5. The overall analysis shows that monohull has a remarkable effect on shallow water at Fr<0.3. While at higher speeds, catamarans have a lower influence on the squat, sinkage and trim factors in shallow water conditions.

1. Introduction
Many advances in the hull and numerous areas of efforts to reduce fuel consumption have been made as a result of ship technology advancements. Multihulls are one approach to reduce resistance that has gotten a lot of attention in this endeavor. At high speeds, multihulls exhibit less drag than monohulls, according to numerous studies. Besides the hull's shape, the selection of the suitable outrigger configuration can dramatically affect the decrease in the resistance component of the multihull. A form that is also quite commonly used on ships with minimum drag and high speed is the chined hull. Research on the chine shape on a multihull to get the optimum ship [1]-[4]. However, the reliability of the ship is also determined by the conditions of the waters traversed. Shallow and confined waters are conditions that can cause quite complex problems for ships. Many theoretical and numerical analyses of the influence of shallow water on ships or other sorts of disturbances have been acquired through several investigations. Moreover, developing a primary method for solving ship hydrodynamic difficulties in shallow water. Ship hydrodynamic resistance prediction in shallow water conditions is critical for estimating ship power design requirements. Wave viscosity and resistance, sinkage and trim, propulsion efficiency, and far-field wave systems can all be
affected by shallow waters. The research [5] on variations of hull form and the effect of shallow water to improve shore ship design recommendations. The investigation of [6] in the influence of depth change on viscous resistance on scale effects using the RANS CFD approach. [7] utilized the Fluent code to implement the RANS-VOF technique. [8] used the Star-CCM code to estimate heave and pitch motion in shallow water at full scale. Furthermore, [9] used an algorithm from the theory of potential hydrodynamic interactions of ships on sinkage and trim in shallow water.

The research focused on using ANSYS Aqwa to run computational simulations based on the RANS-VOF technique to analyze monohulls and chine-shaped catamarans. An analysis of the squat, sinkage, and trim factors on a monohull and chine catamarans on shallow water factors. The k-ω SST turbulence model is used to set the solver on the incompressible RANS problem on an unstructured mesh using the finite volume method formulation. The study looks at how differences in water depth affect the squat, sinkage, and trim components of waves.

2. Ship Motion Response

A floating object has six degrees of freedom (6 DOF). The ship's motion consists of three translational movements and three rotational movements based on the ordinate axis. Assuming that the motion is linear and harmonic, then the differential equation for the motion of the couple can be written as:

\[
\sum_{n=1}^{6} \left( M_{jk} + A_{jk} \xi_k + B_{jk} \xi_k + C_{jk} \xi_k \right) = F_j e^{i\omega t} \quad (1)
\]

where \( j = 1,...,6 \), \( M_{jk} \) is the component of the mass matrix of the ship, \( A_{jk}, B_{jk} \) are the matrix for the coefficients of added and damped mass, \( C_{jk} \) is the coefficients of the return hydrostatic force, and \( F_j \) is the amplitude of the excitation force in complex quantities. \( F_1, F_2, F_3 \) are the amplitude of the excitation force resulting in surge, sway and heave, while \( F_4, F_5, F_6 \) are the excitation moment for roll, pitch and yaw. The amplitudes of excitation forces that induce surge, sway, and heave are \( F_1, F_2, F_3 \), respectively, whereas the amplitudes of excitation moments for roll, pitch, and yaw are \( F_4, F_5, F_6 \).

The effect of regular waves at each frequency can be determined by measuring the response or Response Amplitude Operator (RAO). RAO is also known as a Transfer Function because it transfers external loads (waves) in response to a structure. The RAO equation in its general form as a frequency function is written as follows:

\[
[R AO(\omega e)]^2 = \left( \frac{\text{motion response amplitude}}{\text{wave amplitude}} \right)^2 = \left( \frac{Ra}{\zeta a} \right)^2 \quad (2)
\]

\[
S(\omega) = 487.2 \alpha H_s^2 T_p^{-4} \omega^{-5} \exp\left[-1948.2 T_p^{-4} \omega^{-4}\right] \gamma \quad (3)
\]

where \( Ra \) is the amplitude of the motion response in meters, \( \zeta a \) is the amplitude of the wave in meters. Equation 3 is the JONSWAP spectrum equation, as the wave spectrum is chosen based on the real conditions of the sea under consideration. Where \( S(\omega) \), wave spectrum [m²·sec/rad], \( \gamma \) peakedness parameter [m], \( \omega \), wave frequency [rad/sec], \( \alpha=H_s^2/16 \) is calculated to make the total area under the spectrum.

3. Simulation setting

When ships move in shallow water, a phenomenon occurs in which the clearance, or under keel clearance, is reduced, resulting in a squat. Alternatively, a squat is a condition characterized by a difference in flow velocity and a change in water pressure along a ship's hull. Ship squat and trim changes cause the ship to dive towards the stern or the bow, called sinkage. It is critical to predicting sinkage and trim phenomena of large vessels in shallow and confined waters to avoid grounding accidents [10]. Mathematical studies and computational techniques have been carried out to evaluate ship squat [11] and ship performance in shallow water [7]. And [12] studied with CFD the wave pattern in water conditions' subcritical, critical and supercritical regions. This research looked into the squat, sinkage, and trim aspects of monohull and catamaran hulls. The monohull of the motorboat Petrus Sianturi was taken from study data from the Indonesian Transportation Research and Development.
Agency's Research and Development Center for SDP Sea Transportation. Then from the monohull passenger ship is modifying into a catamaran with a chine hull by maintaining the ratio main dimension and volume displacement. Analysis of two hulls comparing in a condition of the ratio of water dept and draft \( h/T \): 1.2; 1.3; 1.5, and Longitudinal of the model (LCG) was changed in varied -10%, -20%, -30%, 10%, 20%, and 30%. The motorboat and catamaran lines plan are shown in figures 1-2, the main dimensions in table 1.

**Table 1.** Main properties of model

| Parameter                        | motorboat Petrus Sianturi | Catamaran hull chine |
|----------------------------------|---------------------------|----------------------|
| Length Overall (LOA)             | 19 m                      | 19 m                 |
| Length Between Perpendicular (LPP)| 16.6 m                    | 17.929 m             |
| Breadth (B)                      | 6.9 m                     | 8.978 m              |
| Height (H)                       | 1.65 m                    | 3 m                  |
| Draught (T)                      | 0.6 m                     | 0.6 m                |
| Coefficient Block (C_B)          | 0.42 m                    | 0.279                |
| Coefisien of Midship (C_M)       | 0.6 m                     | 0.332                |
| Coefisien Waterline (C_W)        | 0.71 m                    | 0.562                |
| Displacement (\( \Delta \))      | 25.65 Ton                 | 25.65 Ton            |
3.1. Setting of hydrodynamic diffraction simulation

Hydrodynamic diffraction simulates the complex 3D motion of linear radiation. It analyses diffraction on double bodies by considering the interaction of hydrodynamic effects between bodies and calculating the order of waves through the square of the transfer matrix function at various water depths. Hydrodynamic diffraction simulation settings for water depths of 0.9, 0.78, and 0.72 m, water density 1000 Kg/m$^3$, and water boundary area at $x$ 100 m, $y$ 100 m. The wave amplitude of 0.2 m is determined according to the average wave amplitude of Lake Toba, North Sumatra, Indonesia.

To determine the element size by determining the minimum point and maximum point of wave frequencies that can be used to simulate hydrodynamic diffraction. The analysis was validated using element number convergence on meshing and numerical uncertainty evaluation. Figure 3 depicts the meshing results on the model, and achieving convergence at the force difference is not substantial. The meshing on monohull uses an element size of 0.175 with a defecturing tolerance of 0.0875. While meshing on chine catamaran is 0.45 with defeaturing tolerance of 0.225.

![Figure 3. Meshing results on the model, and achieving convergence](image)

3.2. Setting of hydrodynamic time response

To calculate acceleration and analyze the ship in shallow water was using Hydrodynamic Time Response. The hydrodynamic time response is set in the shallow water condition at ratio $h/T$: 1.2; 1.3; 1.5, and the density is 1.000 kg/m$^3$. The wave direction is established at head sea - 180° of the angle between wave and vessel - following sea is 0°; beam sea is 90°, and quartering is 45°. Using simple harmonic motion with ten of the wave frequencies numbers: 1.6 x10$^{-2}$ until 60.3 x10$^{-2}$ Hz. Furthermore, analysis movements on heaving, rolling and pitching with simple harmonic motion. The JONSWAP spectrum is used in the wave spectrum type to find the acceleration model. For the RAO analysis using the frequency domain, the modelling is analyzed by the 3D diffraction analysis method to get the RAO value for each incident wave direction and wave period.

4. Investigated hull form in depth variations

This study investigates the squat and sinkage of shallow water with variations in water depth to draft ratio $h/T$: 1.2; 1.3; and 1.5, differences in speeds 0.25; 0.5; and 0.75, and LCG changes of -10%, -20%, -30%, 10%, 20%, and 30%. A comparison of the results of investigations of squats, sinkage, and monohulls and catamarans at $h/T$ ratio of 1.2 is shown in figures 4-7. A comparison of the results of investigations of squats, sinkage, and monohulls and catamarans are shown in figures 4-5.

According to a comparison of the squat investigations on monohull and catamaran (figure 4), at a ratio of $h/T$ 1.2, the monohull had an average squat effect of 0.044 m, and the catamaran had an average squat effect of 0.039 m. At $h/T$ 1.3, the average squat on the monohull is 0.05 m, whereas the catamaran is 0.035 m. Furthermore, a monohull's squat at ratio $h/T$ 1.5 is 0.046 m, while a catamaran is 0.033 m.
The sinkage investigation on the trim effect with LCG changes in shallow water conditions shows the ratios 1.2, 1.3, and 1.5 in Figures 5, 6, and 7, respectively. At the h/T 1.2 ratio (figure 5), the minor sinkage effect is achieved in trim by stern conditions with an LCG -10% and an average of 0.083 m on monohull and 0.064 m on catamaran. While on trim by bow with 10% LCG produces the negligible sinkage effect on monohull of 0.068 m and catamaran of 0.06 m.

![Figure 4](image1.png) ![Figure 5](image2.png) ![Figure 6](image3.png)

**Figure. 4.** The average comparison of squats investigations on monohull and catamaran

**Figure. 5.** The average comparison of sinkage investigations at h/T 1.2 on monohull and catamaran

**Figure. 6.** The average comparison of sinkage investigations at h/T 1.3 on monohull and catamaran
At the h/T ratio of 1.3 (figure 6), a minor sinkage effect was obtained in trim by stern conditions with LCG -10% with an average of 0.073 m on monohull and 0.059 on catamaran. In trim by bow condition with 10% LCG also produces the minor sinkage effect on monohull of 0.054 m and catamaran of 0.053 m. On the other hand, monohull and catamaran with the h/t ratio of 1.5 (figure 7) LCG -10%, an average of 0.09 m on monohull and 0.08 m on catamaran. In trim by bow situation with 10% LCG experience the least sinkage, on monohull is 0.06 m while catamaran sinkage is 0.05 m.

### 5. Results and Discussion

According to the simulation results, the most significant effect of squats occurs at the h/T ratio of 1.2 is shown in figure 8. At Fr 0.25, the squat effect of a monohull is 18.8% less than that of a catamaran. However, at Fr 0.5 and 0.75, the catamaran has a 9.83% lower average squat effect than the monohull. At the 1.2 h/T ratio, both models showed the most significant sinkage at 10% LCG. When trim by stern is shown in figure 9, at Fr 0.25, the monohull has an average 12.5% lower sinkage effect than the catamaran hull. However, when Fr was 0.5 and 0.75, the catamaran hull had a 39.4% lower sinkage effect. While in trim by bow, at Fr 0.25, monohull has an average sinkage effect of 21.5% lower than the catamaran hull. However, at 0.75, the catamaran had the lowest sinkage effect with a difference of 25.4%. The significant difference at h/T 1.2 of the two hulls indicated that the rounded monohull shape factor resulted in a higher flow velocity than the catamaran's chine shape. It is consistent with the study [10], which investigated the results of the catamaran and has a smaller sinkage value than monohull in the range of Fr 0.5 to 1.0.
Figure 9. The significant sinkage in trim by stern condition at h/T 1.2 Fr 0.25 and Fr 0.75

Figure 10-11 shows the wave pattern of CFD simulation results at Fr 0.25 and Fr 0.75. The wave pattern in shallow waters shows that the division of the hull into catamarans tends to have a more significant wave-induced motion at Fr 0.25 than Fr 0.75. The capture indicates that the wave resistance of the monohull is more extensive than that of the monohull. At a limited depth, the velocity will increase, and sinkage increases rapidly with speed. Therefore, catamarans produce a smaller sinkage than monohulls.

Figure 10. Comparison on contour wave monohull and catamaran at Fr 0.25.

Figure 11. Comparison on contour wave monohull and catamaran at Fr 0.75.

6. Conclusions
This study compared the squat factor of monohull rounded vessels and chine catamarans under various shallow water conditions. Sinkage and trim have also been studied by varying the LCG point and speed changes. At a depth ratio of h/T 1.3, the chine catamaran has a sinkage effect that is up to 40.4% lower than the monohull. Overall, the chine catamaran has a lower impact on squat, sinkage, and trim than a rounded monohull at Fr > 0.5.
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