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TRADITIONAL CATAMARAN HULL FORM CONFIGURATIONS THAT REDUCE TOTAL RESISTANCE

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ABSTRACT

Catamaran resistance is very complex compared to monohull resistance, so it is particularly worthy of research. The below-water-level hull form influences the fluid flow characteristics around the ship, which either increases or decreases the total resistance. This study focuses on developing a new hull form by using the Lackenby Method to modify an existing hull form in such a way that reduces the total resistance. The total resistance was calculated using computational fluid dynamics, since the Navier-Stokes equation is built into the Tdyn software. The research results show that hull form changes can in fact decrease or increase the ship's total resistance. The best new hull form was chosen for its value of least total resistance.

Keywords: Catamaran; CFD; Hull Form; Lackenby Method; Resistance

1. INTRODUCTION

The catamaran is so famous and successful as a transportation mode not only because of its large dock area, but also because of the comfort and safety of its stability (Seif & Amini, 2004; Zouridakis, 2005).The success of research and development efforts in passenger catamarans inspired the present researchers to study the fishing vessel (Setyawan et al., 2010). The findings indicate that the catamaran's total resistance is lower than that of a monohull ship with the same displacement.

The catamaran's resistance problems have been discussed in the scientific forum, as its resistance component is more complex than that of a monohull ship. This is due to the complexity of the interaction effect and the interference of the catamaran's viscous and wave-making resistance components. Several studies on catamaran resistance have been conducted in the past, including earlier experiments by (Everest, 1968; Oving, 1985; Pien, 1976), as well as a theoretical study (Doctors, 1991).

Computational fluid dynamics (CFD) is a numeric solution for fluid dynamics (Bertram, 2000). In the case of ships, CFD help in expressing the fluid flow phenomenon around the hull, including the interference and interactive resistance components in the catamaran and multihull (Deng et al., 2010; Siqueira et al., 2007). The present study yielded results similar to (Utama, 1999) study, which applied CFD using the CFX™ software to calculate the reducing viscous resistance component of the catamaran ship, with error differences below 5%.

Previous researchers have used Tdyn to calculate and predict ship resistance (Iqbal & Utama, 2014; Samuel et al., 2015; Yousefi et al., 2013), though the results of the present study differ

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slightly from the findings of previous research. The empirical calculation has been used as a method to determine the catamaran's total resistance (Molland et al., 2004); this was accomplished by adding wave interference (Jamaluddin et al., 2012).

In the previous research, the traditional monohull fishing vessel used by fisherman in Cilacap was modified into a catamaran while still keeping the draught (T). This doubled the ship's capacity, though it also almost quadrupled the ship's resistance (Samuel et al., 2015).

To reduce the ship's total resistance, several researchers worked to optimize the hull shape. One research altered the ship's shape coefficient in order to influence the shape's resistance (Kim et al., 2010).

The present research aims to reduce the catamaran's total resistance by modifying the initial hull form using the Lackenby Method. The best new hull form was chosen according to the lowest total resistance value.

2. METHODOLOGY

The researchers began by creating an initial 3D model of the ship, which was then expanded into eight different models using the Lackenby Method. After modifying the initial model, the researchers used a CFD approach that had been verified by the empirical question to calculate resistance. The model demonstrating the lowest resistance was selected as the best.

The initial hull form model was a traditional fishing vessel located in Cilacap, Central Java, Indonesia, which had been modified into a catamaran. The catamaran form was obtained by directly measuring the ship's geometry, as shown in Figure 1. Figure 2 is a 3D model of the ship. The dimensions of the catamaran ship can be seen in Table 1. The measurements were used in the ship resistance calculation process using a scale of 1:10.

Figure 1 Catamaran hull form

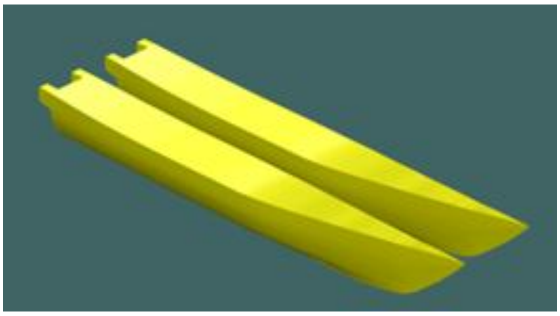


Figure 2 3D ship model

Table 1 Comparison of the ship's main dimensions

Dimension	Full Scale	1:10 Scale
Length Over All (LOA)	10.00 m	1.00 m
Length of Water Line (LWL)	8.72 m	0.87 m
Breadth (B) Demihull	1.01 m	0.10 m
Breadth Over All (BOA)	2.88 m	0.28 m
Depth (H)	0.80 m	0.08 m
Draft (T)	0.50 m	0.05 m
Wetted Surface Area (WSA)	23.76 m^2	0.23 m^2
Volume	4.65 m^3	0.00465 m^3
Displacement	4.76 ton	0.00476 ton
Coefficient Block (Cb)	0.52	0.52

The Lackenby Method was used to modify the hull form (Lackenby, 1950), as well as to change the parallel middle body form, based on references from Figure 3. The modified hull form includes a modified bow's entrance, which was altered by changing the upper angle parameter (α), the lower angle parameter (β), and the length of entrance of the Curve of Sectional Area (x), as shown in Figure 4. The changes of these variations were limited to ± 10% from the initial parameter.

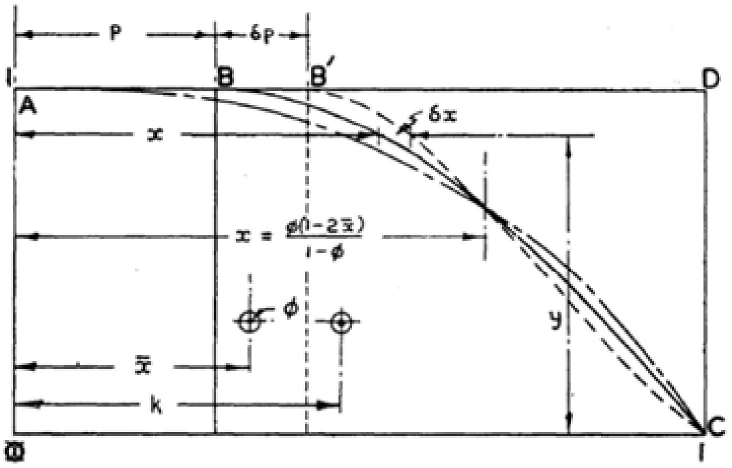
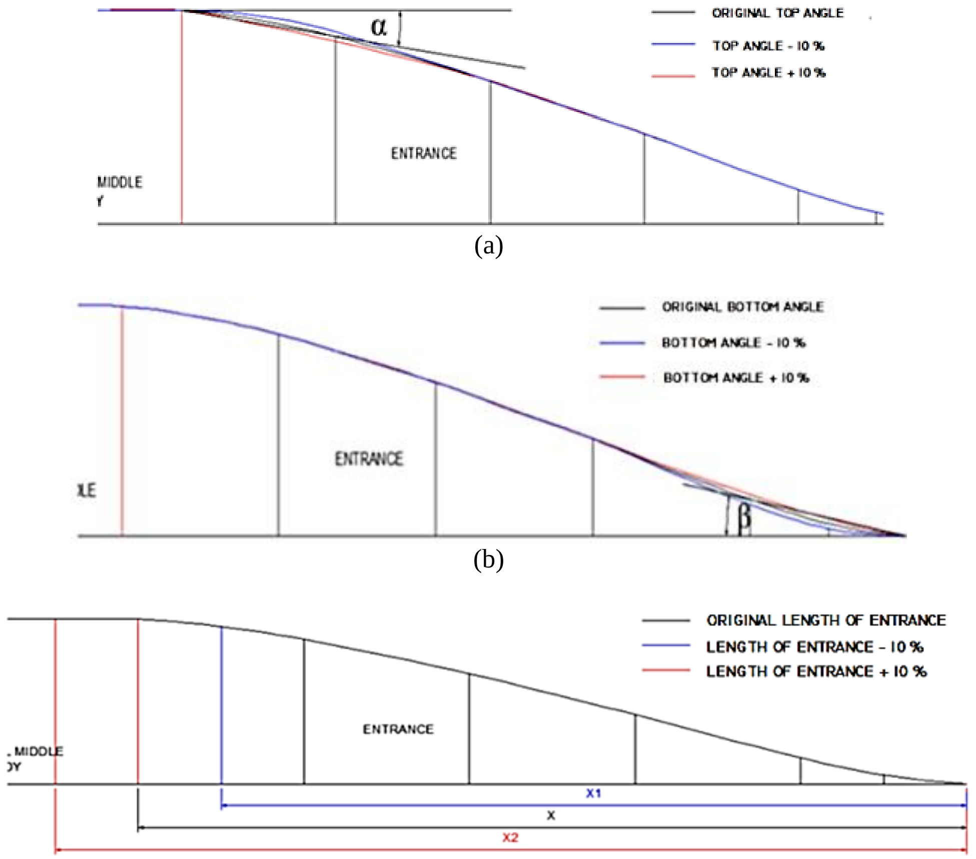


Figure 3 CSA entrance variations (Lackenby, 1950)



(a) (b) (c)

Figure 4 Upper angle parameter, α (a); lower angle parameter, β (b); and the length of entrance of sectional area curve, x (c)

The area changes for every station of each model was obtained from Table 2. The new hull form was made according to the Scheltema de Heere Method (Zhang et al., 2008). Figure 5 shows the body plans derived from each of the eight generated models. The initial model and the eight new models of the new hull form were simulated using CFD software, Tdyn with five velocity variations, which is given in Froude number (Fr). The Froude number was used to convert the real-scale vessel velocity to the hull model velocity (10:1), which was then fed into the CFD software simulation. The five velocity variations available in this research ranged between 3 and 12 knots, or Fr 0.17–0.66.

Table 2 Model comparison

Model	α (°)	β (°)	X (m)
Model A	2.0268	2.4084	4.0050
Model B	2.0268	2.4084	4.8950
Model C	2.0268	2.9436	4.0050
Model D	2.0268	2.9436	4.8950
Model E	2.4772	2.4084	4.0050
Model F	2.4772	2.4084	4.8950
Model G	2.4772	2.9436	4.0050
Model H	2.4772	2.9436	4.8950

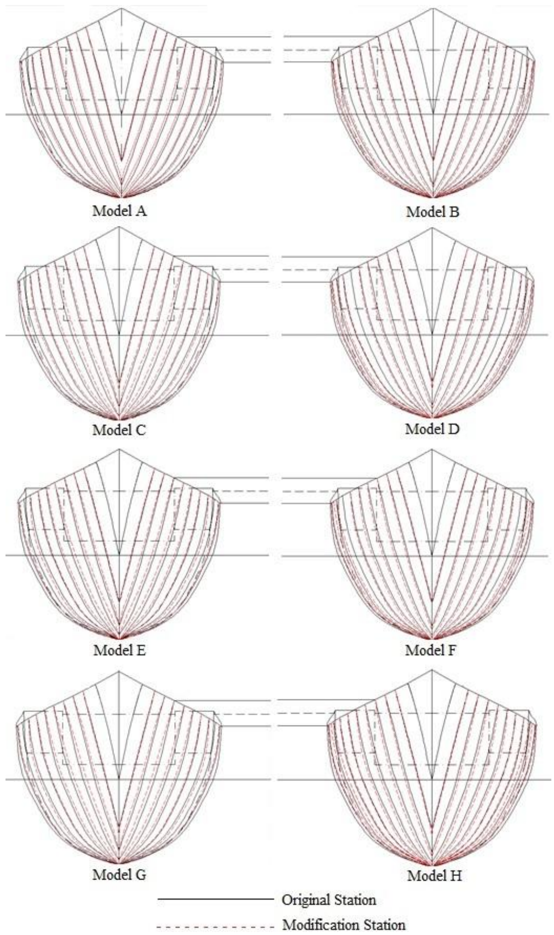


Figure 5 Original and new body plans

For the simulation program, this study used Tdyn's commercial package of CFD software (Tdyn, 2014a; 2014b). It makes use of three different methods to compute ship resistance: a potential flow method, a boundary layer method, and Reynolds Average Navier-Stokes (RANS) equations. The Boundary Conditions step determines the boundary condition in numerical simulations for five cases: Inlet, Outlet, Wall, Bottom, Free Surface, and Wall (Figure 6).

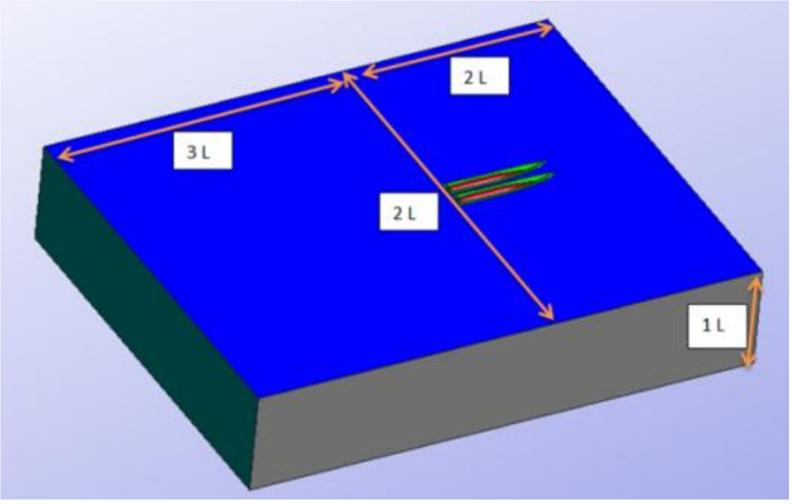


Figure 6 Boundary conditions

The Navier-Stokes Incompressible equation is shown in Equation 1, along with three dimension instructions at the (0,*t*) interval (Swennberg, 2000):

$$\begin{pmatrix} \rho\left(\frac{\delta u}{\delta p} + (u.\nabla)u\right) + \nabla p - \nabla.(\mu\nabla u) = \rho f \ in\ \Omega\ x\ (0,t) \\ \nabla u = 0\ in\ \Omega\ x\ (0,t) \end{pmatrix} \quad (1)$$

In this equation, u = u (x,t) indicates the velocity vector, p = p(x,t) indicates pressure area, ρ indicates density, μ indicates dynamic fluid viscosity, and f indicates the volume metric velocity. Spatial discretization from the Navier-Stokes equation was carried out using the element method, while for the duration discretization, which can be considered an implicit two-step process, the "fractional step method" was used (Kleinstreuer, 1997). The Galerkin, standard methods used for discretization incompressible Navier-Stokes equations, led to numerical instability (García, Oñate, Sierra, Sacco, & Idelsohn, 1998).The Shear Stress Transport (SST)equation was used to express the turbulent flow model. The SST models have also been used in many previous studies (F.R. Menter, 1994);(Florian R Menter, 1993);(Swennberg, 2000); (Bardina, Huang, & Coakley, 1997).

The empirical calculation for the catamaran's total resistance is expressed in Equation 2 (Insel & Molland, 1992). The form factor value for a catamaran vessel was obtained using the Molland's Form Factor equation (Molland, Wellicome, & Couser, 1996), and then modified (Jamaluddin et al., 2012), as shown in Equation 3. (Jamaluddin et al., 2012) also proposed the equation for calculating wave interference (τ), as shown in Equations 4–9. Thereafter, the result of the total resistance coefficient (C_{TCAT}) was distributed to equations of common total resistance (RT), as shown in Equation 10.

$$C_{TCAT} = (1+\beta k)CF + \tau CW \quad (2)$$

$$(1+\beta k) = 3.03\ (L/Vol^{1/3})^{-0.40} + 0.016\ (S/L)^{-0.65} \quad (3)$$

$$\tau = 0.068\ (S/L)^{-1.38},\ (\text{at } Fr = 0.19) \quad (4)$$

$$\tau = 0.359\ (S/L)^{-0.87},\ (\text{at } Fr = 0.28) \quad (5)$$

$$\tau = 0.574\ (S/L)^{-0.33},\ (\text{at } Fr = 0.37) \quad (6)$$

$$\tau = 0.790\ (S/L)^{-0.14},\ (\text{at } Fr = 0.47) \quad (7)$$

$$\tau = 0.504\,(S/L)^{-0.31}, \text{ (at Fr = 0.56)} \tag{8}$$
$$\tau = 0.501\,(S/L)^{-0.18}, \text{ (at Fr = 0.65)} \tag{9}$$
$$R_{TCAT} = 0{,}5.\rho.v^2.WSA.C_{T\,CAT} \tag{10}$$

3. RESULTS AND DISCUSSION

3.1. Total Resistance Verification

The CFD resistance calculation results were validated in order to determine the error level. This model test result was validated using a combination of calculations, the empirical formula, and Slender Body. Figure 7 shows the comparison of the total resistance coefficient based on the empirical equation and the calculations from the CFD-Tdyn software for each Froude number. The CFD empirical equation error was below 5% for each Froude number.

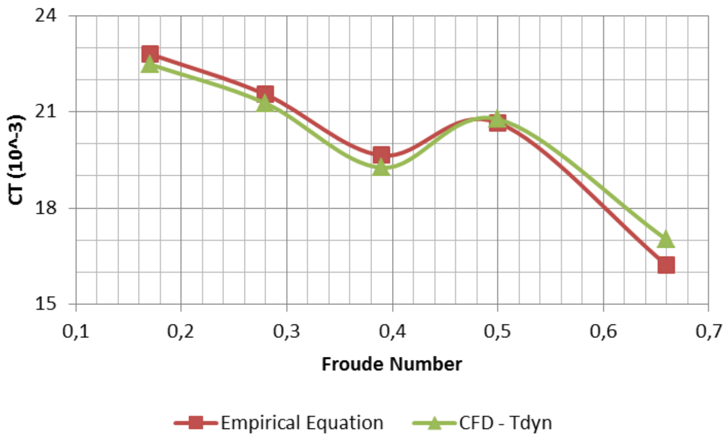


Figure 7 Comparison CT of empirical equation and CFD Tdyn on original model

3.2. Total Catamaran Resistance

Table 3 and Figure 8 show the Ct comparison of each model. The lowest value, bolded, was found for three models at each Froude number. At Fr 0.17, Model A had the lowest Ct, while Model F had the lowest Ct at Fr 0.39. Model D had the lowest overall Ct at Fr 0.28, 0.50 and 0.66.

The model with the lowest Ct was selected as the best. Because the lowest Ct was different at each Fr, selecting the best model depended on which Fr was used as the operational ship speed. In this case, the operational ship speed was determined to be 12 knots, or Fr 0.5. Therefore, Model D was selected as the best model.

Regarding the demihull, Model D had the lowest form factor (1+k) at 1.3274. The form factor of the original model was 1.3343. Therefore, Model D’s form factor is 0.52% lower that of the original model. However, the difference is quite small, so it cannot account for the difference in total resistance. The significant difference in total resistance is based on comparing that of each model’s, as well as whether the resistance is bigger or smaller than the original’s.

Table 3 C_T comparisons for each catamaran vessel model

Fr	C_T ($\times 10^{-3}$)								
	Original	Model A	Model B	Model C	Model D	Model E	Model F	Model G	Model H
0.17	22.49	**21.63**	22.21	21.97	21.78	22.82	22.28	23.04	22.21
0.28	21.26	21.65	21.49	20.95	**20.83**	21.73	21.80	21.83	20.95
0.39	19.26	20.99	19.30	19.81	19.05	20.22	**18.92**	20.33	19.19
0.50	20.77	21.86	19.94	21.43	**19.56**	21.34	20.47	21.42	19.74
0.66	17.01	17.47	16.27	17.30	**15.95**	17.25	16.72	17.31	16.44

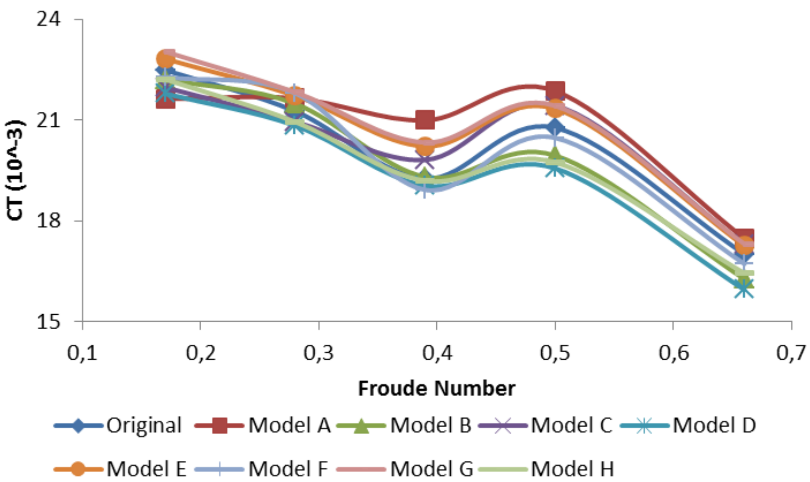


Figure 8 Coefficient of total resistance comparison

4. CONCLUSION

The efforts to reduce the total resistance of the traditional catamaran fishing vessel were successfully carried out. The changes to the catamaran hull form show that the fluid form that surrounds the ship hull influences ship resistance. Model D was chosen as the best new hull form because it has the least total resistance, with a Froude number of 3. This new hull can reduce the total resistance by 6.5%.

5. ACKNOWLEDGEMENT

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