Pentamaran configuration design with modeling hull form for resistance minimization

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Abstract. Multi-hull ship had characteristics with complex geometry configurations. In the early stage design, multi-hull ship with proper configurations can be producing both minimum resistance and power consumption. Increasing number of hull as in pentamaran will increase frictional resistance, but total resistance can be reducing by decreasing wave making resistance with a slender hull form. With CFD tool used to examine minimum resistance with modified modelling of chine hull form on variation i.e. deadrise angles, waterline section of entrance angle and longitudinal section of stem angle. All simulations were conducted with fix separation on S/L 3/16 and Froude number up to 0.7. Comparison with the original hull form, chine hull form C35 II in deadrise 35° and angle of entrance 15° more advantageous with maximum resistance drag reduction 20.38%. The results of the study had been displayed in table and charts of chine pentamaran which having the smallest total resistance expressed in coefficient of friction and wave resistance.

1. Introduction
Experimental and numerical modeling techniques were essential to obtaining designs with good hydrodynamics, both performance and safety. Experimental for multi hull ships was first performed by [1] on a catamaran to obtain optimal hull form with minimum resistance. [2] had tested outrigger configurations of multihull to investigated interference resistance for catamaran, trimaran and tetramaran. Experimentally studied about pentamaran configurations had been studied by: [3], [4], [5], [6] and [7]. Numerical approaches to investigation of wave interference effects, seakeeping performances and the optimal separation distance between the hulls were founded in [8], [9], [10].

Due to a hull form is very influential on the ship's resistance, it is necessary to getting design with proper configuration on the multi hull ship. Researches on multihull generally used Wigley hull form, while chine hull form in some studies shown advantages such as: reducing resistance, easier and faster in the building process. [8] had compared chine and Wigley model on catamarans, which Wigley had a higher value of Cw (wave coefficient) at Fr <0.6, while chine hull form Cw tends to decrease at Fr > 0.6 and lift coefficient increases with increasing angles of deadrise. Agree with [8], [11] had used multihull with chine on variations deadrise angle 0°-20°, which the lift coefficient improved with increasing deadrise angle and Fr. This research is investigating resistance components and drag reduction to the position effect of the side-hulls from both Wigley and chine hull form with modelling modified at variation of deadrise angles on 25°, 30°, 35°; angle entrance: 5°, 10°, 15° and stem angle: 0°.
The experimental data were using the results of [6], which the original Wigley hull form changed to variations chine hull form with outriggers position configuration. From the experimental results will be compared with the results of numerical analysis by using CFD tool.

2. Hull form
This research is a comparative study between Wigley and chine with modification of hull form and outriggers configuration. The modification of hull form conducted to chine with dead rise angle: 25°, 30°, 35°, stem angle: 0° (vertical straight), and entrance angle: 5°-15°. Preliminary analysis was performed on Wigley and chine with dead rise angle: 25°, 30°, 35°, while angle of entrance (15°) and stem angle actually used model of [6] experiment. The hull form of both Wigley and chine characteristics are listed in table 1.

| Hull form Characteristics | Wigley | Chine 25° | Chine 30° | Chine 35° |
|---------------------------|--------|----------|----------|----------|
|                           | Main   | Inner side | Outer side | Main   | Inner side | Outer side | Main   | Inner side | Outer side | Main   | Inner side | Outer side |
| Length                    | 2.00 m | 1.00 m    | 0.75 m    | 2.40 m | 1.02 m    | 0.93 m    | 2.75 m | 1.08 m    | 0.93 m    | 3.00 m | 1.12 m    | 0.93 m    |
| Beam                      | 0.20 m | 0.10 m    | 0.07 m    | 0.20 m | 0.10 m    | 0.07 m    | 0.20 m | 0.10 m    | 0.07 m    | 0.20 m | 0.10 m    | 0.07 m    |
| Draft                     | 0.07 m | 0.07 m    | 0.06 m    | 0.07 m | 0.07 m    | 0.06 m    | 0.07 m | 0.07 m    | 0.06 m    | 0.07 m | 0.07 m    | 0.06 m    |
| Depth                     | 0.15 m | 0.15 m    | 0.14 m    | 0.15 m | 0.15 m    | 0.14 m    | 0.15 m | 0.15 m    | 0.14 m    | 0.15 m | 0.15 m    | 0.14 m    |
| WSA                       | 0.39 m²| 0.18 m²   | 0.11 m²   | 0.55 m²| 0.30 m²   | 0.21 m²   | 0.61 m²| 0.31 m²   | 0.21 m²   | 0.69 m²| 0.32 m²   | 0.21 m²   |
| B/T                       | 2.86 m | 1.43 m    | 1.17 m    | 2.86 m | 1.43 m    | 1.17 m    | 2.86 m | 1.43 m    | 1.17 m    | 2.86 m | 1.43 m    | 1.17 m    |
| Δtot                      | ≈24.5 kg |          |          | ≈24.5 kg |          |          | ≈24.5 kg |          |          | ≈24.5 kg |          |          |

The experimental data of [6] on the smallest resistance Wigley pentamaran configuration IIa (S/L 3/16 and R/L 1/20) used as a configuration reference for this research. Transformation Wigley to chine hull form with differences L/B of main hull, constant B/T and similar displacement have been produced 6 new configurations. The cross section of both pentamaran hull form of Wigley and chine at midship is shown in figure 1. And the six new configurations position of configuration is defined in table 2.

Table 1. Hull form Characteristics

Figure 1. Centre line half view of pentamaran hull form
Table 2. Six configurations position of chine pentamaran

| Chine 25° (C25) | Chine 30° (C30) | Chine 35° (C35) |
|-----------------|-----------------|-----------------|
|                 | I               | I               | I               |
|                 | II              | II              | II              |
| S/L             | 3/16            | 3/16            | 3/16            |
| R/L             | 1/16            | 1/33            | 1/8             |

3. Numerical Study

3.1. CFD approach

CFD approach was a practical step to predictions of the flow around the hull, flow separation, etc., which solved by the Reynolds averaged Navier-Stokes (RANS) equations. The first analysis was investigation of the accuracy turbulent model which corresponds to the experimental data results. The investigations were on K-ε model, Shear Stress Transport (SST) and Baseline (BSL) Reynolds. The K-ε model used to simulate characteristics of turbulent flow, where K is turbulent kinetic energy determines in the turbulence, ε. The SST model and BSL Reynolds stress models were a combination both of k-ω model and k-ε model depending on the fluid regions. [12] identified SST model was a variant of k-ω model in the inner boundary layer and a transformed of k-ε model in the outer boundary layer and the free stream. [12] showed BSL Reynolds stress allows anisotropic turbulence effects to separation off curved surfaces of model complex flow.

3.2. Correlation with experiment

Both modeling and meshing process generated in ICEM well done with repetitive process. For verification, i.e. convergence and the assessment of numerical uncertainty with increasing number of elements of model, which constitute the solution to approach the analytical solution. Processing mesh was repeated 6 times with the number of elements obtained ranging from 0.6 M, 1 M, 6 M, 8 M, 10 M and 11 M, respectively. It has been carried out to the total resistances (force) which element size both boundary and ship hull i.e.: 0.1; 0.005 to 0.003. Evaluation result of meshing convergence is shown in figure 2. The result for 3 turbulent models at variation of Froude number 0.1 – 0.7 is shown in figure 3, which the K-ε model provided a closer match with the experimental data. The highest deviation of total resistance (force) value occurs at Fr 0.7 with error for SST and BSL to over 10%. Then, based on the comparison result of turbulence models with the experimental data of [6], further analysis used ICEM settings with number elements of 10 M and K-ε model.

3.3. Multi Hull Resistance Components

Following the diagram of [13] explains the total resistance consists of two components i.e.: viscous resistance (Rv) as energy lost in wake and wave resistance (Rw) as energy in the form of water waves.
\[ R_T = R_V + R_W \] 

With ITTC-57, viscous resistance \((R_V)\) can be estimated by equation:

\[ R_V = (1 + k)R_F \]

where \(R_T\) = frictional resistance; \((1+k)\) = form factor of hull.

Numerical computation in CFX- Post, frictional resistance \((R_T)\) could be calculated by performing an area integral of the wall shear in the x-direction. While determine the magnitude of form factors \((1+k)\) of six chine models was using [14] plot, a regression method from slow speed data. The form factor \((1+k)\) of six chine models of pentamaran predicted from Prohaska method that are: C25_I=1.11; C25_II=1.14; C30_I=1.24; C30_II=1.2; C35_I=1.44; C35_II=1.37, respectively. In figure 6 to 8, the measurement nondimensionalized of total resistance coefficient \(C_T\), frictional coefficient \(C_F\) and wave coefficient \(C_W\) as follows,

\[ C_T = \frac{R_T}{\frac{1}{2}\rho V^2 S}; C_F = \frac{R_F}{\frac{1}{2}\rho V^2 S}; C_W = \frac{R_W}{\frac{1}{2}\rho V^2 S} \]

where \(V\) = velocity; \(S\) = wetted area of hull. Furthermore, figure 7 expressed drag reduction of Wigley pentamaran to chine hull form was calculated by the equation,

\[ D_R(\%) = \left| \frac{C_{T_{\text{wigley}}} - C_{T_{\text{chine}}}}{C_{T_{\text{wigley}}}} \right| \]

Figure 4. Total resistance coeff. \((C_T)\) on chine models pentamaran

Figure 5. Frictional resistance coeff. \((C_F)\) on chine models pentamaran

Figure 6. Wave resistance coeff. \((C_W)\) on chine models pentamaran

Figure 7. Drag reduction \((D_R)\) on chine models pentamaran

Based on the comparison of six configurations in figure 4 to 6 showed C35_II had the smallest \(C_T\) and \(C_F\) also generates smaller \(C_W\) than the others. All of six configurations appeared hump and hollow phenomenon on percentage of drag reduction. A negative percentage drag reduction indicates a detrimental hull form of chine model than Wigley. The drag reduction of C35_II had the highest
percentage values of 20.38% at Fr 0.2 though not as a whole at increasing Fr. Even the model C25_I at the highest Fr generated the biggest drag reduction: 8.67% and smaller C\textsubscript{W} than C35_II, but had the largest C\textsubscript{T} and C\textsubscript{F} values. Overall the economics of a ship was seen from the smallest value of total resistance. The six models have been analyzed and the results model C35_II more advantageous compared with Wigley and other chine models.

4. Modeling Hull Form
From preliminary analysis of chine pentamaran, the smallest total resistance coefficient has been generated by model C35_II. For further analysis, this model is selected as initial model then changed its shape with variations of entrance angle. Modeling variations of entrance angle are 5\degree-15\degree with stem vertical straight (stem angle 0\degree) in similar displacement and configurations as C35_II. From these combinations generate 3 new hull forms with shape characteristics are shown in the table 3.

| Table 3. Chine models with changed stem and variations of entrance angle |
|-----------------------------|-----------------|-----------------|
| Deadrise (degree) | Stem (degree) | Entrance (degree) |
| C35_II (as initial) | 35 | 47 | 15 |
| C35_IIA | 35 | 0 | 5 |
| C35_IIB | 35 | 0 | 10 |
| C35_IIC | 35 | 0 | 15 |

Figure 8. Total resistance coeff. (C\textsubscript{T}) of chine with vertical straight stem

Figure 9. Frictional resistance coeff. (C\textsubscript{F}) of chine with vertical straight stem

Figure 10. Wave resistance coeff. (C\textsubscript{W}) of chine with vertical straight stem

Figure 11. Drag reduction (D\textsubscript{R}) of chine with vertical straight stem

Stem angle with vertical straight rise effect to larger form factors, which the form factor (1+k) of new chine hull form that are: C35_IIA=1.55; C35_IIB=1.56; C35_IIC=1.52, respectively. With the change of stem angle and variation of the entrance angle on initial model C35_II does not indicate the reduction of components resistance. The smaller stem angle raises increasing wave resistance, which means increasing total resistance. Figure 8 to 10 shows model C35_II still provides the smallest both...
C_t and C_w but the highest C_r. In figure 11, the drag reduction graph of all models have similar trend with hump and hollow phenomenon, where drag reduction (D_r) of model C35_II bigger than other model and the biggest of 20.38% at Fr 0.2.

5. Conclusion
Total resistance tends to be smaller on higher L/B with constant B/T on similar displacement. Outriggers on longitudinal position give a strongly effect to the components resistance especially on wave resistance. Pentamaran with chine hull form at high speeds, Fr 0.4 to 0.7, there are in general two favorable with increasing deadrise; decreasing total resistance and increasing drag reduction. However, change of entrance with smaller angle and stem on vertical straight give detrimental effect to the components resistance, both wave and drag reduction. All the results comparison of chine models shows model C35_II better than the others with drag reduction of 20.38%. Further it is planned to study pentamaran with chine hull form on position optimization of outriggers and optimum angle of: deadrise; stem; and entrance.

6. References
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