Analysis of trimaran-pentamaran side hull location based on
clearance and staggers with stern form variations

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Abstract. An optimum design of ship is to achieve the required speed with minimum power
requirements. On multihull, sidehull position against to mainhull influences the friction resistance
and its stability. Frictional resistance of multi-hull increases due to the addition of wetted surface
area of hull, but wave making resistance can be lowered by a slender hull form. This research
are experimental tests of trimaran with five Wigley hulls on a combination transom and without
transom. The test varied on stagger, clearance and trim at several speeds. A ship with formation
arrow tri-hull on forward was given to prove the resistance reduction due to cancellation wave
which was indicated by negative interference. The influence diverse position of sidehull has
shown that model non-transom (NT) stern moreover give beneficial resistance than model with
transom (WT) at high speed. Similarly, in the trim conditions that NT more favorable on trim
specifically for high speed depending on the position of the sidehull to the mainhull.

1 Introduction

Multihull remains an interesting subject for some marine
applications even in the next few years. They have been
widely applied in high-speed transport with good
hydrodynamic performance, larger deck areas and
excellent stability characteristics.

All possibilities in reducing resistance of multi-hull
ships by slenderess shape of hull and its placement.
Several studies had proved multihull besides influence of
mainhull form parameters, also variable factors from
sidehull and its relative position to mainhull. Sidehull
position against to mainhull influences the friction
resistance and its stability [1]. Frictional resistance of
multi-hull increases as a result of the addition of wetted
surface area of hull, but wave making resistance can be
lowered by a slender hull form. [2] indicates that
decreases of the wave resistance and increased of the
friction resistance is influenced by the ratio of length to
width (L/B) due to viscous factor. Moreover, the
influence of viscosity on the hydrodynamic of multihull
more analyze by [3]. Then [4] with comparison of
experimental and theoretical approach on investigation
of multihull (catamaran) hull clearance. Furthermore,
deep expression by [5] studied on effects of clearance
of between hull on resistance, trim and discussion on
longitudinal wave cuts.

The slender hull as known as Wigley (parabolic hull)
form by [6] on catamaran, trimaran, quadrimaran (tetramaran) and pentamaran. As well as [7] - [12] by determining the configuration of multihull on
optimum distance of Wigley hull such as: catamaran,
trimaran and tetramaran, with and without longitudinal
of stagger. The studies of configurations of Wigley hull
form on multihull has been proven effective in resistance
deduction. And here used a variation of transom stern on
mainhull and sidehull to know the resistance
characteristic, especially its effect on wave resistance.
Other research has concerned a transom stern hull, such
as [13] showed favorable resistance characteristics at
high speeds, which give a significant influence on the
wave resistance and wave wash. And [14] had
obtained the best clearance and stagger on multihull with variation
transom stern to enhance the interference effect and
reflected wave patterns.

Aim of this study is experimental studies on
trimaran-pentamaran using wigley hullform to obtain
staggered configuration, clearance and trim with
combination of stern with transom and without transom.

2 Experimental tests

This research use trimaran with five hulls, outrigger will
be varied on stagger and clearance. An experimental
tensive test based on the ITTC.

2.1. Models characteristics

The design of pentamaran was not an ordinary
pentamaran design with five hulls of same dimensions
connected transversally. Here it like a trimaran with each
of the side of the main hull consists of 2 side hulls. The
parameters of the pentamaran are given in Table 1 and
within its lines plan are sketched in figure 1 and 2.
Which Figure 1 is design of pentamaran describe main

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hull with transom stern and variation side hulls: transom stern on front and no transom on after.

Fig.1. Set up trimaran-pentamaran configuration with transom on both mainhull and after hull of sidehull as WT model (with transom)

Fig.2. Set up trimaran-pentamaran configuration no transom as NT model (no transom)

2.2 Positioning

Model experiments were developed to allow some configurations regarding of resistance components and trim. Variations position of stagger are 0.35 and 0.40, is ratio of distance of stern mainhull to stern of after sidehull to mainhull length. As for variation position of clearance, among others, 1.05, 1.20, 1.35, 1.50, is ratio of distance centerline of mainhull to centerline of sidehull to mainhull width. Detail of name models experiment and configuration of both WT model (with transom) and NT model (no transom) are shown in Table 2.

| Model          | Stagger | Clearance |
|----------------|---------|-----------|
| WT/ NT 1       | 0.35L   | 1.05B     |
| WT/ NT 2       | 0.35L   | 1.20B     |
| WT/ NT 3       | 0.35L   | 1.35B     |
| WT/ NT 4       | 0.35L   | 1.50B     |
| WT/ NT 5       | 0.40 L  | 1.05B     |
| WT/ NT 6       | 0.40 L  | 1.20B     |
| WT/ NT 7       | 0.40 L  | 1.35B     |
| WT/ NT 8       | 0.40 L  | 1.50B     |

2.3 Experimental set-up

The experiment test was constructed in water tank of 50 m length, 10 m width, and 2 m depth of Universitas Indonesia related to various instruments; set of DAQ, voltage regulator, electric motor, load cell, speed marker and computer for data acquisition. The inhibitory dynamometer shall measure horizontal tensile strength with a tolerance 0.2% or 0.05 N of the maximum capacity of the dynamometer measurements whichever is greater. The model (Fig. 3) was tested in calm water, in accordance to International Towing Tank Conference (ITTC) 1978, components of calm-water ship resistance. And Its configurations have been performed at the different of hull separation reported in Table 2. Here was analyzed various configurations and trims on speed range corresponds to Froude numbers between 0.4 and 0.7. The test is investigated the influence transom and trim angle on 0°; 0.5°; 1.0°. Which the trim will be done after gets the best configuration (minimum resistance) of stagger and clearance.

| Parameter           | Mainhull with transom | Mainhull no transom | Sidehull with transom | Sidehull no transom |
|---------------------|-----------------------|---------------------|-----------------------|---------------------|
| Length over all (LOA) m | 1.8                   | 1.8                 | 0.5                   | 0.5                 |
| Breadth (B) m       | 0.18                  | 0.18                | 0.05                  | 0.05                |
| Height (H) m        | 0.17                  | 0.17                | 0.12                  | 0.12                |
| Draft (T) m         | 0.08                  | 0.08                | 0.03                  | 0.03                |
| Block coefficient (cb) | 0.5                   | 0.46                | 0.45                  | 0.42                |
| Displacement (Δ) kg | 11.46                 | 10.48               | 0.223                 | 0.213               |
| Wetted surface area m² | 0.38                  | 0.37                | 0.033                 | 0.033               |
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3 Hydrodynamic

The direct resistance resulting of contributions from the fluid viscosity ($R_V$), and wave resistance ($R_W$), which can be expressed as

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

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

where $R_T$ is total resistance considered to summation of wave resistance $R_W$, influence from viscosity, $R_V$, and wave-pattern generation. While itself of the viscosity is the embodiment of friction drag $R_F$ and form factor $k$, which obtained by Prohaska’s method from low-speed measurements.

The evaluation of the total resistance to the results of experiment is expressed in total resistance coefficients, defined as

$$C_T = \frac{1}{2} \rho V^2 S \quad (3)$$

which frictional drag coefficient $C_T$ is calculated from ITTC 1957 correlation line formula and the wave drag coefficient $C_W$ obtained after both of total resistance and friction are known.

$$C_F = 0.075/(\log Re - 2)^2 \quad (4)$$

The multihull will not be separated from the interference factors IF generated by each hull, which it was a very strong influence on the total resistance especially at high speed. The interference can be approximated by standard eq. (5) or (6).

$$IF = \frac{R_{\text{penta}} - (R_{\text{main}} + 2R_{\text{front}} + 2R_{\text{after}})}{(R_{\text{main}} + 2R_{\text{front}} + 2R_{\text{after}})} \quad (5)$$

$$\Delta C_T = C_{\text{penta}} - (C_{\text{main}} + 2C_{\text{front}} + 2C_{\text{after}}) \quad (6)$$

Eq. (5) total resistance pentamaran $R_{\text{penta}}$, mainhull resistance $R_{\text{main}}$, sidehull resistance in front $R_{\text{front}}$ and after $R_{\text{after}}$. And Eq. (6) $\Delta C_T$, interference resistance coefficient which results from subtraction the total resistance as a pentamaran $C_{\text{penta}}$ to the sum of resistance coefficient of mainhull $C_{\text{main}}$, sum of total resistance coefficient of sidehull in front $C_{\text{front}}$ and sum of total resistance coefficient of sidehull in after $C_{\text{after}}$.

According to [15] that the interference factor ideally is a negative value. Percentage interference can be expressed in Eq. (7). Negative percentage interference indicates the resistance of the pentamaran was less than the each of hull as separately and summed.

$$\%C_T = \frac{C_{\text{penta}} - (C_{\text{main}} + 2C_{\text{front}} + 2C_{\text{after}})}{C_{\text{penta}}} \quad (7)$$

About trim was more affected by the side-hull position even if its position closer to the main hull. The nondimensional calculate for trim using [16].

$$\text{Trim} = -(\Delta Z_{\text{bow}} - \Delta Z_{\text{stern}}) 2g/V^2 \quad (8)$$

where $g$, gravity in m/s$^2$, $V$, velocity in m/s, $\Delta Z_{\text{bow}}, \Delta Z_{\text{stern}}$ are variation in free model of bow draft (m) and stern draft (m) respectively.

4 Experimental Results

4.1 Pentamaran with transom (WT)

Experimental results of resistance components of all configuration pentamaran with transom (WT) versus $F_n$ are plotted in figure 3 – 5.

$$\Delta C_T = C_{\text{penta}} - (C_{\text{main}} + 2C_{\text{front}} + 2C_{\text{after}})$$

$$\%C_T = \frac{C_{\text{penta}} - (C_{\text{main}} + 2C_{\text{front}} + 2C_{\text{after}})}{C_{\text{penta}}}$$
It can be observed that the best configuration with the lowest resistance are model WT 4, stagger 0.35L and clearance 1.5B (Fig. 4). The experiment results of Cw (Fig. 5) and IF (Fig. 6) give similar trend with the coefficient of total resistance $C_T$, and model WT4 still the best result. But model WT5 also shows lower results at Fn 0.7, although for Fn 0.4-0.5 they have significant differences.

**4.2 Pentamaran no transom (NT)**

The results of resistance components of all configuration pentamaran no transom (NT) are shown in figure 7 – 9.

It can be seen the longitudinal location of the side hulls affects the total resistance coefficient much more than clearance. The total resistance in Figure 7 shows that NT 4 (stagger 0.35L, clearance 1.5B) and NT 7 (stagger 0.4L, clearance 1.35B) has the least resistance at Fn $\leq$ 0.5, which indicates that the best width can be minimize wave and reduction of total resistance. The best resistance (minimum resistance) for NT models are generated by model NT3, stagger 0.35L and clearance 1.35B (Fig. 7 – 8), although at Fn 0.5 it not the lowest result.
The interference factor IF as shown in Fig. 9 that some of models have a negative interference for Fn > 0.5, which is beneficial to resistance. Therefore, it can be a destructive interaction of an individually wave system. And the best results of IF were generated by NT 3 (stagger 0.35L, clearance 1.55B) and NT 7 (stagger 0.4L, clearance 1.35B).

The comparison results of WT and NT model for all the configurations are shown in figures 10 (stagger 0.35L) and 11 (stagger 0.4L). It can be seen for stagger 0.35L at high speed NT model give less resistance than WT model. And with increase of stagger (0.35L to 0.4L) NT still the lowest resistance than WT model. This indicates there was a strong effect of transom for slender hulls in particular at high speed which beneficial to reduce resistance.

4.3 Trim

Results regarding trim angle for WT and NT are plotted in figure 12-13.

The running trims was done with trim angle on 0°; 0.5°; 1.0° for all configurations after gets the best configuration of stagger and clearance. Shown in Fig. 12 was a WT 4 model that the trim angles for all conditions get reduction as increasing Fn. But on trim angle 0.5 has extremely changed on total resistance at Fn 0.7. Fig. 13 was trim results of NT7 model shows favorable for resistance results on trim angle 0.5 and 1.0 specifically for high speed. Although on displacement condition give unfavorable at Fn 0.6.

5 Conclusions

A comprehensive experimental campaign has been performed to hydrodynamic analysis of trimaran-pentamaran with stern variations. It has been observed that: hydrodynamic of of trimaran - pentamaran strongly depends on the side hull longitudinal location (stagger) besides of transom stern; transom stern (WT model) well at low and high-speed but performs poorly in the intermediate speeds of Fn = 0.4 to 0.5 in particular on stagger 0.35L and clearance 1.05 B; non-transom stern (NT model) also well at low and high-speed ranges, moreover give beneficial resistance than WT model. It well at most of the speeds higher than Fn 0.5; the interference factor IF of both WT and NT have a negative interference for Fn > 0.5. The best results for WT was generated by WT4, stagger 0.35L and clearance 1.5B. Furthermore, for model non-transom was generated by NT 3 (stagger 0.35L clearance 1.55B) and NT 7 (stagger 0.4L clearance 1.35B); and trim condition more favorable for NT model than WT on trim angle 0.5 and 1.0 specifically for high speed. It is off course depending on position of side hull to main hull.

Some work must be still dedicated to defining some criteria to a be able to consider as additional on shape of the hulls and side hull positions.

This work has been financially supported by by PITTA Grant 2018 funded by DRPM Universitas Indonesia with no. 2562/UN2.R3.1/HKP.05.00/2018. The authors wish to appreciation for the valuable support from pentamaran team of Department of Mechanical Engineering.

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