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10 Upper Belgrave Street
London SW1X 8BQ

Telephone: 020 7235 4622
Fax: 020 7259 5912

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AUTHORS' CONTACT DETAILS

Andi Jamaluddin
Indonesian Hydrodynamic Laboratory (IHL) Surabaya, Indonesia
andi99@engineer.com

Ferry Manuhutu
Universiti Malaysia Terengganu, Malaysia
ferdomanu@yahoo.com

Peter Sanders
BMT Design & Technology, Melbourne, Australia
psanders@bmtdt.com.au

Kazuhiko Shiotani
JFE Steel Corporation, Japan
k-shiotani@jfe-steel.co.jp

Ketut Utama
ITS, Surabaya, Indonesia
kutama@na.its.ac.id

Arief Suroso
Dept of Ocean Engineering-ITS, Indonesia
arief_suroso@yahoo.com

Wolter R Hetharia
Université de Liége, Belgium
hethariawr@yahoo.com

Aries Sulisetyono
Institut Teknologi Sepuluh Nopember (ITS) Indonesia
sulisea@na.its.ac.id

Clive Evans
Lightning Naval Architecture, Australia
navlight@lna.com.au

Daeng Paroka
Hasanuddin University, Indonesia
d_paroka@yahoo.com

Bastien Abeil
Maritime Research Institute Netherlands, The Netherlands
b.abeil@marin.nl

Muhammad Alham Djabbar
Hasanuddin University, Indonesia
alham.djabbar@yahoo.com

Sunaryo
Department of Mechanical Engineering, University of Indonesia
naryo@eng.ui.ac.id

Daniel M Rosyid
Department of Ocean Engineering, ITS Surabaya, Indonesia
dmrosyid@gmail.com

Johannes M Herman
Marine Engineering, Pattimura University
herman_tsp_unpatti@yahoo.com

Eka Taniputra
Orela Shipyard, Indonesia
eka@orela.co.id

Richard Birmingham
Newcastle University, UK
r.w.birmingham@newcastle.ac.uk

THE EFFECTS OF HULL MODIFICATION ON DESIGN PARAMETERS OF MEDIUM-SPEED MONOHULL PASSENGER FERRIES

W R Hetharia, A Hage and Ph Rigo, Université de Liége, Belgium

SUMMARY

The development of medium-speed monohull passenger ferries has shown their better performance in some maritime countries recently. With the operational speeds may reach 23 knots, those ships are classified as semi-displacement ships where the range of those speeds are beyond the hump speed. In fact, those ships need a lot of energy to maintain their speeds. Since the database was not available and provided for the optimization process of those ships then a base ship of 254 passengers was designed in this study. The modifications of hull dimensions of the base ship were executed due to the ship layouts. The effects of changes in resistance, stability and other design parameters were analyzed in this study. An example of optimization process for one configuration of ship layout is presented in this paper.

NOMENCLATURE

$A_1 .. A_{27}$	Coefficients in equation (1)
A_T	Transom area (m^2)
A_X	Maximum section area (m^2)
B	Molded beam of the submerged hull (m)
C_B	Block coefficient
C_M	Midship coefficient
C_P	Prismatic coefficient
C_{WP}	Waterplane coefficient
C_∇	Beam-loading coefficient
D	Molded depth (m)
Fn	Froude number (nondimensional)
GM_T	Transverse metasenter height (m)
L	Molded ship length (m)
L_{CB}	Longitudinal center of buoyancy (m. %L)
P_B	Brake power (kW)
P_E	Effective power (kW)
R_T	Total resistance (kN)
T	Design molded draft (m)
T_h	Heave natural period (s)
$T\phi$	Roll natural period (s)
T_Θ	Pitch natural period (s)
U	Coefficient in equation (1) = $\sqrt{2}i_e$
V	Ship speed (m/s, knot)
W	Ratio A_T/A_X in equation (1)
X	Ratio $\nabla^{1/3}/L$ in equation (1)
Z	Ratio ∇/B^3 in equation (1)
w	Taylor wake fraction
t	Thrust deduction factor
α_E, i_e	Angle of entrance of load waterline (degree)
η_h	Hull efficiency
η_o	Propeller efficiency
η_r	Relative rotative efficiency
η_s	Seal efficiency
η_b	Line shaft bearing efficiency
∇	Molded volume at the design waterline (m^3)
Δ	Displacement at the design waterline (t)

1. INTRODUCTION

Recent development of medium-speed passenger ferries has brought a new challenge in the maritime fields. Those ships operate in some regions of the world such as Mediterranean, Asia, Pacific, Central America and Europe with the speed range of 18 to 25 knots. The existence of those ships is to fulfill an empty speed region between conventional ferries and high speed crafts (HSC). Since the emerging, those ships had been built and operated in all regions of the world for the specific routes. The application of the hull material of Aluminum in recent years to those ships gives the benefits for the additional payload or reducing the power. Those ships are operating in short-sea distance where most of them are multi-hulled type (catamarans). However, due to their simplicity, the monohulls type are developed also and have a potential future markets. In fact, those ships operate at the range of Froude numbers Fn from 0.55 to 0.80 which is beyond the hump speed ($Fn > 0.50$). Therefore, they need a great engine power to maintain their service speed. The efforts should be done in order to optimize the engine power of the ship. To minimize the engine power or ship resistance then the hull dimensions and geometrical forms should be taken into account. However this effort would affects other design parameters. From the existing database of ships, it was found that for an input of number of passengers those ships have a difference in dimensions and engine power. In this study, a base (parent) ship was designed and modified for its dimensions. The modification process is conducted based on the layout of the ship. The layout is arranged due to the passenger distribution along the ship length and ship beam. In addition, the layout is arranged also for passenger distribution on main deck and upper decks. This arrangement will end-up with the variation of ship length and beam. Furthermore, one configuration of those layouts is evaluated and optimized in this study.

2. LITERATURE REVIEW

The medium-speed passenger ferries are classified as semi-displacement ships [1, 2] and in other references it is known also as semi-planing [3]. From the structural point of view, due to their speeds and lighter displacements, they are classified as High Speed Craft (HSC) [4]. The term of medium-speed may be found in Reference [2]. The recent term for medium-speed may be found in the maritime fields where the speeds is not exceed 25 knots. Due to their operational range those ships are classified as short-sea ferries and have the speeds that do not generally exceed 25 knots [5].

2.1. THE EFFECTS OF DIMENSIONS AND FORMS FOR SHIP PERFORMANCE

The products of a ship design are dimensions and geometrical hull forms. These products, in fact, should satisfy the best performance of the ship. This may be achieved by modifying them in such a way until they fulfill the target of final result. Modification the dimensions and hull forms may be executed by changing them in some patterns. In fact, these may affect the design parameters of the ship. As stated by Watson [6] and Parsons [7] that the changing of hull dimensions (length, breadth, draft, height) and hull forms (coefficients) will affect the powering, cost, stability and other ship parameters. In fact the modified hull dimensions and forms may be applied further for the optimization process due to the required optimization objectives. Beside the ship dimensions, the hull forms play the important roles also for the ship parameters. They are represented by C_B, C_M, C_P, C_{WP}, L_{CB}, α_E. They may be found at some references for some types of ships. Also for optimization process, the range of values of those coefficient may be found in References [7,8].

2.2. RESISTANCE AND PROPULSION OF SEMI-DISPLACEMENT SHIPS

Due to their special hydrodynamic aspects, some studies has been executed concerned these ships. Molland [1] presents some statistical data for the computation of resistance of semi-displacement ships such as dimensional ratios of $L/\nabla^{1/3}$ = 6.0 to 9.0; L/B = 5.0 to 7.0; B/T = up to 5.0 which affect the resistance and stability. Larsson [3] presents the information concerning the best value of transom area (A_{tr}) for those semi-planning ships.

The systematic series of resistance data of semi-displacement ships that may be used as a basis for preliminary power estimates are found in References [1, 3, 9, 10]. From all the existing resistance series, the resistance of the semi-displacement ships depend on the parameters such as [1, 10]:

- Length displacement ratio = $L_{WL}/\nabla^{1/3}$
- Beam-loading coefficient $C_\nabla = \nabla/B^3$.
- Angle of entrance of the load waterline = i_e
- Ratio of transom area to maximum section area = A_T/A_X

Meanwhile, some series methods also include the parameters such as: ratio of B/T, LCB, C_B, C_P, C_{WP}.

Two statistical methods were suitable for the computation of ship resistance for those kind of ships, i.e. Savistsky pre-planing [9] and WUMTIA [1]. The statistical resistance prediction method derived by Mercier and Savitsky is suitable for the semi-planning ships. The general form of the resistance equation adopted by Mercier and Savitsky is as follows:

$$R_T/W = A_1 + A_2X + A_4U + A_5W + A_6XZ + A_7XU + A_8XW + A_9ZU + A_{10}ZW + A_{15}W^2 + A_{18}XW^2 + A_{19}ZX^2 + A_{24}UW^2 + A_{27}WU^2 \quad (1)$$

where: $X = \nabla^{1/3}/L$; $Z = \nabla/B^3$; $U = \sqrt{2i_E}$; $W = A_T/A_X$.

The values of the coefficients A_1 to A_{27} and correction factors are presented in Reference [9]. This method is provided in the Maxsurf software.

The effective power of the ship is computed as:

$$P_E = R_T \text{ x } V \quad (2)$$

where: R_T = total resistance and V = speed of the ship

The engine power (brake power P_B) is computed in relation with the effective power P_E [7].

$$P_B = P_E / (\eta_h \eta_o \eta_r \eta_s \eta_b \eta_t) \quad (3)$$

where:

η_h = hull efficiency;
η_o = propeller efficiency;
η_r = relative rotative efficiency = 1.0
η_s = seal efficiency;
η_b = line shaft bearing efficiency;
η_t = transmission efficiency;
$\eta_s \eta_b$ = 0.97 for machinery amidships
η_t = 0.975 for medium speed diesel plant

Hull efficiency is computed as:

$$\eta_h = (1 - t)/(1 - w) \quad (4)$$

where:

w = Taylor wake fraction $= 0.5C_B - 0.05$ (5)
C_B = block coefficient
t = thrust deduction factor $= 0.6\,w$ (6)

The maximum continuous rating (MCR) of the main engine is determined by adding a power service margin as 10% to the brake power.

$$MCR \geq (1 + MS)\, P_B \quad (7)$$

where: MS = power service margin

Two screw propeller units are used for the ship. The screw propellers are evaluated based on the propeller data from the Wageningen B-Screw Series [9]. The evaluation for the cavitations of the propellers is executed based on Burril Diagram of cavitations.

2.3. STABILITY REQUIREMENTS FOR MEDIUM-SPEED PASSENGER SHIPS

The stability criteria that should be fulfilled by all passenger ships is not only due to the initial metasenter height (GMTo). In fact, the ship stability criteria should fulfilled at the large angle of inclinations. The stability criteria that should be applied for the ship stability are based on the HSC Code 2000 MSC 97(73)-Annex 8 Monohull Intact, HSC Code 2000 Chapter 2 Part B Passenger Craft Intact and IMO MSC 36(63) HSC Code Monohull. Those criteria include:

- Angle steady hell ≤ 16 deg
- Angle steady hell/margin line immersion ≤ 80%
- Area1/Area2 ≥ 100 %
- Area 0-GZ_{max} ≥ 0.055 m.rad
- Area 30 to 40 ≥ 0.03 m.rad
- Angle GZ_{max} ≥ 15 degree
- Initial GMt ≥ 0.15 m
- Angle passenger crowd ≤10 degree
- Angle high speed turning ≤10 degree

It is quite difficult to find this information from the existing similar ships. Therefore, a parent ship is designed and provided the parametric model data for the future optimization process.

2.4. SEAKEEPING REQUIREMENTS FOR MEDIUM-SPEED PASSENGER SHIPS.

For the initial ship design, the sea keeping parameters were evaluated for rolling, pitching and heaving natural periods [7]. Those are computed due to the following formulas:

Roll natural period: $T\phi = 2.007\, k_{11} / \sqrt{GM_T}$ (8)

where: $k_{11} = 0.40\, B$

Pitch natural period:

$T_\Theta = 1.776\, C_{WP}^{-1} \sqrt{(T\, C_B\, (0.6 + 0.36\, B/T)}$ (9)

Heave natural period:

$T_h = 2.007 \sqrt{(T\, C_B(B/3T+1.2)/C_{WP})}$ (10)

3. DATABASE OF PARENT SHIP

Since it is quite difficult to find the database of similar ship with the hull material of Aluminum, then a base ship was designed in this study. Generally, the data of the existing ships are provided such as main dimensions, speed and engine power. Other detail data such as details of weights, centers and geometrical hull forms are quite difficult to be found. Stability is an important parameter that is required for medium speed passenger ferries. The criteria of stability at the large angle of inclination (*GZ* curve) are evaluated during the design process. One important objective of design the base ship is to avoid some uncertainty factor during the modification or optimization process [7]. If the database is not available, one way to do is designing the parent ship. The results of the parent ship would be explored next for a specific objective function. As stated by Gale [11]: "The point designs, once they have been developed, can be used as parents to explore the effects of parametric variations in other, second order parameter".

In the design process, a number of cycles (iterations) are required to arrive at a satisfactory solution [11, 6, 7]. Particularly in designing a passenger ferry several important key factors should be concerned and included [11, 12, 13, 14, 15]. Those key factors include: spaces, access, services rooms, arrangement, accommodation and safety for passengers, services and facilities for ship operations. Also scantling, weights and centers, stability, safety and seakeeping are important parameters for ship operation. All requirements and rules imposed for the ship design are strictly required during design process. The parameters of parent ship are presented in Table 1. The layout of the ship is shown in Fig. 1.

Parameters	Value	Unit
Total number of passengers	254	
Number of seats in row	10	
Number of crews	5	
Number of pax main-upper decks	177-77	
Pax distributions main-upper decks	70-30	%
Service speed	19.98	knots
Navigation range	200	n.m
Length overall, L_{OA}	32.00	m
Length of waterline, L_{WL} (= L_{BP})	29.00	m
Ship beam (at main deck), B	7.00	m
Ship beam (waterline), B_{WL}	6.69	m
Draft, T	1.388	m
Deck height, D	2.600	m
Displacement, Δ	105.3	Tone
Volume displacement ∇	102.7	m^3
Block coefficient, C_B	0.382	
Midship coefficient, C_M	0.547	
Prismatic coefficient, C_P	0.697	
Water plane coefficient, C_{WP}	0.76	
Long. C. of buoyancy, Lcb (fr AP)	48.33	% Lwl
Vertical center of buoyancy, KB	0.967	m
Radius metacenter, BM_T	5.374	m
Vertical center of gravity, KG	3.039	m
Initial metacenter, GM_T	3.302	m
Total resistance (at 19.98 knots)	93.6	kN
Total engine power (MCR)	2402	hp
Total propulsion efficiency η_t	0.588	
Period of rolling, Tϕ	2.97	Second
Period of pitching, T_Θ	2.31	Second
Period of heaving, Th	2.65	Second

Table 1: Parameters of the parent ship

Other ship database are described as follows:

- The structure components of the ship were determined based on the Rules for the Classification of High Speed Craft [4].
- Type of ship: passenger ferry/class B.
- Type of passenger accommodation: seat in passenger saloon.
- The hull material of the ship: Aluminum Alloy. The types of alloys used for the ship are 5083 H111 for plating and 6082 T6 for profile.

- Type of main engine: MTU Marine Diesel Engine 10V 2000 M70.
- Rated power: 1205 bhp (Rated speed is 2250 rpm).
- Gearbox: ZF 3000 (i = 2.0)
- Type of selected screw propeller: B 4-70 (BAR : 0.70, Number of blades: 4, P/D: 0.799, Diameter: 1.078 m, Efficiency: 0.584)
- Maximum speed for the ship: 19.98 knots

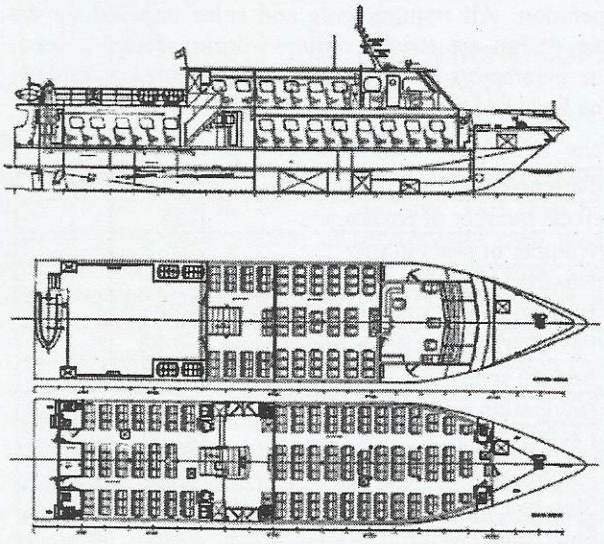

Figure 1: Layout of the parent ship

The total weight of the ship is computed directly from the parent ship. The weights and their centers are presented in Table 2. A margin weight of 4% is added to the ship lightweight. In addition, a margin of VCG of 0.150 m was added for the VCG of the ship lightweight [7].

Items weight	Weight (tone)	LCG (m)	VCG (m)
Structural weight	38.902	-0.628	2.882
Machinery and systems	15.725	-2.900	1.418
Ship outfits	13.960	-0.381	3.773
Sum LWT	68.587	-1.099	2.728
Margin weight	2.743	-1.099	2.728
DWT (pax & liquids)	33.922	0.764	3.355
Total weight	105.252	-0.498	2.930

Table 2: Weight and centers of the parent ship

4. MODIFICATION OF HULL DIMENSIONS

As stated earlier that the resistance of the semi-displacement ships depend on the parameters length displacement ratio $L_{WL}/\nabla^{1/3}$ and beam-loading coefficient $C_\nabla = \nabla/B^3$. In fact, for the small passenger ships such as medium-speed passenger ferries this may be achieved by the layout of the ship. For the real case, the layout is arranged by passenger distributions due to the length, width as well as main-upper decks. The parent ship has 254 passengers. Numbers of seats for passengers in a row due to the ship beam are 10 seats. The ship was named for P254S10. The passenger distribution main-upper deck is 70-30%. The similar way was done for the same number of passengers with number of seats are 9. The ship was named for P254S9. The distribution of passengers was done by shifting each seat row of passengers from main deck to upper deck or vice versa. It was noticed that during the shifting of seats, the weight components of passengers and their belongings were not changing. The only effect of movement of passengers was the changing of vertical and longitudinal centers of weights. In fact, this shifting of passengers affected the ship length and beam due to the required space. In addition, the weight of structural items and its centers were changed. As a result the total ship weight or displacement of the ship was changed.

During the modification for P254S10 and P254S9 due to the pax distribution main-upper decks, the main dimensions such as ship beam, deck, midship cross-section and transom area were kept to be constant. The main changing of the ship parameters were: beam, length, displacement, block and prismatic coefficients, longitudinal center of buoyancy, and half angle of entrance. The main difference of P254S10 and P254S9 is ship beam which is 7.00m for P250S10 and 6.50 m for P254S9.

Assume that during the modification of ship length, the structural elements were constants then structural weight was changed. To add or reduce one meter length of ship for P254S10, the longitudinal structural weight will change as much as 0.818 tone (2.10 % of total structural weight) for all structures below the main deck. With the addition of transverse structures this will change 1.033 tone (2.65 % of total structural weight). In addition, for the structure components of the upper deck, weight changes by 0.235 tone (0.6 %) for longitudinal structures and 0.262 ton (0.67 %) for longitudinal and transversal structures. The similar way for P254S9, the longitudinal structural weight will change as much as 0.775 tone (1.991 % of total structural weight) for all structures below the main deck. With the addition of transverse structures this will change 0.976 tone (2.51 % of total structural weight). In addition, for the structure components of the upper deck, weight changes by 0.228 tone (0.59 %) for longitudinal structures and 0.254 tone (0.65 %) for longitudinal and transversal structures. The structural weight decreases as much as 1.256 tone (3.23 %) as the ship configuration changed from P254S10 to P254S9. The ship parameters due to the modification of length and beam are presented in Table 3.

The parameters of ship resistance and stability were computed by using Maxsurf software. The criteria that have been used for the ship stability are based on HSC Code 2000 MSC 97(73) - Annex 8 Monohull Intact, HSC Code 2000 Chapter 2 Part B Passenger Craft Intact and IMO MSC 36(63) HSC Code Monohull Intact. In addition, the ship resistance was computed based on the statistical method of Savitsky pre-planning. The results of the computations are shown in Figures 2 to 9.

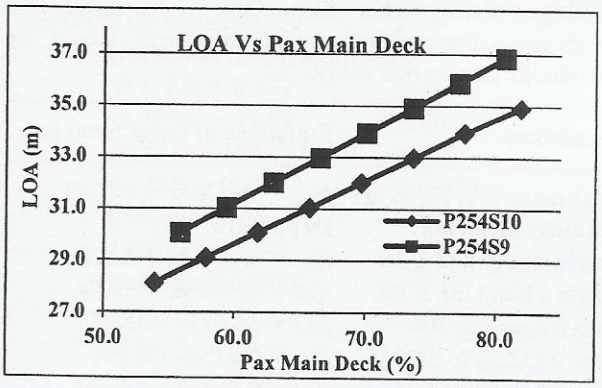

Figure 2: Ship length due to passenger distribution on main deck

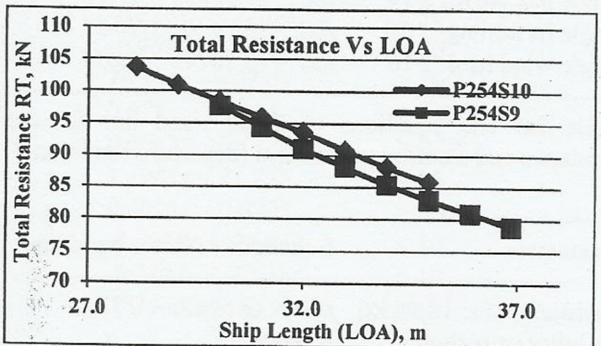

Figure 3: Total resistance due to ship length

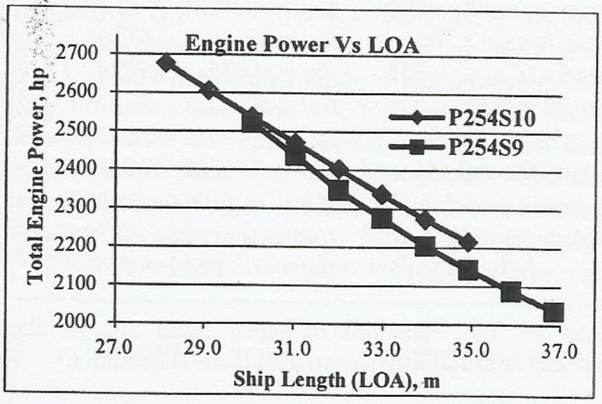

Figure 4: Total engine power due to ship length

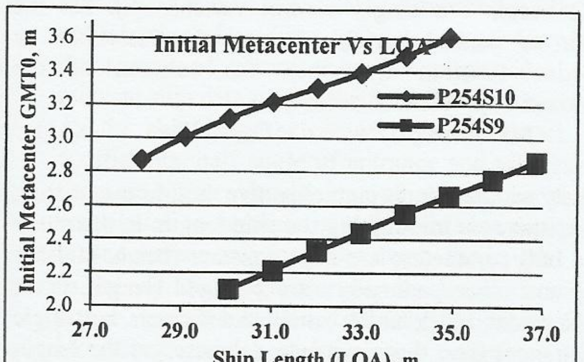

Figure 5. Initial metacenter due to ship length

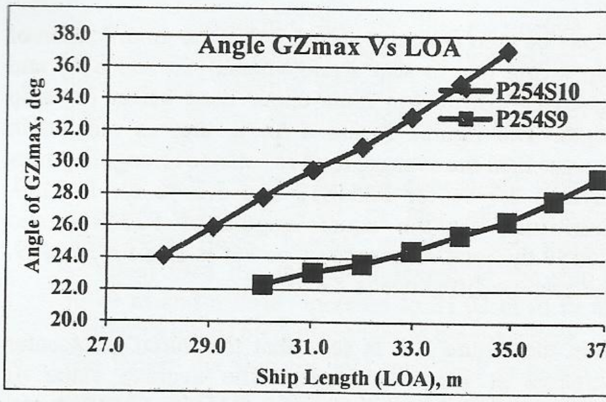

Figure 6. Angle of GZmax due to ship length

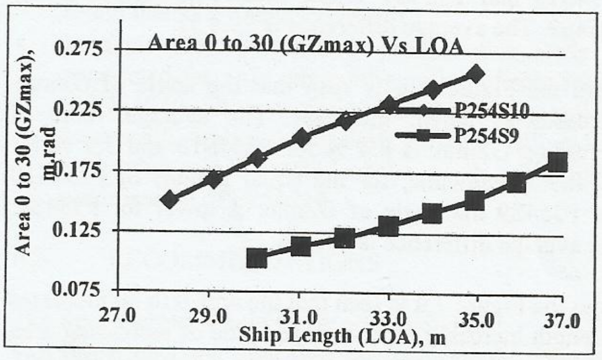

Figure 7. Area 0 to 30 due to ship length

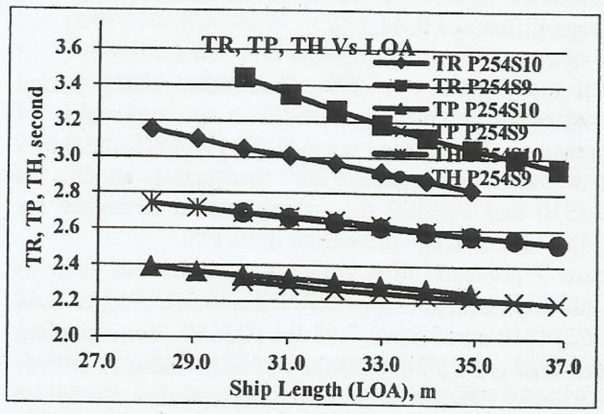

Figure 8. Periods of Tr, Tp and Th due to ship length

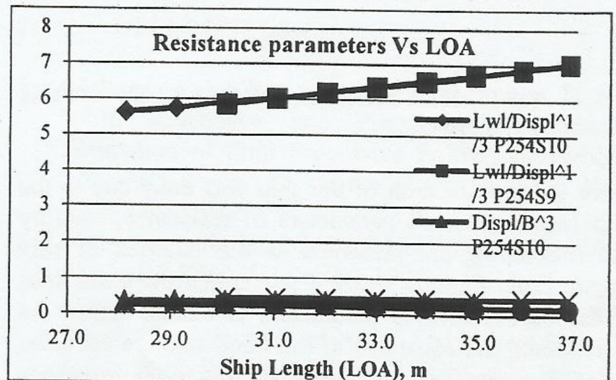

Figure 9. Resistance parameters due to ship length

It may be seen from the Figure 2 that the modification of ship layout due to seat arrangements (S9 and S10) and passenger distribution main-upper deck affect the ship length. The figures 3 and 4 show that as the length increase then the average total resistance or engine power decrease 2.7 % for P254S10 and 3.0 % for P254S9. Meanwhile, for the equal lengths of P254S10 and P254S9 the total resistance or power is less for P254S9. The average difference is 2.8 %.

From the Figure 5 it is seen that the initial metacenter increases as length increases. The average value of increasing initial metacenter is 3.6 % for P254S10 and 4.6 % for P254S9. Meanwhile, for the equal lengths of P254S10 and P254S9 initial metacenter is lower for P254S9. The average difference is 29.4 %.

From the Figure 6 it is seen that the angle of *GZ*max increases as length increases. The average value of increasing *GZ*max is 6.4 % for P254S10 and 3.9 % for P254S9. Meanwhile, for the equal lengths of P254S10 and P254S9 the angle of *GZ*max is lower for P254S9. The average difference is 23.7 %.

From the Figure 7 it is seen that the area 0 to 30 increases as length increases. The average value of increasing area 0 to 30 is 8.0 % for P254S10 and 8.8 % for P254S9. Meanwhile, for the equal lengths of P254S10 and P254S9 the area 0 to 30 is lower for P254S9. The average difference is 44.5 %.

From the Figure 8 it is seen that the rolling period decreases as length increases. The average value of decreasing rolling period is 1.6 % for P254S10 and 2.5 % for P254S9. Meanwhile, for the equal lengths of P254S10 and P254S9 the rolling period is higher for P254S9. The average difference is 10.1 %.
Figure 9 presents other resistance parameters such as length-displacement ratio $L/\nabla^{1/3}$ which are 5.63 to 6.68 for P254S10 and 5.86 to 7.03 for P254S9. Beam-loading ratios ∇/B^3 are 0.33 to 0.35 for P254S10 and 0.42 to 0.44 for P254S9. Ratios of area transom to area maximum A_T/A_M are 0.216 to 0.203 for P254S10 and 0.281 to 0.179 for P254S9.

5. OPTIMIZATION PROCCESS FOR P254S10

Since the modification of the ship was done due to the ship length, then all parameters of resistance, stability and seakeeping are presented as the function of ship length. From Figures 3 to 9 it seems that the trend lines of the curves of ship parameters is almost linear. As assumption, the equations of the trend line are set to be linear. The equations of linear trend line of the resistance and stability parameters are presented at Table 3. The parameters seakeeping (periods of rolling, heaving and pitching) are not evaluated further here. Especially for rolling period, the values are smaller (≈ 3 seconds) than what is expected which is about 12 seconds for the passenger ferries. This phenomena exists mostly for passenger ships where special treatment would be introduced later in this study.

Parameters	Equations of linear trend line
Resistance (*Vs*: 19,98 kt)	$f(x) = -2.6267x + 177.45$
Stability criterion:	**Departure**
Angle steady hell ≤ 16	$f(x) = -0.1712x + 8.972$
Angle s.h/m.l im. ≤ 80	$f(x) = -0.7959x + 39.94$
Area1/Area2 ≥ 100	$f(x) = 16.631x - 368.65$
Area 0-GZ_{max} ≥ 0.055	$f(x) = 0.0158x - 0.291$
Area 30 to 40 ≥ 0.03	$f(x) = 0.0059x - 0.0872$
Angle GZ_{max} ≥ 15	$f(x) = 1.8814x - 28.881$
Initial GMt ≥ 0.15	$f(x) = 0.1053x + 0.0686$
Angle pax crowd ≤ 10	$f(x) = -0.3326x + 17.19$
Angle hs turning ≤ 10	$f(x) = -0.2418x + 10.51$
Angle wind heel ≤ 16	$f(x) = -0.1614x + 8.655$

Table 3a: The equations of linear trend line for the resistance and stability parameters (departure condition)

Parameters	Equations of linear trend line
Resistance (*Vs*: 19,98 kt)	$f(x) = -2.6267x + 177.45$
Stability criterion:	**Arrival**
Angle steady hell ≤ 16	$f(x) = -0.2264x + 11.08$
Angle s.h/m.l im. ≤ 80	$f(x) = -0.9613x + 46.573$
Area1/Area2 ≥ 100	$f(x) = 16.496x - 407.64$
Area 0-GZ_{max} ≥ 0.055	$f(x) = 0.075x - 0.3876$
Area 30 to 40 ≥ 0.03	$f(x) = 0.0062x - 0.1126$
Angle GZ_{max} ≥ 15	$f(x) = 1.4948x - 21.735$
Initial GMt ≥ 0.15	$f(x) = 0.1029x - 0.0795$
Angle pax crowd ≤ 10	$f(x) = -0.5099x + 23.952$
Angle hs turning ≤ 10	$f(x) = -0.2828x + 12.186$
Angle wind heel ≤ 16	$f(x) = -0.2166x + 10.745$

Table 3b: The equations of linear trend line for the resistance and stability parameters (arrival condition)

The objective of the study is to find the minimum resistance of the modified ship. Here the length of ship (L_{OA}) becomes a single control variable (x). Set the length as control variable x and the resistance as objective function f(x) then the solution of the optimization problem is stated as:

$$\text{Minimize: } f(x) = -2.6267x + 177.45 \qquad (11)$$

In fact, another important objective beside minimizing the resistance is minimizing the ship length. In this study some hull parameters are kept constant (beam, midship area) and other parameters are changed (length, draft, displacement, block and prismatic coefficients, half angle of entrance) then the resistance decreases as the length increases as seen at the resistance curve in Figure 3. Then, to find the minimum resistance based on minimum length, the solution of the optimization problem is stated as:

Maximize: $f(x) = -2.6267x + 177.45$ (12)

Subject to the constraints:

(for departure condition)

$$
\begin{aligned}
-0.1712x + 8.972 &\le 16 \\
-0.7959x + 39.94 &\le 80 \\
16.631x - 368.65 &\ge 100 \\
0.0158x - 0.291 &\ge 0.055 \\
0.0059x - 0.0872 &\ge 0.03 \\
1.8814x - 28.881 &\ge 15 \\
0.1053x + 0.0686 &\ge 0.15 \\
-0.3326x + 17.19 &\le 10 \\
-0.2418x + 10.51 &\le 10 \\
-0.1614x + 8.655 &\le 16 \\
x &> 0
\end{aligned}
$$

(for arrival condition)

$$
\begin{aligned}
-0.2264x + 11.08 &\le 16 \\
-0.9613x + 46.573 &\le 80 \\
16.496x - 407.64 &\ge 100 \\
0.075x - 0.3876 &\ge 0.055 \\
0.0062x - 0.1126 &\ge 0.03 \\
1.4948x - 21.735 &\ge 15 \\
0.1029x - 0.0795 &\ge 0.15 \\
-0.5099x + 23.952 &\le 10 \\
-0.2828x + 12.186 &\le 10 \\
-0.2166x + 10.745 &\le 16 \\
x &> 0
\end{aligned}
$$

Using excel solver to solve the problems, it was found that for departure condition, the minimum length of ship (L_{OA}) is 28.18 m. Meanwhile the minimum length of the ship for arrival condition is 30.77 m. In fact, for the arrangement of the ship, the minimum length may fit the nearest length based on the arrangement. Therefore, based on the stability of the ship at arrival condition, the length of the ship was selected for L_{OA} = 31.03 m to fit the percentage of 66% passenger at the main deck.

6. CONCLUSION & RECOMMENDATION

6.1. CONCLUSION

- Since there is lack of available database provided for optimization of medium-speed passenger ferry, then the results of parent ship design provides some relevant ship data during the modification process.
- As the ship length increases then, the draft, hull coefficients, half angle of entrance and ratio A_T/A_M decrease. The decreasing of those parameters contributed to decrease of ship resistance though the wetted surface area increases due to the length
- In general, the longer the ship the less resistance or power meanwhile the stability parameters are increasing and seakeeping parameters are decreasing. The narrower the ship the less resistance or power meanwhile the stability parameters are decreasing, the rolling period is increasing, but pitching and heaving periods are decreasing. The decreasing of ship beam contributes so much for the stability and seakeeping
- For the input design of 254 passengers with the constant beam of 7.00 m and other constant parameters (deck height, midship and transom sections) then the minimum length of the ship is 30.70 m and a little increase to 31.03 m to fit the configuration of 66% passenger at the main deck.
- The longer the ship the less resistance or power of the ship, however the selection of lower length also benefits for construction and operational costs. Then the minimum resistance and other parameters were found due to the selected length.
- In fact, the optimization process this study is conducted for only one configuration of ship which is P254S10. Other variations of ship configurations (seat configurations) and draft variation will end-up with other results instead of the results achieved by optimization of P254S10.

6.2. RECOMMENDATIONS

The future works would be recommended for:

- Variation of ship beams and drafts for the modification and optimization process
- Optimizing the hull forms and local refinement to reduce the resistance
- Optimizing the ship structure in order to reduce the structural weight of the ship
- Executing the model tests in order to achieve better results of ship resistance.
- Selecting the proper screw propeller to reduce the engine power

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