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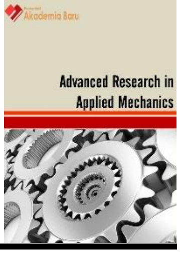

The Changes of Ship Parameters on Stability and Resistance during Operation

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Wolter R Hetharia[1], Andre Hage[2,*], Philippe Rigo[2]

[1] Faculty of Engineering, Pattimura University, Ambon, Indonesia
[2] University of Liege - ANAST, Rue Louvrex 14, 4000 Liège, Belgium

ABSTRACT

During the operation of a ship, there are liquids consumption of fuel and water that affect the ship weight, draft and position of weight centre. Consequently, this loading condition affects the ship parameters such as stability, resistance, speed and others. The raising of the vertical centre of weight affects the ship stability while decreasing the draft allows to increase the speed. Two important ship parameters evaluated in this paper are the resistance and stability. To prove this phenomena, two semi-displacement ships were designed, computed and evaluated. The resistance and stability parameters were computed at ship departure, during operation and arrival conditions. To confirm the results of computation, two ship models were developed and tested in the towing tank to validate the effects of draft, resistance and speed during travel time. The stability parameters were evaluated during the changes of loading conditions. The results of ship resistance and stability are presented in equation forms and show the changes of ship speed, travel time, and the quality of stability parameters.

Keywords:
liquid consumption, weight, ship parameters

1. Introduction

Ships during the operation need fuel for the engines and waters for consumption on board. Those liquids change with the ship travel time and reduce at certain level depend on consumption on board. The reducing of the liquids affects the total weight, displacement, draft, dimensions, centre of weight, etc. This means that during the ship travel the displacement and draft will decrease gradually. As a consequences, the ship resistance will decrease. If the engine power is kept constant during the travel time then, the speed will increase. This condition will cause the real travel time of the ship will be shorter than an average estimated time. Meanwhile, the reducing of liquids, placed at the bottom tanks, will affect the centre of ship weight. Since there is a change in centre of weight and draft then the parameters of centre of buoyancy and radius of metacentre will change and as consequence the stability parameters.

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[*] *Corresponding author.*
E-mail address: ahage@uliege.be

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The big and modern ships are equipped with control systems for loading conditions. In fact, most small semi-displacement passenger ships (capacity of 100 to 300 passengers), are not equipped with the control loading systems. This study were executed in order to evaluate the stability and resistance parameters for semi-displacement passenger ships. The results of resistance and stability parameters are presented in equation forms. The results will be developed more for future application of control system on semi-displacement passenger ships. In addition, the reducing of ship travel time will be benefit for ship owners and operators to estimate the fuel consumption. Furthermore, the stability parameters will be controlled during ship operation.

2. Literature Review

2.1 Semi-Displacement Passenger Ships

Recently, semi-displacement passenger ships have been developed and operated by ship operators due to their excellent performances. Austal Ships, UK ferry operator, FBMA Marine, and Port of Al Khaiman are ship operators that take the benefits of those ships. The use of lighter hull materials such as Fibre-Reinforced Plastic (FRP) or Aluminium give benefits such as increasing payload or speed. Semi-displacement passenger ships (Figure 1) operate at short sea distance or connecting the islands [1-4]. Their service speeds are ranging from 19 to 25 knots or Froude numbers (Fn) are from 0.55 to 0.80. The definition of semi-displacement ships is found in Molland [5] where such ships have Froude numbers, Fn, from 0.5 to 1.0. Meanwhile, Larsson [6] defined the intermediate region of $0.5 < Fn < 1.0$ as “semi planning speed range”. According to Nicolaysen [7], the speed range of ships with Froude numbers $0.5 < Fn < 0.75$ is for semi-displacement ships.

Fig. 1. Existing semi-displacement passenger ships

2.2 Resistance and Propulsion of Semi-Displacement Ships

The systematic series of resistance data of semi-displacement ships are found in Molland [8], Larsson [9], Lewis [10] and Mercier *et al.*, [11]. There are two resistance methods available for semi-displacement ships which are the WUMTIA (Wolfson Unit for Marine Technology and Industrial Aerodynamics) data series and the statistical resistance prediction method derived by Mercier and Savitsky [10, 11]. A general form of resistance equation adopted by Mercier and Savitsky is presented as

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

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

The values of coefficients A_1 to A_{27} and correction factors are presented in Lewis [10]. This method is provided in the Maxsurf software that can be used to get the results.

To find the resistance of full-scale ship from model test the result was predicted based on Froude method. It is noticed also that the effects of air resistance C_{AA} and appendage drags are taken into account of total resistance coefficient (C_{TS}) for the full-scale ship [8].

Effective power $(P_E) = \text{total resistance} \times \text{ship speed} = R_T \times V_S$ (2)

Delivered power $(P_D) = PE / QPC = PE / \eta_D$ (3)

The total installed power (P_I) or brake power (P_B) should exceed the delivered power (P_D) by an amount of power lost in the transmission systems, and by a power margin to allow for roughness, fouling and weather. The amount of margin may be decided by the designer at a design process.

Installed power $P_I = (P_E/\eta_D)\times(1/\eta_T)+margin$ (4)

$$P_I = P_E/(\eta_D \times \eta_T) = P_E/(\eta_O \times \eta_H \times \eta_R \times \eta_T) + margin \quad (5)$$

where:
η_D = quasi-propulsive coefficient (QPC)
η_O = open water efficiency
η_H = hull efficiency = $(1-t)/(1-w)$
w = wake fraction
t = thrust deduction factor
η_R = relative rotative efficiency
η_T = transmission efficiency,

The normal continuous rating (NCR) may be set for 10 % below the maximum continuous rating (MCR) [8]. The screw propellers were selected based on the propeller data from the Wageningen B-Screw Series [10]. The evaluation of propeller cavitation was executed based on the Burril Diagram.

2.3 Stability Parameters of Semi-Displacement Ships

Semi-displacement ships are classified as “High-Speed Craft” (HSC). Therefore, the stability requirements of these ships are in accordance with the rules of high-speed crafts. The stability criteria are based on HSC Code 2000 MSC 97(73)-Annex 8 Monohull Intact, HSC Code 2000 Chapter 2 Part B Passenger Craft Intact, IMO MSC 36(63) HSC Code Monohull Intact and The International Code on Intact Stability 2008 (2008 IS Code) [12-14]. The stability parameters that should be considered are the initial metacentric height (GM_0) and other stability parameters at large angles of inclination. All information concerning the stability parameters are stated in IMO 2008 IS Code for semi-displacement passenger ships. In addition, two standard loading conditions for the passenger ships that should be considered are the ship in fully loaded (departure condition) and the ship in fully loaded with only 10 % stores and fuel remaining (arrival condition). Previous studies executed by the author for semi-displacement passenger ships [1-4] shown that the stability parameters, at large angles of inclination, should be concerned instead of applying the initial metacentric height GM_0. Also, the stability parameters at arrival condition are more critical than those at departure condition.

3. Ship Design and Experimental Set-Up

3.1 Design of Semi-Displacement Passenger Ships

Two semi-displacement passenger ships have been designed by the author [1-4] in order to prove the changes of the ship parameters. They are a parent ship and a modified ship. Some data were collected from the existing ships as a reference for the parent ship design [1-4, 15]. Each ship has the capacity of 254 passengers. The hull material is Aluminium. The ship autonomy is 200 n.m. The service speed is 20 knots. The ships were designed to follow the design process for the passenger ships. The iteration process in ship design were evaluated, analyzed and modified until the design process satisfies the objectives and requirements. All requirements and rules imposed for the ship design were applied during design process [16-22]. The general arrangement of the parent ship is shown in Figure 2. Furthermore, the parent ship was modified due to the length, beam and draft (modified ship). During ship modification, the total payload of 254 passengers were kept constant.

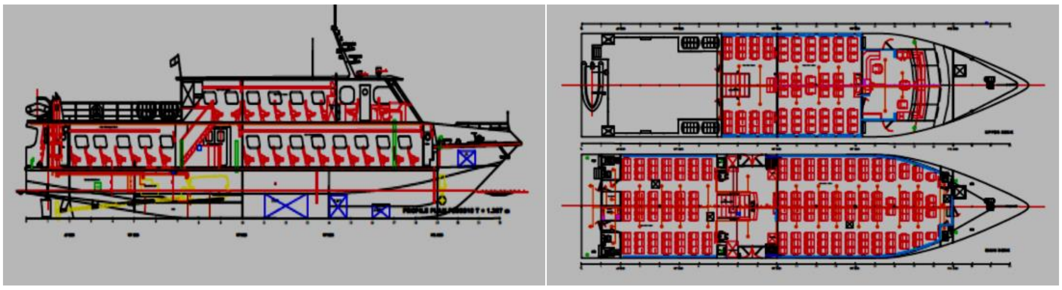

Fig. 2. The general arrangement of the parent ship

The effects of weight, draft, resistance and speed changes of the ships and models were proven by the existing resistance method (Savitsky Pre-planning) and by the experiment scale models. A scale factor (λ = 27) was set to develop the models. The dimensions and other parameters of ships and models are presented in Table 1.

Table 1
The parameters of the full-scale ships and models

Ship parameters	Unit	Scale factor, λ = 27			
		Full-scale ship		Ship models	
		Parent	Modified	Parent	Modified
Length overall, L_{OA}	m	32.00	36.85	1.185	1.365
Length of WL, L_{WL}	m	29.09	34.75	1.078	1.287
Ship beam, B	m	7.00	6.50	0.259	0.241
Beam of waterline, B_{WL}	m	6.69	6.18	0.248	0.229
Ship draft, T	m	1.40	1.37	0.052	0.051
Deck height, H	m	2.60	2.60	0.096	0.096
Ship displacement, Δ	t, (kg)	107.3	109.0	5.452	5.538
Block coefficient, Cb		0.384	0.362	0.384	0.362
Midship coefficient., Cm		0.550	0.540	0.550	0.540
L_{CB} (from midship)	% L_{WL}	-1.96	-2.00	-1.96	-2.00

Two units of main engines, MTU Marine Diesel Engine 10V 2000 M72, were applied as the prime mover for the ships. Each main engine has a maximum continuous rating (MCR) of 1205 HP. Two units of screw propellers are provided for the ship. The propulsion parameters are screw propeller type B4-70, propeller diameters are 1.119 m, ratio *P/D* is 0.81, propeller efficiency is 0.592, maximum ship speed is 20.1 knots, specific fuel consumption is 223.4 l/hour (one engine), and total efficiency is 0.577 for parent ship and 0.58 for modified ship. Some details such as lightweight, deadweight, liquids and their centres were required to compute stability parameters in Maxsurf software. The loading conditions were examined for the parent and modified ships as required by existing regulation (2008 IS Code).

3.2 Experimental Set-Up

The results of resistance computation from Savitsky pre-planning method were validated by the results of model tests. The extrapolation method to estimate the results of model test to the full-scale ship was used based on the Froude method [8, 9, 10]. The ship models were formed by high-density closed-cell foam covered by fibre-reinforced plastic (FRP). The models were shaped by NC cutting machine owned by DN&T (Design Naval & Transports) office, Liege, Belgium. The ship models were tested at the towing tank of University of Liege, ULiege-ANAST (Figure 3). The ship parameters measured during the tests were speed, resistance, trim and sinkage.

Fig. 3. The ship models are underway

4. Results and Discussions

4.1 Results of Ship Resistance

The computation of ship resistance for Savitsky Pre-planning method was executed by using Maxsurf software. The results of the resistance are presented in Table 2 and Table 3, and are shown at Figure 4 and Figure 5. The increasing of speed due to the travel time tends to be linear.

Table 2
Results of the Parent Ship

								Computation			Experiment Model		
No	Fuel (t)	Total Liquid (t)	Liquid Ratio (%)	Liquid Consum. (t)	Displa-cement (t)	Travel Time (h)	Draft (m)	Resist. (kN)	Power NCR (kW)	Speed (knot)	Resist. (kN)	Power NCR (kW)	Speed (knot)
1	6.00	8.60	100	0.00	107.27	0.00	1.400	95.41	1692	20.03	109.13	1966	20.22
2	4.20	6.02	70	2.58	104.69	4.74	1.383	92.91	1692	20.57	106.36	1966	20.75
3	2.40	3.44	40	5.16	102.11	9.48	1.365	90.28	1692	21.17	103.50	1966	21.32
4	0.60	0.86	10	7.74	99.53	14.22	1.354	87.82	1692	21.76	101.21	1966	21.93

Note: All speeds were set for a constant engine power of 1692 kW for the computation method, and 1966 kW for the model tests. The value of total efficiency, $(\eta_D \times \eta_T)$ is 0.577

Table 3
Results of the Modified Ship

		Total						Computation			Experiment Model		
No	Fuel (t)	Liquid (t)	Liquid Ratio (%)	Liquid Consum. (t)	Displacement (t)	Travel Time (h)	Draft (m)	Resist. (kN)	Power NCR (kW)	Speed (knot)	Resist. (kN)	Power NCR (kW)	Speed (knot)
1	6.00	8.60	100	0.00	108.30	0.00	1.366	70.44	1243	20.03	91.04	1631	20.21
2	4.20	6.02	70	2.58	105.74	4.74	1.356	68.78	1243	20.51	88.97	1631	20.68
3	2.40	3.44	40	5.16	103.19	9.48	1.332	67.18	1243	21.00	86.93	1631	21.17
4	0.60	0.86	10	7.74	100.64	14.22	1.324	65.57	1243	21.52	85.54	1631	21.64

Note: All speeds were set for a constant engine power of 1243 kW for computation method and 1631 kW for the model tests. The value of total efficiency, $(\eta_D \times \eta_T)$ is 0.580

It may be seen from Table 2 and Table 3 that the results of resistance from experimental model tests compared to those from computation method of Savitsky Pre-Planning are different. The differents are 13 % for the parent ship and 23 % for the modified ship. As stated by the author in reference [23] that the application of Savitsky Pre-Planning method for semi-displacement passenger ships should be evaluated again due to some hull configurations of those ships. Therefore, in this study the changes of ship parameters are based on the experimental results. From Table 2 and Table 3, it is seen that since the engine power was set constant at departure condition. The engine power was set at 966 kW for the parent ship and 1631 kW for the modified ship. In addition, the total efficiency is set constant 0.577 for the parent ship and 0.58 for the modified ship. Since the engine power was set constant and total efficiency is assumed to be constant during the travel time then the decrease of resistance will increase the ship speed.

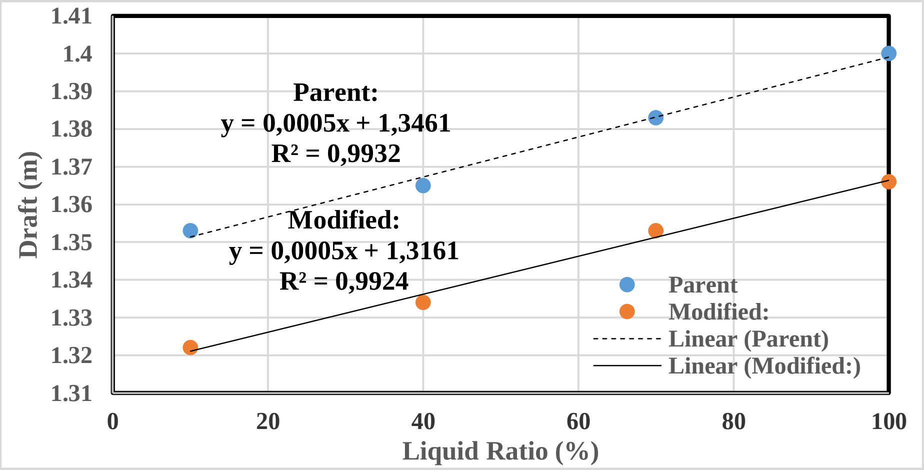

Fig. 4a. Changes of Draft Vs. Liquid Ratio

It is seen from Figure 5 that the relations between speed and real travel time of both ships are presented in regression equations.

Parent ship : $y = 0.1203\,x + 20.20 \quad R^2 = 0.999$ (6)

Modified ship : $y = 0.1008\,x + 20.208 \quad R^2 = 0.999$ (7)

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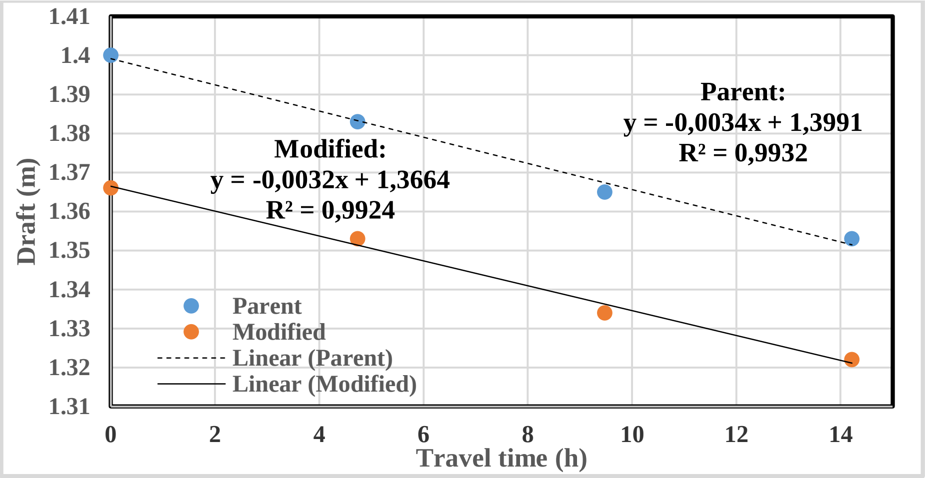

Fig.4b Changes of Draft Vs. Travel Time

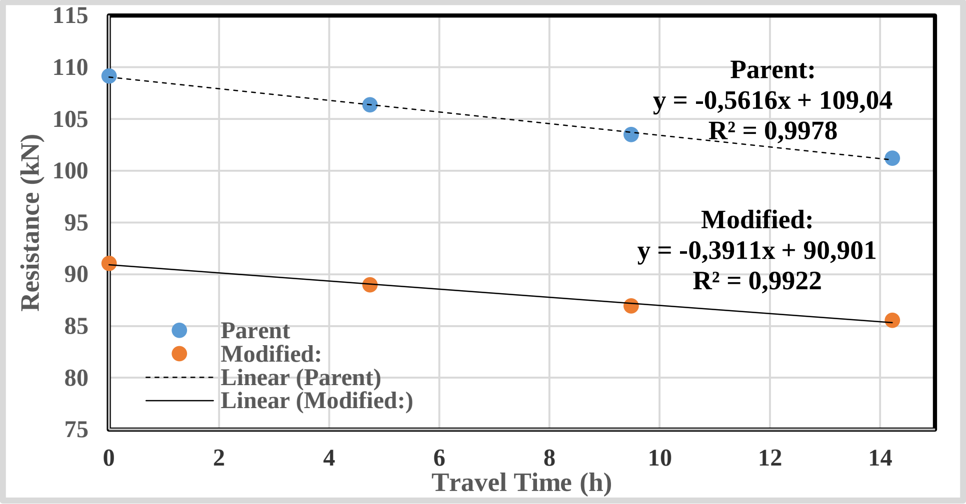

Fig. 5a. Changes of Resistance Vs. Travel Time

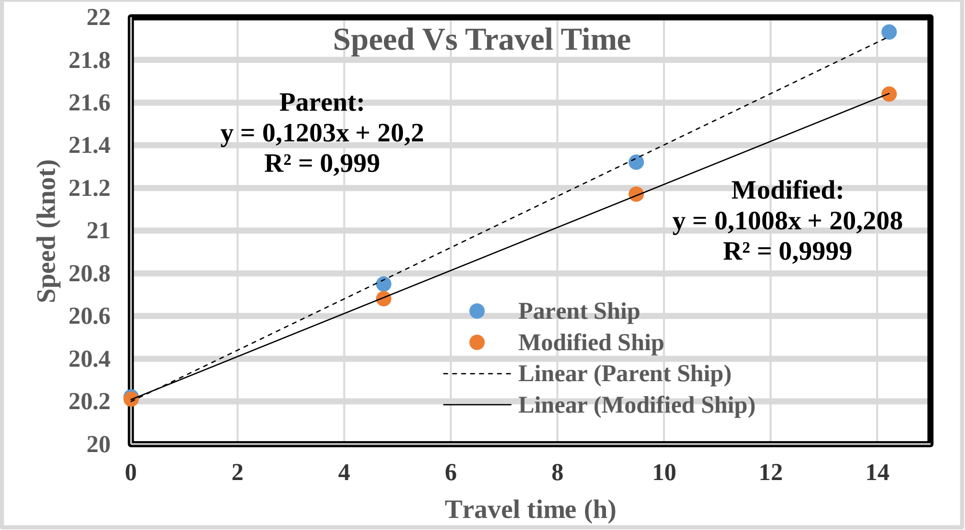

Fig. 5b. Changes of Speed Vs. Travel Time

To compute the travel time, the equation (6) is modified for the parent ship as follows:

$$\text{Distance} = \text{speed x travel time} = \{(0.1203\, t) + 20.2\}\, t = 0.1203\, t^2 + 20.2\, t \qquad (8)$$

For example:

Distance is 200 n.m, Speed is 20 knots, then the estimated travel time is 10 hours.

Finding the distance and trying some values of travel time at equation (8), it is found that the travel time is 9.37 hours or reduced by 0.63 hours (6.3 %) of average estimated time (10 hours).

Also, using the similar way for the equation (7), the travel time is 9.45 hours or reduced 0.55 hours (5.5 %) of average estimated time for modified ship.

4.2 Results of Stability Parameters

The results of computation of stability parameters of parent and modified ships are presented in Table 4. The computations of stability parameters were executed by using Maxsurf software. All loading and tank conditions were considered as required by the rules. Besides, the results of stability parameters were compared to an existing ship [16] as a comparison of the study. The stability parameters were considered at large angles of inclination as shown in Table 4. They are presented in four conditions as explained before in this paper. It may be seen from Table 4 that the stability parameters decrease during ship operation. In addition, two stability parameters are presented as function of travel time as seen in Figure 6. It is seen from Figure 6 that the stability parameters (weather criterion and GZ_{max} decrease due to the travel time. The curves of stability parameters tend to be linear.

Table 4

The stability parameters with different loading conditions

No	Ship Parameters	Unit	Stability Criteria	Parent ship				Modified ship			
1	Travel Time	hour		0.00	4.74	9.48	14.22	0.00	4.74	9.48	14.22
2	Fluid Ratio	%		100	70	40	10	100	70	40	10
3	Draft	m		1.400	1.383	1.365	1.354	1.366	1.356	1.332	1.324
	Stability Parameters										
4	Weather criterion (≥)	%	100.0	225.5	206.9	193.6	178.1	202.1	180.2	160.5	140.6
5	*Area 0 to 30* (≥)	m.rad	0.055	0.247	0.228	0.197	0.175	0.198	0.179	0.155	0.139
6	*Area 30 to 40* (≥)	m.rad	0.030	0.107	0.099	0.094	0.089	0.089	0.084	0.077	0.072
7	GZ_{max} *at 30* or > (≥)	m	0.200	0.606	0.573	0.553	0.529	0.509	0.477	0.459	0.434
8	*Angle* GZ_{max} (≥)	degree	25.00	33.20	29.50	27.30	25.50	35.00	31.02	27.28	24.50
9	Initial metacentre GM_0 (≥)	m	0.150	3.320	3.334	3.353	3.382	2.920	2.924	2.931	2.940
10	Heel angle pass. crowd (≤)	degree	10	5.80	6.10	6.30	6.60	5.90	6.10	6.40	6.80
11	Heel angle high speed turning (≤)	degree	10	3.00	3.10	3.2	3.40	2.80	2.90	3.10	3.20
12	Heel angle wind action (≤)	degree	16	2.20	2.30	2.40	2.50	2.80	2.83	2.87	2.90

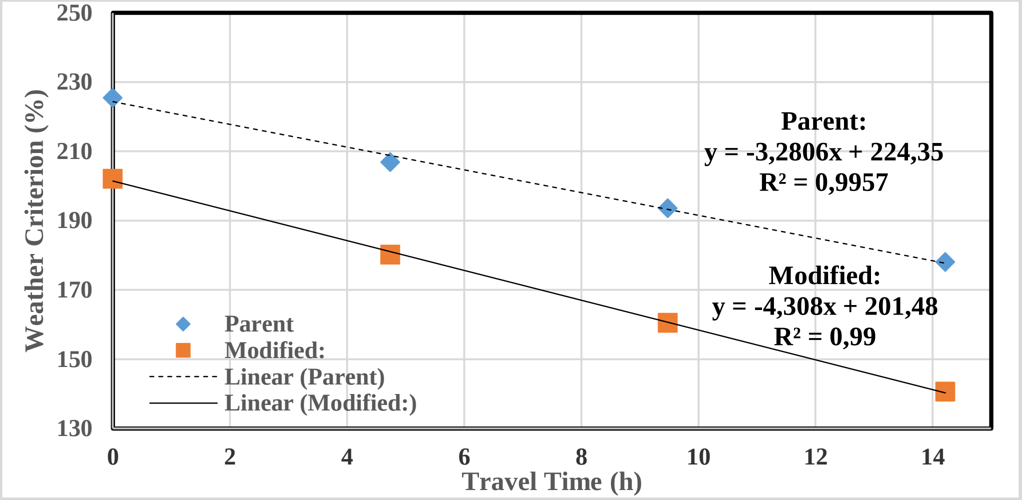

Fig. 6a. Changes of Stability Parameters on Travel Time

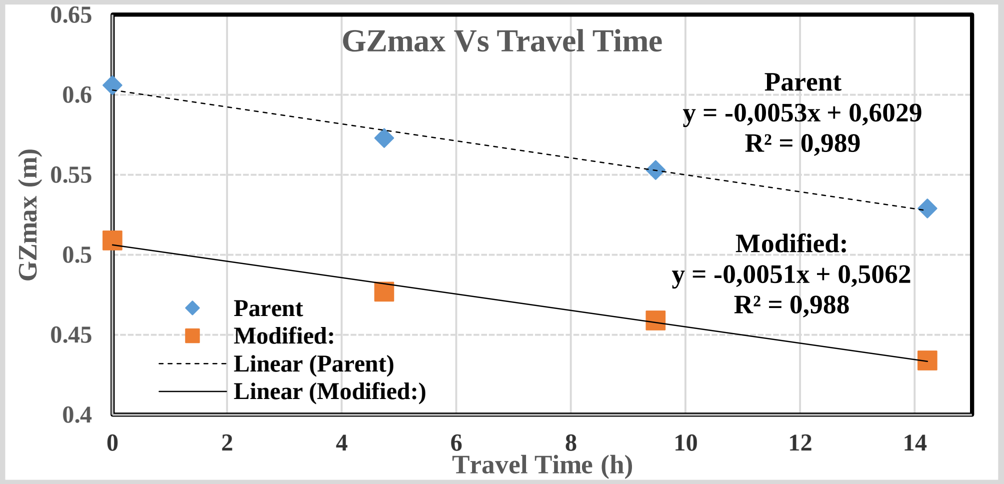

Fig. 6b. Changes of Stability Parameters on Travel Time

All stability parameters are presented in form of the equations as the function of travel time (x) as seen in Table 5. The coefficients of determination R^2 are presented to indicate that the model is a good fit for the data. The criterion of stability parameters are also presented in order to check ship stability during the travel time.

4.3 Discussion

The results of ship resistance and engine power from existing computation methods and model tests are in good pattern but there is a difference of 13 % from model test to results of computation for the parent ship and 23 % for the modified ship. This difference may account for other effects such as appendage resistance, air resistance and model-ship correlation which were included in model test. In addition, the application of Savitsky Pre-Planning method for these semi-displacement passenger ships should be considered again due to the differences to the model tests as stated by the author in reference [23]. Therefore, the data was developed based on the model test.

Table 5
The equation of ship parameters as function of the travel time

No	Stability Parameters	Unit	Stability Equations Note: x = travel time	
A	Parent Ship			
	Weather criterion (≥ 100)	%	y = - 3.2806 x + 224.35;	R^2 = 0.9957
	Area 0 to 30 (≥ 0.055)	m.rad	y = - 0.0052 x + 0.2488;	R^2 = 0.9921
	Area 30 to 40 (≥ 0.030)	m.rad	y = - 0.0012 x + 0.1061;	R^2 = 0.9847
	GZ_{max} *at 30* or greater (≥ 0.20)	m	y = - 0.0053 x + 0.6029;	R^2 = 0.9891
	Angle GZ_{max} (≥ 25.00)	degree	y = - 0.5338 x + 32.67;	R^2 = 0.9708
	Initial metacentre GM_0 (≥ 0.15)	m	y = 0.0043 x + 3.3165;	R^2 = 0.9734
	Heel angle passenger crowd (≤ 10)	degree	y = 0.0549 x + 5.810;	R^2 = 0.9941
	Heel angle high speed turning (≤ 10)	degree	y = 0.0274 x + 2.980;	R^2 = 0.9657
	Heel angle wind action (≤ 16)	degree	y = 0.0211 x + 2.200;	R^2 = 1.0000
B	Modified Ship			
	Weather criterion (≥ 100)	%	y = - 4.308 x + 201.48;	R^2 = 0.9994
	Area 0 to 30 (≥ 0.055)	m.rad	y = - 0.0042 x + 0.1979;	R^2 = 0.9921
	Area 30 to 40 (≥ 0.030)	m.rad	y = - 0.0012 x + 0.0892;	R^2 = 0.9953
	GZ_{max} *at 30* or greater (≥ 0.20)	m	y = - 0.0051 x + 0.5062;	R^2 = 0.9885
	Angle GZ_{max} (≥ 0.15)	degree	y = - 0.7473 x + 34.81;	R^2 = 0.9946
	Initial metacentre GM_0 (≥ 0.15)	m	y = 0.0014 x + 2.9187;	R^2 = 0.9727
	Heel angle passenger crowd (≤ 10)	degree	y = 0.0633 x + 5.850;	R^2 = 0.9783
	Heel angle high speed turning (≤ 10)	degree	y = 0.0295 x + 2.790;	R^2 = 0.9800
	Heel angle wind action (≤ 16)	degree	y = 0.0072 x + 2.799;	R^2 = 0.9966

The standard procedure of towing tank model test was fulfilled during executing the model test. The process of constructing the models, setting the equipment and test conditions were kept to be in a proper way. All external effects during the test was avoided to keep the test in good condition. It is seen from the tables and figures that as the liquids reduce then the draft, displacement and resistance decrease. Therefore, for a fix engine power (at departure), the ship speeds increase and travel time decreases compared to the average estimated time. The relationship between the speed and the travel time will be useful for ship operators who may estimate the real travel time during ship operation. The draft changes from departure (liquids 100%) to arrival (liquids (10%) are 3.3 % for the parent ship and 3.1 % for the modified ship. The total efficiency of propulsion system is assumed to be constant for this small changes of draft therefore, the engine power is assumed to be constant during the travel time.

It can be seen from Table 4 that as the travel time increases the quality of stability parameters decrease. In this case, stability parameters become less than the initial values at departure condition (liquid 100 %) or greater for some values. The stability parameters are presented in the equations as function of travel time (Table 5) that may be useful for the ship operator during ship operation.

5. Conclusions

The changes of liquids consumption on board during the ship operation have shown some phenomena. It may be concluded from the study some key points as follows:

1. During the ship operation the consumption of liquids decreases the ship weight, displacement, draft, resistance and quality of stability parameters.
2. As the speed increases the travel time will be shorter than the average estimated time if the engine power is kept to be constant during the ship travel. This is shown in the previous example the reducing travel time of 6.3 % for the parent ship and 5.5% for the modified ship.

3. Due to the changes of centre of weight, the quality of stability parameters decrease at certain level even they are still fulfil criteria IMO 2008 IS Code.
4. All the stability parameters and speed are presented in form of the equations that may be developed for future application in automatic ship operation system.

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References

[1] Hetharia, W. R., A. Hage, and Ph Rigo. "Preliminary design study on medium-speed monohull passenger ferries." In *Proc. The 8th International Conference on HIPER 2012*, pp. 100-111. 2012.

[2] Hetharia, Wolter Roberth, Philippe Rigo, and Andre Hage. "Preliminary study of hull dimension optimization of medium-speed monohull passenger ferries." In *NAV 2012 17th International Conference on Ships and Shipping Research*. 2012.

[3] Hetharia, Wolter, André Hage, and Philippe Rigo. "Preliminary study of medium-speed monohull passenger ferries." In *International Conference on Technologies, Operations, Logistics and Modelling for Low Carbon Shipping LCS 2011*, pp. 187-191. Osman Turan and Atilla Incecik, 2011.

[4] Hetharia, W. R., A. Hage, and Ph Rigo. "Hull Dimensions Optimization of Medium-Speed Monohull Passenger Ferries." In *Proceedings of the 9th International Conference on High-Performance Marine Vehicles, HIPER2014*, pp. 5-16. 2014.

[5] Molland, Anthony F., ed. *The maritime engineering reference book: a guide to ship design, construction and operation*. Elsevier, 2011.

[6] Larsson, L., and H. C. Raven. "Ship resistance and flow (Principles of naval architecture series)." *Alexandria, VA: SNAME* (2010).

[7] Nicolaysen, K. H. "CATRIV-Workpackage WP 4.2, Innovative Vessels Concepts for Waterborne Passenger Transport-Working Group ZE VWS." (1999): 8-12.

[8] Hudson, Dominic A., Anthony F. Molland, and Stephen R. Turnock. *Ship Resistance and Propulsion: Practical Estimation of Propulsive Power*. Cambridge University Press, 2014.

[9] Larsson, L., and H. C. Raven. "Ship resistance and flow (Principles of naval architecture series)." *Alexandria, VA: SNAME* (2010).

[10] Mandel, P. "Resistance Propulsion and Vibration." *ser. Principles of Naval Architecture* (1977).

[11] Mercier, John A., and Daniel Savitsky. *Resistance of transom-stern craft in the pre-planing regime*. No. SIT-DL-73-1667. STEVENS INST OF TECH HOBOKEN NJ DAVIDSON LAB, 1973.

[12] International Maritime Organization. *International code on intact stability, 2008*. Inter-Governmental Maritime, 2009.

[13] The Rules of International Code of Safety for High-Speed Craft, 2000 HSC Code.

[14] The Rules of International Code of Safety for High-Speed Craft, 2008 Edition.

[15] Report No. SPO.1.11.15706Y/STB-1, 2011, Ship Name PACIFIC 271, PT Palindo Marine Shipyard, Singapore 12 October 2011.

[16] Parsons, M. G. "Ship Design and Construction." *IVolume Chapter 11 Parametric Design Tomas Lamb editor* (2003).

[17] Knox, J., 2004, Ferries - Ship Design and Construction, Chapter 38, Vol. 2. SNAME Publication, Jersey City, NJ, USA

[18] Levander, K. "Passenger Ships-Ship Design and Construction." *Ch* 37 (2004): 37-1.

[19] Calhoun, S. R., and S. C. Steven. "Human Factor in Ship Design-Ship Design and Construction." *Ch* 15 (2003): 15-1.

[20] Olson, Henry A. "Trends in modern ferry boat designs." (1990).

[21] Gale, P. A., 2003. The Ship Design Process- Ship Design and Construction – Chapter 5, Vol. 2, SNAME Publication, Jersey City, NJ, USA

[22] Watson, David GM. *Practical ship design*. Vol. 1. Elsevier, 1998.

[23] Hetharia, W. R., de Fretes, E. R and Gaspersz, F, 2015, A Review on The Resistance of Hard Chine Semi-Displacement Ships, Proceedings of the ICSOT Indonesia 2015, The Royal Institution of Naval Architecture, 4 – 5 November 2015, Surabaya, Indonesia