11th International Conference on Marine Technology
MARTEC 2018

THE CHANGES OF SHIP PARAMETERS DURING OPERATION

Wolter R HETHARIA[1], Andre HAGE[2] and Philippe RIGO[3]

[1]Faculty of Engineering, Pattimura University, Ambon, Indonesia, hethariawr@yahoo.com
[2]University of Liege - ANAST, Liege, Belgium, ahage@uliege.be
[3]University of Liege - ANAST, Liege, Belgium, ph.rigo@uliege.be

ABSTRACT

During ship operation, there are liquids consumption of fuel and water that may affect the ship weight, draft and position of ship weight centre. Consequently, this loading condition affects the ship parameters such as stability, resistance, speed and others. The raising of the vertical gravity centre affects the ship stability while decreasing the draft allows to increase speed. Two important ship parameters evaluated in this paper are resistance and stability. Two semi-displacement ships (with initial and modified dimensions) were designed, computed and evaluated for this issue. The resistance and stability parameters were computed at ship departure, operation and arrival conditions. In addition, two ship models were tested in a towing tank to validate the effects of draft, resistance, speed and time travel. The results showed the increase of ship speed while decreasing the quality of stability parameters.

Keywords: *liquid consumption, draft, weight centre, stability, ship parameters.*

1.0 INTRODUCTION

During the operation of a ship there is consumption of liquids (fuel and water) which are reduced with the ship travel time. The reducing of those liquids affects ship parameters such as total weight, displacement, dimensions, centre of weight, etc. Reducing of ship displacement has a direct impact on draft. This means that during ship travel displacement and draft will decrease gradually. Furthermore, ship resistance decreases and for a constant engine power the speed may increase. This means that real travel time of ship will be shorter than average estimated time, which is distance/speed. On the other hand, reducing of liquids affects the centre of ship weight. In this case the centre of weight, centre of buoyancy and radius of metacentre will change, and as consequence the stability parameters, at initial and large angle of inclination, will change.

To prove this issue, two semi-displacement ships (parent and modified) were designed, computed and evaluated. Compared to other kind of passenger ships, semi-displacement passenger ships mostly do not use water ballast system during the operation. Therefore, the changes of ship parameters depend only on liquid consumption. The liquids on board consist of fuel oil, fresh water and grey water and for this work, they were set for 100 % (departure), 70% (operation), 40 % (operation) and 10% (arrive). Ship parameters such as resistance, power, speed, travel time and stability were computed for those four loading conditions. The ship parameters were computed based on the existing formulas. In addition, scale models of those two ships were developed and tested in the towing tank of the University of Liege (Belgium) where the results of resistance were compared to those of existing computation methods. The results of computation and model tests are presented and shown the changes of the ship parameters. The stability parameters are presented and show the change of their quality during ship operation.

2.0 LITERATURE REVIEW

2.1 Semi-Displacement Passenger Ships

Semi-displacement ships have been recently developed and operated by ship owners and 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. They are mostly applied for passenger ships (Figure 1) and operated at short sea distance [1, 2, 3, 4]. Their service speeds are ranging from 19 to 23 knots and Froude numbers (*Fn*) of 0.55 to 0.75. Definition of semi-displacement ships is found in Molland [5] where semi-displacement 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.

Figure 1: The 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:

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

where:

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

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) = total resistance × ship speed = $R_T \times V_S$ (3)

Delivered power (P_D) = $PE / QPC = PE / \eta_D$ (4)

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 $P_I = (P_E/\eta_D)\times(1/\eta_T)+margin$ (5)

$$P_I = P_E/(\eta_D \times \eta_T) = P_E/(\eta_O \times \eta_H \times \eta_R \times \eta_T) + margin \quad (6)$$

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, 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, 13, 14]. The stability parameters that should be considered are initial metacentric height (GM_0) and other stability parameters at large angles of inclination. All information concerning stability parameters are stated in IMO 2008 IS Code for semi-displacement passenger ships. In addition, two standard loading conditions for passenger ships that should be considered are ship in fully loaded (departure condition) and 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, 2, 3, 4] shown that 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.

3.0 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, 2, 3, 4] in order to prove the changes of ship parameters. They are a parent ship and a modified ship. Some data were collected from the existing ships as a reference for parent ship design [1, 2, 3, 4, 15]. Each ship has the capacity of 254 passengers. Hull material is Aluminium. Ship autonomy is 200 n.m. 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, 17, 18, 19, 20, 21, 22]. General arrangement of the parent ship is shown in Figure 2. Furthermore, the parent ship was modified: length, beam and draft (modified ship). During ship modification, the total payload of 254 passengers are kept constant.

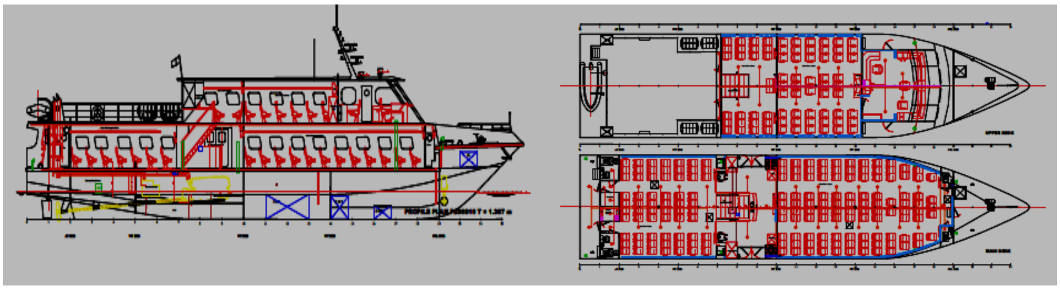

Figure 2: General arrangement of the parent ship

The effects of weight, draft, resistance and speed changes of the ships and models were proven by the existing resistance methods and by 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: 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: 1.119 m, ratio *P/D*: 0.81, propeller efficiency: 0.592, maximum ship speed: 20.1 knots, the specific fuel consumption: 223.4 l/hour (one engine), total efficiency: 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 are speed, resistance, trim and sinkage.

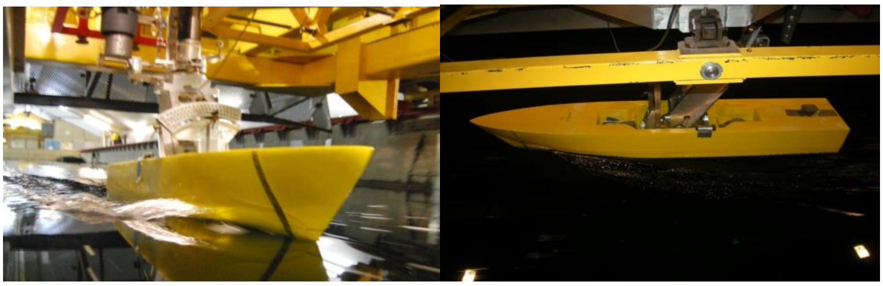

Figure 3: The ship models are underway

4.0 RESULTS AND DISCUSSIONS

4.1 Results of Ship Resistance

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

Table 2: Results of the Parent Ship

No	Fuel (t)	Total Liquid (t)	Liquid Ratio (%)	Liquid Consum. (t)	Displa-cement (t)	Travel Time (h)	Draft (m)	Computation			Experiment Model		
								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	1648	20.57	106.36	1904	20.75
3	2.40	3.44	40	5.16	102.11	9.48	1.365	90.28	1602	21.17	103.50	1853	21.32
4	0.60	0.86	10	7.74	99.53	14.22	1.354	87.82	1558	21.76	101.21	1812	21.93
Note: All speeds were set for a constant engine power of 1692 kW for computation and 1966 kW for experiment model tests. Value of total efficiency $(\eta_D \times \eta_T) = 0.577$													

Table 3: Results of the Modified Ship

No	Fuel (t)	Total Liquid (t)	Liquid Ratio (%)	Liquid Consum. (t)	Displa-cement (t)	Travel Time (h)	Draft (m)	Computation			Experiment Model		
								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	1214	20.51	88.97	1596	20.68
3	2.40	3.44	40	5.16	103.19	9.48	1.332	67.18	1186	21.00	86.93	1560	21.17
4	0.60	0.86	10	7.74	100.64	14.22	1.324	65.57	1157	21.52	85.54	1535	21.64
Note: All speeds were set for a constant engine power of 1243 kW for computation and 1631 kW for experiment model tests. Value of total efficiency $(\eta_D \times \eta_T) = 0.580$													

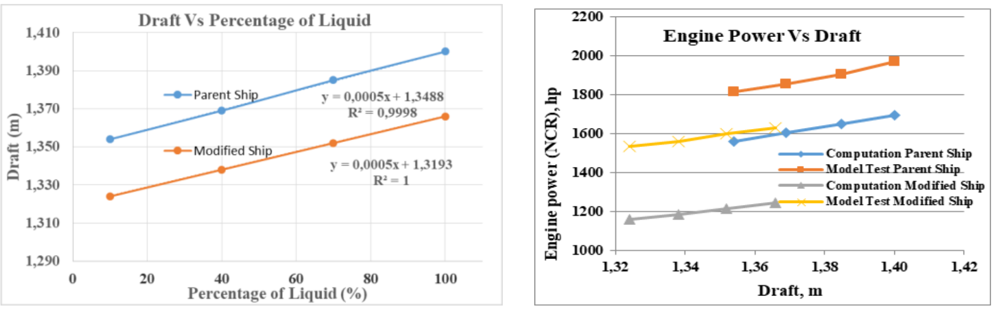

Figure 4: Draft Vs. Power versus Draft and Speed versus Draft of the Ships

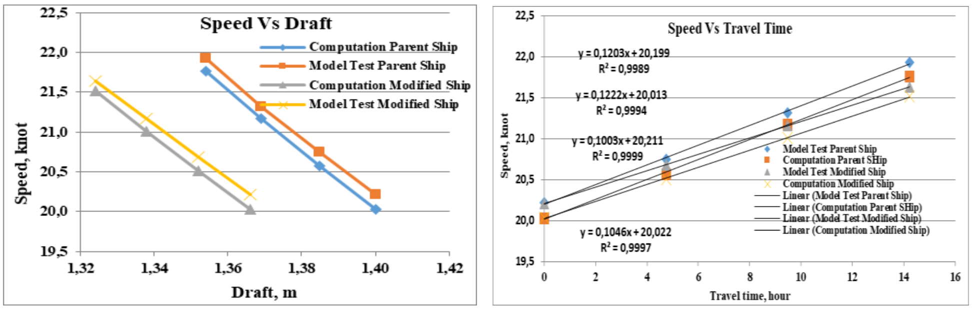

Figure 5: The changes of ship speed due to draft and travel time

The relations between speed and real travel time of both ships are presented at Figure 5.

Parent ship, computation:	$y = 0.122\ x + 20.01$	$R^2 = 0.999$	(7)
Parent ship, model test:	$y = 0.120\ x + 20.19$	$R^2 = 0.998$	(8)
Modified ship, computation:	$y = 0.104\ x + 20.02$	$R^2 = 0.999$	(9)
Modified ship, model test:	$y = 0.100\ x + 20.21$	$R^2 = 0.999$	(10)

For example: Distance = 200 n.m., Speed = 20 knots, Estimated travel time = 10 hours.
Modified the equation (8) for the parent ship:
Distance = speed x travel time = $\{(0.120\ t) + 20.19\}\ t = 0.120\ t^2 + 20.19\ t$

Finding the distance and trying some values of travel time (t), it is found that the travel time is 9.38 hours, reduced by 0.62 hours (3.1 %) of average estimated time (10 hours). Also, using the modified the equation (10) for modified ship, the travel time is 9.45 hours, reduced 0.55 hours (2.75 %) of average estimated time

4.2 Results and Evaluation of Stability Parameters

The results of computation of stability parameters are presented in Table 4. The computations of stability parameters were executed using Maxsurf software. All loading and tank conditions were considered as required by the rules. Beside the results of computation from parent and modified ships, the stability parameters were also compared to an existing ship [16] as a comparison.

The stability parameters were considered at large angles of inclination as shown in Table 4. The stability parameters are presented for four conditions as explained before in this paper. It may be seen from Table 4 that the stability parameters decrease during ship operation. All stability parameters are presented in equations as function of liquid percentage (x) include the coefficients of determination R^2. Percentage of stability parameters when arriving (10 % liquid) compared to those at departure (100 % liquid) are presented in Table 5.

Table 4: Stability parameters with different loading conditions

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

4.3 Discussion

The results of ship resistance and engine power from existing computation methods and model tests are in good pattern. There is a difference of 12.7 % for the parent ship and 22.8 % for the modified ship. This difference may account for appendage resistance, air resistance and model-ship correlation which were included in model test. During the construction and executing of models tests some conditions were kept to be in a proper way. It may be seen from the tables and figures that as the liquids reduce then the draft, displacement, resistance and power decrease (for the same speed). As consequences, for a fix engine power (at departure), the ship speed may increase and travel may decrease compared to the initial average estimated time. The results obtained from computation and model test have proven that the real travel time is shorter than average estimate time. The relationship between speed and the real travel time is useful for ship operators who may estimate a real travel time during the ship operation.

It can be seen from Table 4 that as the draft decreases the quality of stability parameters decrease. In this case, those parameters become smaller than the initial values (departure, liquid 100 %) or greater than the initial values, like for the case of heel angles. Stability parameters are also presented in equations as function of liquid percentage (Table 5). This may be useful for a ship operator also to have such consideration when ship is in operation.

Table 5: Equation of ship parameters as function of the liquid percentage

No	Stability Parameters	Unit	Equations Note: x = liquid percentage	R^2	Parameter changes, departure versus arrive (%)
A	Parent Ship				
	Weather criterion (≥)	%	y = 0.518 x + 172.52	0.996	79
	Area 0 to 30 (≥)	m.rad	y = 0.0008 x + 0.166	0.992	71
	Area 30 to 40 (≥)	m.rad	y = 0.0002 x + 0.085	0.985	83
	GZ_{max} *at 30* or > (≥)	m	y = 0.0008 x + 0.519	0.989	87
	Angle GZ_{max} (≥)	degree	y = 0.0843 x + 24.237	0.971	77
	Initial metacentre GM_0 (≥)	m	y = -0.0007 x + 3.385	0.973	102
	Heel angle passenger crowd (≤)	degree	y = -0.0087 x + 6.677	0.994	114
	Heel angle high speed turning (≤)	degree	y = -0.0043 x + 3.413	0.966	113
	Heel angle wind action (≤)	degree	y = -0.0033 x + 2.533	1.000	114
B	Modified Ship				
	Weather criterion (≥)	%	y = 0.6807 x + 133.41	0.999	70
	Area 0 to 30 (≥)	m.rad	y = 0.0007 x + 0.1309	0.995	70
	Area 30 to 40 (≥)	m.rad	y = 0.0002 x + 0.07	0.995	81
	GZ_{max} *at 30* or > (≥)	m	y = 0.0008 x + 0.425	0.989	85
	Angle GZ_{max} (≥)	degree	y = 0.1175 x + 22.989	0.994	70
	Initial metacentre GM_0 (≥)	m	y = -0.0002 x + 2.941	0.973	101
	Heel angle passenger crowd (≤)	degree	y = -0.010 x + 6.85	0.978	115
	Heel angle high speed turning (≤)	degree	y = -0.0047 x + 3.257	0.98	114
	Heel angle wind action (≤)	degree	y = -0.0011 x + 2.91	0.996	104

5.0 CONCLUSIONS

The changes of liquid consumption on board have shown some phenomena during ship operation. These issues may be concluded as follows:

1. During the ship operation the consumption of liquids decreases ship weight, displacement, draft, resistance and quality of stability parameters decrease but the speed increases.
2. As the speed increases the travel time is shorter than average estimated time if the power is kept to be constant since departure.
3. All stability parameters, speed and travel time are presented in form of equations that may be developed for future application in automatic ship operation system.

ACKNOWLEDGEMENTS

Special thanks to:

- The University of Liege (ULiege-ANAST) for the towing tank facilities that have been used for the model tests
- DN&T (Design Naval & Transports) office, Liege, Belgium for developing the models.

REFERENCES

1. Hetharia, W. R., A. Hage and Ph. Rigo, 2012. Preliminary Design Study on Medium-Speed Monohull Passenger Ferries. *Proceedings of the 8th International Conference on HIPER 2012*, The University of Duisburg-Essen, Institute of Ship Technology, Ocean Engineering+ Transport Systems (ISMT), Duisburg, Germany, 27 – 28 September 2012, (2012-A), pp. 100-111.

2. Hetharia, W. R., A. Hage and Ph. Rigo, 2012. Preliminary Study of Hull Dimension Optimization of Medium-Speed Monohull Passenger Ferries, *Proceedings of the 17th International Conference on Ships and Shipping Research & Advancing With Composites 2012 Symposium, NAV2012.* ATENA-Associazone Italiana Di Technica Navale, Naples, Italy, 17-19 October 2012, (2012-B), pp. 7-8.
3 Hetharia, W. R., A. Hage and Ph. Rigo, 2011. Preliminary Study of Medium-Speed Monohull Passenger Ferries, *Proceedings of the International Conference on Technologies, Operations, Logistics and Modelling for Low Carbon Shipping (LCS 2011)*. University of Strathclyde, 22-24 June 2011, Glasgow, Scotland, United Kingdom, (2011), pp. 187-192.
4. Hetharia, W. R., Hage A., & Rigo, Ph., 2014. Hull Dimensions Optimization of Medium-Speed Monohull Passenger Ferries. *Proceedings of the 9th International Conference on High-Performance Marine Vehicles, HIPER2014*. National Technical University of Athens, School of Naval Architecture & Marine Engineering, Greece, Athens, 3 – 5 December 2014, pp. 5-16.
5. Molland, A. F, 2008. *The Maritime Engineering Reference Book – A Guide to Ship Design, Construction and Operation*, Butterworth-Heinemann, Oxford, UK
6. Larsson, L and C. R. Hoyte, 2010. *Ship Resistance and Flow, The Principles of Naval Architecture Series*. The SNAME, 601 Pavonia Avenue,Jersey City, NJ, USA
7. Nicolaysen, K. H., 1999. CATRIV – Workpackage WP 4.2, Innovative Vessels Concepts for Waterborne Passenger Transport - *Working Group ZE VWS (TU Berlin)*, pp. 8-12
8. Molland, A. F., Turnock, S. R., & Hudson, D. A., 2011. *Ship Resistance and Propulsion – Practical Estimation of Ship Propulsive Power*. Cambridge University Press, 32 Avenue of the Americas, New York, USA.
9. Larsson, L and C. R. Hoyte, 2010. *Ship Resistance and Flow, The Principles of Naval Architecture Series*. The SNAME, 601 Pavonia Avenue,Jersey City, NJ, USA
10. Lewis, E. V., 1988. *Resistance, Propulsion and Vibration - Principles of Naval Architecture*. The Society of Naval Architects and Marine Engineers, Vol. 2, SNAME Publication, Jersey City, NJ, USA
11. Mercier, J.A. & Savitsky, D (1973). Resistance of Transom-stern Craft in the Pre-planning Regime”. *Report 73-1667*. Stevens Institute of Technology, USA, 8
12. International Maritime Organization (2008), *International code on intact stability, 2008 (2008) IS Code*, MSC 83/28/Add.2, Annex 13.
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., 2003. *Parametric Design. Chapter 11 - Ship Design and Construction*, Vol. 2, Written by an International Group of Authorities, Thomas Lamb, Editor, SNAME Publication, Jersey City, New York, USA
17. Knox, J., 2004, *Ferries - Ship Design and Construction*, Chapter 38, Vol. 2. SNAME Publication, Jersey City, NJ, USA
18. Levander, K, 2004. *Passenger Ships- Ship Design and Construction*. Chapter 37, Vol. 2, SNAME Publication, Jersey City, NJ, USA
19. Calhoun, S. R. and S. C. Steven, 2003. *Human Factor in Ship Design - Ship Design and Construction*, Chapter 15, Vol. 2. SNAME Publication, Jersey City, NJ, USA
20. Olson, H. A., 1990. Trends in Modern Ferry Boat Design-*Presented at the February 8*, 1990 Meeting of The Northern California Section of The SNAME, 6–37.
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, D. G. M, 1998. *Practical Ship Design*, Elsevier Ocean Engineering Book Series, Volume I, ELSEVIER