# THE EFFECT OF DRAFT CHANGING TO SHIP SPEED

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## ABSTRACT

The changing of draft due to liquid consumption on board during ship operation affects ship parameters particularly the engine power and speed. For a constant engine power, ship speed will increase for a long travel time. Therefore, the real ship travel time will be shorter than an average estimated time. This issue was proved by the computation of engine power and speed of two semi-displacement (parent and modified) ships from the existing method. The results of computation were validated by model tests in the towing tank. The results of computation and model test have proved that the real travel time is shorter than an average estimated time. The results of computation and model test are presented in form of the equations for easy application. The outcome of this work may be used by ship operators as a reference to estimate the real ship travel time.

***Keywords:*** liquid consumption, draft, speed, travel time

## INTRODUCTION

Real ship operation depends on its duty and route. During the ship operation there are some changing of ship parameters such as fluid consumption (fuel and fresh water) during the travel. This condition ends-up with reducing the fluid, displacement and draft. This condition changes ship parameters particularly stability and resistance. The change of ship resistance affects the speed. If the engine power is kept to be constant during the travel, then the speed will increase since the resistance reduced. As a result, the real time travel of ship will be shorter than estimated average time.

Two semi-displacement ships were designed and modified to prove this issue. The resistance of the ships were computed based on Savitsky Pre-Planning method (Lewis, 1988; Mercier et al., 1973). The ship displacement was set to the condition of fluid on board (fuel, fresh water and grey water) which are 100%, 70%, 40% and 10%. The changing of resistance, power and speed of the ships were computed for those loading conditions. The changing of speed due to ship draft and time travel were presented. Two ship models were developed and tested in the towing tank to prove this issue. At the end, the result of computation of real travel time was presented and compared to average estimated time. The result will be used by ship operators as a guidance to estimate a real travel time for such semi-displacement ships.

## LITERATURE REVIEW

### Semi-Displacement Passenger Ships

Semi-displacement passenger ships have been developed and operated by some ship owners and operators recently due to their better performances. The Austal Ships, The UK ferry operator, FBMA Marine, Port of Al Khaiman (Significant Ships Small Ships, 2009; Ship and Boat International, 2009; FBMA Marine Inc., 2007; Work Boat

World, 2006) are ship operators that take the benefits of these kind of ships. The use of lighter hull materials such as Fiber-Reinforced Plastic (FRP) or Aluminum gives benefits such as increasing payload or speed. Definition of semi-displacement ships is found in Molland (2008) where semi-displacement ships have Froude number, *Fn* from 0.5 to 1.0. Meanwhile, Larsson (2010) defined the intermediate region of $0.5 < Fn < 1.0$ is called semi planning speed range. According to Nicolaysen (1999), the speed range of ships with Froude numbers $0.5 < Fn < 0.75$ are called semi-displacement ships.

**Resistance and Propulsion of Semi-Displacement Ships**

The resistance of medium-speed passenger ships depends on the ship parameters of ship main dimensions (length $L$, beam $B$, and draft $T$), speed ($V_S$ ), ship ratios (length beam ratio $L/B$, displacement-length ratio $\nabla^{1/3}/L$ or $L/\nabla^{1/3}$, beam-loading coefficient $C_V = \nabla/B^3$), geometrical hull forms (prismatic coefficient $C_P$, block coefficient $C_B$, midship area coefficient $C_M$, position of longitudinal centre of buoyancy $LCB$) and types of ship ends (angle of entrance, types of stern).

The resistance data of semi-displacement ships are found in some references. The systematic series of resistance data of semi-displacement ships are found in Molland (2011), Larsson (2010), Lewis (1988) and Mercier et al. (1973). There are two resistance methods available for semi-displacement or semi-planing ships which are WUMTIA (Wolfson Unit for Marine Technology and Industrial Aerodynamics) data series and Statistical resistance prediction method where this resistance method was derived by Mercier and Savitsky (Mercier et al 1973; Lewis, 1988). The application of regression equations are for all vessels in pre-planing mode. The systematic series of the resistance data of the semi-displacement ships that may be used as a basis for preliminary power estimates are found in Lewis (1988) and Mercier (1973).

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:

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

The values of the coefficients $A_1$ to $A_{27}$ and correction factors are presented in Lewis (1988). This method is provided in the Maxsurf software.

The resistance of full-scale ships were predicted based on Froude method. It is noticed that in order to predict the total resistance for that approach methods, the effects of air and appendage drags are taken into account. The air resistance coefficient $C_{AA}$ is included into the total resistance coefficient ($C_{TS}$). The resistance of appendages, as percentages of hull naked resistance is added as much as 8 % for the full-scale ship (Molland, 2011).

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 ($P_B$) will exceed the delivered power ($P_D$) by an amount of power lost in the transmission systems (shafting and gearing losses), 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 $$P_I = (P_E/\eta_D)\times(1/\eta_T)+margin\ (roughness, fouling, weather) \quad (5)$$

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

where: $\eta_D$ = quasi-propulsive coefficient (*QPC*)
$\eta_O$ = open water efficiency
$\eta_H$ = hull efficiency = $(1-t)/(1-w)$
$\eta_R$ = relative rotative efficiency
$\eta_T$ = transmission efficiency
$w$ = wake fraction
$t$ = thrust deduction factor

The ship operator may run the engines up to the normal continuous rating (*NCR*). This normal continuous rating may be set for 10 % below the maximum continuous rating (*MCR*) (Molland, 2011). The screw propellers were selected based on the propeller data from the Wageningen B-Screw Series (Lewis 1988). The evaluation of propeller cavitations was executed based on the Burril Diagram. Since the resistance of ship depends on speed, dimensions and displacement of ship then a changing of these parameters will affect the resistance, power and speed of the ship.

## SHIP DESIGN AND EXPERIMENTAL SET UP

### Design of semi-displacement passenger ship

To prove the effect of draft changing in this study, two semi-displacement passenger ships was selected. They are a parent and modified ships, designed by the author (Hetharia, 2011; Hetharia, 2012; Hetharia, 2013; Hetharia, 2014). Each ship has the capacity of 254 passengers, hull material is Aluminum, the autonomy is 200 n.m, service speed is 20 knots. Dimensions and other ship parameters are presented at Table 1. The ships were designed to follow the design process for the passenger ships (Parsons, 2003; Knox, 2004; Levander, 2004; Calhoun et. al., 2003; Olson, 1990; Gale, 2003; Watson, 2003). 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 strictly adhered to during design process. General arrangement of the parent ship is shown in Figure 1. Furthermore, the parent ship was modified due to length, beam and draft (modified ship). During ship modification, the total payload of 254 passengers and ship displacement are kept constant.

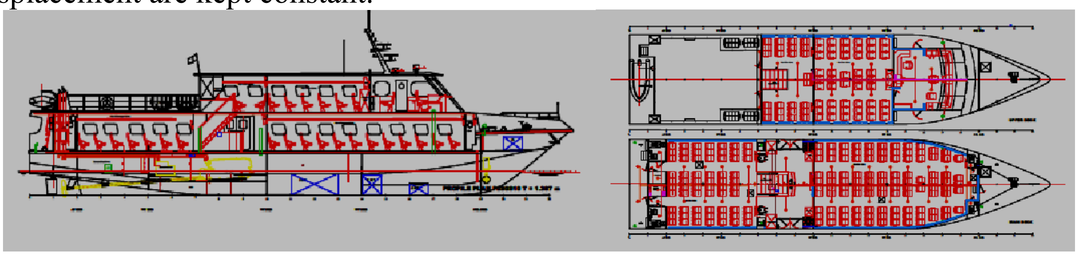


Figure 1. General arrangement of the parent ship

Two units of main engines, MTU Marine Diesel Engine 10V 2000 M72, are applied as the prime mover of the parent and modified ships. Each main engine has the maximum continuous rating (MCR) of 1205 hp with the engine rotation speed of 2250 rpm. The specific fuel consumption is 223.4 l/hour. 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, total efficiency: 0.577 for parent ship and 0.58 for modified ship.

The effect of draft changing to ship speed was proven theoretically by the existing resistance methods and by experiment models. A scale factor λ = 27 was set to develop the models. The dimensions and other parameters of full-scale ships and models are presented at 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 | 1.109 | 1.287 |
| Ship beam, *B* | m | 7.00 | 6.50 | 0.259 | 0.241 |
| Beam of waterline, $B_{WL}$ | m | 6.69 | 6.69 | 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 | 5.542 | 5.538 |
| Block coefficient, *Cb* | | 0.384 | 0.362 | 0.384 | 0.362 |
| Midship coefficient., *Cm* | | 0.550 | 0.540 | 0.550 | 0.540 |
| Prismatic coefficient, *Cp* | | 0.698 | 0.671 | 0.698 | 0.671 |
| Water plane coeff., *Cwp* | | 0.848 | 0.831 | 0.848 | 0.831 |
| Wetted surface A., *WSA* | $m^2$ | 194.4 | 215.2 | 0.267 | 0.295 |
| Midship area, $A_X$ | $m^2$ | 5.16 | 4.56 | 0.007 | 0.006 |
| $L_{CB}$ (from midship) | % $L_{WL}$ | -1.96 | -2.00 | -1.96 | -2.00 |

**Experimental Set-up**

The results of resistance computations from Savitsky pre-planning method was validated by the model tests. The results obtained from the model tests were used to estimate the resistance of full-scale ships. The extrapolation method to estimate the results of model test to the full-scale ship was used based on the Froude method (Molland, 2011; Lewis, 1988; Larson, et. al., 2010).

The ship models were formed by high-density closed-cell foam covered by fibre-reinforced plastic (FRP). The models were shaped by multiple-axis cutting machine owned by DN&T (Design Naval & Transports) office, Liege, Belgium. A sand strip turbulence stimulator was fixed at models (Molland, 2011; Lewis, 1988; Larson, et. al., 2010. The ship models were tested at the towing tank of University of Liege (ULg-ANAST) (Figure 2). Some external effects were avoided during the tests. The ship parameters measured during the tests are model speed, resistance, trim and sinkage.

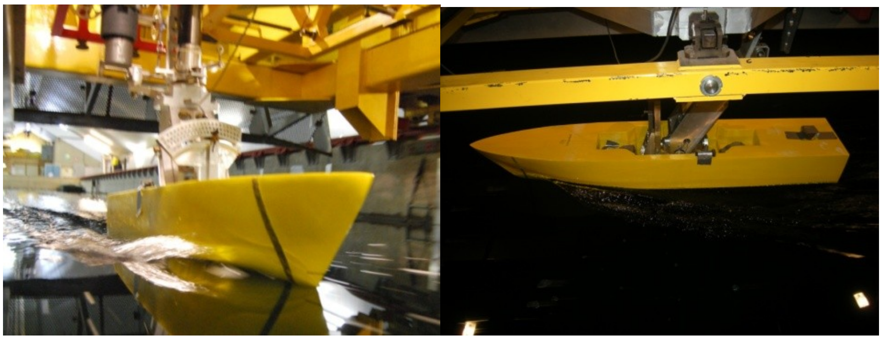


Figure 2: The ship models are underway

## RESULTS AND DISCUSSION

### Results of Computation and Model Test

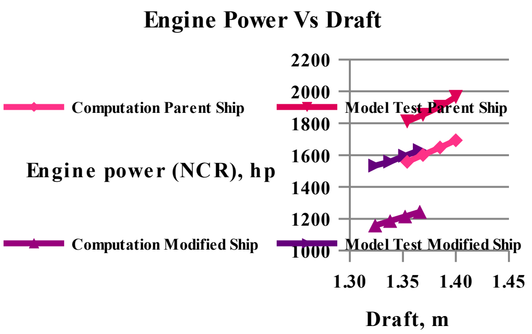
The computation of ship resistance for the Savitsky pre-planning was executed by using Maxsurf. The results of computations of the resistance are presented at Table 2, Table 3 and Figure 3.

Table 2. Results of Parent Ship

| No | Fuel (t) | 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 | 1.385 | 92.91 | 1648 | 20.57 | 106.36 | 1904 | 20.75 |
| 3 | 2.40 | 3.44 | 40 | 5.16 | 102.11 | 9.48 | 1.369 | 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 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 Modified Ship

| No | Fuel (t) | 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 | 1.352 | 68.78 | 1214 | 20.51 | 88.97 | 1596 | 20.68 |
| 3 | 2.40 | 3.44 | 40 | 5.16 | 103.19 | 9.48 | 1.338 | 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 constant engine power of 1243 kW for computation and 16.31 kW for experiment model tests. Value of total efficiency $(\eta_D \times \eta_T) = 0.580$ | | | | | | | | | | | | | |



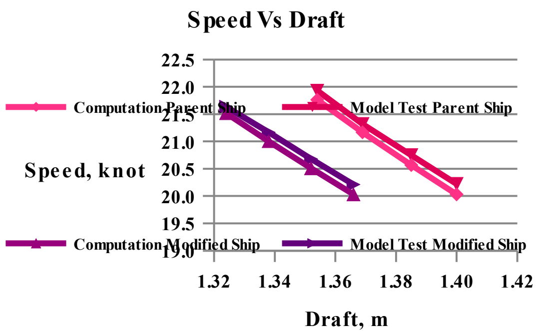



Figure 3. Engine Power Vs Draft and Speed Vs Draft of the Ships

The relations between speed and real travel time of both ships are presented at Figure 4. Those relations are resumed as follows:

| | | | |
|---|---|---|---|
| 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) |

An estimate of travel time was made for those two ships based on experiment results with some assumptions of:

- The engine power was set to be constant during the travel time, which is 1966 kW for the parent ship and 1631 kW for the modified ship.
- The total efficiency $(\eta_D \times \eta_T) = 0.577$ for parent ship and $(\eta_D \times \eta_T) = 0.58$ for modified ship

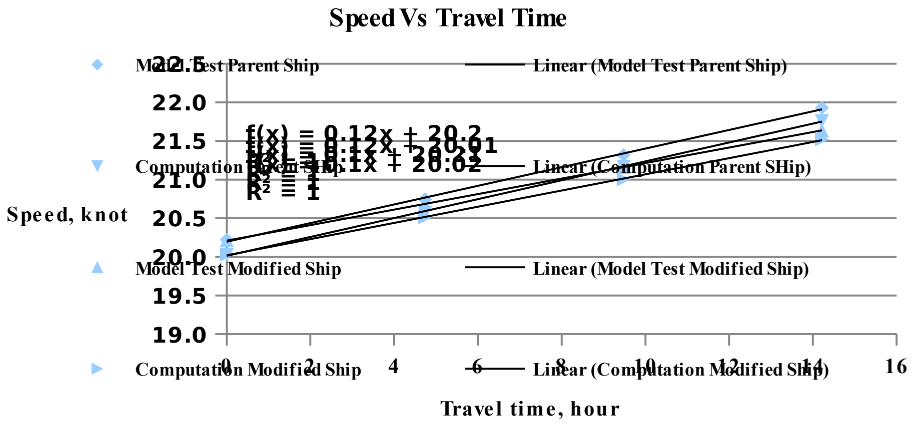



Figure 4. Changing of Speed Due to Travel Time of The Ships

For example:

Distance = 300 n.m, ship speed = 20 knots, then estimated travel time is 15 hours. Using the equation (8) for the parent ship, and by inserting a fixed distance and trying some values for real travel time (t), it is found that:

$$\text{Distance} = \text{speed x travel time} = \{(0.120\ t) + 20.19\}\ t = 0.120t^2 + 20.19t$$

The travel time is 13.74 hours or reduced 1.26 hours (8.4 %) of average estimated time. Also, using equation (10) for modified ship, it is found that:

$$\text{Distance} = \text{speed x travel time} = \{(0.100\ t) + 20.21\}\ t = 0.100t^2 + 20.21t$$

The travel time is 13.90 hours or reduced 1.1 hours (7.3 %) of average estimated time.

## Discussion

The results of ship resistance from existing method and model tests for the resistance and engine power are in good pattern. In fact, there is a difference of 12.7 % for parent ship and 22.8 % for modified ship. This difference accounts for appendage resistance of 8 %, air resistance and model-ship correlation coefficients which were included in model test. Meanwhile, a big difference for modified ship were caused by a higher length-beam ratio which is not proper for Savitsky Pre-Planning method.

During the construction of models and executing the model tests some conditions were kept to be in a proper way. Those conditions included: model precision, calibration of instruments and external effects on models. It may be confirmed that the data obtained from the model tests were valid.

The results obtained from computation and model test have proven that the real travel time is shorter than average estimate time. The period of real travel time depends on travel distance and fluid consumption on board which reduce the displacement and draft. Therefore, the speed will increase and real travel time will be shorter. The increasing of speed and engine power due to draft changing tends to be linear. Also, the increasing of speed due to real travel time tends to be linear.

The equations of speed due to the real travel time are presented in equations. This will be useful that users may estimate a real travel time due to a certain distance.

## CONCLUSION AND FUTURE WORK

### Conclusion

The study of real travel time of ship was made for two semi-displacement passenger ships. This work was executed for the computations and model tests with two full-scale ships having different dimensions. The results were presented and compared for the parent ship and modified ship. The conclusions of this study are described as follows:

- Both results of computations and model tests have proven that there are reducing real travel time of ship compared to average estimate time.
- Both results of computation and model tests have different values. However, for practical application, it is better to use the result of model tests.
- The results are presented in equations where users may use for any kinds of distance for similar ship configuration

### Future Work

The study with only two unit of ships are not suitable to define a general conclusion for the ship. Therefore, a future work should be developed for any ship dimensions and configurations.

## ACKNOWLEDGEMENTS

Special thanks to:

- The University of Liege (ULg-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 ship models.

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