Weight estimation of custom motor yachts in the range between 45 and 65 meters length

Ryohei Sugimoto

Master Thesis

presented in partial fulfillment of the requirements for the double degree:
“Advanced Master in Naval Architecture” conferred by University of Liege
“Master of Sciences in Applied Mechanics, specialization in Hydrodynamics, Energetics and Propulsion” conferred by Ecole Centrale de Nantes

developed at University of Genoa in the framework of the “EMSHIP” Erasmus Mundus Master Course in “Integrated Advanced Ship Design”

Supervisor: Prof. Dario Boote, University of Genoa
External supervisor: Emanuele Camporese, Azimut-Benetti S.p.A.
Reviewer: Prof. Philippe Rigo, University of Liege

Genoa, February 2012
1. INTRODUCTION

To inform the lightship weight in the early design stage is an important factor to win a contract. Bad quality of weight prediction affects the as-built vessel on many aspects such as load capacity, speed, stability, maneuverability and financial profit. Especially underestimation of lightship weight must be avoided since it makes the draught deeper than expected. Draught plays important role in the registration of the vessel to classification society. There are several requirement from the rules or manufacturer connected with draught. For example, height of portholes from maximum draught is limited by classification society and it’s impossible to modify the place of the portholes upwards. The solution will be to decrease the draught that means decrease of deadweight by reducing fuel or water capacity, for example. On the other hand, accurate weight prediction helps shipyard to obtain clear accounting estimates. And also helps to prepare adequate amount of material or labour.

Lightship weight can be calculated perfectly by summing up everything that will go onboard. The problem is that the ship design is iterative process and detailed calculation in the early design stage is not possible since the design is still flexible. Therefore, in the early design stage, weight is usually predicted by a simple formula with a numeral of the vessel as a variable. Numeral can be calculated using principal dimensions and coefficients which is available in the early design stage. Formula can be easily obtained once a numeral is set.

The goal of this paper is to find the most suitable numerals and formulas that gives the accurate weight prediction of mega yachts. In theory, the sum of all the predicted weights should be equal to the lightship weight. However, since the variability of data, there will be either positive or negative difference. The accuracy of the weight prediction method will be evaluated by statistical indicator. In the end, the weight prediction method together with total power estimation method are presented.
2. DATABASE

In this study, attention was paid to mega yachts which have been built in *Benetti shipyard* ranging from 45 to 65 metres which are different from large commercial vessels in some aspects, hull form, relative speed, propulsion, stabilizer, etc.

All the information of 21 mega yachts ranging from 45 to 65 meters which have been built in *Benetti shipyard* were gathered. The information contains; main dimensions, gross tonnage, lightship weight, maximum and cruising speed, weight and centre of gravity of all components on board, and so on. The database was structured in Excel spreadsheet. General information of the yachts are as shown in Table 1 and Fig. 1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Main hull</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Superstructure</td>
<td>Aluminium*</td>
</tr>
<tr>
<td>Gross tonnage</td>
<td></td>
<td>500–1450</td>
</tr>
<tr>
<td>Overall length</td>
<td></td>
<td>45–65 m</td>
</tr>
<tr>
<td>Maximum speed</td>
<td></td>
<td>15 ~ 17 knot</td>
</tr>
</tbody>
</table>

* Superstructure of a yacht of 65 meters is partly made of steel

![Figure 1. Vessel length distribution](image-url)
3. METHODOLOGY

3.1. Regression Analysis

In this study, weight prediction method was developed using regression analysis. Regression analysis is the statistical method used to find correlation between variables for the purpose of predicting future values. The aim of using this analysis is to predict the value of certain variable by using the input value and correlation between two variables. For example, if \( y \) is a function of \( x \), it can be written \( y = f(x) \). The aim is to obtain the value of \( y \) by using \( f(x) \) and the value of \( x \). The value of \( x \) is known or obtained by simple calculation, however, the correlation between \( x \) and \( y \), that is, formula to calculate the value of \( y \) must be found somehow. Regression analysis is the method to find this relationship statistically.

In this study, \( y \) is lightship weight, weight of main hull and superstructures, main machinery weight, total power, area of insulation/damping/anti-condensation treatment, and so on. And \( x \) is numerals which can be easily calculated using dimension or specification of the yacht. The correlation between \( x \) and \( y \) is obtained using Excel then finish or go back to choose another \( x \) depends on if the correlation is the strong or week. The flowchart is shown in figure 2. For each \( y \), proper \( x \) and the correlation should be found.

![Flowchart of regression analysis](image)

Figure 2. Flowchart of regression analysis
3.2. Weight Breakdown

The lightship was divided into a number of groups such as main hull and superstructures, main machinery, outfitting. This is called first level weight breakdown. There are many ways of classification and each shipyard has each system. The weight breakdown system of Benetti was used in this study and it is shown in Fig. 3.

Figure 3. Weight breakdown system of Benetti
According to this weight breakdown system, lightship weight can be calculated by summing up the weights of all groups, shown in (1).

\[ LSW = \sum_{n=1}^{9} W_n \]  

(1)

where

\begin{align*}
LSW &= \text{lightship weight [ton]} \\
W_n &= \text{weight of the group number } n \text{ [ton]}
\end{align*}

<table>
<thead>
<tr>
<th>( n )</th>
<th>name</th>
<th>( n )</th>
<th>name</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Structures of Hull and Superstructures</td>
<td>6</td>
<td>Electric and Electronic Systems</td>
</tr>
<tr>
<td>2</td>
<td>Insulation and Outfitting</td>
<td>7</td>
<td>Main Machinery</td>
</tr>
<tr>
<td>3</td>
<td>Auxiliary Machinery</td>
<td>8</td>
<td>Joinery and Partition</td>
</tr>
<tr>
<td>4</td>
<td>Piping</td>
<td>9</td>
<td>Liquid</td>
</tr>
<tr>
<td>5</td>
<td>Ventilation, Conditioning and Fridge</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There are several advantages of dividing lightship weight into a number of groups.

- Increase of prediction accuracy
- Calculation of weight distribution
- Cost estimation
- Flexibility of prediction
4. NUMERALS USED FOR WEIGHT PREDICTION

To find the most suitable numeral is one of the most important processes in regression analysis procedure. Until now, a lot of weight prediction methods and proper numerals were developed. Besides those numerals, new numeral, named “cubic number” was developed in this study. This numeral is calculated by the formula (2-3).

\[ C_n = L_{BP} \cdot B \cdot (D + H) \]  
\[ H = A / L_{BP} \]

where

\[ H = \text{mean height of the superstructure [m]} \]
\[ A = \text{projected area of the superstructure [m}^2]\]

Cubic number represents approximate volume of the yacht. There are some advantages of using Cubic number:

- Easily obtained by simple calculation
- Doesn’t depend on characteristics that can vary in gross tonnage calculation performed by classification society or surveyor
- Strong correlation with gross tonnage (GT estimation)
5. RESULT

5.1. Weight Prediction Method

The weight estimation methods of all the groups were developed using regression analysis. Finally lightship weight was calculated by summing up estimated weight of each weight group. Hereinafter, this prediction method will be called sum-up method.

\[ LSW = \sum_{n=1}^{9} W_n + W_D \]  

where

\[ W_D = \text{the weight of fixed ballast and difference of lightship weight between database and inclining test [t]} \]

Estimation method of the group \( W_D \) was developed in the same way as another weight group. Additionally, direct lightship weight estimation method, called one-equation method, was developed by regression analysis as well. The lightship weight can be obtained only by one formula, it means weight breakdown is not used in this method. For these two methods, the estimated lightship weight was compared with the one obtained by inclining test and error was calculated. The accuracy of the methods were discussed.

The results of sum-up method and one-equation method are shown in Fig. 5. The error distribution of sum-up method is shown in the left figure and the one of one-equation method is shown in the right figure. And statistical indicators are compared in Table 3.

![Figure 5. Comparison between sum-up method (left) and one-equation method (right)](image-url)
Table 3. Comparison of statistic value

<table>
<thead>
<tr>
<th></th>
<th>Sum-up method</th>
<th>One-equation method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean error [%]</td>
<td>1.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Standard deviation [%]</td>
<td>3.9</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Mean error is the average value of error and standard deviation indicates how much variation or dispersion exists from the average or mean value. A low standard deviation indicates that the data is distributed close to the mean, while high value indicates that the data are spread out over a wide range of values. Therefore, both mean error and standard deviation should be as small as possible. Small value of mean error doesn’t mean accurate weight prediction if the value of standard deviation is high since low mean error comes by compensation of huge positive and negative errors in this case.

It can be said that dividing lightship weight into several groups increases the certainty of the lightship weight prediction since the value of standard deviation was decreased. Sum-up method is more accurate and flexible method with a little bit more calculation. And one-equation method is simple and quick method. Both method can be used depends on conditions. For example, firstly, one-equation method can be used to obtain approximate lightship weight quickly then sum-up method can be used for more detailed weight information.

5.2. Total Power Prediction Method

Total power prediction method was also developed using regression analysis. The estimated total power was compared with installed total power and error was calculated. The result as shown in Fig.6 and Table 4 was obtained.
Table 4. Statistical indicators of total power prediction result

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean error [%]</td>
<td>-7.5</td>
</tr>
<tr>
<td>Standard deviation [%]</td>
<td>3.8</td>
</tr>
</tbody>
</table>

Figure 6. Error distribution
7. CONCLUSIONS AND PROPOSALS

7.1. Conclusions

- The lightship weight was divided into several main groups using Benetti’s weight breakdown system.
- Numeral named cubic number was developed.
- The weight prediction methods for each main group were developed by regression analysis.
- Two lightship weight prediction methods were developed. One predicts lightship weight by summing up all the estimated weights of main groups, the other method uses single formula which directly obtained by regression analysis.
- Total power prediction method was developed by regression analysis.
- Mean error of 1.1 % and standard deviation of 3.9 % were obtained by lightship weight prediction using sum-up method.
- Mean error of 0.1 % and standard deviation of 4.5 % were obtained by lightship weight prediction using one-equation method.
- Mean error of -7.5 % and standard deviation of 3.8 % were obtained by total power prediction method.

7.2. Future Work Proposals

- More data should be gathered to increase reliability of the methods.
- Margin should be taken into account more in detail for wider usage of the method.
- Additional calculation should be done to develop practical cost estimation method.
8. ACKNOWLEDGEMENTS

First of all, my deepest appreciation goes to professor Rigo Philippe, coordinator of EMSHIP Programme. Everything started from his idea and I could have precious and fruitful experience that not everybody can have in their lives.

I would like to thank to professor Dario Boote, my supervisor in Italy. It was my great pleasure to study naval architecture in the country with deep and rich history of yachts.

I would like to express my gratitude to Emanuele Camporese, my external supervisor, technical manager of Benetti Shipyard. My purpose of joining this programme was to do my internship at this one of the best company in the world. Camporese gave me a lot of useful advice and knowledge from practical point of view. Moreover, I learned many things from his positive attitude toward his job.

I want to thank all of my colleagues to gave me great time in western countries. With Ivan, I spent happy and funny time always with smile, delicious food, coffee and discussion about anything. Zsolt told many things to me and it was a great time that three of us from different country live together with a lot of interaction. Five month in Italy with Marko, Patrick, Ivan and Zsolt passed so quickly with a lot of memories. Thank you very much.

Unfortunately due to lack of the space, I would not write to everybody one by one. Akram, Bogdan, Cristian, Desta, Do, Huggo, Juliana, Jimmy, Krzysztof, Margus, Martin, Rachid, Tomasz, Vu, Wafaa and Yohannes, thank you, شكرا, mulțumesc, gracias, amesegënallô, cảm ơn bạn, obrigado, terima kasih, dziękuję, aitäh, hvala, merci, and ありがとう！

This thesis was developed in the frame work of the European Master Course in “Integrated Advanced Ship Design” named “EMSHIP” for “European Education in Advanced Ship Design”, Ref.:159652-1-2009-1-BE-ERA MUNDUS-EMMC.

Master Thesis developed at University of Genoa, Genoa
### 9. REFERENCES

<table>
<thead>
<tr>
<th>Type</th>
<th>Reference</th>
</tr>
</thead>
</table>