**BAITA ENGINEERING**
*Journal of Naval Architecture and Marine Engineering*
Vol. 1 No. 1, December 2023, pp. 1-10, ISSN: 3025-8286

# The Correlation of The Hull-Forms Parametric to The Ship's Propulsion of Tugboats with Two Propulsion

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Article Information

***Article History:***
Received: March 28, 2023
Accepted: May 19, 2023
Published: December 1, 2023

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**ABSTRACT**

*This paper aims to determine the correlation of power propulsion to hull-forms parametric of twin-propulsion Tugboats. By using the regression method, an analysis of the technical data of existing tugboat is carried out, where the data is obtained by collecting data on Tugboats that are registered and operation as many as 381 tugboats. From the results of the analysis was carried out, it was found that the relations model power propulsion to hull-forms parametric, then the model was validated by testing the existing tugboat to determine how many errors the relations model. Based on the results of the analysis carried out, power propulsion affects the hull forms parametric, where the increase in power propulsion will increase the value of the hull forms parametric in this case main dimension of the tugboat (L, B, D and T). The value of power propulsion to main dimension of tugboat has a different effect on each type of tugboat.*

***Keywords:*** *Correlation, Hull-forms parametric, Power Propulsion, Tugboats.*

https://doi.org/10.30649/baitaengineering.v1i1.7



## 1. INTRODUCTION

Based on its function, a tugboat is a ship that is used to tow or push a large ship. Determine the design parameters of the tugboat namely: the technical specifications of the ship, including the hull forms parameters, generally based on the ability to tow or push a large ship. Where the ability to tow or push the tugboat depends on the size of the engine power or thrust of the ship. Therefore, naval architect often only provide data on the towing ability of the tugboat by the ship owner.

The ship design procedure known as Spiral design was first introduced by J.H. Evans, 1959. Spiral design is a series of sequential and iterative ship design procedures to determine the main dimensions of the ship and several other design results (Taggart, 1980) (Apostolos Papanikolaou, 2014). Ship design procedures according to (A. Papanikolaou et al., 2009) that is: Mission, Function, Form, Performance and Economics. While the stages of ship design according to (Apostolos Papanikolaou, 2014) that is: Concept design, Preliminary design, Contract design and Detailed design, whereas for concept design and preliminary design known as basic design and merged at the stage preliminary design. Preliminary ship design is the initial stage in ship design which is based on the needs and specifications of the ship owner. Including the main technical and economis characteristics of the ship.

The initial stage of designing a ship is to determine the main dimensions and hull-forms of the ship, it requires some information to be asked to the ship's owner, including: Cargo type/Ship type, Payload/Deadweight, Ship speed and Shipping route (C.B., 2004)(Apostolos Papanikolaou, 2014). The parameters that affect the hull-forms of the ship's hull include: The slenderness of the ship hull-form ($L/V^{1/3}$), Main dimensions (Displ. L, B, T, D), Ratios of main dimensions (L/B. L/D, B/T, B/D) and hull-form coefficient of the ship (Cb, Cp, Cwp, Cm) (Thomas, 2003)(Munazid et al., 2010)(Permana et al., 2018)(Rohmad & Munazid, 2018)(Permana & Awwalin, 2019).

The design of tugboats is slightly different from the design of other ships for example: General cargo, Bulk carrier, Ore carrier, Tanker, Container vessel, etc, in the preliminary design the ship owner usually only provides information the propulsion of the tugboat. Therefore, the problem that must be solved for the naval architect when designing a tugboat, where in theory the power of the tugboat propulsion is determined after the hull-form of the tugboat is designed, for this reason this paper discusses how the relationship between the propulsion of the tugboat and the hull-forms parameters of the tugboat. To solve these problems, data collection on technical specifications of tugboats with two propeller that have been registered/built and operating is carried out, including: Main dimensions, Main Engine, Ship Propulsion, Deadweight, Ship speed and Shipping route. From this data, statistical methods were carried out to analyze the relationship between the ship's propulsion and several hull-form parameter of the tug boat, with this relationship naval architect will be assisted in determining the hull-forms parametric of tugboat.

## 2. METHOD

### 2.1. Tugboat

According (Thomas, 2003) A tugboat is a ship that is used to tow or push ships, in order to serve ships that are anchored in ports and to serve ships or floating buildings that do not have their self-propulsion, such as barges, offshore platforms, floating cranes, floating docks etc. Based on the work area, tugboats are divided into three (3) types of tugboats, namely:

a. Ocean Tugboat, is a tugboat for ocean shipping where the function and task of the tugboat is to tow or push a ship or floating structure that does not have its self-propulsion.
b. Harbour Tugboat, is a tugboat operating in port waters, where the function and task of the tugboat is to push or tow larger ship anchored or vice versa in port waters.
c. Coastal Tugboat, is a tugboat that operates in shallow waters, coastal or rivers, where its function is to tow or push larger ships in shallow water, coastal and river.

### 2.2. Procedure Ship Design

Ship design in the past was more of an art than a science, it really depended on the experience of the ship designer. The solution to the ship design problem is practically developed using the heuristic method, namely a method that comes from a process of trial and error that is often done for decades. Gradually, the trial and error method was replaced by knowledge/science, which eventually formed the semi-empirical method and existing ship statistical data. A modern databased approach in ship design considers ships as very complex system and integrates several; subsystems and components thereof, for example subsystems for cargo storage and handling, energy/electricity generation and ship propulsion systems, accommodation for crew/passengers, ship navigation etc.

In general, the ship design stages can be simplified into four main stages, namely: Concept design, Preliminary design, Contract design, and Detail design. According to (A. Papanikolaou et al., 2009) As in Figure 1 the sequence of the ship design process, the ship is designed to fulfill the specific requirements or mission of the ship's customer (Mission); determine certain functions of the ship (Function); hull-form, space, weight (Form); ship's technical performance (Performance) and ship's economic characteristics (Economics).

According to (Apostolos Papanikolaou, 2014) the objectives of preliminary ship design, include the following: Selection of main ship dimensions; Development of the ship's hull-form (watted and above water parts); Specification of main machinery and propulsion system type and size; Estimation of auxiliary machinery type and powering; Design of General arrangement of main and auxiliary spaces (cargo spaces, machinery spaces and accommodation); Specification of cargo-handling equipment; design of main structural elements for longitudinal and transverse strength; control of floatability, stability, trim and freeboard (stability and load line regulations); tonnage measurement. It is necessary to understand that the determination of all the above ship design elements is the subject of design to compliance with the specification of various national and international maritime rules and regulations, which enforced by national and international authorities.

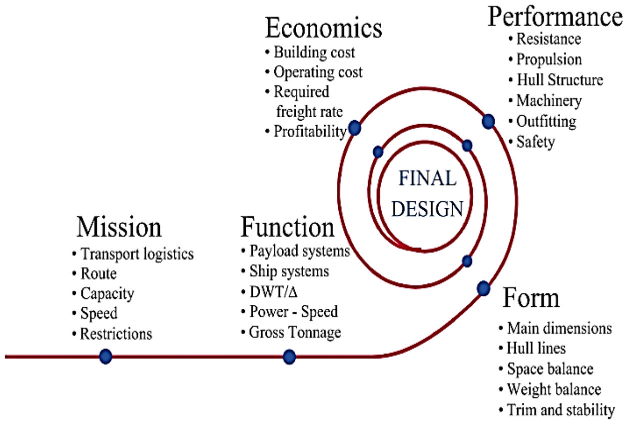



**Figure 1.** Procedure Ship Design (A. Papanikolaou et al., 2009)

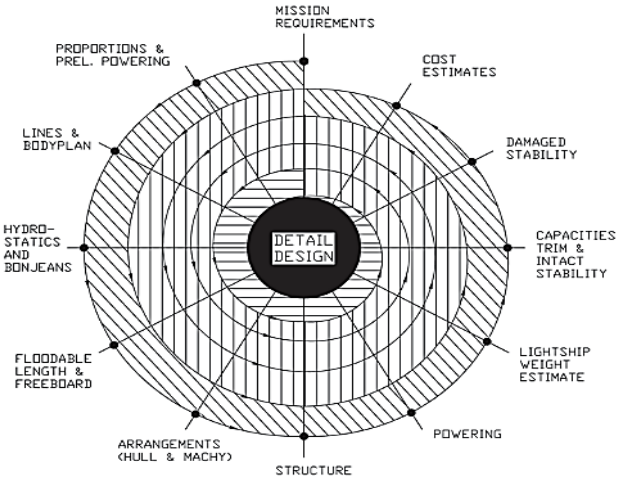



**Figure 2.** Spiral Design, J.H. Evans, 1959 (Taggart, 1980) (Apostolos Papanikolaou, 2014)

The ship design procedure is known as the spiral design, originally introduced by J.H. Evans, 1959 as in Figure 2 (Taggart, 1980) (Apostolos Papanikolaou, 2014). Spiral design is a method that describes a series of sequential ship design process through various design steps with iterative procedures in determining the main dimensions and other design elements. Some notes that need to be considered in the spiral design are as follows:

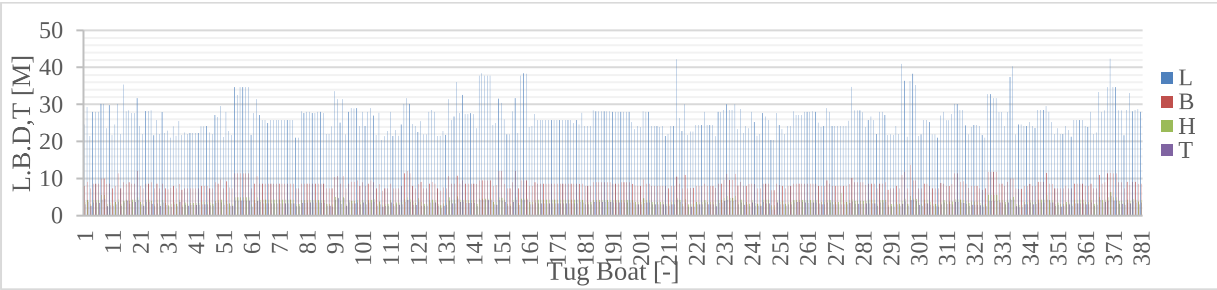
a. Concept Design Feasibility Study: in this design stages, translating the requirements of the ship owner/customer into the technical characteristics of the ship, for example the main dimension of the ship or the hull forms parameter including: Length of ship (L), Breadth of ship (B), Draft of ship (T), Height of ship (H), Block coefficient (Cb), etc.
b. Preliminary Design: in this stage is a more comprehensive description of the various steps of the ships design stages carried out in the first stage (concept design feasibility study), including: determining ship design element that are more accurate than the previous design.

c. Contract Design: the purpose at this stage is to complete calculations and design drawings and to prepare technical specifications of the ship design, all o which are an inseparable part of the shipbuilding contract between the ship owner and the shipyard appointed by the ship owner in the construction of the ship.
d. Detailed Design: at this stage is the final stages of the ship design procedure which is carried out in detail from all structural elements and all components on the ship.

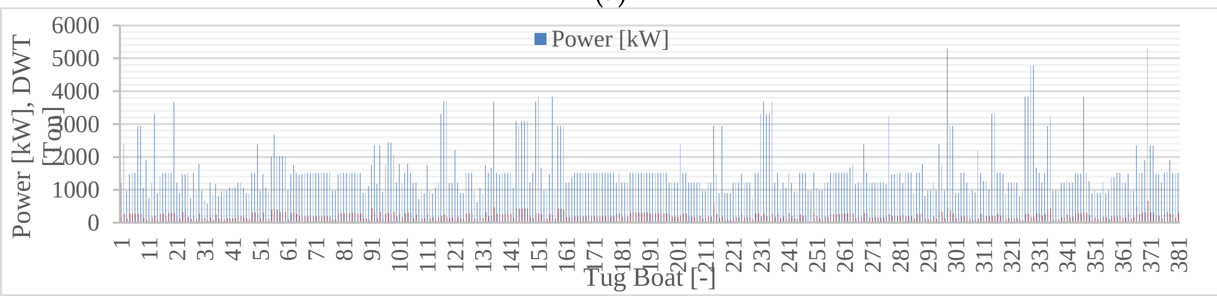
## 3. RESULT AND DISCUSSION

### 3.1. Data of Tugboat

Based on the registered and already operating in the form of technical data on tugboats. Including: Deadweight (DWT), Power of ship propulsion, Main engine, Main dimension, Number of main engine, Ship speed and Ship's area of operation. By regression analyzing the existing tugboat data to relate the tugboat engine power with several of hull forms parameter, this is very necessary in the preliminary design of tugboats, where with information on the ability to tow and push the tugboat capabilities, namely the ship's propulsion engine, naval architect can determine the main dimension and other hull forms parameters of the ship.




(a)




(b)

**Figure 3.** Technical data of tugboat, (a) Main dimension, (b) Power and DWT

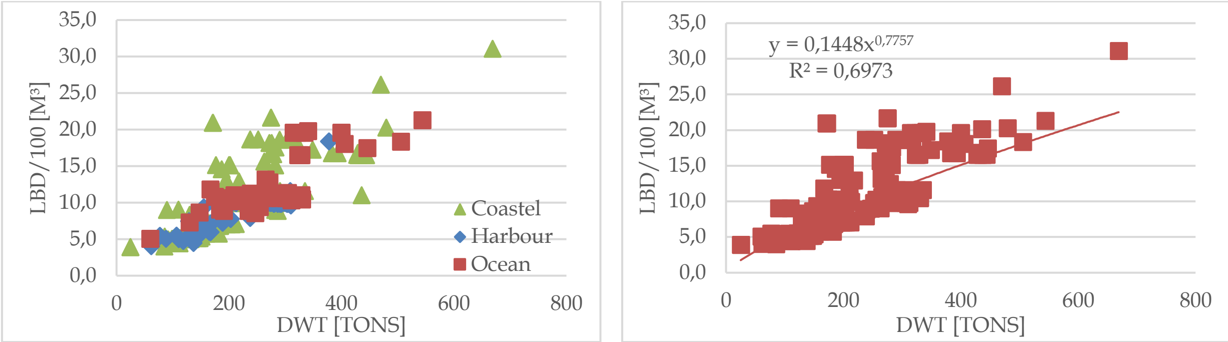
Technical data of tugboats collected is tugboats operating in oceans, harbours and coastal which have two propulsion with engine power ranges of 600 to 6000 kW. The data collected were 381 tugboats which describe the main dimension of the tugboats in Figure 3 (a) while those that describe engine power and deadweight are in Figure 3 (b).

### 3.2. Correlation of Volumetric Numeral LBD

#### *3.2.1. To Deadweight (DWT)*

With regression analysis of the exsisting tugboat data, from the analysis carried out, it was found that the relations of volumetric numeral LBD to deadweight. Figure 4 (a) illustrates the relations of the volumetric numeral LBD to deadweight of each type of tugboats, while Figure 4 (b) illustrates the relations of the volumetric numeral LBD to deadweight of tugboats with $R^2$=0,6973 as in equation (1), where LBD/100: is a volumetric numeral LBD, DWT: is deadweight of tugboats.

$$LBD/100 = 0{,}1448\,DWT^{0{,}7757} \quad (1)$$




(a) (b)

**Figure 4.** Correlation of volumetric numeral LBD to Power propulsion

### *3.2.2. To Power Propulsion*

The analysis that has been carried out on the existing tugboat data shows the relations of the volumetric numeral LBD to power propulsion of the tugboats as shown in the Figure 5, where increasing the power propulsion value of tugboats will increase the volumetric numeral LBD value. Based on the type of tugboat, the type of ocean tugboat has a higher volumetric numeral value than the other two types and the type of coastal tugboat has a lower value.

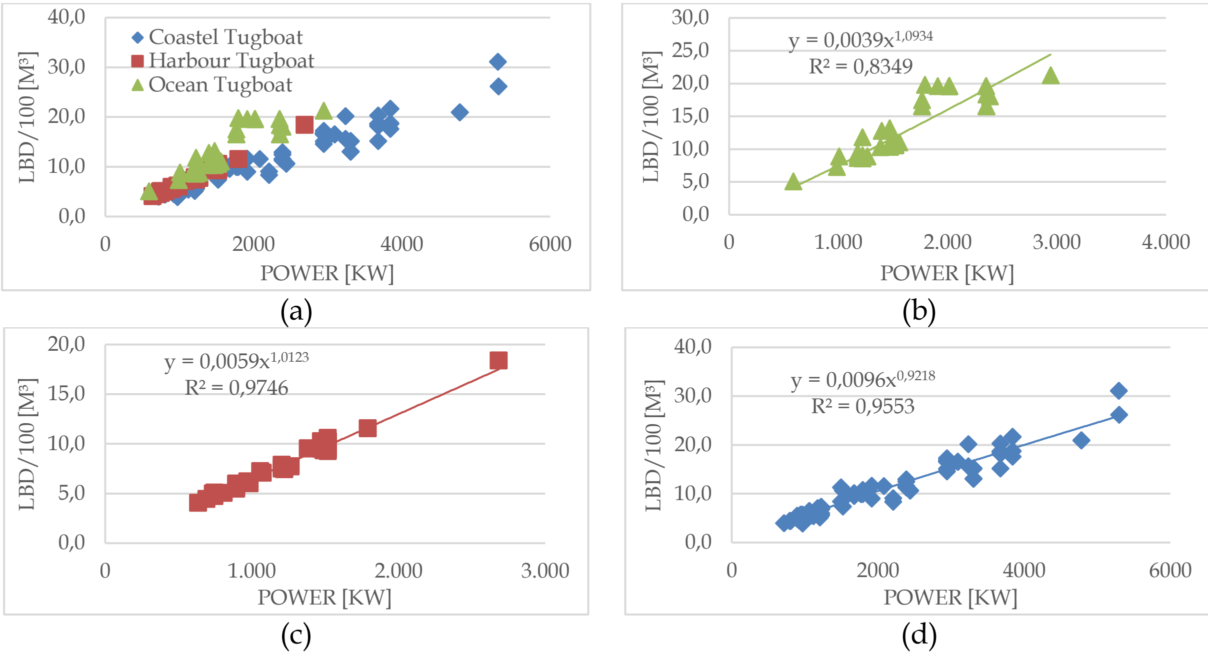



**Figure 5.** Correlation of volumetric numeral LBD to Power propulsion, (b) ocean tugboats, (c) harbour tugboat, (d) coastel tugboat.

$$LBD/100_{OT} = 0,0039\ P^{\ 1,0934}\ \ [M^3] \quad (1)$$

$$LBD/100_{HT} = 0,0059\ P^{\ 1,0123}\ \ [M^3] \quad (2)$$

$$LBD/100_{CT} = 0,0096\ P^{\ 0,9218}\ \ [M^3] \quad (3)$$

Correlation of volumetric numeral LBD to power propulsion can be illustrated in equation (1) for the ocean tugboat type, equation (2) for the harbour tugboat type and equation (3) for coastal tugboat type. Where: $LBD/100_{OT}$: is a volumetric numeral LBD of ocean tugboat type; $LBD/100_{HT}$: is a volumetric numeral LBD of harbour tugboat type; $LBD/100_{CT}$: is a volumetric numeral LBD of coastel tugboat type; *P*: is power of main engine [kW].

## 3.3. Correlation of Dimension to Power Propulsion

### *3.3.1. Length of Tugboats (L)*

Based on the results of the analysis carried out the relations of length of tugboat (L) to power propulsion as illustrated in Figure 6, where increasing the power propulsion value of tugboats will increase the length of tugboats (L), for ocean tugboat has a higher length of tugboat value than harbour and coastal tugboat, while for coastal and harbor tugboat the length value is almost the same.

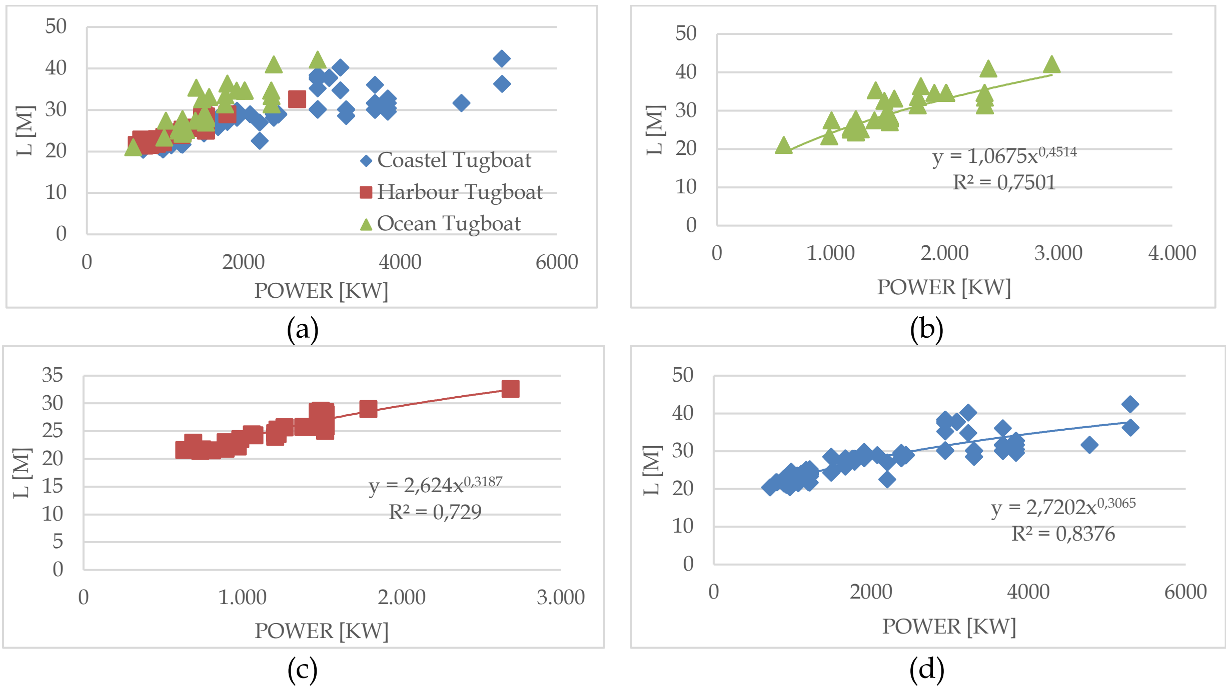



**Figure 6.** Correlation of length (L) to Power propulsion, (b) ocean tugboats, (c) harbour tugboat, (d) coastal tugboat.

Correlation of length to power propulsion can be illustrated in equation (4) for the ocean tugboat type, equation (5) for the harbour tugboat type and equation (6) for coastal tugboat type. Where: $L_{OT}$: is length of ocean tugboat; $L_{HT}$: is length of harbour tugboat; $L_{CT}$: is length of coastal tugboat and $P$: is power of main engine [kW].

$$L_{OT} = 1{,}0675\ P^{\ 0{,}4514}\ \ [M] \tag{4}$$

$$L_{HT} = 2{,}624\ P^{\ 0{,}3187}\ \ [M] \tag{5}$$

$$L_{CT} = 2{,}7202\ P^{\ 0{,}3065}\ \ [M] \tag{6}$$

### *3.3.2. Breadth of Tugboats (B)*

Based on the results of the analysis carried out the ralations of breadth of tugboat (B) to power propulsion as illustrated in Figure 7, where increasing the power propulsion value of tugboats will increase the breadth of tugboats.

$$B_{OT} = 0{,}6248\ P^{\ 0{,}3694}\ \ [M] \tag{7}$$

$$B_{HT} = 1{,}0749\ P^{\ 0{,}2849}\ \ [M] \tag{8}$$

$$B_{CT} = 1{,}0095\ P^{\ 0{,}2898}\ \ [M] \tag{9}$$

Other than that the correlation of breadth (B) to power propulsion can be illustrated in equation (7) for the ocean tugboat type, equation (8) for the harbor tugboat type, and equation (9) for coastal tugboat type. Where: $B_{OT}$: is breadth of ocean tugboat; $B_{HT}$: is breadth of harbour tugboat; $B_{CT}$: is breadth of coastel tugboat and $P$: is power of main engine [kW].

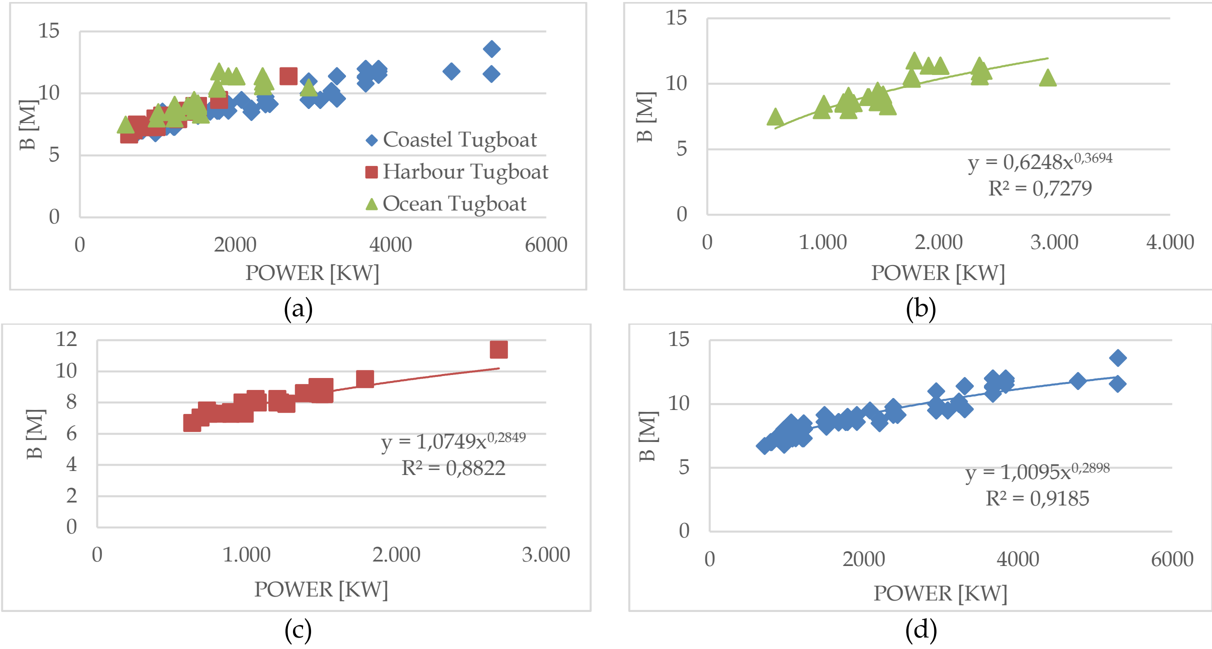



**Figure 7.** Correlation of breadth (B) to Power propulsion, (b) ocean tugboats, (c) harbour tugboat, (d) coastal tugboat.

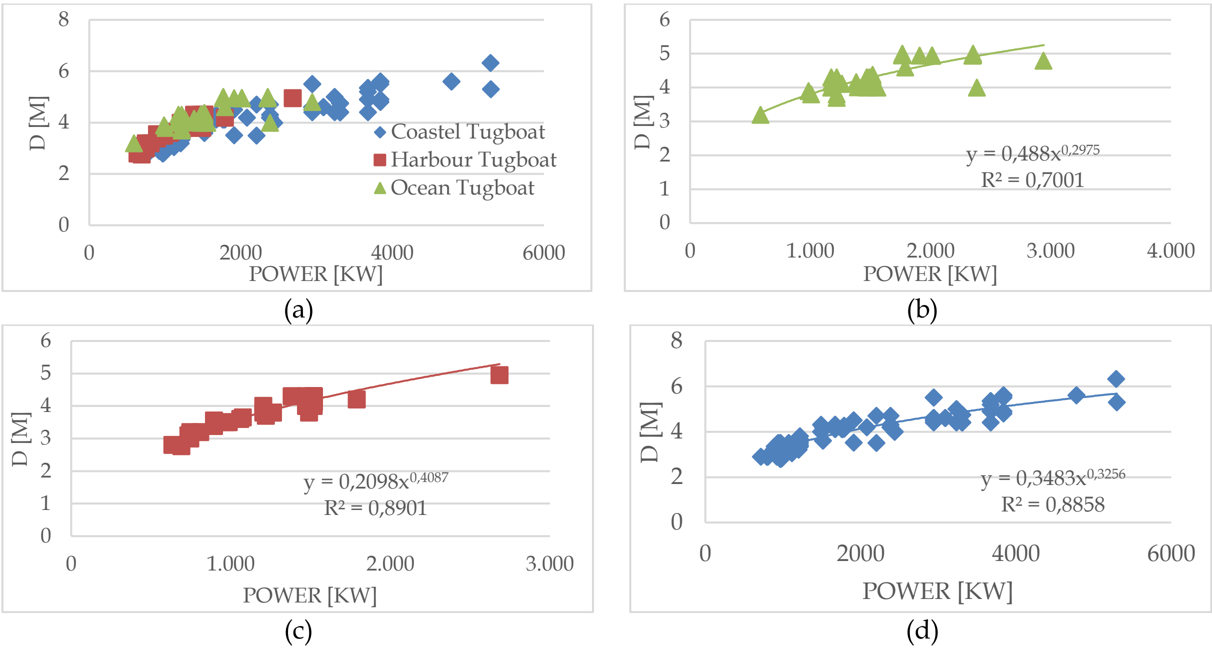



**Figure 8.** Correlation of height (D) to Power propulsion, (b) ocean tugboats, (c) harbour tugboat, (d) coastel tugboat.

### *3.3.3. Height of Tugboats (D)*

Correlation of height to power propulsion can be illustrated in equation (10) for the ocean tugboat type, equation (11) for the harbour tugboat type and equation (12) for coastal tugboat type. Where: $D_{OT}$: is height of ocean tugboat; $D_{HT}$: is height of harbour tugboat; $H_{CT}$: is height of coastal tugboat and $P$: is power of main engine [kW].

$$D_{OT} = 0{,}488\ P^{\ 0{,}2975}\quad [M] \tag{10}$$

$$D_{HT} = 0{,}2098\ P^{\ 0{,}4087}\quad [M] \tag{11}$$

$$D_{CT} = 0{,}3483\ P^{\ 0{,}3256}\quad [M] \tag{12}$$

Other than that the correlation of height to power propulsion can be illustrated in Figure 8, where increasing the power propulsion value of tugboats will increase the height of tugboats.

### 3.3.4. Summer Draught (T)

Based on the results of the analysis carried out the correlation of summer draught of tugboat (T) to power propulsion as illustrated in Figure 9, where increasing the power propulsion value of tugboats will increase the summer draught of tugboats (T). Other than that the correlation of summer draught (T) to power propulsion can be illustrated in equation (13) for the ocean tugboat type, equation (14) for the harbor tugboat type, and equation (15) for coastal tugboat type. Where: $T_{OT}$: is breadth of ocean tugboat; $T_{HT}$: is breadth of harbour tugboat; $T_{CT}$: is breadth of coastal tugboat and $P$: is power of main engine [kW].

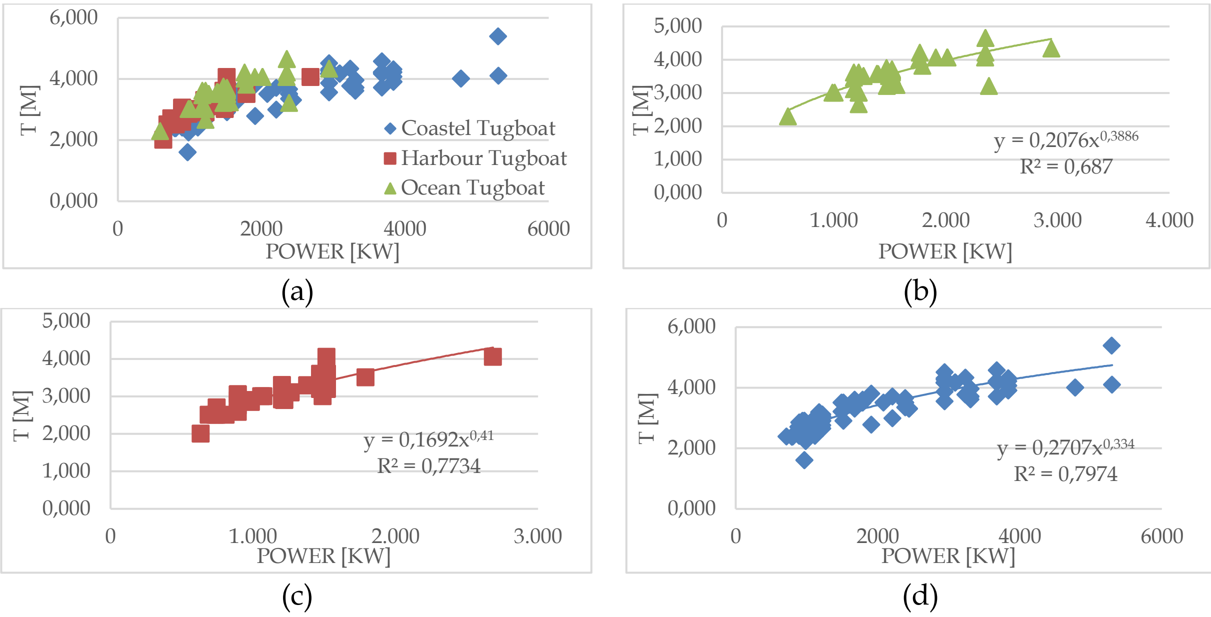



**Figure 9.** Correlation of height (D) to Power propulsion, (b) ocean tugboats, (c) harbour tugboat, (d) coastel tugboat.

$$T_{OT} = 0{,}2076\ P^{\ 0{,}3886}\quad [M] \tag{13}$$

$$T_{HT} = 0{,}1692\ P^{\ 0{,}41}\quad [M] \tag{14}$$

$$T_{CT} = 0{,}2707\ P^{\ 0{,}334}\quad [M] \tag{15}$$

## 3.4. Aplication and Validation

To validate the correlation model of the hull forms parametric to the power propulsion that can be used in the tugboat design on preliminary design stage, it is necessary to apply the existing reactions model in the design of the tugboat and validate the results of the model. For this reason, it is necessary to determine the main dimension of tugboat and compare it with comparison tugboat and empirical. The comparison tugboat is a tugboat that is registered and operates in the ocean, harbor and coastal which has two power propulsion. The comparison tugboat data as shown in Table 1.

**Tabel 1**. The Comparison Tugboat

| Tugboat | Type | L [M] | B [M] | D [M] | T [M) | Speed [Kn] | DWT [Tons] | P [kW] |
|---|---|---|---|---|---|---|---|---|
| TB-01 | Ocean Tug | 47,00 | 10,00 | 5,00 | 4,00 | 10,0 | 484 | 2386,25 |
| TB-02 | Ocean Tug | 31,00 | 99,00 | 4,00 | 3,20 | -- | -- | 1790,00 |
| TB-03 | Harbour Tug | 29,00 | 12,00 | 5,10 | 3,60 | 12,0 | -- | 2796,37 |
| TB-04 | Harbour Tug | 32,14 | 13,29 | 5,50 | 3,60 | 14,0 | -- | 4041,27 |
| TB-05 | Coastal Tug | 21,00 | 7,00 | 3,30 | 2,60 | 8,4 | -- | 808,00 |
| TB-06 | Coastal Tug | 29,50 | 9,00 | 4,25 | 3,25 | 12,5 | -- | 1640,00 |

Based on the comparison tugboat data, using the correlation of hull form parametric to poer propulsion model as in equation (4) to (15), the results of the determination using the model and validation model as shown in Table 2.

**Tabel 2**. Validation Model

| Main Dimension | Type | Data [M] | Model [M] | Difference [M} | $E\% = \frac{(D-M)}{D}$ |
|---|---|---|---|---|---|
| Length (L) | Ocean Tug | 47,00 | 45,72 | 1,28 | 2,40 |
| | Ocean Tug | 31,00 | 31,38 | -0,38 | -1,23 |
| | Harbour Tug | 29,00 | 32,38 | -3,38 | -11,66 |
| | Harbour Tug | 32,14 | 37,01 | -4,87 | -15,15 |
| | Coastal Tug | 21,00 | 21,17 | -0,17 | -0,81 |
| | Coastal Tug | 29,50 | 26,29 | 3,21 | 10,88 |
| Breadth (B) | Ocean Tug | 10,00 | 11,05 | -1,05 | -10,50 |
| | Ocean Tug | 9,00 | 9,93 | -0,93 | -10,33 |
| | Harbour Tug | 12,00 | 10,31 | 1,69 | 14,08 |
| | Harbour Tug | 13,29 | 11,45 | 1,84 | 13,84 |
| | Coastal Tug | 7,00 | 7,02 | -0,02 | -0,29 |
| | Coastal Tug | 9,00 | 8,62 | 0,38 | 4,22 |
| Height (D) | Ocean Tug | 5,00 | 4,53 | 0,47 | 9,40 |
| | Ocean Tug | 4,00 | 4,16 | -0,16 | -4,00 |
| | Harbour Tug | 5,10 | 5,37 | -0,27 | -5,29 |
| | Harbour Tug | 5,50 | 6,24 | -0,74 | -13,45 |
| | Coastal Tug | 3,30 | 3,08 | 0,22 | 6,67 |
| | Coastal Tug | 4,25 | 3,87 | 0,38 | 8,94 |
| Draught (T) | Ocean Tug | 4,00 | 4,26 | -0,26 | -6,60 |
| | Ocean Tug | 3,20 | 3,81 | -0,61 | -19,06 |
| | Harbour Tug | 3,60 | 4,38 | -0,78 | -21,67 |
| | Harbour Tug | 3,60 | 4,09 | -0,49 | -13,61 |
| | Coastal Tug | 2,60 | 2,53 | 0,07 | 2,69 |
| | Coastal Tug | 3,25 | 3,21 | 0,04 | 1,23 |

Based on the validation results from the model with existing comparison tugboat data as shown in Table 2, the correlation model obtained is that there are several models that have a slightly larger error percentage, especially the correlation model used to determine off the draught of tugboat on the ocean tugboat and harbor tugboat types. This error range is still acceptable as described by (Bekhit & Lungu, 2019). The Naval Architect will consider a value that fully covers the difference between the numerical and experiment estimate known as a sea margin of 15%. Overall the correlation model is applied to the tugboat design at the preliminary design stage.

## 4. CONCLUSION

Based on the results of the analysis carried out, power propulsion affects the hull forms parametric, where the increase in power propulsion will increase the value of the hull forms parametric in this case main dimension of the tugboat (L, B, D and T). The value of power propulsion to main dimension of tugboat has a different effect on each type of tugboat. The classification of the type off tugboat is based on the ship's operating area where each operating area has different characteristics that affect the characteristics of tugboat.

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