Jurnal
Teknologi

Full Paper

EHP VALUE OF MINI LNG SHIP WITH FORM FACTOR FROM PROHASKA AND IRLS METHOD USING SHIP RESISTANCE TESTING DATA

Article history
Received
26 November 2022
Received in revised form
29 March 2023
Accepted
9 April 2023
Published Online
25 June 2023

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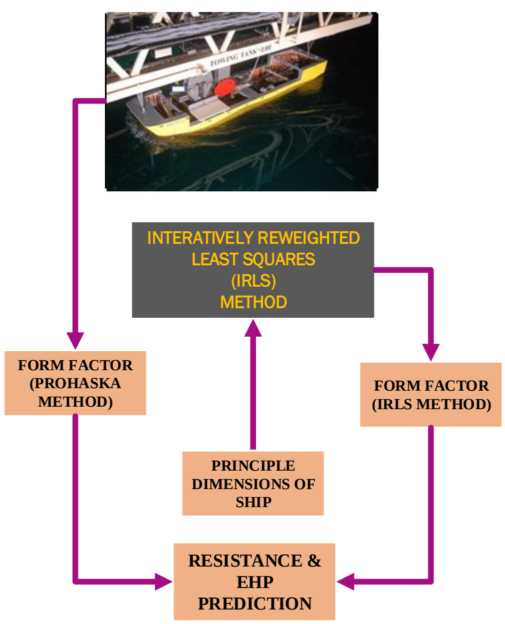
Graphical abstract



Abstract

The ship model test was believed to be one of the effective methods for figuring out the boundaries and reliability of the ship's horsepower. The ship's form factor determines a full-scale ship's effective horsepower. Determination of the form factor value can be done experimentally through the Prohaska method. The new method proposed in this study is employed the regression Iteratively Reweighted Least Squares (IRLS) method by utilizing the principle dimension of the ship, such as L_{WL}, B, C_B, C_P, C_M, W_{SA}, T, Δ. etc. The Indonesian Hydrodynamics Laboratory has a database of ships with various principle dimensions which have undergone the towing model test. Through the database, the form factor can be predicted with the IRLS method. The method is then verified and validated with the Prohaska method. The result shows a good agreement with the Prohaska method. The obtained results from the IRLS method also show that the EHP & Resistance calculations are identical with old fashion Prohaska methods. The residual bias factor established by the IRLS method was verified in comparison to the value of the form factor generated by the Prohaska method. Comparison between the two methods results in a small error.

Keywords: Effective Horse Power, experimental, form factor, linear regression method, Prohaska method

1.0 INTRODUCTION

The ability to scale the resistance of one vessel to another, or more broadly, to scale from the test model to full size, is critical. The magnitude of this resistance will be used in estimating the required thrust. Since the designer can concentrate on how each component of the drag affects the total drag, this concept of resistance decomposition helps in the hull design. The ship resistance can be separated into two components with different legal structures and extrapolated independently from the model to a full-scale ship size in the traditional treatment [1]. Since displacements and velocities are not desirable to modify, the pressure resistance component is very important in design and shape optimization [2]. Since full-scale ship drag cannot be tested directly, we relied on model testing to study ship drag [3]. The ship's powering test took place in the

Towing Tank (TT) basin, where testing was carried out using a scaled-down replica. The ship form factor is required in the extrapolation method to calculate the resistance of a full-scale ship using the model test results when determining the strength of a full-scale ship. [4, 5, 1]. The Prohaska method, using the exponent n = 4 and the correlation line at ITTC'57, can be used to calculate the form factor. Equation $K_S - K_M = 1.91. (\lambda -1). 10\text{-}3$ was calculated using the ITTC'57 correlation line. The effect of scale on the form factor can be estimated[6].

Towing tank tests and extrapolation procedures have been used for more than a century to predict vessel performance in deep, calm waters. In an effort to standardize and improve initial towing tank testing and extrapolation techniques, the International Towing Tank Committee (ITTC) was founded in 1933. It started with the relatively simple William Froude method and evolved over time through a number of revisions [7].

Hull waves are generated as the ship's speed increases, which changes the resistance of the shape. In other words, both the Reynolds number and the Froude number begin to have an impact on the form factor. But very serious fundamental studies have to be done to examine how hull waves affect shape resistance [8].

Garca-Gómez (2000) and Min and Kang (2010) investigated the form factor's Reynolds number dependence and proposed approaches for estimating the form factor at full scale from model experiment results [6, 8].

The form factor of a ship during model tests and the same value can be used when extrapolating the results to full scale. On the other hand, previous studies showed that the form factors vary with the Reynolds number and many attempts have been made to remedy the problem [9].

For example, Min and Kang (2010) used an experimental database to find that when the scale factor approaches unity, the vessel form factor exhibits two distinct characteristics. First of all, Min and Kang (2010) show that as the scale factor decreases, the number of ships increases in the form factor. They also put out the idea of a "final form factor" (1+k∞). They characterized it as a "form factor at design speed for a full-scale ship." According to their research, this milestone was actually reached around Re = 10^9 [8, 10].

Basically, the problem of predicting the resistance characteristics of a ship is always difficult. This is influenced by three factors: accuracy, time, and application cost. One of the most crucial steps in the ship design process is the prediction of the resistance and strength of the ship at a particular speed set by the owner's needs [11]. One of the two techniques for estimating wave resistance is the tensile test on the towing tank. This method, which employs a geometrically identical test model, is thought to be the most trustworthy for gathering precise ship resistance data. Testing will be used to determine how the ship model's Froude number, coefficient of residual resistance, and needed form factor relate to one another. The test is directly measured by the sum of the resistance at each speed.

The Froude number equivalence, which results in an essential Reynolds number (Re) inequality, is the cause of the hydrodynamic inequalities of flow around full-scale vessels and models. The model-size hull laminar boundary layer is made to resemble a fully turbulent boundary layer with the addition of artificial particles including sand grains, small pins, and trip wires. Due to the hydrodynamic instability caused by the turbulent stimulators, which harmonize their viscous friction with the full-scale vessel, the laminar boundary layer of the model-scale vessel becomes turbulent [12]

The role of turbulence stimulators has been fairly acknowledged due to the significant experience with their use that has been accumulated over a long period of time in the experimental measurements of ship resistance. Previously to the IMO regulations, these tests were carried out at low Fr to determine a hull form's form factor; however, the IMO requirements have mandated that these tests be performed at an unheard-of low Fr. The validity of the assumption that the flow zone in the front half of a model-scale ship is still fully turbulent, or the effectiveness of the turbulence stimulators at extremely low Fr, is a major concern when performing towing tank tests at very low Fr [13].

By bypassing potential modeling assumptions and simplifications such as omitting non-linear phenomena or condensed effects in calculations, these model-scale experiments seek to represent real-world prototypes. These models may have non-negligible deviations from full-scale prototypes. Three categories can be made from this difference [14], namely Types of model effects, Measurement effects, and Scale effects are caused by the difference between the forces acting on the full-scale structure and the model [15].

1.1 Form Factor

The ratio of flat plate resistance to viscous resistance, calculated by subtracting the total resistance from the wave resistance, is known as form factor (1+k) [16]. The Hughes approach, on which the Prohaska method is based, has a different definition of the form factor. By combining the frictional resistance in a two-dimensional flow and the viscous coefficient (C_V), this method defines the form factor in three dimensions.

In the Prohaska method the form factor can be determined through experimentation by drawing a test model in the range Fr < 0.2. At low speeds, the value of the C_W coefficient is close to zero.

$$(1 + k) = \frac{C_T}{C_F} \tag{1}$$

$$C_T = (1 + k)\, C_F + aF_r^n \tag{2}$$

In which at low speed, assumed

$$C_W = aF_r^n \tag{3}$$

The form factor is calculated via a C_T/C_F vs Fr^4/C_F straight line plot that intersects the ordinate (Fr = 0) at 1+k [17, 18]. This can be seen Figure 1.

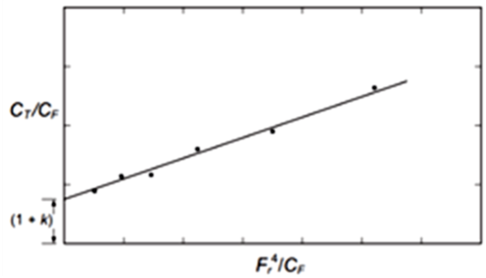


Figure 1 Graph - Prohaska Plot [19]

Form factors could be determined consistently according to the ITTC's 1978 standard. However, the Reynolds number range for these low-speed tests is nearly always far lower than 10^7, and the flow around the model ship is not at its most turbulent. Form factors in this range of Reynolds numbers are not constant but change over time. The ITTC's 1978 definition's two fundamental presumptions are therefore inconsistent with observed physical occurrences[8]. Instead of conducting a test, one can use statistical methods such as linear regression to find the form factor. Mennen and Holtrop also developed a statistical method to forecast total stomach resistance [20, 11].

This study uses the least squares multiple linear regression method to determine the Form Factor, which will be compared with the Prohaska method. The principle dimensions of ship displacement (L_{WL}, B, T, C_B, C_M, C_P, and W_{SA},) will be the predictor variables, where the previous research conducted by Widodo *et al.* (2022) found outlier data [21].

Acorcding to Grubbs' initial definition from 1969 [22], an outlier is one that appears to deviate significantly from other individuals in the sample in which it occurs. In addition, "observations (or subsets of observations) that appear to be inconsistent with other data sets" [23] and "data points that are significantly different from other data points, or do not conform to expected normal behavior, or conform to the behavior expected. normal" [24] is another precise definition. Outliers in the data, errors in experimental observations, and problems with data collection all impact the experimental design [25].

1.2 Iteratively Reweighted Least Squares (IRLS)

The Least Squares Method (MKT), which is frequently used to estimate the regression model's parameters, has a number of requirements, one of which is that the ε_i error be normal. When the data contains outliers, this method is vulnerable. Data that deviates from the majority of patterns and is located outside the data center are considered outliers. The error is no longer normally distributed or its variance is no longer homogeneous as a result of the outlier error [26]. When the data has significant outliers or abnormal random changes, a robust linear model is effective for filtering linear correlations by building a regression equation model that is robust or resistant to outliers [25]. M estimation is a popular regression technique. IRLS is a type of parameter estimator that uses this strategy. The most popular strong regression estimation approach is the M-estimate. This method is an extension of maximum likelihood estimation, which maximizes the probability function. $L(x_1, x_2, \dots, x_n; \theta)$. Where,

$$L(x_1, x_2, \dots, x_n; \theta) = \pi_{i=1}^{n} f(x_i; \theta) \tag{4}$$

The basis of the M-estimate is to obtain an estimator thet minimizes the weighting of the residual function $\rho(e_i)$: [27]

$$\min \rho(e_i) = \min \rho(y_i - \textstyle\sum_{i=1}^{n} x_{ij}\beta_j); \quad i = 1,2,\dots,n; k = 1,2,\dots,p \tag{5}$$

Residual standardization can be obtained by dividing the residue by the scale. The solution to Equation (2) is obtained by solving :

$$\min \sum_{i=1}^{n} \rho(u_i) = \min \sum_{i=1}^{n} \rho\left(\frac{e_i}{\sigma}\right) = \min \sum_{i=1}^{n} \rho\left(\frac{y_i - \sum_{i=1}^{n} x_{ij}\beta_j}{\sigma}\right) \tag{6}$$

For to get $\hat{\beta}_m$, the standard deviation of the residual must be estimated using the following strong estimate, [27]:

$$\hat{\sigma} = \frac{med|e_i - med(e_i)|}{0.6745} = \frac{MADE}{0.675} \tag{7}$$

There are two fundamental "operations" that occur when discussing a robust estimation of some quantity with a single unstructured sample (Tukey and Hampel, Prince- ton Robustness Seminar). A small amount of random "contamination" must be "thrown in," including "outliers," "gross errors," "bad values," and whatever else one chooses to call them. Everyone knows by now that the percentage of gross data errors typically ranges from 0.1% to 10% depending on the circumstance, with several percent being the rule rather than the exception [28].

The choice of method is IRLS, Given that the median is more resistant to outliers than the mean, the absolute deviation around the median was adopted in [Equation 7]. The value of the middle-ranked object is known as the median (or the average of the two central objects if the dataset is an even size) [29].

This paper discusses how to obtain ship form factor values using the IRLS method, which so far uses the Prohaska method through testing ship models at low speeds (Fr. 0.1 to 0.2), which sometimes produces negative residual coefficients, which affect the residual resistance. empirically it can be shown by the equation [30]:

$$C_T = \frac{R_T}{\frac{1}{2}\rho\, v^2 (S_m - S_S)} \tag{8}$$

$$C_R = \frac{R_T - R_R}{\frac{1}{2}\rho\, v^2 (S_m - S_S)} \qquad (9)$$

From the above equation the probability is, With a negative residual coefficient, it is likely that the residual resistance will be greater than the total resistance.

The form factor results through the IRLS and Prohaska methods will be compared. In order to see the percentage deviation of the form factor value obtained through IRLS method, the resistance and EHP of the Full-Scale Mini LNG vessel will be calculated by extrapolation using the form factor values of the two methods. The IRLS method has a conceptual basis that is simpler and easier to apply, where the approach is through the principle dimensions of the displacement vessel, namely: L_{WL}, B, T, C_B, C_M, C_P, W_{SA} & Δ. which in turn will shorten the testing time of the model resulting in a reduction in testing costs.

2.0 METHODOLOGY

The study uses two methods, testing with the Mini LNG ship model and the IRLS method using a database of displacement ship model resistance test results that have been carried out in the Indonesian Hydrodynamics Laboratory.

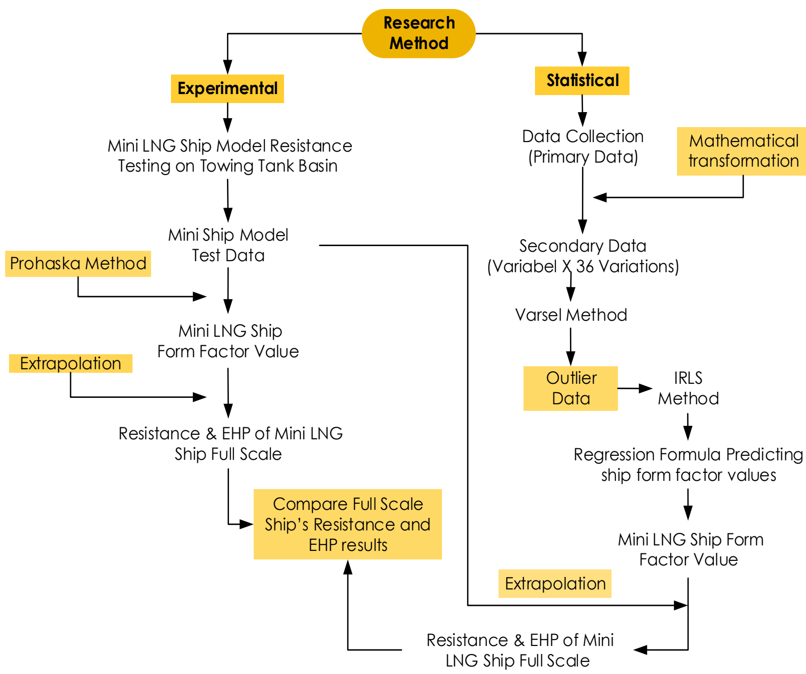


Figure 2 Research Method

2.1 Experimental

The method used in the towing tank test is based on the idea that the wave generation force can be increased directly from the model to the ship if the Froude number, geometric similarity, kinematic similarity, and dynamic similarity are maintained. The recent addition of the form factor has changed Froude's approach. With the newer approach, the entire model's resistance is divided into wave resistance and viscous resistance [31].

The International Towing Tank Conference (ITTC) introduced the model-ship correlation coefficient into approaches like ITTC-57 and ITTC-78 to account for the increase in the surface roughness of ships. These two techniques fix the discrepancy between the resistance of a model and a full-scale ship, but they are insufficient for determining the impact only brought on by surface roughness. Townsin (1985) made an effort to address this issue by enhancing ITTC-78 and putting forward a strategy for taking the Reynolds number into account. [32]. Using the ITTC approach, a ship's total resistance coefficient is specified as follows:

$$C_{TS} = (1 + k)\, C_{FS} + \Delta C_F + C_A + C_W + C_{AA} \qquad (10)$$

Based on these developments, it is necessary to conduct research on the prediction of ship resistance and EHP based on model scale testing. In ship model studies, side wall effects are typically disregarded because they are not readily apparent in calm water [33]. Testing through the towing tank basin to determine the overall resistance of the ship model, where the form factor value is required in estimating the amount of resistance and effective horsepower of a full-scale ship, is known as the extrapolation process.

The research methodology is illustration in Figure 2, where form factor values are obtained under two conditions: experimentally using the Prohaska method and statistically using IRLS. The experimental methodology in this study employs a Mini LNG ship model test to a scale of 11.428 at the Indonesian Hydrodynamics Laboratory's Towing Tank (TT) basin. A variety of speeds were used to test this model, with the low speed test at Fr 0.1 to 0.2 being used to get the form factor value that would be used in the extrapolation process to get the resistance and EHP of a full-scale ship. The results of the full-scale ship resistance and EHP measurements from the two method then be compared.

The Figure 3 below is an example of a visualization of the Mini LNG ship model testing at different speeds, which was carried out in the Towing Tank basin.

(a). Vm = 0.918 m/s (b). Vm = 1.367 m/s

Figure 3 Resistance Test of Mini LNG Ship Mode

2.2 Statistical Method

- Data collection is obtained from the results of tests that have been carried out at IHL. From the data collection, forty-six data were obtained from the results of the displacement ship model resistance test. The data consists of ship model resistance testing data and principal dimensions (this data will be used to obtain the form factor or variable Y and variable X data).
- Primary data (principal dimensions), through mathematical transformation into secondary data (Variable X) 36 variations.
- The best choice for variable X is chosen using the VARSEL (Variable Selection & Least Squares) method.
- The outlier data test using the Grubbs method is the residual assumption test on the chosen variables.
- Processing of selected variable data with IRLS method
- The Formula regression equation obtained to predict the value of the form factor for mini LNG ships
- Form factor to extrapolate the resistance test results of the Mini LNG ship model to obtain the resistance and EHP of the Mini LNG full-scale ship.

The mathematical conversion of primary data (the ship's main data) into secondary data is shown below.

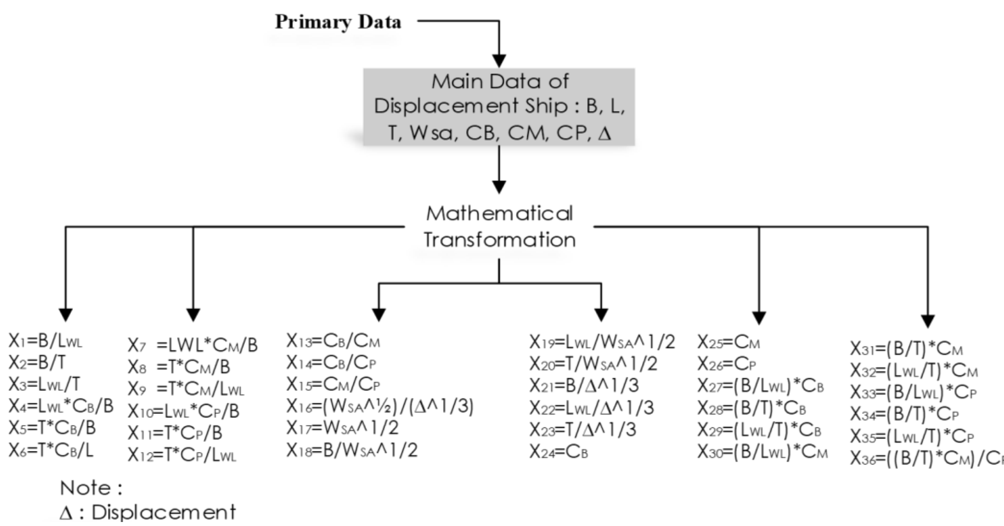


Figure 4 Primary Data Mathematical Transformation

This study utilizes a displacement ship model resistance test database that has been conducted at IHL. The principal dimensions for ships L_{WL}, B, T, C_B, C_M, C_P, W_{SA}, Δ, are called primary data and mathematically become 36 variations of secondary data as predictor variables (X) which are illustrated in Figure 4. and Variable Y (form factor values) obtained by the Prohaska method by utilizing the data from displacement ship resistance testing results.

Therefore, it is crucial to develop scalable outlier detection techniques to handle large datasets when there is a lot of data (Volume). The cost of computation increases proportionally with data size, making the process expensive and slow. It is crucial that these outliers are found quickly in order to reduce contaminated data, prevent data contamination, and ensure that the data provides a timely value (Velocity and Value)[34], for outlier-detected data, the IRLS method is used to obtain the regression equation.

3.0 RESULTS AND DISCUSSION

3.1 Test Resistance of the Mini LNG Ship Model

The following is a list of the data needed to test the Mini LNG ship model in the IHL Towing Tank basin.

Table 1 The principle dimension of Mini LNG Ship

Parameter	Symbol	Full Scale	Model Scale	unit
Length on waterline	L_{WL}	46.44	4.064	m
Breadth moulded on WL	B	11.4	0.997	m
Depth moulded	H	3.5	0.306	m
Draught moulded on FP	T	2.5	0.218	m
Displacement	Δ	1054.7	0.706	m^3
Wetted Surface Area	W_{SA}	673	5.153	m^2
Block Coefficient	C_B	0.794	0.374	-
Midship Section Coefficient	C_M	0.987	0.503	-
Prismatic Coefficient	C_P	0.804	0.747	-

Table 2. Data of the Mini LNG ship model's resistance testing

V_M (m/s)	R_M (N)	Fr	$(R_e)_M$	C_{TM}	C_{FM}
0.761	6.72	0.122	3.48E+06	0.005	0.00364
0.913	9.16	0.147	4.20E+06	0.00469	0.00351
1.066	12.9	0.171	4.87E+06	0.0049	0.00341
1.217	17.52	0.195	5.57E+06	0.0051	0.00333
1.370	23.42	0.219	6.25E+06	0.00541	0.00326
1.522	33.47	0.245	6.98E+06	0.0062	0.0032
1.674	43.66	0.269	7.67E+06	0.0067	0.00314
1.826	62.64	0.293	8.35E+06	0.0081	0.0031

The Figure 5 below displays the Mini LNG ship model's test results.

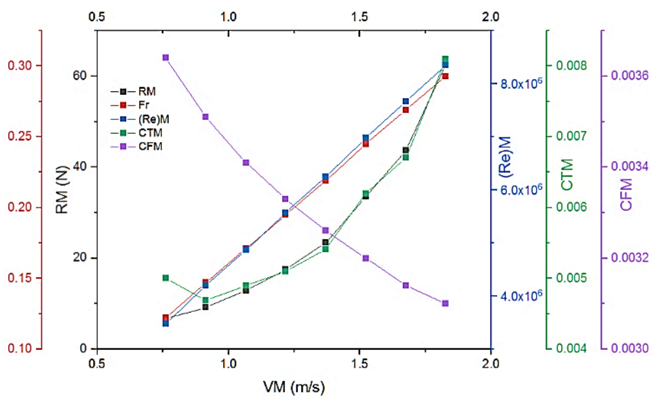


Figure 5 Graph of the results of the Mini LNG model resistance test

Scale effects are applied to experimentally acquired results since it is impossible to establish total hydrodynamic equivalence between the model and a full-scale ship[35]

Total vessel resistance coefficient (C_T) and correlation allowance (C_A), which is the coefficient of addition to the correlation resistance of the ship model, the formula for the coefficient of frictional resistance by ITTC -1957, must be coupled between model - ship with Form Factor (1+k), thus[16, 36].

$$C_T = C_{Tm} - (1 + k)\,(C_{Fs} - C_{Fm})\,C_A \qquad (11)$$

In which,

$$C_{FS} = \frac{0.075}{(Log\ 10R_n - 2)^2} \qquad (12)$$

$$C_A = 0.006\,(L_{WL} + 100)^{-0.16} - 0.00205 \qquad (13)$$

$$C_{Tm} = \frac{R_{Tm}.9.81}{0.5\,\rho S V^2} \qquad (14)$$

$$F_r = \frac{V}{\sqrt{L_{Wl}.g}} \qquad (15)$$

A form factor of 1.2972 is calculated using data from the ship model resistance test (Table 2) and the Prohaska plotting graph (Figure 1).
Extrapolation using form factor values, Table 1, Table 2, and [Equations 11, 12, and 13] produced the Table 3 below.

Table 3 C_{TS}, R_{TS}, and EHP of a Mini LNG full-scale ship with a form factor of 1.2972

VS (m/s)	$(Re)_S$	C_{FS}	C_{TS}	R_{TS} (kN)	EHP (kW)
2.572	1.39E+08	0.00199	0.00355	8.09	20.81
3.087	1.67E+08	0.00194	0.00333	10.94	33.76
3.601	1.95E+08	0.00190	0.00361	16.16	58.21
4.116	2.22E+08	0.00186	0.00387	22.64	93.16
4.630	2.5E+08	0.00183	0.00424	31.33	145.06
5.144	2.78E+08	0.00181	0.00507	46.30	238.19
5.659	3.06E+08	0.00178	0.00561	61.98	350.75
6.173	3.34E+08	0.00176	0.00705	92.63	571.81

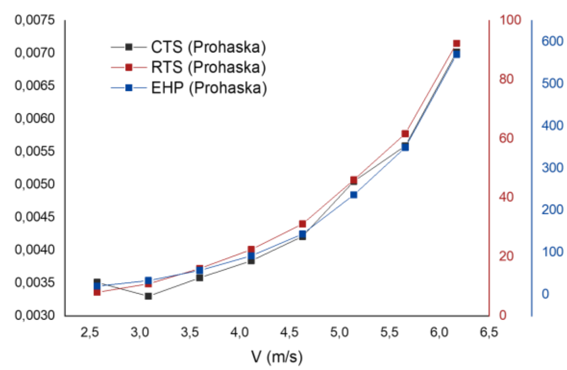


Figure 6 The value of CTS, RTS, and EHP of mini LNG vessels with Prohaska method

Figure 6 shows the total coefficient (CTS), resistance (RTS), and energy consumption (EHP) of Mini LNG vessel in graph form with 1+k using the Prohaska method

3.2 Results of processing displacement ship data

Of the thirty-six variations of the X variable processed through the VARSEL method, six of variables X were obtained, namely: X_{19}; X_{26}; X_{17}; X_1; X_{23}; X_{27}. Below are the results of the VARSEL method.

Table 4 Variables selected with the VARSEL method

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	0.075478	0.063993	1.179466	0.2466
X_{19}	-0.004570	0.017582	-0.259954	0.7965
X_{26}	-0.122822	0.036277	-3.385646	0.0018
X_{17}	0.001128	0.000234	4.825033	0.0000
X_1	0.230028	0.102990	2.233500	0.0324
X_{23}	0.053417	0.028004	1.907479	0.0652
X_{27}	0.200274	0.144075	1.390063	0.1738

3.2.1 Outlier Data Test

the outlier test is carried out using the Grubbs method, which compares the standard deviation of the sample with the difference between the suspected results and the overall average of the data [37], Grubbs formula and the outlier data is shown in the Table 5 below.

$$G = \frac{|suspect\ value - \bar{x}\ |}{s} \quad (16)$$

Table 5 Outlier Data

Variable	Y	X_{19}	X_{17}	X_1	X_{23}
Row	33	37	8	33	2
Outlier	0.1847	2.7692	93.6002	0.4013	0.6763

There are outlier data, so the IRLS method is needed to obtain the regression equation formula. Using the IRLS technique, the results of the data analysis were obtained as the coefficient variable X.

Table 6 IRLS Method M Estimation Huber Type I Standard Errors & Covarian

Variable	Coefficient	Std. Error	z-Statistic	Prob.
C	0.068863	0.06965	0.988697	0.3228
X_{19}	-0.00314	0.019136	-0.16424	0.8695
X_{26}	-0.12094	0.039484	-3.06304	0.0022
X_{17}	0.001159	0.000254	4.556773	0
X_1	0.250616	0.112094	2.235764	0.0254
X_{23}	0.052176	0.030479	1.711825	0.0869
X_{27}	0.181971	0.156811	1.160442	0.2459

The z-statistic test was conducted to determine the level of correlation between the z-statistic value and the α value. Test z-statistic values are shown figure below.

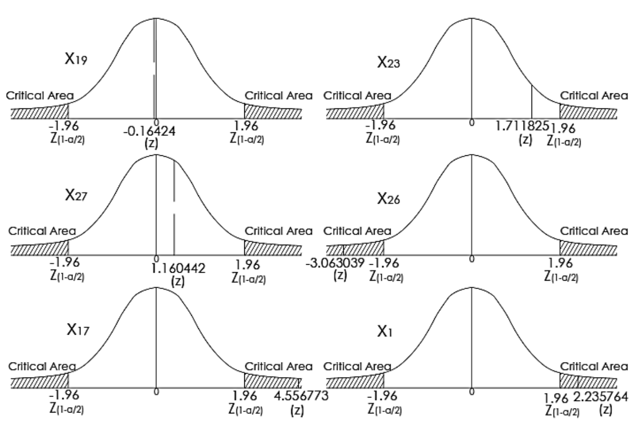


Figure 7 The two-tailed z-statistical test on α values

Table 6 shows, the probability of each variable X is:

- X_{19}; X_{23} and X_{27} are above the value of α (α = 0.05),
- X_{26}; X_{17}; and X_1 is below the value of α (α = 0.05),

Below is a model of the form factor prediction formula, which is based on Table 7,

log Y = 0.068863 – 0.00314*X_{19} – 0.12094*X_{26} + 0.001159* X_{17} + 0.250616*X_1 + 0.052176*X_{23} + 0.181971*X_{27}

Based on Figure 4, variable X is:

$X_{19} = \frac{L_{WL}}{\sqrt{W_{SA}}}$; $X_{26} = C_P$; $X_{17} = \sqrt{W_{SA}}$

$X_1 = \frac{B}{L_{WL}}$; $X_{23} = \frac{T}{\sqrt[3]{\Delta}}$; $X_{27} = \frac{B}{L_{WL}}\ C_B$

The formula of the regression equation predicts the value of the form factor:

$$Log\ Y = 0.068863 - 0.00314.\left(\frac{L_{WL}}{\sqrt{W_{SA}}}\right) - 0.12094.(C_P) + 0.001159.\ \left(\sqrt{W_{SA}}\right) + 0.250616.\left(\frac{B}{L_{WL}}\right) + 0.052176.\left(\frac{T}{\sqrt[3]{\Delta}}\right) + 0.181971.\left(\frac{B}{L_{WL}}\ .C_B\right)$$

log Y = Y'

(1+k) = $10^{Y'}$

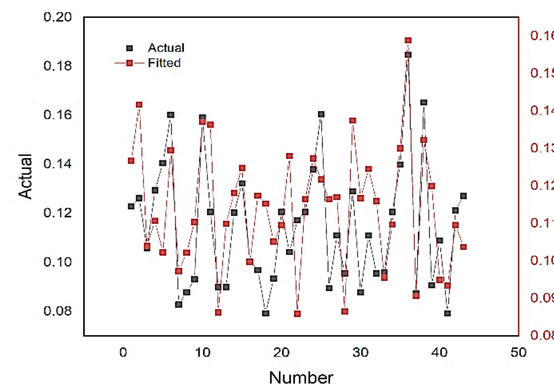


Figure 8 Variable Y's actual and fitted values

The difference between the real and fitted values is shown in Figure 8; using IRLS, an error of 0.1 to 3 percent is obtained.

The form factor of the Mini LNG ship is 1.276057405 based on the regression equation formula, the principle dimensions of Mini LNG vessels (L_{WL}, B, C_B, C_P, C_M, W_{SA}, T, Δ), and through extrapolation using form factor, Table 2, and [Equations 11, 12, and 13], we get the C_{TS}, R_{TS}, and EHP Mini LNG ships shown in Table 7 and Figure 9 below.

Table 7 C_{TS}, R_{TS}, and EHP of a Mini LNG full-scale ship with a form factor of 1.276057405

V (m/s)	CTs	RTs (kN)	EHP (kW)
2.572	0.00358	8.17	21.01
3.087	0.00336	11.05	34.09
3.601	0.00365	16.31	58.72
4.116	0.00391	22.81	93.89
4.63	0.00427	31.55	146.08
5.144	0.00510	46.57	239.55
5.659	0.00564	62.30	352.52
6.173	0.00707	92.99	574.06

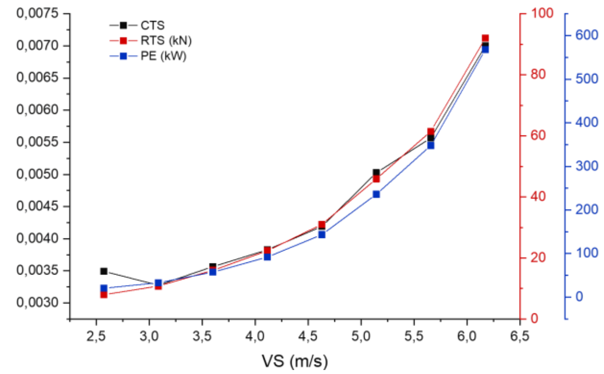


Figure 9 The value of CTS, RTS, and EHP of mini LNG vessel with IRLS method

Figure 9 shows the total coefficient (CTS), resistance (RTS), and energy consumption (EHP) of Mini LNG vessel in graph form with 1+k using the IRLS method

3.3 Discussion

Table 6 and Figure 7 show the z-statistic values, probability value and z-statistic test, where variable X_{19}; X_{23}; and X_{27} have a probability value above α (α = 0.05) and the results of the z-statistic test are outside the shaded area (critical area) so that it can be stated that this variable has a less significant effect on variable Y. This is the opposite for variable X_{26}; X_1; and X_{17}.

The amounts of the C_{TS}, R_{TS}, and EHP that differ between Prohaska and IRLS are listed in the Table 8 below.

Table 8 The difference between the results Prohaska and the IRLS method

	Metode Prohaska			Metode IRLS			The difference between the results Prohaska and IRLS method		
V (m/s)	C_{Ts}	R_{Ts} (kN)	EHP (kW)	C_{Ts}	R_{Ts} (kN)	EHP (kW)	(A)-(A_1)	(B)-(B_1)	(C)-(C_1)
	(A)	(B)	(C)	(A_1)	(B_1)	(C_1)	%	%	%
2.572	0.00355	8.09	20.81	0.00358	8.17	21.01	0.8	1.0	1.0
3.087	0.00333	10.94	33.76	0.00336	11.05	34.09	0.9	1.0	1.0
3.601	0.00361	16.16	58.21	0.00365	16.31	58.72	1.1	0.9	0.9
4.116	0.00387	22.64	93.16	0.00391	22.81	93.89	1.0	0.8	0.8
4.63	0.00424	31.33	145.06	0.00427	31.55	146.08	0.7	0.7	0.7
5.144	0.00507	46.3	238.19	0.0051	46.57	239.55	0.6	0.6	0.6
5.659	0.00561	61.98	350.75	0.00564	62.3	352.52	0.5	0.5	0.5
6.173	0.00705	92.63	571.81	0.00707	92.99	574.06	0.3	0.4	0.4

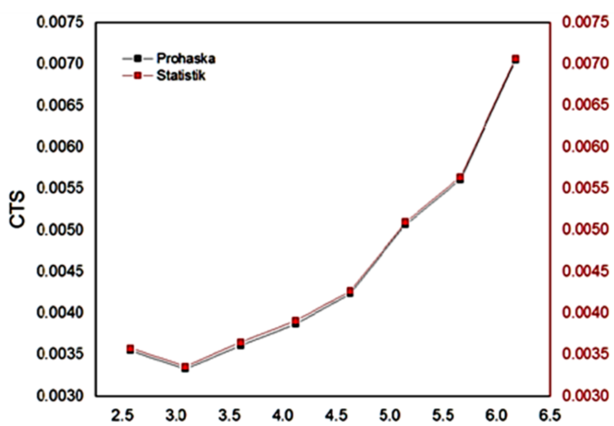


Figure 10 V vs CTS, Mini LNG Vessel with (1+k) from IRLS and Prohaska Method

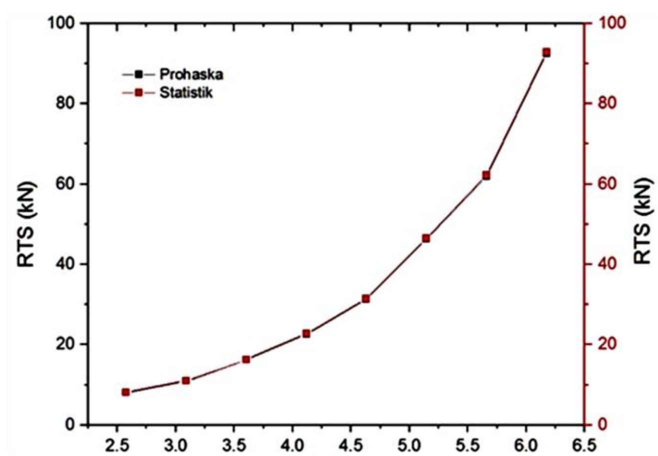


Figure 11 V and RTS, Mini LNG Vessel with (1+k) from IRLS and Prohaska Method

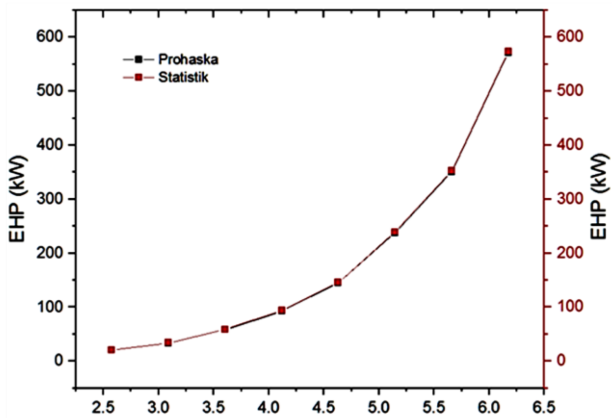


Figure 12 V vs EHP, Mini LNG Vessel with (1+k) from Regression Equation and Prohaska Method

The IRLS method can be used as an alternative to obtaining (1+k). The results obtained from the two methods, namely the Prohaska method and IRLS provide a good agreement, in contrast to the Prohaska approach which requires an experimental stage to get (1+k)

As can be observed in Figure 10, Figure 11, and Figure 12, when the C_{TS}, R_{TS}, and EHP lines overlap, the C_{TS}, R_{TS}, and EHP values are generated using the Prohaska technique form and the IRLS statistical method are incredibly similar. In Figure 10, the divergence between the statistical approach and the C_{TS} line of the Prohaska methodology decreases as the speed rises to 5.5 m/s. The two lines intersect when the speed is greater than 5.5 m/s. Figure 11 and Figure 12, the R_{TS} and EHP lines are parallel to one another.

The phenomenon shown in Figure 10 and Table 8 can be explained [see Equation 12], where the difference in form factor between the Prohaska and IRLS approaches decreases with increasing speed due to a decrease in the fluid coefficient (C_F), which is shown in Figure 5, this occurs as a result of an increasing Re value.

4.0 CONCLUSION

The issue of ship resistance is one that is continually being explored because of the dynamic environment of ship navigation, the need to enhance ship performance, and the need to create more precise methods for estimating resistance. Test the ship by pulling it through the towing tank basin is the most accurate way to anticipate resistance, but it is costly and time-consuming [38]. In order to save time and money while testing low-speed ship models, it is highly advantageous to use the IRLS approach to establish the form factor.

Conclusions and recommendations can be drawn from the calculation of the full-scale Mini LNG ship resistance and the amount of EHP using the Prohaska and IRLS methods, where the difference in the results of the two methods is shown in Figures 10, 11, and 12. These figures demonstrate that the Prohaska and IRLS methods have CTS, RTS, and The EHP is almost the same with the difference between the two methods being 0.1% to 1.1%.

It is simple to calculate form factor values statistically using linear regression equations, and this method uses main ship data that is already known, such as LWL, B, T, CB, CP, CM, and WSA. This is in contrast to the Prohaska method, which calls for testing a ship model in a towing tank basin with Fr 0.1–0.2.

This research will serve as the basis for additional research by developing a method to discover a regression formula that can be used globally, not only for ship displacement but also for fast ships. It is necessary to develop the iteration and transformation system for variable X, which of course necessitates extensive research and is frequently more difficult.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper.

Acknowledgements

This research was supported by the Hydrodynamics Technology Laboratory-BRIN in data collection and testing of the Mini LNG ship model, and the Sepuluh Nopember Institute of Technology Surabaya in deepening theory on shipping and statistics.

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