International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 889-895 www.ijaem.net ISSN: 2395-5252

Application of Cubic Method to Gas Carrier Ships Prelimanary Design

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Submitted: 10-05-2022 Revised: 15-05-2022 Accepted: 18-05-2022

ABSTRACT: This work present thirteen new empirical formulas derived from Microsoft statistical Analysis add-in in EXCEL for Windows regression analysis of existing 207 gas carrier ships. These formulas and the presented new method show how to apply the well-known cubic method in ship design to the preliminary design of gas carrier ships in particular. The input variables to this method are the ship owners' requirements comprising of total gas tank capacity or deadweight and ships speed. The exemplified result obtained is impressive and compare very well with the particulars of existing gas carrier ships.

KEYWORDS Gas, Carriers, ship, Design, cubic method.

I INTRODUCTION

Gas carrier ships description are well presented in literature [1], [2], [3], [4], [5] and other references. Design formulas and method for these type of vessels can found in [6], and [7] references. The cubic method in ship design is simple and well known in literature [8], [9] and others. It is based on few factors which includes:

K_D known as Deadweight Coefficient

$K_D = DWT/\Delta$; CB = ∇/LBT and $\Delta=\nabla.\rho$ (t),

Where, DWT is deadweight of the ship (t),

Δ = displacement in tonnes of the ship,

L, B, T are respectively length between perpendiculars, Breadth and draft of the ship, and ∇ is the displacement in cubic meter. Based on the C_B equation it was derived that

$$L=\left[\frac{\text{Dwt x }(L/B)^2\text{ x }B/T}{\rho\text{ x }C_B\text{ x }K_D}\right]^{1/3} \quad \text{----(1)}$$

or simply,

$$L=\left[\frac{\nabla\text{ x }(L/B)^2\text{ x }B/T}{C_B}\right]^{1/3} \quad \text{-------(2)}$$

Therefore, B = L/(L/B) and T = B/(B/T)

Where: L = LBP = Length between perpendiculars (m).

B = moulded ship breadth (m).

T = design draught (m).

ρ = density of sea water =1.025t/m3

In Watson's textbook [9] he gave the values of K_D for different types of ships but not specifically for gas carrier ships. This work investigate on K_D values for gas carrier ships and presents a new method for calculation the main dimensions of gas carrier ships based on this cubic method. The dimensions of the projected ship is obtained by determining the values of the form factors L/B, B/T, C_B and ∇ for a ship with a deadweight DWT or cubic meters volume of gas tanks the ship is to transport as demanded by the ship owner and substituting them in the above stated equations.

II METHOD

The method to determine the actual variables in the equation (2) or (3) accurately for gas carrier ships as related to ship owner's requirements is the main challenge in this case. The most important ship owner requirements are the volume of tank T_C of liquefied or pressurized gas, or the deadweight and the speed of ship v. Regression analysis of data from existing ships gives empirical formulas relating to the T_C and v and other variables which can be used to design similar ships. Based on the data collected and analyzed on gas carrier ships, as described in previous publication [10], [11], [12] more 13 empirical formulas are derived by regression analysis and presented in this paper. These formulas relate to the owners variables for a reasonable estimation of following design variables:

- The displacement -∇, or K_D – Deadweight Coefficient and Dwt – deadweight.
- The Block coefficient- C_B
- The value of L/B and B/T ratios for gas carrier ships.

III MODELING AND ANALYSIS

The design variables listed above are obtained as function to Tc, v and D_{WT} from the existing gas carrier ships.

Fig 1 to 13 below show regression analysis scatter diagrams, the regression analysis equations with their R^2 correlation coefficients derived from the data collected from 207 ships. Table 1 summarize the formulas shown in the figures. The Y dependent variables, and the X independent variables of the formulas in first column are shown in the second and third columns for each respective row in this table

Table 2 show the method of computation of the variable using the Y values computed from the formulas in table 1.

In Table 2 for instance the ratio B/T is computed as: {LB(**1**)}/{LT(**7**)}in column 1.

This mean that the values of LB and LT are calculated as Y dependent variables from Table 1 on the row 1 and 7 respectively as quotient to result in the value of B/T desired. The X independent variable for row 1 is Tc while that of row 7 is v which are taken from the owner's requirements. In the above similar order the other values of B/T in column 2, 3, and 4 are calculated and the mean of the four value of B/T are computed **Mean(1,2,3,4,)** as the predicted **B/T** value required. Similarly the other variables of □ □ □and $\mathbf{C_B}$ are calculated.

The value of **L/B** presented in the author previous work [12] is constant value of **L/B =6.17**.

Where **L = $\mathbf{L_{OA}}$, (**same for the formulas in Table 1) which means L_{OA}/B instead of L_{BP}/B hence a correction factor is needed and derived from the similar ship data as shown in Fig 15 and stated in formula 13 in Table 1.

That is:

$$L_{BP}/B = L_{AO}/B - 0.8909(L_{OA}/B) - 1.3 \text{---------}(3)$$

There was no formula for K_D as its value did not show good correlation with other ship parameters. Fig 14 show the scatter diagram with respect to L/B and B/T. The data collected show a mean value of K_D = 0.6333 which can be used for gas carrier ships.In the computation we can use this value as one alternative for calculation of displacement as can be observed in Table 2 (last row of column 4).

The regression analysis used here is the Microsoft EXCELL ad-in program, and the collected data covered the ranges of dimensions:

L = 63m to 333m, B = 11m to 55m, D = 4.5m to 32.3m, T = 4.2m to 13.1m.

IV RESULTS AND DISCUSSION

The resulting formulas in Table 1 and the methodology presented in Table 2 are validated by an example using an owner's requirement of: **Tc = 3500m^2** and **v = 14kts.** The value of Dwt is calculated as a value of two equations namely:

$\ln(D_{WT}) = 0.872\ln(Tc) + 0.864$ derived equation 2 in Table 1

$D_{WT} = 0.4873Tc + 2652.3$ [ ] published equation 13 in Table 3 The mean of these two equations yielded $\mathbf{D_{WT} = 3639.849t.}$

These input values are labled X1 in Table 1 columns while Y1 is the calculated values for X1 value in the various formulas in row 1 to 12.

The values of Y1 is substituted into the methods in Table 2 and the results are shown in Table 3. The final result from Table 3 are:

B/T = 2.7635, ∇ = 6336.839m^3, and $\mathbf{C_B}$ = 0.7596. Substituting these values in the cubic method equation (2) introduced above yields the desired values of $\mathbf{L_{BP}}$**, B, and T,** of the gas carrier ship to carry 3500m^2 of gas cargo at **14**kts requested by the ship owner.

Other preliminary parameters can be calculated based on the equations from my previous works shown in Table 4[10], [11] using the above results of Tc, v, L, B, T as input. This substitution shown in Table 5 yielded additional parameters for the vessels being designed as:

L_{OA} = 98.04m,L_{BP} = 92.40m, B = 15.80m, D = 9.10, T = 5.72m, T_{MAX}= 6.20m, D_{WT}= 3639.85t

= 6336.84m^3, Tc = 3500m^3, v = 14kts and P = 3675.15Kw. Where,

P = main ship propulsive power, T_{max} = maximum draught of the vessel D = depth of the ship.

Note that the predicted **dimensional**

$\mathbf{C_B = 6336.84/(92.391*15.797*5.716) = 0.7595}$

is the same as the predicted **formula $\mathbf{C_B}$ =0.7595.** This is excellently acceptable consistency.

The existing LPG ship particulars for these three ships namely: Orchid Coral IMO 9526980, Jasmine coral IMO 9691319 and Senna 2 IMO 9005182 are compared with particulars of the above projected design ship in Table 5. It show that the average percentage deviation for the three existing ships to the design ship dimensions predicted is less than 9% for the respective dimensions except in the dimension of D – depth 14.8% less and P – power 11.05% less. However, the increased power of 11.05 % predicted an increase in speed of 6.25% in the predicted projected design ship. These differences are negligible and can be easily optimized in the later more rigorous later stages of the ship design.

V CONCLUSION

The generally known cubic method formula for ship design is explained and the variables in it identified. The formulas necessary to utilize this method in the design of gas carrier ships hitherto has not been known due to the fact that this type of vessels are relatively new in service. In the presented paper empirical formulas are derived from existing gas carrier ships data by regression analysis using Microsoft EXCELL AD-IN software. The data from existing vessels are collected from the internet. The formulas correlate the ship parameters with the ship owner's requirements factors of gas tank capacity, deadweight and ship speed. The formulas derived are factors in the computation of the cubic method variables which lead to the calculation of the main dimension of the projected new vessel satisfying the need of the owner's requirements. Thirteen of these formulas and two constants are derived and shown as well as used in demonstration of the method by an example. In the example the owner's requirement is 3500m2 gas tank volume, and 14kt speed of ship. The result is compared to the particulars of three similar existing gas carrier ships. The mean percentage deviation of the particulars of the similar existing vessel was less than 9% for the dimensions predicted in all the dimensions except depth which was 14.8% and the main engine power of 11.05%deviation. The depth and main power could be optimized in more advanced stages of ship design. The formulas, constants and method shown here can be used in the preliminary design of gas carrier ships of different types.

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International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 889-895 www.ijaem.net ISSN: 2395-5252

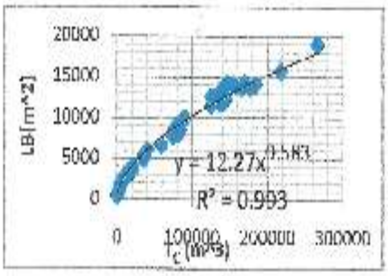

FIG. 1. REGRESSION ANALYSIS OF L.B AGAINST Tc

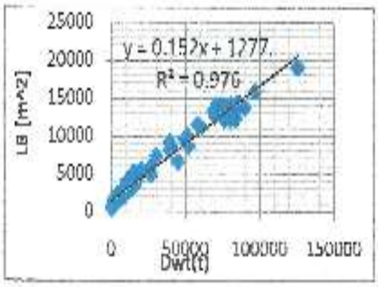

FIG. 2. REGRESION ANALYSIS OF L.B AGAINST Dwt

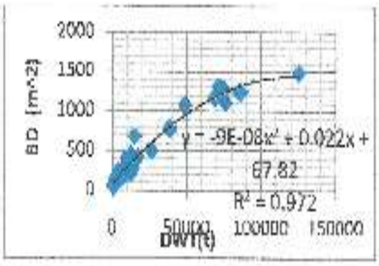

FIG. 3. REGRESSION ANALYSIS OF B.D AGAINST Dwt

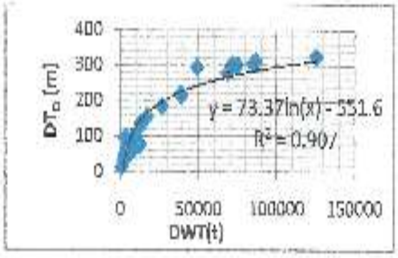

FIG. 4. REGRESION ANALYSIS OF DT AGAINST Dwt

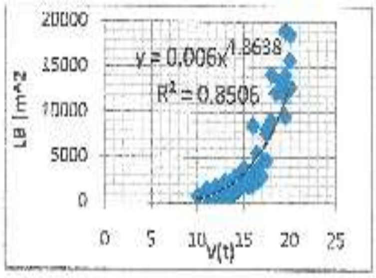

FIG. 5. REGRESION ANALYSIS OF L.B AGAINST v

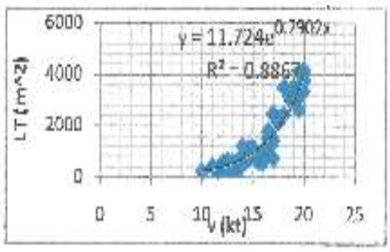

FIG. 6. REGRESION ANALYSIS OF L.T AGAINST v

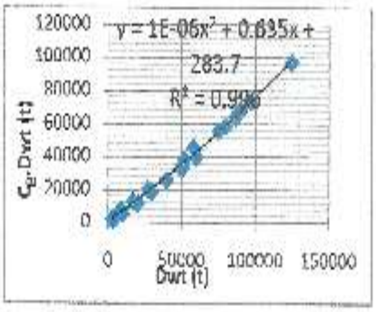

FIG. 7. REGRESION ANALYSIS OF C_B.Dwt AGAINST Dwt

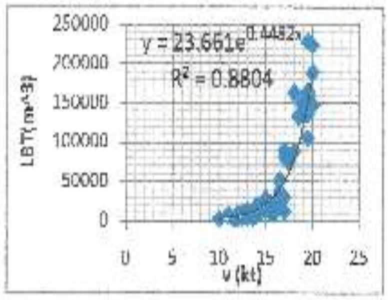

FIG. 8. REGRESION ANALYSIS OF LBT AGAINST v

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Volume 4, Issue 5 May 2022, pp: 889-895 www.ijaem.net ISSN: 2395-5252

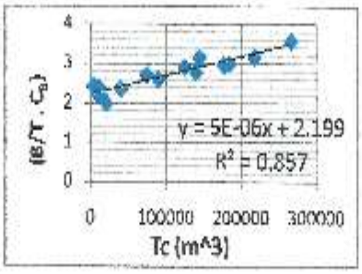

FIG. 9. REGRESION ANALYSIS OF B/T AGAINST Tc

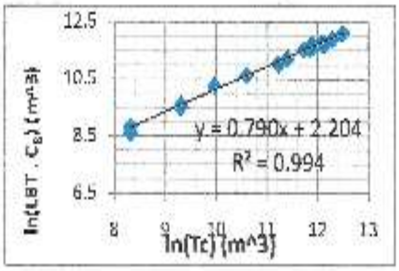

FIG. 10. REGRESION ANALYSIS OF LBT AGAINST Tc

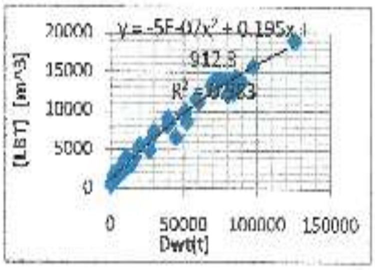

FIG. 11. REGRESION ANALYSIS OF LBT AGAINST Dwt

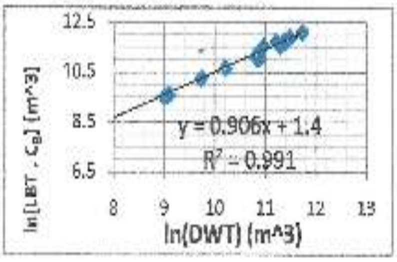

FIG. 12. REGRESION ANALYSIS OF LBT.C_B AGAINST Dwt

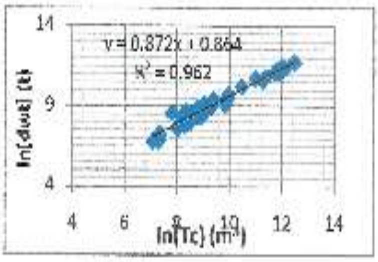

FIG. 13. REGRESION ANALYSIS OF Dwt AGAINST Tc

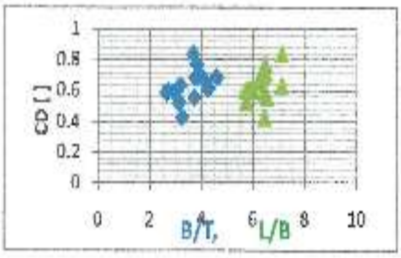

FIG. 14. SCATTER PLOT OF D AGAINST K_D,ON L/B. & B/T

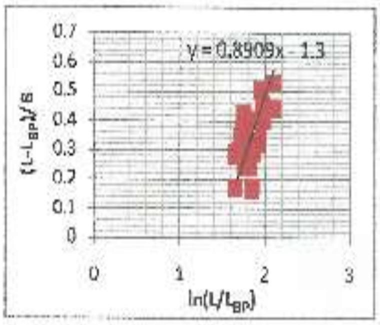

FIG. 15. REGRESION ANALYSIS OF Dwt AGAINST Tc

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Table 1. Derived formulas whose plots are shown in fig 1 to 13 above

	Y	X	X1	Y1	no
Y=12.2*x^0.583	**LB (m^2)**	**Tc (m^3)**	3500	1420.861	**1**
Y=0.872*x + 0.864	**ln(dwt)**	**ln(Tc) (m^3)**	8.161	7.980	**2**
Y=0.152*x + 1277	**LB (m^2)**	**dwt (t)**	3639.849	1830.257	**3**

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 5 May 2022, pp: 889-895 www.ijaem.net ISSN: 2395-5252

Y=9E-08*x^2+0.022*x+67.82	**BD (m^2)**	**dwt (t)**	3639.849	149.089	**4**
Y=73.376*ln(x) - 551.62	**DT (m^2)**	**dwt (t)**	3639.849	50.041	**5**
Y=11.724*e^(0.2902x)	**LT (m^2)**	**v (kt)**	14	681.597	**6**
Y=0.006*x^4.8638	**LB (m^2)**	**v (kt)**	14	2252.624	**7**
Y=23.661*e^(0.4482x)	**LBT (m^3)**	**v (kt)**	14	12564.468	**8**
Y=1E-06*x^2+0.6353*x+283.79	**C_B*dwt**	**dwt (t)**	3639.849	2609.435	**9**
Y=0.7907x + 2.2042	**ln(∇)**	**ln(Tc) (m^3)**	8.161	8.657	**10**
Y=5E-06x + 2.1996	**C_B*B/T**	**Tc (m^3)**	3500	2.2171	**11**
Y= 0.9065x + 1.4	**ln(∇)**	**ln(D_{WT}) (t)**	7.98	8.514	**12**
Y = 0.8909x – 1.3	**(L – L_{BP})/B**	**L/B**	6.17	0.3212	**13**

Table 2. Method of computation of variables based on the formulas in table 1

Column 0	1	2	3	4
B/T =	{LB(**1**)}/{LT(**7**)}	{LB(**3**)}/{LT(**6**)}	{LB(**7**)}/{LT(**6**)}	{BD(**4**)}/{DT(**5**)}
B/T =	**Mean(1,2,3,4,)**			
□□ □ □□□ □ □ □ □	EXP(In(∇))(**10**)	LBT(**8**)*(C_{B*}Dwt(**9**)/Dwt)	EXP(ln(Dwt)(**12**)	Dwt/(K_D*ρ)
□□ □ □ □ □	**Mean(1,2,3,4)**			K_D = 0.6333
C_B =	C_{B*}Dwt(**9**)/Dwt	C_B*B/T(**11**)/(**B/T**)		
C_B =	**Mean(1,2)**			
L_{OA}/B =	**CONSTANT =**	**6.17**FOR GAS CARRIERS[ ]		
L_{BP}/B =	**L_{OA}/B – 0.3212**	**5.849**		

Table 3. Summary for computation of main dimension of the gas carrier ship forTc =3500$m^3$and v = 14kts by proposed method.

B/T =	2.0846	2.6852	3.3049	2.9793
B/T =	**2.7635**			
□ (m^3) =	5748.666	9007.560	4983.88	5607.251
□ **(m^3) =**	**6336.839 m^3**			
C_B =	0.7169	0.8022		
C_B =	**0.7596**			
L_{BP} =	**92.391 m**			
B =	**15.797m**			
T =	**5.716m**			
C_B (Check)	**0.7596**			

Table 4.Regression analysis formulas derived from the data of gas carrier ships colleted[ ] [

REGRESSION EQUATIONS	unit	(.) Eqn No.	[ref.]
Dwt = 0.4873Tc + 2652.3	**(t)**	**(14)**	**[10]**
$P = 38.243(v/(Dwt))^{-0.793}$	**(kw)**	**(15)**	**[10]**
$P = 93.262v^3 - 3557.2v^2 + 45659v - 194203$	**(kw)**	**(16)**	**[11]**
$L_{BP} = 0.9644L - 2.7074$ and ($L_{OA}/B = 6.17$)	**(m)**	**(17)**	**[11]**
$T_{MAX} = 1.0492T + 0.204$	**(m)**	**(18)**	**[11]**

TABLE 5. Example of prediction of ship dimensions for full gas tank capacity Tc of 3500m3 and speed v = 14kts

Tc =	**3500**	**m^3**
v =	**14**	**kt**
LBP =	**92.391**	**m**
B =	**15.797**	**m**
T =	**5.716**	**m**
$D_{WT} = 0.4873Tc + 2652.3$ =	4357.850	t
$\ln(D_{WT}) = 0.872.\ln(Tc)$ D_{WT} =	2921.849	t
∴ DWT =	**3639.849**	**t**
$P = 38.243(v/(D_{WT}))^{-0.793}$ =	3627.566	Kw
$P = 93.262v^3 - 3557.2v^2 + 45659v - 194203$ =	3722.728	Kw
□ **P** □ =	**3675.147**	**Kw**
LOA/B = 6.17 LOA =	97.46749	m
LOA = 1.0369LBP + 2.8073 LOA =	98.6075279	m
∴ LOA =	**98.03750895**	**m**
Table 1 (4) BD = 149.089 . D =	9.437804646	**m**
Table 1 (5) DT = 50.041. D =	8.754548635	**m**
∴ D =	**9.096176641**	
$T_{MAX} = 1.0492T + 0.204$ T_{MAX} =	**6.201**	**m**

TABLE 4. COMPARISON OF PREDICTED DIMENSIONS OF DESIGN VESSEL WITH SOME EXISTING SIMILAR SHIPS

		E X I S T I N G V E S S E L S						
DIMENSION	DESIGN SHIP	ORCHID CORAL	%DEV	JASMINE CORAL	%DEV	SENNA 2	%DEV	**AVG(%DEV)**
TC	3500	3517.54	0.501	3519	0.543	3523	0.66	**0.43**
LOA	98.04	97.69	-0.354	97.6	-0.446	100	2.00	**0.30**
LBP	92.39	91.50	-0.959	91.42	-1.053	93.73	1.45	**-0.14**
B	15.80	16	1.285	16	1.285	4	3.82	**1.60**
D	9.10	7.2	-20.844	7.2	-20.844	7.5	-17.55	**-14.81**
T	5.72	5	-12.526	5	-12.526	5.91	3.39	**-5.41**
P	3675.15	2700	-26.534	2700	-26.534	4000	8.84	**-11.05**
DWT	3639.85	3837	5.416	3826.5	5.128	4421	21.46	**8.00**
V	14	10.6	-24.285	16.6	18.571	11.3	-19.28	**-6.25**