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IJPST Optimum Fuel Tank Capacity Estimation for Tug Boats Basing on Existing Vessels

Stephen Chidozie Duru,

Co-ordinator, Department of Marine Engineering,

Niger Delta University ,Amassoma, Bayelsa State, Nigeria.

Abstract: **This research is based on data collected from existing tugboats of the world fleet. Regression analysis done on this data yielded formulas from which the equation for the calculation of optimal fuel tank capacity of tugboats of wide variety of sizes, power, and speed. The regression correlation factor for the finally derived equation is 0.981. This equation will not only meet most of the operational fuel demands of the tugboat but will assure that the freeboard of the projected tugboat design meets stability requirements. The formula very closely predicted existing tugboat fuel tank capacity requirement and can be used as a standard for the fuel tankage of tugboats.**

Keywords - Tugboats, Fuel tankage, Estimation regression analysis, Formula.

I. Introduction

Fuel capacity Fo of a vessel may be calculated as:

$Fo = sfc*H*P + sfc_a*H_a*P_a + F_r$ - - - - - - - - - - 1

where,

sfc, sfc_a = main and auxiliary engine specific fuel consumption (kg/hp/s, respectively.

P, P_a = main and auxiliary Power respectively.

H, H_a = Endurance hours in operation

F_r = Reserve fuel capacity.

In tugboat operation, these factors are not constant but vary depending on the specific towing operation ordered for. The categories of operations can be of these, amongst other kinds [1]:

Surge to theatre distance,- Full power and maximum speed run to or from the operation site.

Sustained speed run – customer specified speed not more than or equal to 80% of full power of the tugboat.

Economic transit distance run in which the vessel is running at designed economic speed and endurance distance without replenishment of fuel.

Operational presence time: -minimum specified time that the specific mission of the tugboat is specified without replenishment of full tankage fuel.

This service conditions together with the limitations of hull dimensions, and freeboard safety requirements, determine the volume of fuel tankage for a tug boat. These factors require careful study in order to determine the relation for optimum capacity of fuel tank for tugboats. This is the main theme of this research.

Publications on fuel capacity, consumption, management and economy are available in literature [2],[3],[4] mainly centred on different aspect of operational fuel requirements for ships generally.

When a tugboat is designed to carry very large fuel tank capacity there is increase in displacement, resistance or power requirements, which is not economical in operation for most of her operation conditions. Very small fuel tank capacity will minimise the hull size leading to lower resistance, higher freeboard, more push power but low endurance as the tugboat will require frequent fuel replenishment leading to loss of operation time.

In this work the actual fuel tankage Fo of a tug boat is rigorously found to be a function of L, B, D, L/B, L/D, LBD, LB, P, v.

That is:

Fo = f(L, B, D, L/B, L/D, LBD, LB, P, v)--------2

Where:

L = Length overall (m), B = Breadth (m),
D = Depth (m), P = Main Power (hp),
V = design Speed (kt), of the tug boat.
LBD = Cubic number (m^3)

This optimal fuel tankage capacity Fo_P (m^3) function is derived in this work basing on the experience obtained from existing tugboat by regression analysis.

II. Material and Method

A collection of 365 tugboats were made from existing tugboats from the world Tugboat fleet, part of which are shown in Table 1. These data are obtained from the internet adverts of various companies such as in [5], [6],[7], and others. These collections are sorted to include those were the fuel tank capacity data are available.

Many variables were formulated for the regression analysis basing on the principal main dimensions of the tugboats but those that were significantly correlated with fuel tank capacity were L,B,D,P,v as well as L/B, L/D, L*B, LBD.

The mathematical model for regression formulas fitted to the data were linear and none linear functions executed by Microsoft EXCEL add in software. These are functions of these types:

Linear, $Y = mx + c$ 2
Power, $Y = m X^c$. 3
Exponential $Y = m e^{cx}$. 4
Logarithmic, $Y = m \ln(X) + c$ 5
Polynomial $Y=aX_n+ aX_{n-1}+..+ aX_1+c$……6

Where Y is a fuel tanks Fo function and, X is the function of the dimension of the tugboats m, c, and n are constants determined by the regression analysis a well-known mathematical procedure according to [8] and others.

With respect to the regression analysis the variables are :

Fo, Fo/v, Fo*(L/B), Fo*(L/D), Fo/L, Fo/D, Fo*(L/D), and Fo/B for Y-axes, as well as

L, L/B, D, LB, LBD, and p for the X-axes.

III. Result And Discussion

The 18 diagrams of the regression analysis are shown in fig.1 to fig 18 with the regression equation shown in each diagram. These are a selection of those diagram whose correlation coefficient R^2 are 0.8 and above.

Out of these 18 figures, fig.1 to fig.16 (denoted as $Fo_{1,}$ $Fo_{2,}$ to Fo_{16}) are direct correlation from the raw data collected.

Fig 17 and 18 are actually from the same data derived from the evaluated mean values Fo_m of the 16 derived correlations from fig. 1 to fig. 16 predicted values shown in Table 1 and Table 1-continued. In the evaluation of $Fo_{1,}$ $Fo_{2,}$ to Fo_{16}, for each of the vessels, the fuel capacity Fo in the Y-axes was made the subject of each formula predicted in the 16 figures equation.

In Table 2 where the 16 corresponding regression equations from the figures are collected, the data sample numbers N and the correlation coefficient R^2 are also shown. Equation 17 and 18 in Table 2 are from fig 17 and 18 respectively. They are the formulas for the actual predicted fuel tank capacity designated as Fo_{p1} and Fo_{p2} respectively.

At the four end rows of column 26, 27, and 28 of Table 1-continued it will be observed that:

- Standard deviation of Fo_m, Fo, Fo_{p1}, and Fo_{p2} are 291.11, 285.32, 309.58, and 289.63 respectively and the mean values are 303.36, 313.99, 316.11 308.32 respectively. These amounted to a percentage deviation from Fo (actual value) of -2.03% , -8.49%, and -1.51% for the standard deviation and 3.39%, -0.67%, and
- 1.81% for the mean values for Fo_m, Fo_{P1}, and Fo_{p2} respectively. This means that the best formula is :

Fo_{p2} = $0.0831(LBD + v +\sqrt{P}) + 74.004$. - - - - - -3

With $R^2 = 0.981$. (Table 2 equation 18)

This equation is the equation for optimum fuel tank capacity for existing or projected tugboat, applicable to the range of the tugboats used in this work as can be seen in the shown diagrams.

IV. Conclusions

A Tugboat operational condition varies widely requiring different fuel capacities. The optimum tankage capacity denoted by Fo_p of a tugboat depends on the demands of operational fuel, the main dimensions of the vessel, the power of main and auxiliary engines and the speed of the vessel.

A collection of 365 tugboats data were sorted and used to determine Fo_p by regression analysis of the Microsoft Excel ad-in. Out of many parametric variables subjected to the regression analysis 16 equations having regression coefficients R^2 greater than or equal to 0.8 were selected and published in this paper. These equations were further analysed to get the formula for Fo_p as:

$Fo_p = 0.0831(LBD + v + \sqrt{P}) + 74.004\ (m^3)$

The is the formula which will give optimal fuel tankage capacity for a tugboat of length overall L(m), breadth B(m) design speed v(kt) and main power P(hp). This formula derived with a correlation factor R^2 =0.981 will also assure adequate freeboard - a leverage for safety and stability- for the existing as well as projected tugboat designs.

References

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Table 1. Some Existing Tugboat parameters and the predicted values fuel tank capacities Fo

E X I S T I N G	V E S S E LS		P A R	A M	E T	E R S			PREDICTED VALUES	
NAME/NO	BUILT	BIULT	L(m)	B(m)	D(m)	P(hp)	v(Kt)	Fo(m^3)	$Fo_1(m^3)$	$Fo_2(m^3)$
STAN2608	DAMEN	1999	26.15	7.95	4.05	2,720.00	12.00	72.20	99.80	125.39
131028-vo	Holland	2005	26.09	7.94	4.05	3,500.00	12.70	81.60	98.83	124.87
DAMEN 2608			26.15	7.95	4.05	2,720.00	12.00	72.20	99.80	125.39
141134-VO	SINGAPORE	1995	28.40	8.40	3.47	2,800.00	12.00	126.20	136.40	146.69
140421-VW	Singapore	2006	29.00	9.00	4.25	3,200.00	12.00	117.00	146.16	161.23
Sea Eagle	turkish		32.50	11.70	5.60	3,129.00	13.00	250.00	203.08	240.38
151204-VA	SINGAPORE	1983	42.00	11.40	5.00	3,120.00	11.50	299.00	357.59	315.62
140827 VN	INDONESIA	2006	37.41	9.00	4.56	3,200.00	12.00	204.00	282.94	218.12
141137-VA		2007	37.00	10.60	4.95	3,200.00	12.00	230.84	276.27	253.63
150632 VA	CHINABV	2012	58.70	14.60	5.50	4,890.00	12.50	475.00	629.20	587.50
121063-VO	SPAIN RINA	1982	25.00	8.40	4.20	2,030.00	12.00	64.70	81.10	125.22
150616-VA	SINGAPORE	2000	60.00	13.80	6.80	8,000.00	14.00	623.00	650.34	568.79
151228 VW	HOLLAND	2007	26.00	11.50	3.50	2,400.00	10.00	110.00	97.36	180.08
121068-VO	MALAY	2012	27.00	9.00	4.10	2,000.00	10.00	154.80	113.63	147.70

140412-VO	MALAY NS	2011	32.10	9.00	4.20	3,200.00	12.00	201.00	196.57	182.20
141125-VO	UK	2014	32.60	9.00	4.30	2,500.00	12.00	118.00	204.71	185.58
120322-VW	MALAY	2016	35.00	11.50	5.62	5,150.00	12.50	220.00	243.74	257.88
432236EA	AFRCA/IRE	1978	37.30	10.84	4.90	3,500.00	9.00	200.00	281.15	261.82
150611 VA	KEPPEL	2004	60.00	16.00	6.00	6,000.00	14.00	550.00	650.34	659.47
150811-VA	US ABS	2015	66.50	16.00	6.50	6,400.00	13.00	590.00	756.06	737.65
150615 VA	SINGAPORE	2013	81.00	16.80	7.50	7,000.00	14.00	1,030.00	991.88	957.64
150613-VA	SINGAPORE	2013	81.00	16.80	7.50	7,000.00	14.00	1,030.00	991.88	957.64
120758-VA	GERMANY	1982	64.50	13.82	6.90	8,160.00	15.50	1,034.30	723.53	616.36
131223-VA	AUTR	2013	91.00	22.00	9.60	21,456.00	17.00	1,200.00	1,154.52	1,419.43
140240VO	INDONESIA	1982	33.52	7.92	3.20	1,273.00	11.00	150.00	219.67	168.79
140413-VO	CHina BV	2014	34.50	9.50	4.60	3,200.00	11.50	278.00	235.61	209.46
120304-VM	SINGAPORE	2012	28.50	8.50	3.80	1,440.00	11.00	180.00	138.02	149.08
131937 VO	china BV	2014	36.00	10.97	5.00	3,200.00	12.00	393.00	260.00	254.24
130937 VO	china BV	2014	36.00	10.97	5.00	3,200.00	12.00	393.00	260.00	254.24
150633 VO	CHINA BV	2009	36.10	10.60	4.90	3,200.00	12.00	400.00	261.63	246.46
141138 va	singapore	2008	38.10	10.60	4.90	3,800.00	12.00	400.00	294.16	262.40
140408-VO	NS	2014	32.40	9.15	4.48	3,200.00	12.00	275.00	201.45	187.30
140409 VO	NS	2009	30.22	9.00	4.38	2,400.00	10.00	269.00	166.00	169.48
SGAPOR	Malaysia	2001	27.00	8.50	4.15	1,600.00	10.00	185.00	113.63	139.49
141043-VO	ABS		29.10	9.00	4.25	2,400.00	11.00	217.00	147.78	161.90
Leslie Foss	LAUSABS	1970	36.58	9.45	4.54	3,000.00	12.00	384.00	269.37	223.08
140802 VN	CHINA	2009	33.00	10.00	4.50	4,000.00	13.00	80.00	211.21	209.21
120917-VO	LR	2012	31.99	11.60	5.36	5,364.00	12.00	205.00	194.79	233.88
Rastar	ussbs		32.00	13.20	5.55	4,930.00	14.00	230.36	195.01	266.23
141057 vw	holland	2012	24.07	12.97	4.00	3,820.00	10.60	120.00	65.97	184.28
140804 VN	CHINA	2013	33.98	10.00	4.50	4,000.00	13.00	80.00	227.15	216.58
151150 VT	TURKEY	2015	22.00	7.70	3.70	600.00	12.00	58.50	32.31	97.42
151131-VO	Malaysia		26.00	8.00	3.65	1,650.00	10.00	150.00	97.36	125.27
1	2	3	3	4	5	6	7	8	9	10

Table 1-continued

	CONTINUATION OF PREDICTED fuel capacity						
NAME/NO	$Fo_3(m^3)$	$Fo_4(m^3)$	$Fo_5(m^3)$	$Fo_6(m^3)$	$Fo_7(m^3)$	$Fo_8(m^3)$	$Fo_9(m^3)$
STAN2608	124.20	107.66	131.03	144.53	141.96	135.24	104.02
131028-vo	130.65	106.82	131.03	144.86	150.24	135.38	103.41
DAMEN 2608	124.20	107.66	131.03	144.53	141.96	135.24	104.02
141134-VO	152.60	117.93	13.36	11.27	49.54	8.93	110.00
140421-VW	160.17	152.27	171.61	182.72	173.83	184.99	156.45
Sea Eagle	221.36	255.83	445.51	634.19	421.36	621.96	337.11
151204-VA	310.71	336.26	323.78	301.28	281.12	325.97	320.36
140827 VN	266.30	262.49	234.51	214.15	223.23	201.81	198.90
141137-VA	261.12	280.37	313.64	326.41	285.37	331.97	273.66
150632 VA	557.25	528.49	425.23	326.19	388.56	407.22	516.30
121063-VO	109.69	94.29	161.47	196.10	165.86	187.44	115.48
150616-VA	643.26	666.88	688.98	714.84	676.86	665.96	599.99
151228 VW	101.93	91.21	19.45	17.94	45.27	22.46	181.84

121068-VO	112.44	120.86	141.18	153.44	124.94	160.75	141.73
140412-VO	199.29	187.43	161.47	152.73	165.86	156.41	166.89
141125-VO	205.60	197.57	181.76	175.05	181.80	175.18	172.67
120322-VW	245.71	292.06	449.57	597.45	408.47	573.65	340.78
432236EA	198.68	280.86	303.49	308.68	208.05	324.57	280.59
150611 VA	643.26	588.43	526.67	450.77	528.14	560.00	627.80
150811-VA	686.17	699.54	628.12	548.33	576.73	622.98	689.42
150615 VA	952.43	955.20	831.01	744.56	807.00	756.44	857.93
150613-VA	952.43	955.20	831.01	744.56	807.00	756.44	857.93
120758-VA	785.53	722.71	709.27	700.27	769.96	642.73	616.89
131223-VA	1,335.29	1,345.37	1,257.07	1,490.96	1,453.98	1,502.09	1,481.70
140240VO	199.11	154.61	-41.42	-25.25	5.97	-35.60	105.10
140413-VO	220.01	233.47	242.62	243.30	220.03	239.82	208.68
120304-VM	141.04	130.33	80.31	74.43	93.61	78.07	123.70
131937 VO	248.50	271.70	323.78	351.49	293.34	365.95	286.92
130937 VO	248.50	271.70	323.78	351.49	293.34	365.95	286.92
150633 VO	249.77	267.41	303.49	318.94	277.41	327.94	267.99
141138 va	275.00	289.57	303.49	302.19	277.41	310.72	274.25
140408-VO	203.07	203.49	218.28	224.34	210.48	218.93	184.16
140409 VO	146.30	172.69	197.99	211.19	162.12	207.47	166.59
SGAPOR	112.44	122.34	151.32	167.30	131.58	163.68	127.99
141043-VO	147.98	153.56	171.61	182.09	159.34	184.35	156.89
Leslie Foss	255.77	252.84	230.76	214.26	220.28	212.89	210.85
140802 VN	228.20	211.44	222.34	225.80	231.47	239.72	215.71
120917-VO	197.90	237.62	396.82	537.44	350.71	548.42	316.36
Rastar	231.09	246.14	434.83	619.73	443.99	692.77	393.56
141057 vw	86.53	75.61	120.89	142.36	118.36	219.68	240.81
140804 VN	241.60	222.61	222.34	219.29	231.47	232.81	219.16
151150 VT	71.83	37.84	60.02	69.55	86.19	66.63	64.70
151131-VO	101.93	95.12	49.88	48.06	65.18	47.71	94.40
	11	12	13	14	15	16	17

Table 1- **Continued**

CONTINUATION OF PREDICTED fuel capacity							
NAME/NO	$Fo_{10}(m^3)$	$Fo_{11}(m^3)$	$Fo_{12}(m^3)$	$Fo_{13}(m^3)$	$Fo_{14}(m^3)$	$Fo_{15}(m^3)$	$Fo_{16}(m^3)$
STAN2608	205.73	67.78	85.40	83.31	105.58	95.68	79.70
131028-vo	275.74	67.11	82.08	79.31	98.28	89.17	76.10
DAMEN 2608	205.73	67.78	85.40	83.31	105.58	95.68	79.70
141134-VO	213.02	66.52	91.78	70.39	81.58	91.23	83.15
140421-VW	249.10	91.94	112.36	109.51	140.16	135.48	110.82
Sea Eagle	242.75	187.54	179.54	230.27	332.71	309.93	220.77
151204-VA	241.94	216.27	269.20	250.08	308.55	310.60	257.23
140827 VN	249.10	131.72	177.31	153.23	173.77	154.47	141.24
141137-VA	249.10	170.76	202.83	201.49	254.42	243.04	198.17
150632 VA	394.48	453.50	543.79	446.97	503.71	576.14	513.16
121063-VO	141.77	71.35	84.03	89.74	121.25	111.74	87.18

150616-VA	632.14	545.41	578.48	582.46	659.41	575.09	508.91
151228 VW	176.30	87.89	108.80	99.80	149.94	223.73	155.34
121068-VO	138.94	83.24	109.59	112.31	159.23	159.05	117.20
140412-VO	249.10	101.54	131.49	116.45	139.71	136.15	118.50
141125-VO	185.54	106.01	136.81	123.08	147.75	140.42	121.99
120322-VW	415.83	201.34	205.67	250.70	350.41	318.40	233.74
432236EA	275.74	180.04	247.50	256.53	364.66	355.36	255.00
150611 VA	483.74	559.31	586.70	523.58	598.32	685.03	600.14
150811-VA	514.70	690.11	762.59	699.75	801.84	838.55	726.97
150615 VA	559.94	1,052.98	1,129.22	1,044.40	1,118.37	1,050.65	965.55
150613-VA	559.94	1,052.98	1,129.22	1,044.40	1,118.37	1,050.65	965.55
120758-VA	643.32	594.96	616.71	584.59	612.25	527.28	504.57
131223-VA	1,214.63	2,077.31	1,665.25	1,913.21	2,183.96	2,061.61	1,754.06
140240VO	69.40	69.09	116.18	71.19	73.22	83.33	85.29
140413-VO	249.10	129.68	166.01	157.69	195.85	182.00	151.82
120304-VM	85.56	75.50	103.82	90.27	112.86	115.70	97.18
131937 VO	249.10	173.99	199.44	206.37	269.69	263.77	207.70
130937 VO	249.10	173.99	199.44	206.37	269.69	263.77	207.70
150633 VO	249.10	164.31	193.68	193.87	247.34	239.03	193.09
141138 va	302.02	174.41	211.36	202.60	250.40	241.45	201.02
140408-VO	249.10	112.21	140.37	133.73	164.98	152.67	128.87
140409 VO	176.30	101.43	137.03	138.85	189.28	175.69	133.91
SGAPOR	100.94	79.20	106.57	109.57	152.50	142.40	107.03
141043-VO	176.30	93.15	119.25	117.91	156.09	150.32	118.56
Leslie Foss	231.14	134.97	175.75	155.39	181.87	170.28	150.74
140802 VN	319.34	125.88	145.79	137.84	169.14	170.08	144.20
120917-VO	433.20	175.39	178.02	222.54	328.26	316.60	220.82
Rastar	397.78	206.83	179.18	232.15	343.65	364.22	253.06
141057 vw	303.76	106.20	108.39	125.65	14.07	313.70	191.38
140804 VN	319.34	130.02	152.87	141.18	170.27	171.01	147.39
151150 VT	3.14	48.90	59.83	59.80	79.80	77.59	61.94
151131-VO	105.73	61.63	89.17	80.08	105.43	106.33	85.06
18	19	20	21	22	23	24	25

Table 1. continued.

26	27	28	29	
	MEAN F_{o1-16}	ACTUAL Fo	Final	prediction
NAME/NO	Fo_m(m)	Fo(m)	Fo_{p1}(m)	Fo_{P2}(m)
STAN2608	114.81	72.20	134.37	149.30
131028-vo	118.37	81.60	134.86	149.69
DAMEN 2608	114.81	72.20	134.37	149.30
141134-VO	90.27	126.20	132.99	148.19
140421-VW	152.43	117.00	162.31	171.88
Sea Eagle	317.77	250.00	265.91	256.69
151204-VA	295.41	299.00	292.28	278.54
140827 VN	205.21	204.00	205.82	207.29

	141137-VA	257.64	230.84	246.95	241.03
	150632 VA	487.35	475.00	520.24	472.55
	121063-VO	121.48	64.70	137.77	152.04
	150616-VA	622.36	623.00	608.74	550.49
	151228 VW	109.96	110.00	154.88	165.87
	121068-VO	131.01	154.80	149.29	161.34
	140412-VO	160.11	201.00	172.97	180.53
	141125-VO	165.09	118.00	177.24	184.00
	120322-VW	336.59	220.00	280.76	268.98
	432236EA	273.92	200.00	250.92	244.31
	150611 VA	579.48	550.00	619.72	560.26
	150811-VA	686.22	590.00	726.26	656.45
	150615 VA	923.45	1,030.00	1,014.83	930.24
	150613-VA	923.45	1,030.00	1,014.83	930.24
	120758-VA	648.18	1,034.30	657.30	593.91
		1,581.90	1,200.00	1,697.70	1,684.70
	120758-VA	82.42	150.00	133.35	148.48
	131223-VA	205.32	278.00	202.95	204.95
	140240VO	105.59	180.00	140.90	154.57
	131937 VO	264.12	393.00	250.29	243.79
	130937 VO	264.12	393.00	250.29	243.79
	150633 VO	250.09	400.00	240.25	235.52
	141138 va	260.78	400.00	251.24	244.57
	140408-VO	183.34	275.00	184.71	190.07
	140409 VO	165.77	269.00	169.73	177.90
	SGAPOR	126.75	185.00	144.29	157.31
	141043-VO	149.82	217.00	161.82	171.49
	Leslie Foss	205.64	384.00	209.11	209.98
	140802 VN	200.46	80.00	201.48	203.74
	120917-VO	305.55	205.00	253.43	246.37
	Rastar	343.76	230.36	288.88	275.71
	141057 vw	163.60	120.00	176.98	183.79
	140804 VN	204.07	80.00	205.96	207.41
	151150 VT	61.09	58.50	109.28	129.12
	151131-VO	84.90	150.00	124.44	141.30
STD DEVIATION	=	291.11	285.32	309.54	289.63
MEAN VALUES	=	303.36	313.99	316.11	308.32
%DEV OF STDEV from Fo	=	-2.03%	0.0%	-8.49%	-1.51%
%DEV OF Mean from Fo	=	3.39%	0.0%	-0.67%	1.81%

Table 2 Tugboat design regression analysis formulas.

N	R^2	Formula	Eq. no
48	0.882	$Fo = 16.264L - 325.5$	1
48	0.890	$Fo*(L/B) = 7517L^2 - 3.8852$-	2
49	0.843	$Fo/v = 1.0516L - 17.149$	3
46	0.931	$Fo*(L/D) = 1.0528L^2 + 62.598L - 1661.7$-	4
48	0.819	$Fo = 202.89D - 690.67$-	5
46	0.804	$Fo*(L/D) = 151.46D^2 + 310.93D - 2810.4$	6
35	0.804	$Fo/v = 13.279D - 41.95$	7
37	0.809	$Fo*(L/B) = 52.927D^2 + 316.89D - 1706.7$	8
46	0.880	$Fo*(L/D) = 7.4542(LB) - 878.02$-	9
38	0.822	$Fo = -2E\text{-}06P^2 + 0.1022P - 57.456$	10
31	0.803	$Fo/v = 0.0513(v/(LBD))^{-0.620}$	11
22	0.80	$Fo/L = 0.2341(v/(LBD))^{-0.620}$	12
22	0.857	$Fo/D = 0.6382(v/(LBD))^{-1.106}$	13
33	0.805	$Fo*(L/D) = 3.6862(v/(LBD))^{-1.228}$	14
31	0.807	$Fo*(L/B) = 2.0257(v/(LBD))^{-1.187}$	15
26	0.812	$Fo/B = 0.4206(v/(LBD))\text{-}0.746$	16
42	*0.981*	$Fop = -1E\text{-}06(LBD + V + \sqrt{P})2 + 0.1049(LBD + V + +\sqrt{P}) + 40.141$	17
42	*0.981*	$Fop = 0.0831(LBD + V + \sqrt{P}) + 74.004$	18

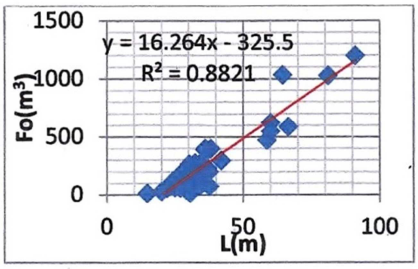

Fig 1. Fo correlated with L

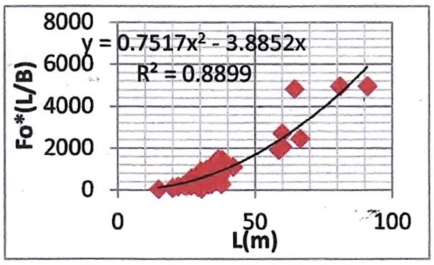

Fig 2. Fo*(L/B) correlated with L

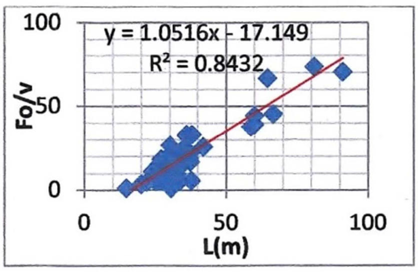

Fig 3. Fo/v correlated L

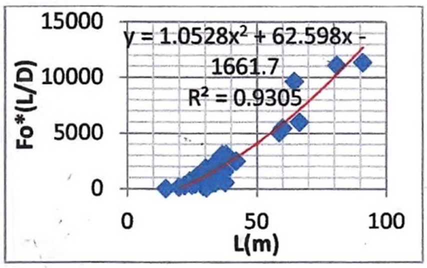

Fig 4. Fo*(L/D) correlated with L

Table 2 Tugboat design regression analysis formulas.

N	R^2	Formula	Eq. no
48	0.882	$Fo = 16.264L - 325.5$	1
48	0.890	$Fo*(L/B) = 7517L^2 - 3.8852$	2
49	0.843	$Fo/v = 1.0516L - 17.149$	3
46	0.931	$Fo*(L/D) = 1.0528L^2 + 62.598L - 1661.7$	4
48	0.819	$Fo = 202.89D - 690.67$	5
46	0.804	$Fo*(L/D) = 151.46D^2 + 310.93D - 2810.4$	6
35	0.804	$Fo/v = 13.279D - 41.95$	7
37	0.809	$Fo*(L/B) = 52.927D^2 + 316.89D - 1706.7$	8
46	0.880	$Fo*(L/D) = 7.4542(LB) - 878.02$	9
38	0.822	$Fo = -2E\text{-}06P^2 + 0.1022P - 57.456$	10
31	0.803	$Fo/v = 0.0513(v/(LBD))^{-0.620}$	11
22	0.80	$Fo/L = 0.2341(v/(LBD))^{-0.620}$	12
22	0.857	$Fo/D = 0.6382(v/(LBD))^{-1.106}$	13
33	0.805	$Fo*(L/D) = 3.6862(v/(LBD))^{-1.228}$	14
31	0.807	$Fo*(L/B) = 2.0257(v/(LBD))^{-1.187}$	15
26	0.812	$Fo/B = 0.4206(v/(LBD))\text{-}0.746$	16
42	*0.981*	$Fop = -1E\text{-}06(LBD + V + \sqrt{P})2 + 0.1049(LBD + V + +\sqrt{P}) + 40.141$	17
42	*0.981*	$Fop = 0.0831(LBD + V + \sqrt{P}) + 74.004$	18

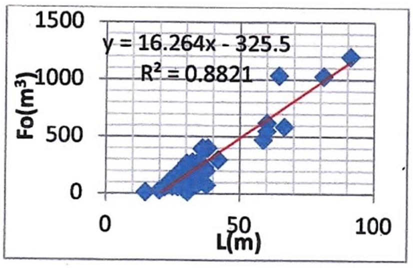

Fig 1. Fo correlated with L

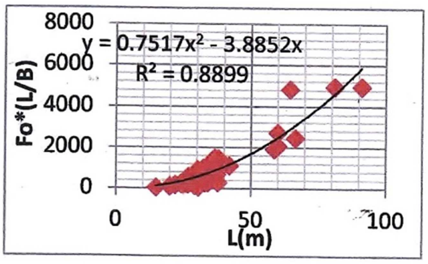

Fig 2. Fo*(L/B) correlated with L

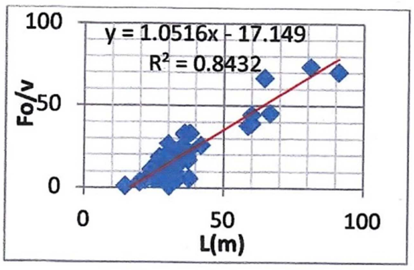

Fig 3. Fo/v correlated L

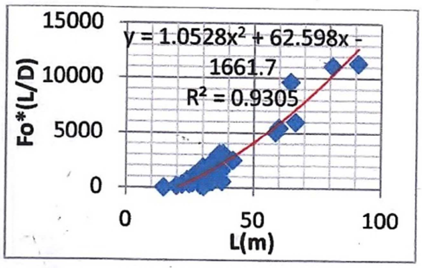

Fig 4. Fo*(L/D) correlated with L

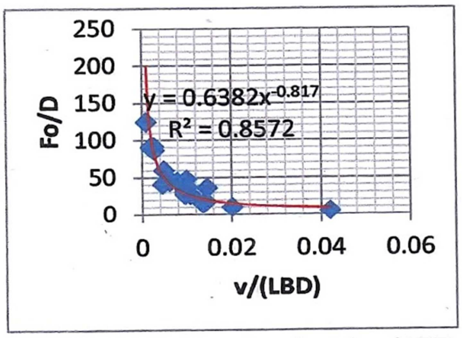

Fig 13. Fo/D correlated with v/LBD

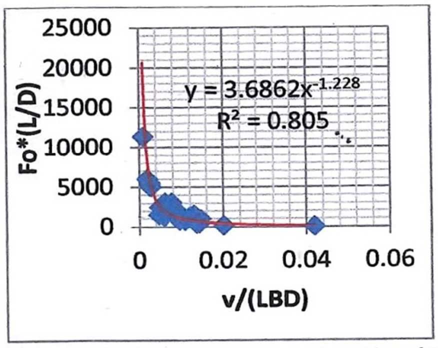

Fig 14. Fo*(L/D) correlated with v/LBD

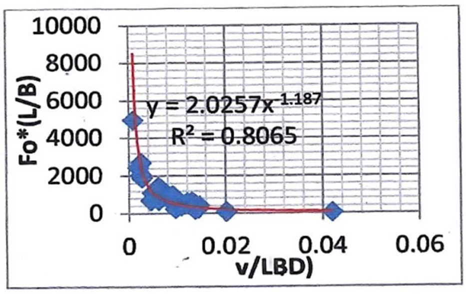

Fig 15. Fo*(L/B) correlated with v/LBD

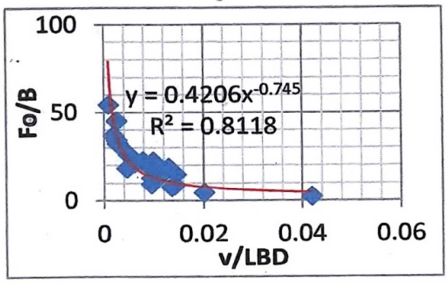

Fig 16. Fo/B correlated with v/LBD

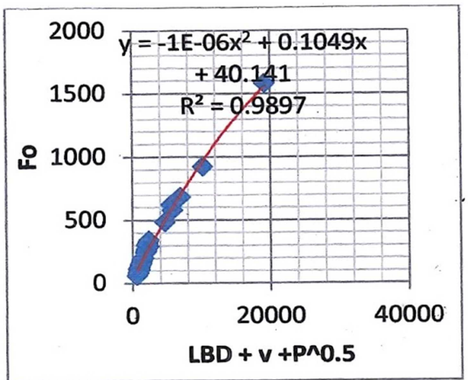

Fig 17 Fo correlated with (LBD+v+√P).

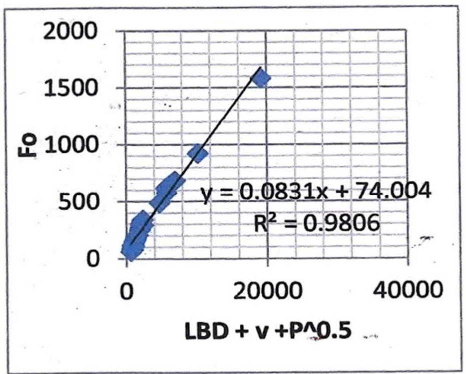

Fig 18 Fo correlated with (LBD+v+√P).