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Propeller Pitch Selection Based on Analysis of Existing Tugboats

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Abstract:- This work presents 42 equations, result of regression analysis between main particulars and screw propeller pitch values for numerous existing tugboats of the world. The correlation coefficients of these regression analysis were upto 0.8 and above. This work enable the selection of screw propeller pitch and diameter for projected or existing design of tugboats at early stage of design of the boat and aid in reduction of the iterative processes in the hydrodynamic sizing of the scew propeller at the advanced design stage. Sample computation using this method for three existing tugboat show 5.3%, 8.9% increase and 18.3% decrease in the predicted pitch values compared with the actual pitch values of the screw propellers of the respective sample tugboats.

Keywords:- *Tugboat, Propeller, Pitch, Diameter, Hull Particulars, Correlations, Formulas.*

I. INTRODUCTION

The screw propeller pitch of the tugboat determine the speed, and the thrust force for a given propeller diameter of the boat. This propeller pitch can vary but the diameter is limited by the depth of the draught and stern shape of the hull of the vessel. The right selection of screw propeller for a tugboat should assure , the maximum attainable bollard pull, the required service speed, less noise, low hull induced vibration or erosion of hull plating, no cavitation, and most importantly the main engine should not be overloaded by the propeller. The main engine should be running at manufacturers specification, without overheating, over speeding, or excessive vibration. The hydrodynamic design procedure for screw propeller design and selection for ships try to achieve these goals by the used of methodical series of ship propeller model test results[1], [2], [3]. This method is usually done at the advanced ship design stage and involve many parameters of the projected ship design. Usually the resistance and power requirements of the hull is calculated and the picth, diameter and other parameters of the screw propeller are calculated to match the vessel main engine in an iterative design process.

Most tugboats operate with B-series or Gawn Seris propeller models and are either fixed pitch, variable pitch, or kort nozzle types as well as vertical cycloidal types [4]. The advanced hydrodynamic helps in selection of the most efficient propeller of the any type for a projected tugboat design.

This work is aimed at obtaining the propeller pitch and diameter as a function of hull and machinery parameters at the early stage of design of tug boats. This work will also reduce the hydrodynamic iterative process work of selection of the propeller at the advanced design stages. The hull amd machinery parameters of existing tugboats is correlated by linear and non-linear regression analysis with the propeller pitch to obtain 41 equations which will predict the propeller pitch of the projected design tugboat. Estimation of new projected boat parameters which would be the input to this process can be obtained from the previous publications of the author [5], [6] and others.

II. MATERIAL AND METHOD

Data for this research were based on a collection of 386 tugboats from which a sub-selection of vessels where propeller pitch and diameter data were available. This set of data is partially shown in Table 1. The internet publications and boat sales advert is the main source of the data [7], [8], [9].

The regression analysis carried on the data collected was done by Microsoft Excel add-in software. The mathematical background for this linear and non-linear regression analysis can be found in many existing books [10], and others.

The Y-axis variables is the propeller pitch P" while the X-axis variable values for the regression analysis are: L, B, D, P, LB, LD, LT, BT, LBD, LBT, PL, PB, P/B, PLB, PL/B, PD/L, PLD, PL/T, PL/BD, PL/BT, PLBD, PLBT, PLD/B, PLT/B, L/√v, LP/v, Pv, P/v, PvL, LTP/v, LDP/v, LBr, LDr, P/r, PDr, LP/r, LB/√r, LBDr, LBD/r, LBT/√r, PLB/r.

Where,
- ✓ L = length overall (m), B = breadth (m),
- ✓ D = depth(m), P = main power (hp) ,
- ✓ T = draught (m) v = speed (kt)
- ✓ r = reduction rear ratio
- ✓ P" = propeller pitch (")
- ✓ D"= propeller diameter(")

Many other factors where investigated but those of correlation factot R^2 equal to or greater than 0.8 are publish in this paper. Each of the above variables were correlated with the propeller pitch P" to give 41 equations shown in fig1 to fig41. The mean of these 41 prediction of the propeller pitch P" is the recommended selection of screw

propeller for the tugboat provided the parameters of the boat are substituted properly.

Corresponding propeller diameter D" can be estimated from the presented correlation of the propeller diameter d"on the pitch p" shown in fig 42.

III. RESULT AND DISCUSSION

The scatter point plotting of data are shown in fig1 to fig 42. In these diagrams the respective regression equation, correlation factor R^2 and the number of data points N are shown on each diagram.

Each diagram is a perspective view of the influence of the variable on the size of the propeller pitch of the tugboats. Therefore, the 41 equations show a multi-variable influence of the tugboat main parameters on the size of the propeller pitch P". The propeller diameter D"to pitch P" diagram (fig 42) show the relationship between the two variables and can be used to obtain the recommended propeller diameter for the pitch obtained already by the presented method.

It must be noted that there are other important parameters of the propeller notably: blade profile shape and size, number of blades, diameter to hub ratio and others. These factors can be determined at the advanced stage of propeller design by way of propeller model test result data as well as the hydrodynamic procedures in order to avoid cavitation and obtain the higher propulsive efficiency that is possible.

Computations of the propeller pitch P" using these 41 formulas for some of the existing tugboats will authenticate their comparative value and validity. This is done using the Microsft Excel worksheet in table 2 to table 3 for three existing tugboats.

In these tables the rows named FORMULA contain the formula number such that 1 represents the formula in fig1, 2 represent the formula in fig2 and so on.till the formula 41 of fig 41 respectively while the rows beginning with P"= is the corresponding computations of propeller pitch using the respective formulas for the tugboat main parameters listed in row 1 an 2. of each table. EXCEL expressions for instnce in Table 1 row 4 will give the following: FORMULA1=2.307*B2+6.3905 =79.45"

FORMULA2 =0.2369*(B2*B2)+6.4467*B2 = 99.2"
FORMULA3=15.19*D2+12.239 =86.37"
Similarly for FORMULA 4,5,6,…….41

In cell I16 the predicted value of P" is the mean of the values computed from FORMULAS 1 TO 41. ACTUAL D", and ACTUAL P" are the real propeller diameter and pitch of the existing tugboat named in the last row.

The predicted propeller diameter designated in row 17 and computed by:

D"=2.232*I20^0.8459 which is the formula in fig 42 .

It can be seen from these tables that:

1. For TUGBOAT "151228VW" built in Holland in 2003 with L = 26m, B= 11.5m D=3.7m T=2.25m, P=2400hp, r= 5.95, v= 10kt, the predicted selection of propeller pitch P" is 70.57", D" is 81.738" respectively while the actual propeller diameter and pitch are 67" and 67" respectively,
2. for TUGBOAT "CHALLENGER" built in the USA in 2003 with L=31.67m, B=10.97m D=4.88m, T=4.11m, p=4200hp, r= 6.0, v=11kt The selection of propeller predicted Pitch P" and diameter D" are 85.61" and 96.25" respectively, while the propeller ACTUAL Pitch P and diameter D" are 78.6"and 84.6" respectively.
3. for TUGBOAT " BEN FOSS" built in the USA in 1980 with L=23.71m, B=8.00m D=3.35m, T=2.95m, p=1700hp, r= 4.65., v=12kt The selection of propeller predicted Pitch P" and diameter D" are 62.04" and 73.30" respectively, while the propeller ACTUAL diameter and pitch are 76"and 76" respectively

These few results show that authenticity of the predicted formulas. The predicted **selection of propeller pitch** are as follows: for "151228VW" tugboat, 5.3% increase, for "CHALLENGER" 8.9% increase and for "BEN FOSS" 18.3% decrease from the actual respective values.

The prediction for the **propeller diameter** are as follows: for "151228VW" tugboat, 21% increase, for "CHALLENGER" 13% increase and for "BEN FOSS" 7.2% decrease from the actual respective values.

Actually the propeller diameter prediction by a single formula is to be regarded as inconclusive study, as a similar analysis is necessary to be done for the prediction of optimum propeller diameter. This has been done and is currently under review for publication.

IV. CONCLUSION

Selection of adequate screw propeller size for tugboat at the early stage of design is usually not possible due to the fact that many ship model test and propeller model test parameters are required to calculate resistance and powering, and eventually select matching propeller size required. This work predict the size of propeller pitch and diameter at the very early design stage of tugboats basing on regression analysis between the main parameters of existing tugboats and their propeller pitch using the Microsoft Excel add in software.

The correlation resulted in 41 equations to predict propeller pitch and an equation relating the propeller diameter with the pitch. The entire equation have

correlation factor R^2 of upto 0.8 and above. A comparative and validatory computation of propeller pitch and diameter was done for three sample exiting tugboats using Excel worksheet. The result show This is based on the predicted 41 multivariate equations.

The result show 21%, 13% increase and 7.2% decrease in the predicted diameters compared with the actual diameters of the propellers for the same respective sample tugboats. Due to the fact that the result for the diameter prediction is based on one equation more study need to be done in that regards.

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NAME OF TUGB OAT	BUILT/CLS	L	B(m)	D(m)	T(m)	ME(hp)	r	D"	P"	V(Kt)
151228 VW	HOLLAND	26.00	11.50	3.50	2.25	2400	5.95	67		10
120109 VW	US	18.29	6.10	2.40	2.01	405	5.34	42		10
141138 va	singapore	38.10	10.60	4.90	4.10	3800	5.75	91		12
BEN FOSS	Usa	23.71	8.00	3.34	2.95	1700	4.65	76	76	12
151150 VT	TURKEY	22.00	7.70	3.70	2.20	600	4.5	59		12
7482TG	USA	21.90	7.35		2.14	2200		69.5		10
PETE	USA	45.42	12.19	6.77		6500	5.95	144	105	15
Double EagleUS	USA	21.34	6.71		2.74	1800	5.17	68	47	11.5
CATHERIN TURECAMO	US	33.83	9.14	4.72		3200	3.8	104		14
7486TG	USA	21.35	7.32		2.26	1500	5	59	62	12
Leslie Foss	USABS	36.58	9.45	4.54	4.11	3000	4.128	103	82	12
Wilbur R Clark	USA	46.18	10.06	5.73		5750	4.39	115		16
11264-TG OM	USA	29.89	8.64		2.75	4200	3	95	58	12
9266 - TG OM	USA	21.96	7.32		2.26	1500	5	64	46	9
11232-tg-om	usa	22.90	7.15		1.83	900	6	66	54	10
10232-TG-OM	USA	18.29	17.56		2.74	3000	5	79	80	10
EL Jaguar US	USA	42.37	10.36	5.24		4200	4.45	155	88	12.5
SUIATTIEUS	USA	37.09	9.14	5.27	5.27	3070	4.613	120	120	
MARIA BRUSCO	TEXAS	38.71	9.75	4.27		3900	2.4	80	67	
BROOKLYN	usa	33.22	9.45	4.27		3900		100	76	10
11406-TG-OM	USA	33.55	8.11		3.05	2250		116	82	12
1873-TG-OM	USA	18.30	5.71		2.30	600	5	50	38.3	10
2359-TG-OM	USA	42.70	12.20		4.88	6480		134	105	12
2978-TG-OM	USA	16.78	6.10		1.53	600	6	54		10
2987-TG-OM	USA	25.93	8.54		1.98	2600	7	75	82	11
4669-TG-OM	USA	15.86	5.71		1.35	600	4.5	46	48	9
13040-TG-OM	USA	28.87	7.55		3.48	2150	3	92	76	10
13039 TG OM	USA	26.84	7.64		3.45	2400	3	92	64	10
10750-TG-OM	USA	19.83	7.32		1.73	1200	5	60	50	10
10265 TG OM	USA	22.88	6.86		2.75	1300	6	66	56	11
9818-TG-OM	USA	32.03	8.26		2.95	2400	3	96	66	12
9163-TG-OM	USA	28.98	9.15		1.98	2400		70	63	10
11153-OT-OM	USA	30.50	7.65		2.75	1200	4	80	60	10
11407-TG-OM	USA	33.55	8.77		3.66	2400		144	112	10
7058 TG-OM	USA	24.61	7.91		2.82	1400	5.7	65	56	11
130718-VN	ISTANBUL	19.95	7.00	3.20	2.20	1200		58		9
140904 VW	TURKEY	14.80	5.90	3.00	2.15	1660		59		11
150419 VT	USA	16.64	6.10	2.32	1.98	900	4.59	48	44	
WEATHERLY	USA ABS	32.00	11.58	5.38	5.23	4720		90.6	85.4	
DEFENDER	USA ABS	31.52	11.28	5.49	4.27	3900		108	117	
challenger	USA ABS	31.70	10.97	4.88	4.11	4200	6	84.6	78.6	11

Table 1:- A collection of the principal dimension of modern Tugboat

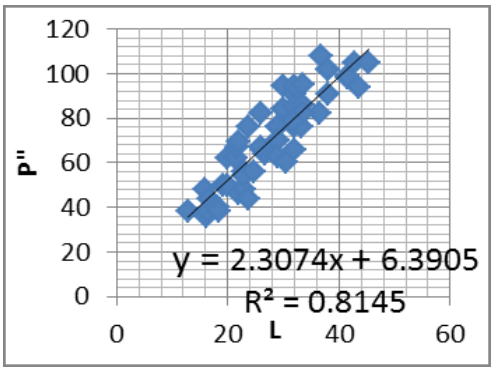

Fig.1:- CORRELATION OF P"and L (N= 57)

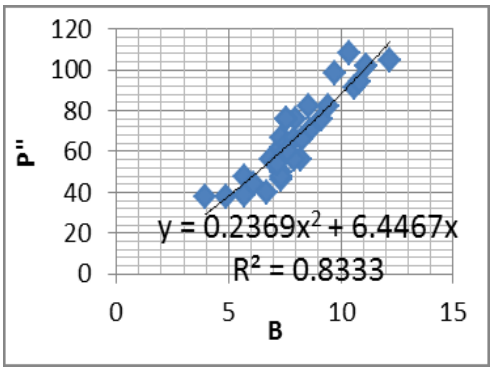

Fig.2:- CORRELATION OF P"and B (N= 34)

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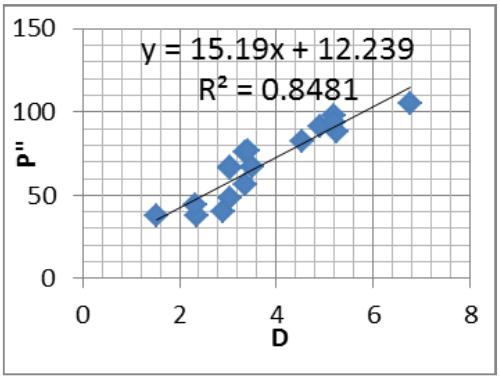

Fig. 3:- CORRELATION OF P"and D (N= 16)

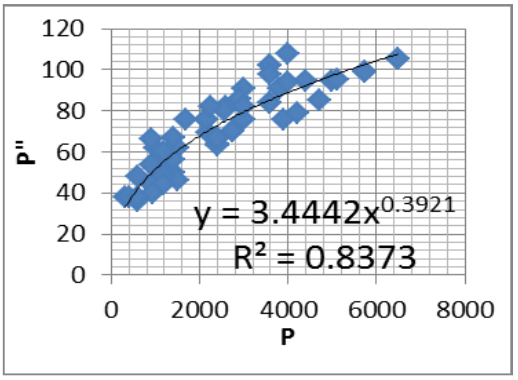

Fig. 4:- CORRELATION OF P"and P (N= 57)

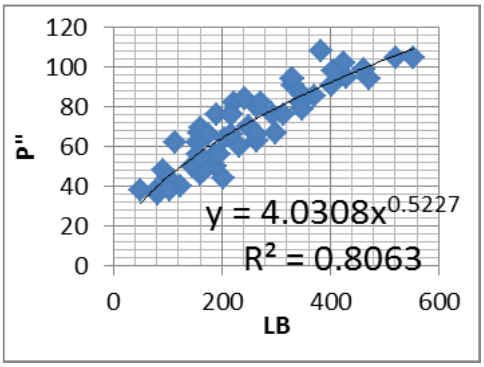

Fig. 5:- CORRELATION OF P"and LB (N= 58)

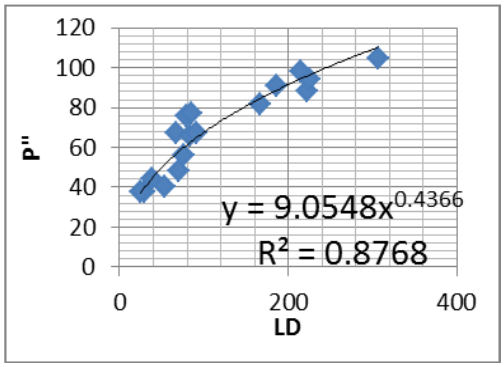

Fig. 6:- CORRELATION OF P"and LD (N=16)

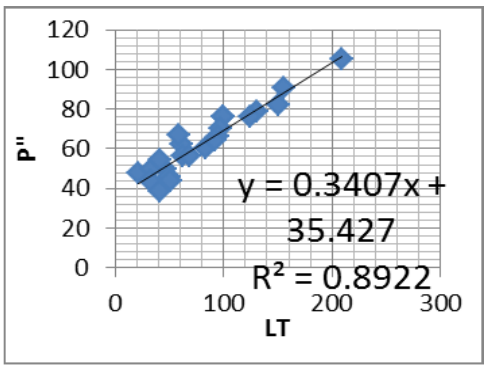

Fig. 7:- CORRELATION OF P"and LT (N= 23)

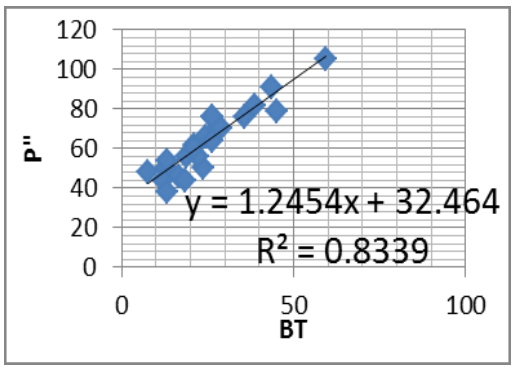

Fig. 8:- CORRELATION OF P"and BT (N=23)

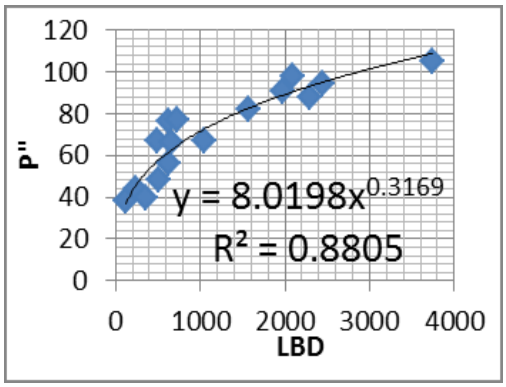

Fig. 9:- CORRELATION OF P"and LBD (N= 16)

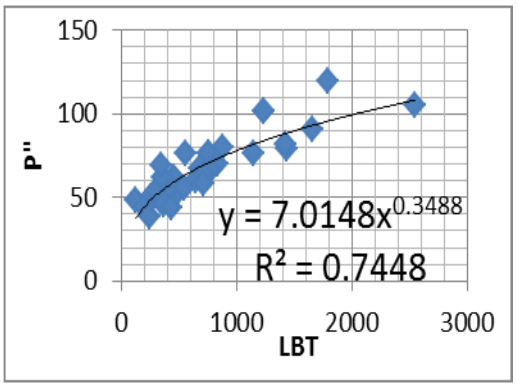

Fig.10:- CORRELATION OF P"and LBT (N= 31)

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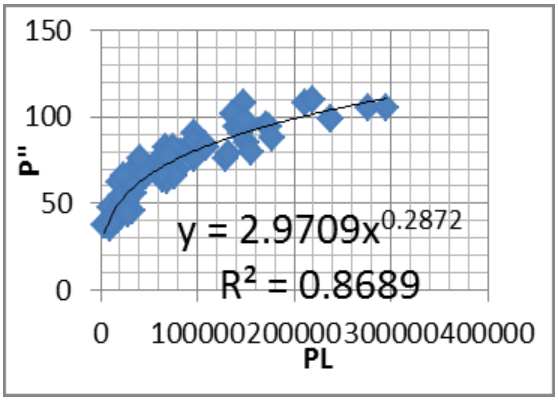

Fig.11:- CORRELATION OF P"and PL (N= 63)

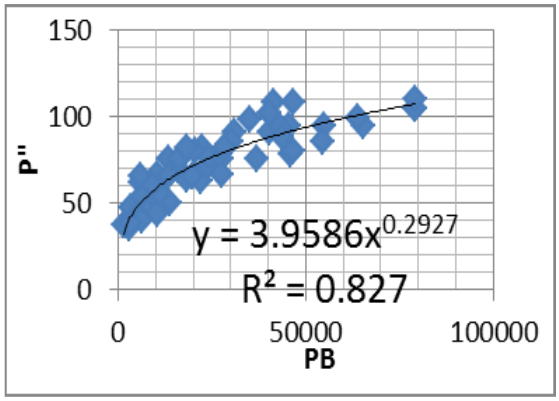

Fig.12:- CORRELATION OF P"and PB (N= 63)

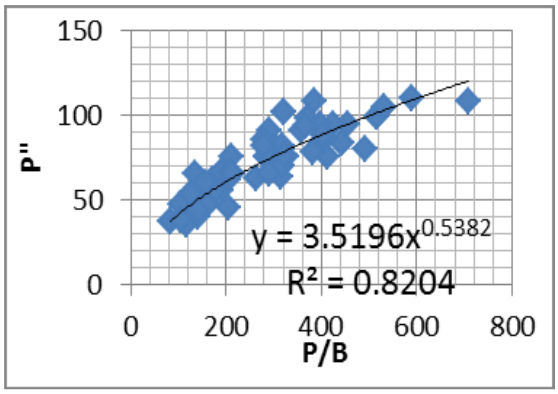

Fig.13:- CORRELATION OF P"and P/B (N=63)

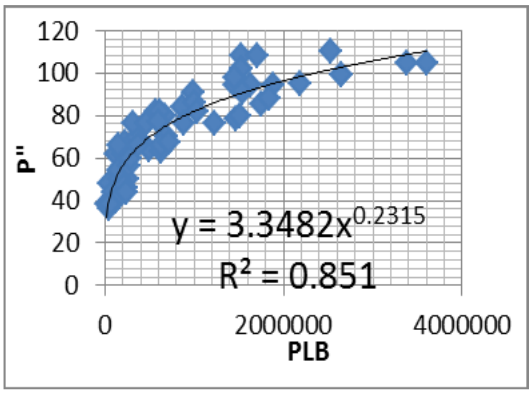

Fig.14:- CORRELATION OF P"and PLB (N=63)

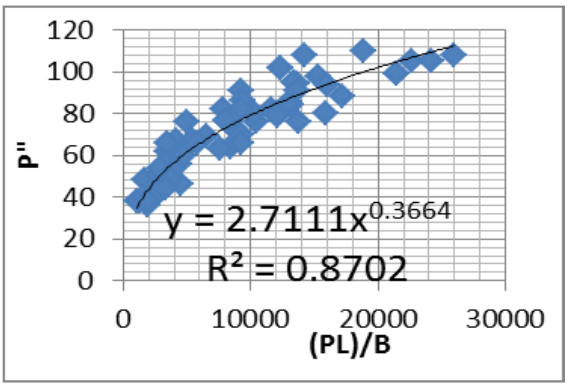

Fig.15:- CORRELATION OF P"and (PL)/B (N=63)

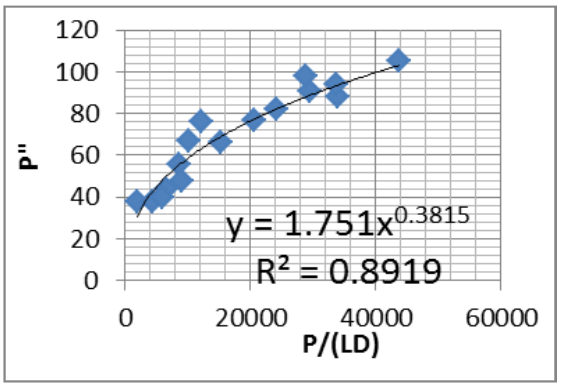

Fig.16:- CORRELATION OF P"and P/(LD) (N=15)

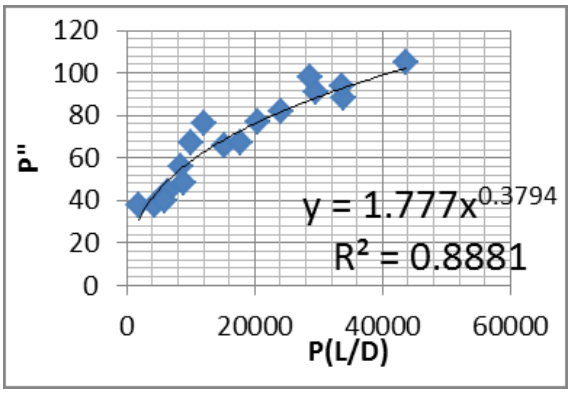

Fig.17:- CORRELATION OF P"and P(L/D) (N= 16)

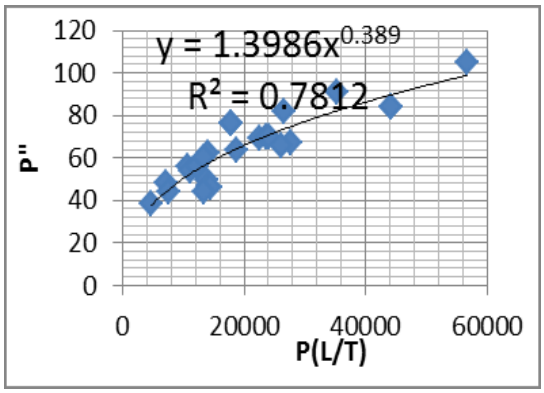

Fig.18:- CORRELATION OF P"and P(L/T)(N=25)

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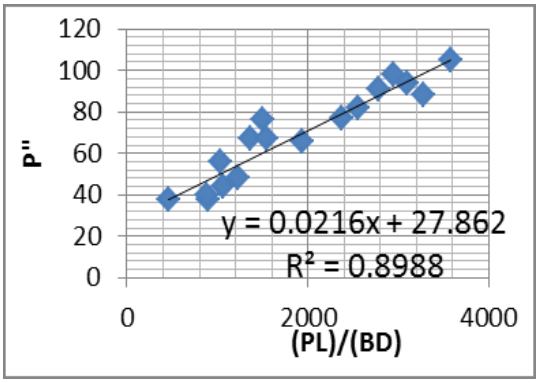

Fig.19:- CORRELATION OF P"and (PL)/(BD) (N=16)

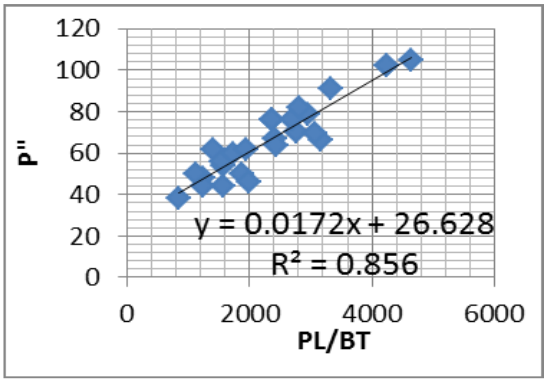

Fig.20:- CORRELATION OF P"and (PL)/(BT) (N=27)

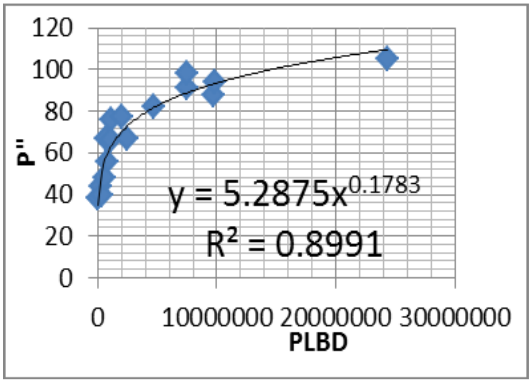

Fig.21:- CORRELATION OF P"and PLBD (N=16)

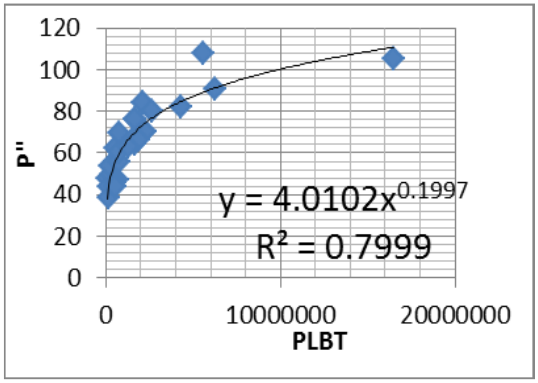

Fig.22:- CORRELATION OF P"and PLBT (N= 28)

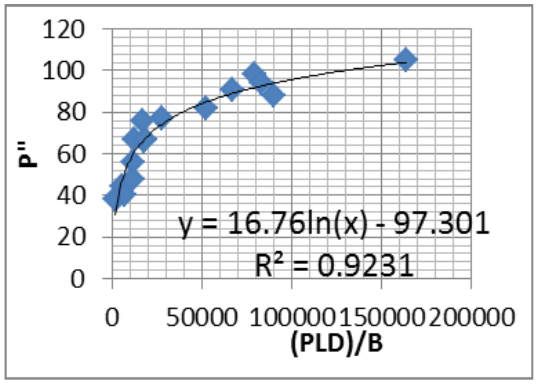

Fig.23:- CORRELATION OF P"and (PLD)/B (N= 16)

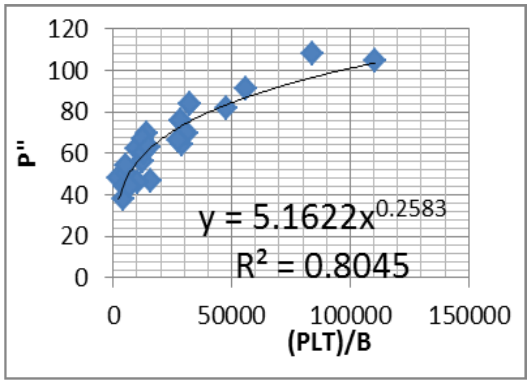

Fig.24:- CORRELATION OF P"and (PLT)/B (N=27)

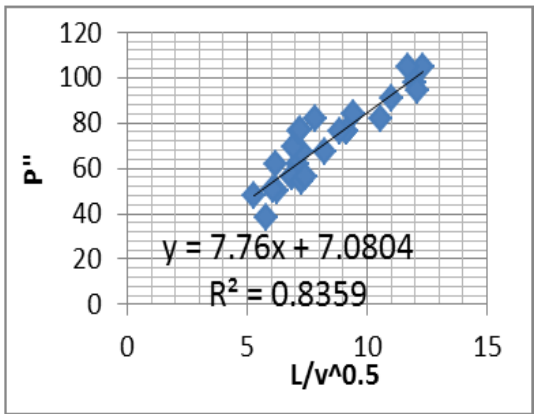

Fig.25:- CORRELATION OF P"and L/√v (N= 27)

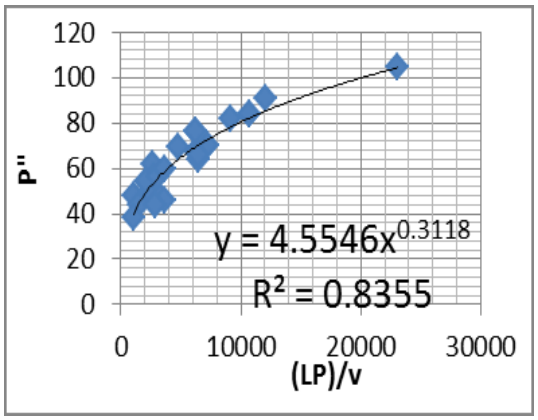

Fig.26:- CORRELATION OF P"and LP/v (N= 25)

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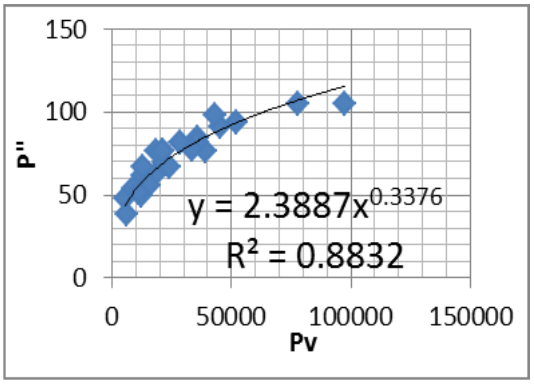

Fig.27:- CORRELATION OF P"and Pv(N=27)

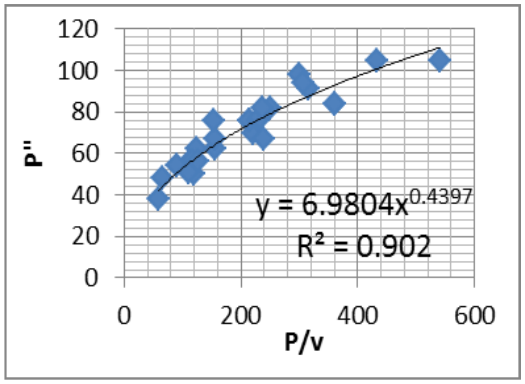

Fig.28:- CORRELATION OF P"and P/v (N= 27)

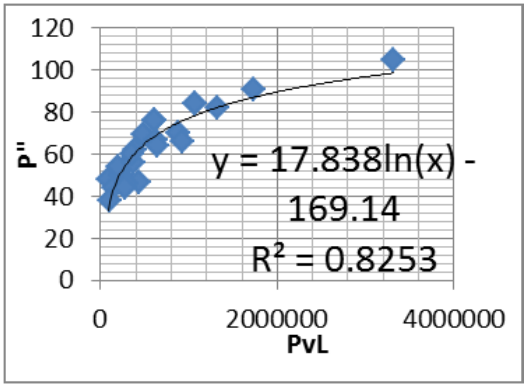

Fig.29:- CORRELATION OF P"and PvL (N= 25)

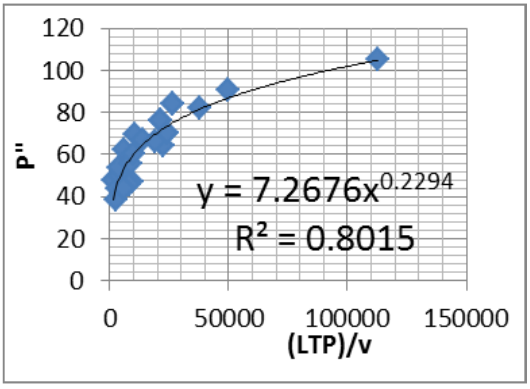

Fig.30:- CORRELATION OF P"and LPT/v (N= 25)

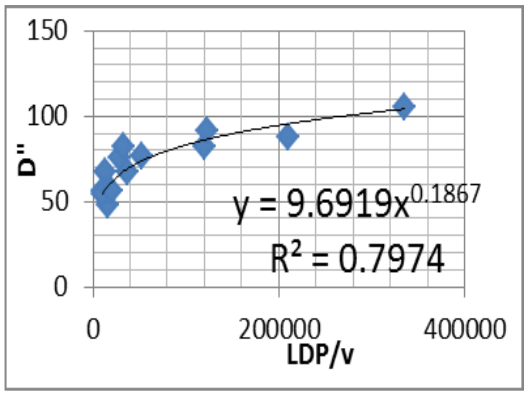

Fig.31:- CORRELATION OF P"and LDP/v(N= 15)

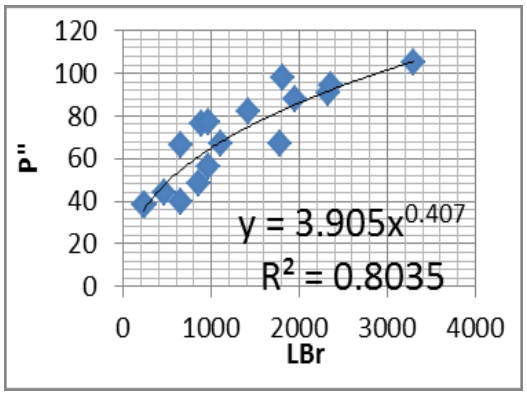

Fig.32:- CORRELATION OF P"and PBr (N= 16)

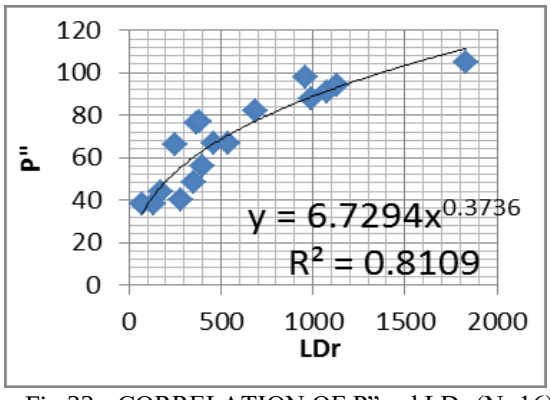

Fig.33:- CORRELATION OF P"and LDr (N=16)

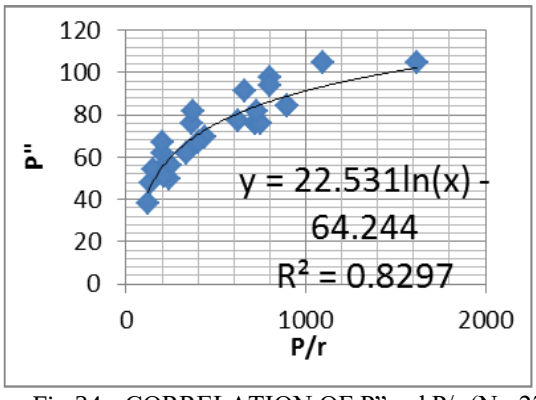

Fig.34:- CORRELATION OF P"and P/r (N= 27)

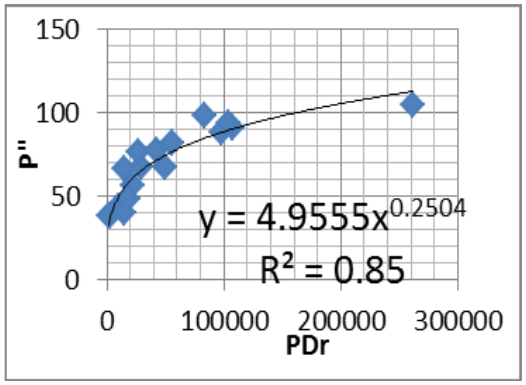

Fig.35:- CORRELATION OF P"and PDr (N=16)

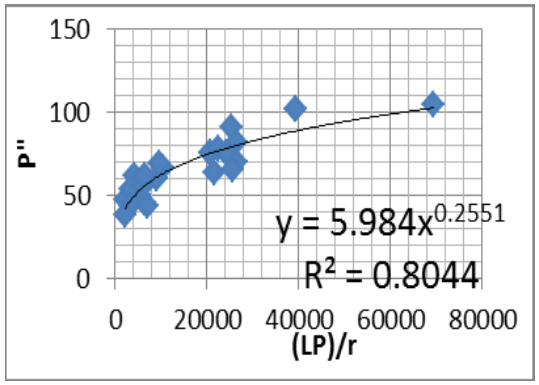

Fig.36:- CORRELATION OF P"and LP/r (N= 27)

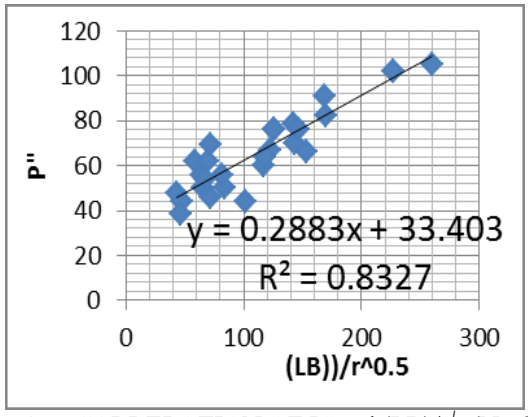

Fig.37:- CORRELATION OF P"and (LB)/√r (N= 27)

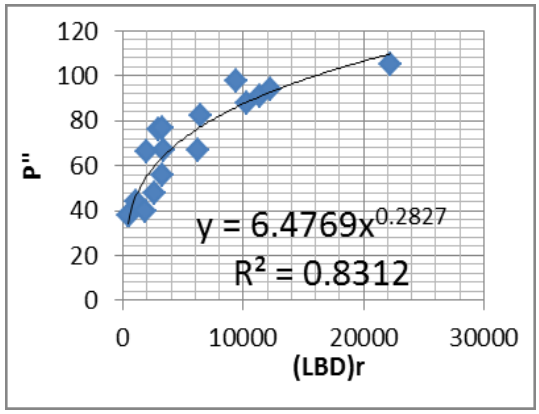

Fig.38:- CORRELATION OF P"and (LBD)r (N= 16)

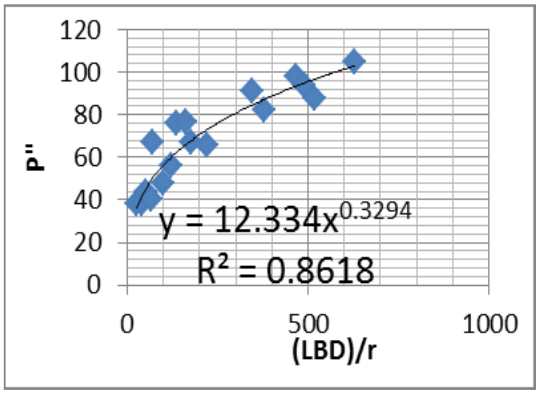

Fig.39:- CORRELATION OF P"and (LBD)/r (N=16)

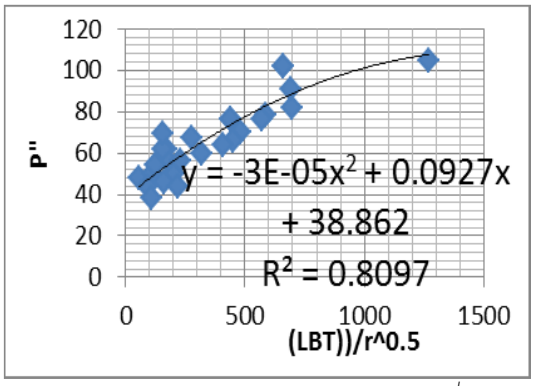

Fig.40:- CORRELATION OF P"and (LBT)/√r (N= 27)

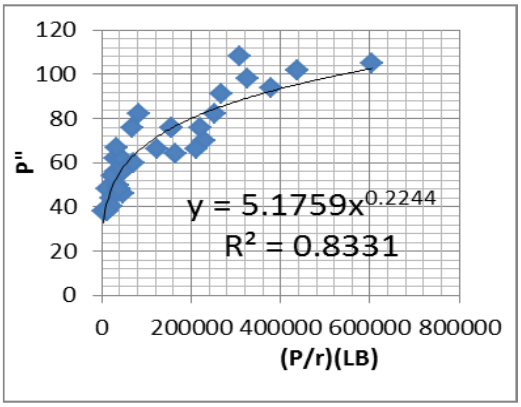

Fig.41:- CORRELATION OF D"and LBDr (N = 34)

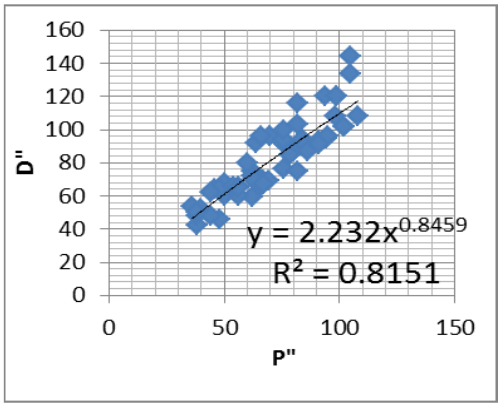

Fig.42:- CORRELATION OF D"and P" (N= 57)

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	A	B	C	D	E	F	G	H	I
1	TUGBOAT	L = 26m	B = 11.5m	D = 3.7m	T = 2.25m	P =2400hp	r = 5.95	v = 10kt	
2		26	11.5	3.7	2.25	2400	5.95	10	
3	FORMULA	1	2	3	4	5	6	7	8
4	P" =	66.37	105.47	68.44	72.85	79.33	66.42	55.36	64.69
5	FORMULA	9	10	11	12	13	14	15	16
6	P" =	73.92	67.98	70.81	78.96	62.35	75.94	63.31	75.91
7	FORMULA	17	18	19	20	21	22	23	24
8	P" =	71.35	74.82	59.54	68.11	73.90	69.65	68.75	58.67
9	FORMULA	25	26	27	28	29	30	31	32
10	P" =	70.88	69.47	71.93	77.71	68.89	64.98	63.25	82.12
11	FORMULA	33	34	35	36	37	38	39	40
12	P" =	72.15	70.94	75.45	63.48	68.74	77.77	68.97	62.15
13	FORMULA	41							
14	P" =	71.49							
15									
16					MEAN OF P"(1 - 50) =				70.57
17	D" =	81.738629				ACTUAL P"= 67"			
18	ACTUAL P"= 67"			TUGBOAT NAME =		"151228VW" HOLLAND 2003			

Table 2:- Calculation Of Pitch For Sampl Tugboat 1 “151228vm”

	A	B	C	D	E	F	G	H	1
1	TUGBOAT	L = 31.67m	B = 10.97m	D = 4.88m	T=4.1m	P =4200hp	r = 6.0	v = 11kt	
2		31.67	10.97	4.88	4.11	4200	6	11	
3	FORMULA	1	2	3	4	5	6	7	8
4	P" =	79.45	99.23	86.37	90.73	85.80	81.69	79.77	88.61
5	FORMULA	9	10	11	12	13	14	15	16
6	P" =	84.63	88.38	88.00	91.74	86.43	89.50	85.00	97.73
7	FORMULA	17	18	19	20	21	22	23	24
8	P" =	85.61	79.45	81.53	77.37	88.12	90.52	86.86	84.37
9	FORMULA	25	26	27	28	29	30	31	32
10	P" =	81.18	85.38	89.73	95.31	84.09	86.84	75.36	87.59
11	FORMULA	33	34	35	36	37	38	39	40
12	P" =	86.40	83.36	93.23	76.84	74.29	87.96	79.16	82.71
13	FORMULA	41							
14	P" =	83.67							
16					MEAN OF P"(1 - 41) =				85.61
17	D" =	96.253157				ACTUAL P"= 78"			
18	ACTUAL D"= 84.6"			TUGBOAT NAME =		"CHALLENGER" USS ABS 2003			

Table 3:- Calculation Of Pitch For Sample Tugboat 2 “Challenger”

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	A	B	C	D	E	F	G	H	1
1	TUGBOAT	L = 23.71m	B = 8.00m	D= 3.34m	T = 2.95m	P=1700hp	r =4.65	v=12kt	
2		23.71	8	3.34	2.95	1700	4.65	12	
3	FORMULA	1	2	3	4	5	6	7	8
4	P" =	61.09	66.74	62.97	63.64	62.53	61.01	59.26	61.86
5	FORMULA	9	10	11	12	13	14	15	16
6	P" =	61.95	63.75	62.45	64.18	62.96	63.10	61.61	65.97
7	FORMULA	17	18	19	20	21	22	23	24
8	P" =	62.84	56.81	60.45	56.00	62.92	62.67	65.79	61.73
9	FORMULA	25	26	27	28	29	30	31	32
10	P" =	60.19	57.27	68.09	61.63	64.34	59.99	55.28	61.72
11	FORMULA	33	34	35	36	37	38	39	40
12	P" =	61.19	68.72	63.42	60.47	58.76	61.96	62.25	60.90
13	FORMULA	41							
14	P" =	63.14							
16					MEAN OF P"(1 - 41) =				62.04
17	D" =	73.301153				ACTUAL P"= 76"			
18	ACTUAL D"= 76"			NAME OF BOAT = "BEN FOSS" BUILT IN USA 1980					

Table 4:- Calculation Of Pitch For Sample Tugboat 3 “Ben Foss”