Prediction of Optimum Propeller Diameter Basing on Analysis of Existing Vessels for Tugboats Design

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Abstract:- **A regression analysis basing on data collected from 386 different tug boats of the world was carried out. This resulted in 51 reliable equations on which the optimum propeller diameter of tugboats can be determined at the early design stage of the vessels. These regression equations published here are based on propeller diameter of the existing tugboats on one hand and the principal dimensions and other important factors of the vessels on the other hand. Microsoft EXCEL add-in software is used for the numerous regression analysis from which the published equations are selected. The bases for the selecting of the equations are their respective coefficients of regression values R^2 which must be equal to or greater than 0.80. A compalative and validatory calculation is presented using these equations to determine the optimum propeller diameter for two tug boats. When the propeller optimum diameter is known at the early design stage, the designer will design the preopeller aperture and wake better innorder to achieve higher propulsion efficiency as well as avoid cavitation.**

Keywords: **Tugboat, propeller diameter, hull particulars, correlations, formulas.**

I. INTRODUCTION

The diameter of screw propeller of a tug boat is importance factor in the proper design of the propulsion of the boat. it depends on the dimensions, and shape of the hull, the size of the main engine, and reduction gear ratio of the tugboat. It is the first requirement in the selection of the propeller pitch and other associated parameters of the propeller in the hydrodynamic selection of the optimum propeller of the boat.

Existing screw propeller types are: fixed pitch propeller, controlable pitch propeller, kort nozzle screw propeller, and others. Their blade element geometry can be of the Gown series, B-scew series, or other types [1], [2], [3] to mention few references.

Propeller diameter is limited in size by draft, and shape of the underwater shape at the stern of the boat as well as the minimum clearance distance required between the hull and the propeller. This minimum clearance is necessary to minimize propeller induced vibration on the hull, erosion of hull plate, as well as improved overall propulsion efficiency [4].

The minimum clearance determinces the maximium scew propeller diameter. The optimum propeller diameter is the actual diameter obtained which together with the pitch and other parameters result in the maximum propulsive efficiency of the vessel at the designed speed of the vessel.

This optimum parameters of the propeller is normally obtained by hydrodynamic computations according to several authorities which rely more on propeller model series test data and ship hull models resistance tests basing on hydrodynamic theories [5], [6], etc.

This work collected the main dimensions of the tugboats of the world together with their screw propeller diameters and pitch amongst others data and performed a linear and non-linear correlation analysis on them. This resulted on useful formulas which aid in the computation of optimum propeller diameter to match with the size of a projected tug boats.

II. MATERIAL AND METHOD

The world tugboat data were collected from these referenced sources [7], [8], [9]. There were 386 number of tugboats data collected and sorted for this work. These were sets of records of length L, breadth B, depth D, draught T all in meters. Others were Main power P in horsepower, propeller diameter D" and ptch P" in inches respectively as well as design speed v in knorts and reduction gear ratio r. Table 1 show abridged part of this collected data.

The data analysis process was executed using the MICROSOFT EXCEL add in software. The mathematical background of this software can be found in existing textbooks [10], and others. The functions fitted to the data were of these types:

linear $Y = mX + c$. 1

power $Y = mX^c$. 2

Exponential $Y = m \ln(X) + c$ 3

Polynomial $Y = aX^n + aX^{n-1} + .. + aX^{1-} + +c$. 4

Where Y is the variable depicting the propeller diameter D" of the tugboat.

X is the geometrical dimensional factor of of the tugboats.

m, c, and n are constants determined by the regreesion analysis.

Actual X variables are the following: L, D, T, P, D/r, T/r, LB, LD, LT, Lv, LBv, LB/v, LB/r, LDr, LTv, LT/r, LT/v, LB/√v, PL, PB, Pv, P/v, P/r, P/B, PLB, PLv, PL/D, PL/v, PDr, PTv, PL/r, PL/B, PLD/B, PL/BD, PLBD, PLB/D, PL/(Br), PLT/B, LBT, PLBT, LBDr, LBD, LBT/√r LBD/r, LB/√r, LBT/r, LBTv, LTP/r, LBT/v, LBT/√v. We have p" (propeller pitch.on Y axis and D" (propeller diameter) on Xaxis for one of the regression analysis.

Each of these 53 X variables predict the Y variable D"

The 50 correlation formulas derived were those that have correlation coefficient of 0.8 and above, even though so many other variable were investigated. Each of these 50 formulas is a perspective influence of the hull variable on the propeller diameter which is being predicted in the design process of tug boats.

The preliminary prediction of propeller pitch P" can be done from the 51th formula for the predicted diameter D".

III. RESULT AND DISCUSSION

.The entire 51 formulas are presented in the scatter diagram Fig 1 to Fig 51 with their individual correlation factor and formula included. The number of data points for each diagram is also included. It can be observed that the power function featured mostly in the regression analysis.

Sample, computations of optimum diameter using these 50 formulas for some of the existing tugboats will authenticate their comparative value and validity.

Let us compute the optimum propeller diameter D" for three tugboats. This is done in Table 2, Table 3 and Table 4 using the Microsft Excel worksheet. 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 50 from fig 50 respectively while the rows with D"= is the corresponding computaions of propeller diameter 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=3.885*(B2)^0.9165 =76.5",

FORMULA2=19.081*(E6)+7.9522=78.6,"

FORMULA3 =22.951*(F6)+18.766=70.4"

Similarly for FORMULA 4,5,6,…….50

FORMULA50 =9.8639*((C6*D6*F6)/I6^0.5)^0.4033=

=85.68"

In cell I16 the predicted value of D"is the mean of the values computed from FORMUIAS 1 TO 50. ACTUAL D", and ACTUAL P" are the real propeller diameter and pitch of the existing tugboat named in the last row.

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

P" = 1.0428*J20^0.9552 which is the formula in fig 51 .

It can be seen from these tables that:

1, For TUGBOAT "151228VW" built in Holland in 2003. The predicted optimum propeller diameter D" is 79,96", P" is 68.51" respectively while the actual propeller diameter and pitch are 67" and 67" respectively,

2, for TUGBOAT " CHALLENGER" built in he USA in 2003. The optimum propeller predicted diameter D" and pitch are 99.73" and 84,62" respectively, while the propeller ACTUAL diameter and pitch are 84.6"and 78.6" respectively.

3, for TUGBOAT "BEN FOSS" built in he USA in 2003. The optimum propeller predicted diameter D" and pitch are 73.68" and 63,37" respectively, while the propeller ACTUAL diameter and pitch are 76"and 76" respectively.

These few exmaplar results show the authenticity of the predicted formulas. The **predicted** propeller parameters where slightly larger than the **actual** ones for the first two tugs, and will definitely result in higher bollard pull for the tug boats. The third boat show nearly the same values for the predicted and actual propeller optimum diameter. However, this facts are true if the propeller is not cavitating. This is a matter that can be fully addressed in the final hydrodynamic tradeoffs of the design process relating to the geometry of the propeller actually installed on the tugboat.

IV. CONCLUSION

The optimum propeller diameter can be determined at the later stage of design of tugboat using the hydrodynamic propeller model test results. Obtaining the optimum parameters can become far fetched at this stage since the propeller aperture at the stern has already limited the propeller diameter. The B-series and the Gown series propeller test results are available for this purpose. To obtain optimum propeller diameter from analysis of actual existing tug boats by regression analysis is presented in this work. This will enable the computation of the propeller optimum diameter D" at the very early design stage so the the design of the propeller apaerture and wake as well as immersion of the propeller can be done properly leading to higher propulsive efficiency.

The regression analysis is between the actual propeller diameter and the main parameters of the tugboats selected form 386 tugboats of the world. Micrsoft EXCEL add in was used to carryout this analysis which resulted in 51 equations selected from many others basing on their correlation coefficient of 0.80 and above. The maximum range of validity with respect to main tug boat parameters as well as the number of data points N for each respective regression formula is presented Fig 1 to 51. Their respective regression equations are also presented in these figures.

To validate the proposed method, the calculation of the optimum propeller diameter using the proposed equations for two existing vessels was done and presented. For the first two tugs there was 19.34% AND 17.88% respective increase in the predited optimum diameter. This is an advantage. The third tug "Ben Foss" the optimum diameter predicted a reduction from the actual propeller diameter by 0.031% which is very negligible. This is a well designed tugboat propulsion system.

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Table 1 A collection of the principal dimension of modern Tugboat

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

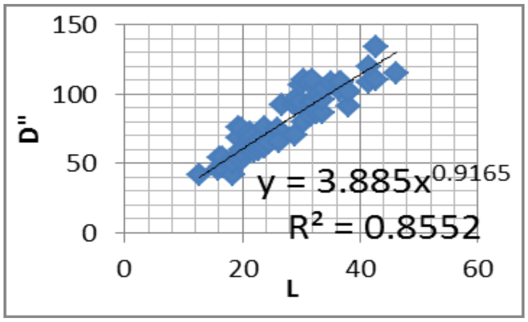

Fig.1 CORRELATION OF D"and L (N=69)

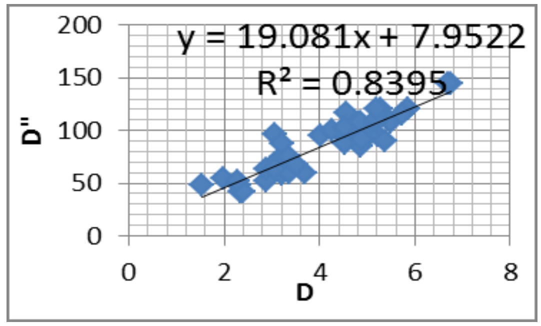

Fig.2 CORRELATION OF D"and L (N= 43)

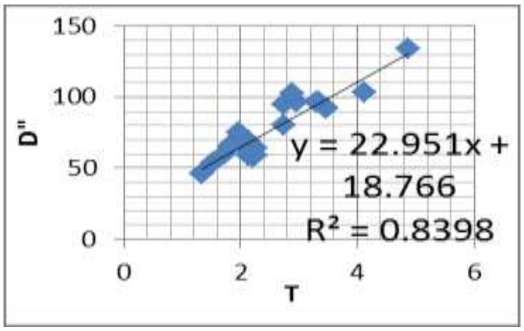

Fig.3 CORRELATION OF D"and T (N= 24)

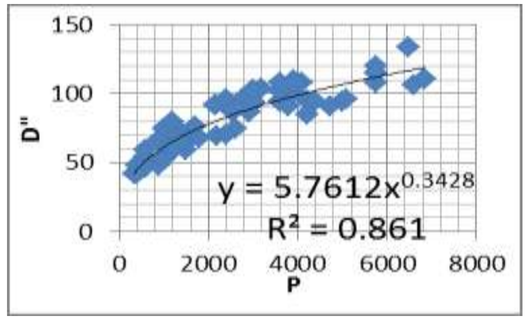

Fig.4 CORRELATION OF D"and P (N= 69)

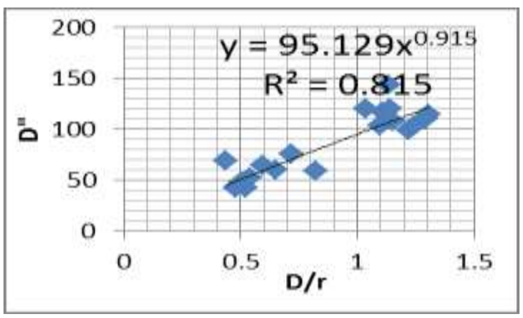

Fig.5 CORRELATION OF D"and D/r (N= 19)

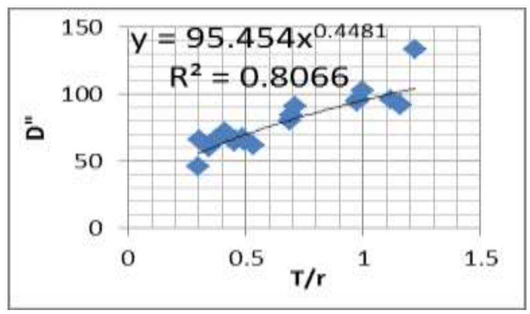

Fig.6 CORRELATION OF D"and T/r (N= 20)

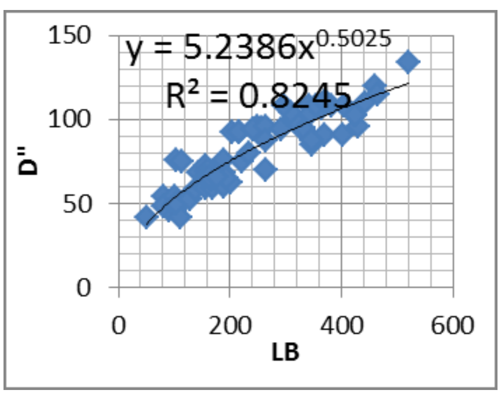

Fig.7 CORRELATION OF D"and LB (N= 69)

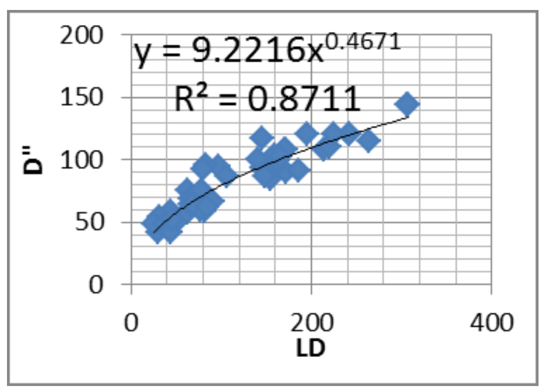

Fig.8 CORRELATION OF D"and LD (N= 45)

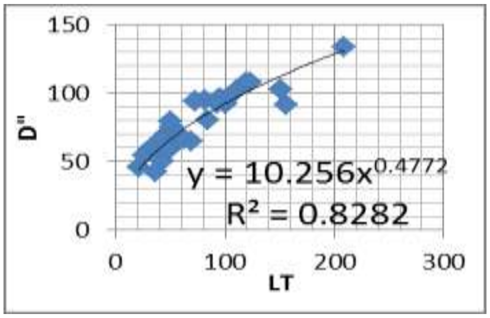

Fig.9 CORRELATION OF D"and LT (N= 36)

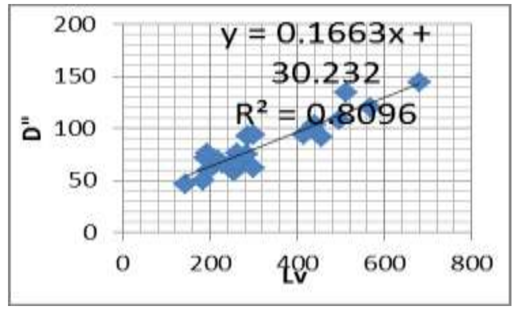

Fig.10 CORRELATION OF D"and Lv (N= 27)

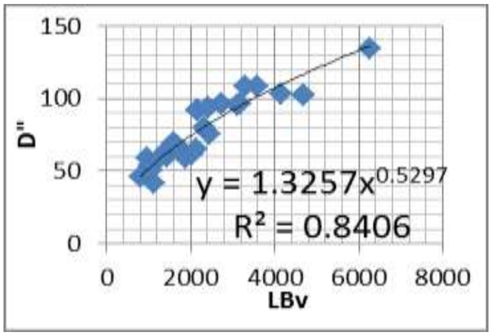

Fig.11 CORRELATION OF D"and LBv (N= 31)

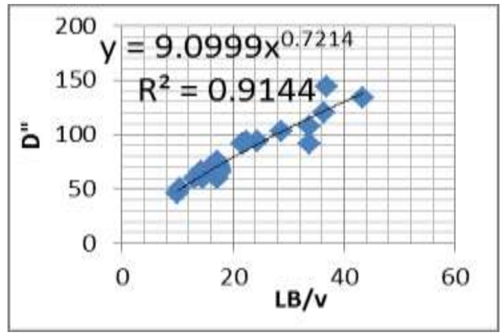

Fig.12 CORRELATION OF D"and LB/v (N= 22)

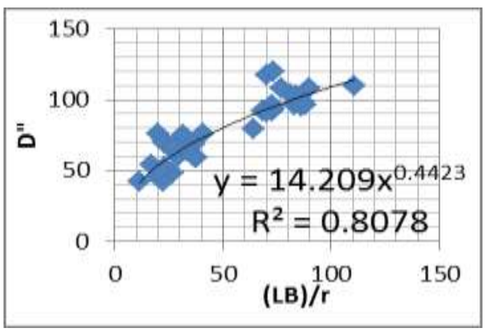

Fig.13 CORRELATION OF D"and LB/r (N=41)

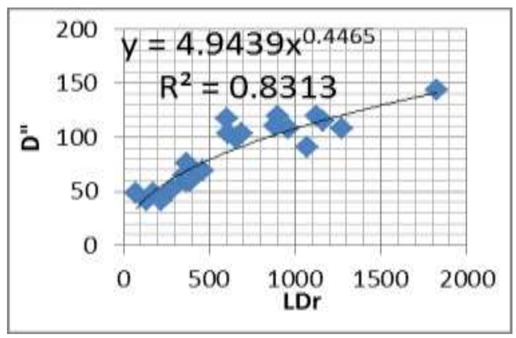

Fig.14 CORRELATION OF D"and LDr (N= 22)

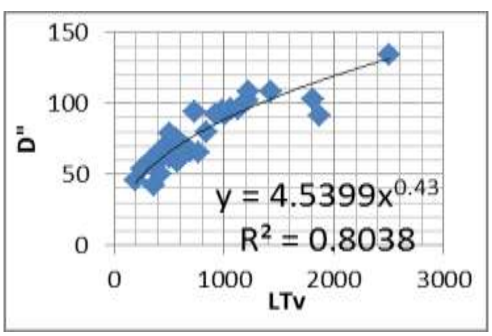

Fig.15 CORRELATION OF D"and LTv (N=36)

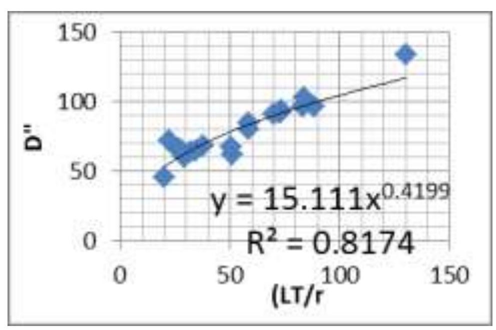

Fig.16 CORRELATION OF D"and LT/r (N= 20)

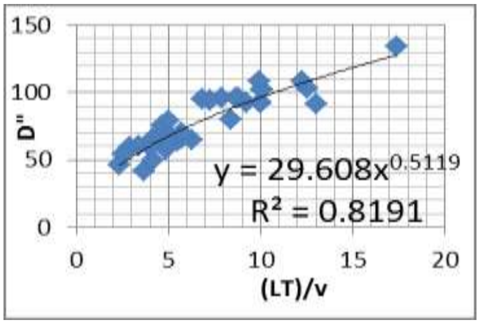

Fig.17 CORRELATION OF D"and LT/v (N=37)

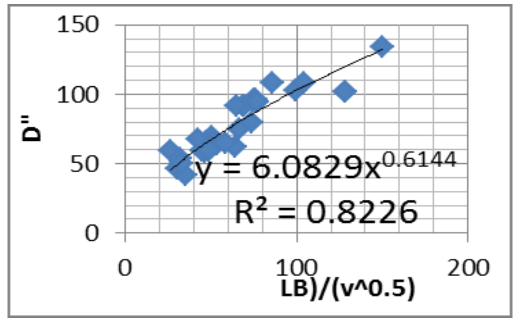

Fig.18 CORRELATION OF D"and LB/√v (N=33)

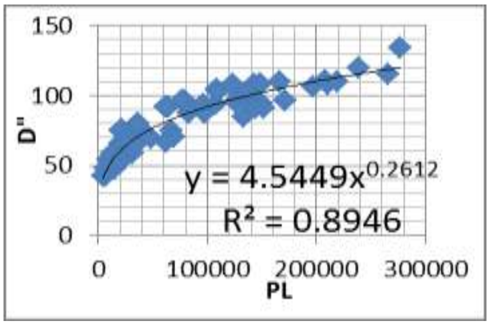

Fig.19 CORRELATION OF D"and PL (N= 70)

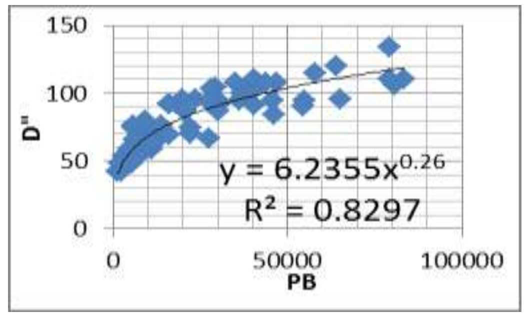

Fig.20 CORRELATION OF D"and PB (N=70)

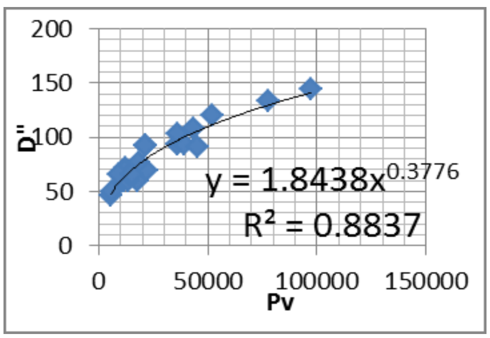

Fig.21 CORRELATION OF D"and Pv (N=23)

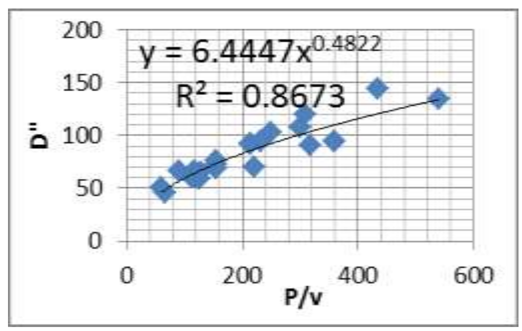

Fig.22 CORRELATION OF D"and P/v (N= 23)

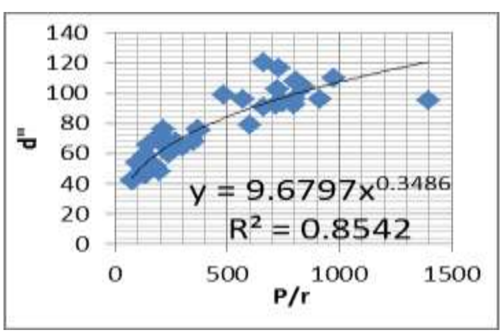

Fig.23 CORRELATION OF D"and P/r (N= 41)

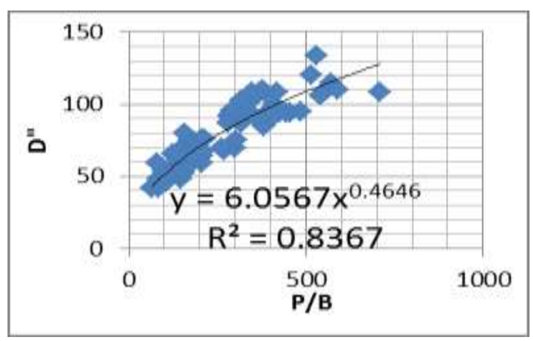

Fig.24 CORRELATION OF D"and P/B (N= 70)

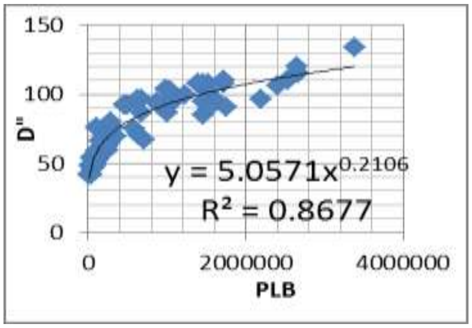

Fig.25 CORRELATION OF D"and PLB (N=70)

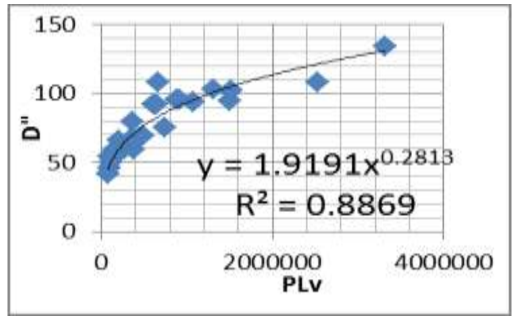

Fig.26 CORRELATION OF D"and PLv (N= 33)

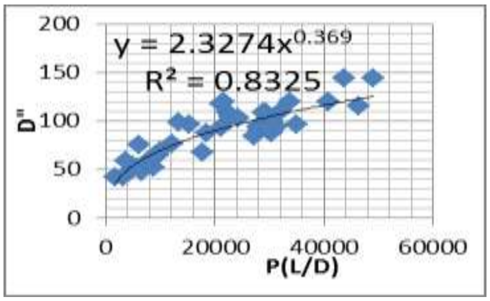

Fig.27 CORRELATION OF D"and PL/D (N=43)

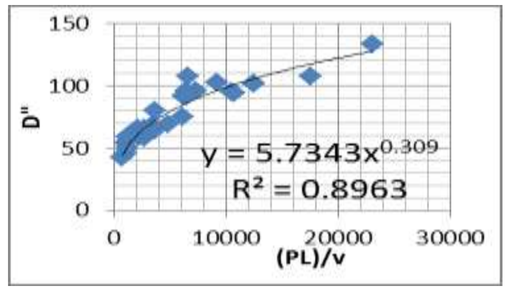

Fig.28 CORRELATION OF D"and PL/v (N=33)

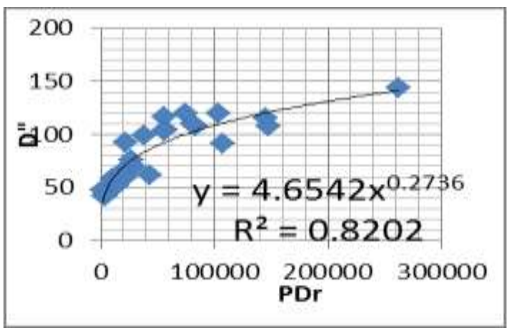

Fig.29 CORRELATION OF D"and PDr (N= 23)

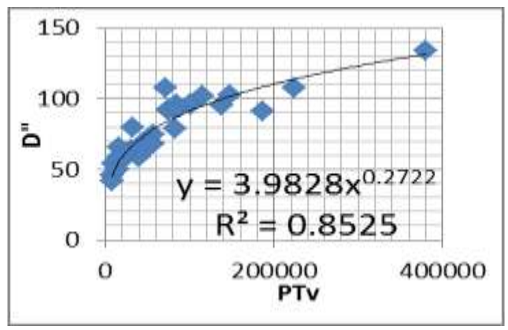

Fig.30 CORRELATION OF D"and PTv (N= 36)

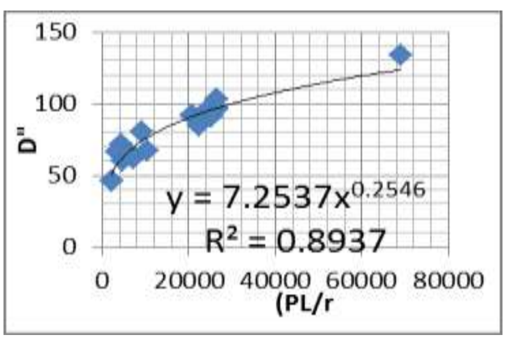

Fig.31 CORRELATION OF D"and PL/r (N= 20)

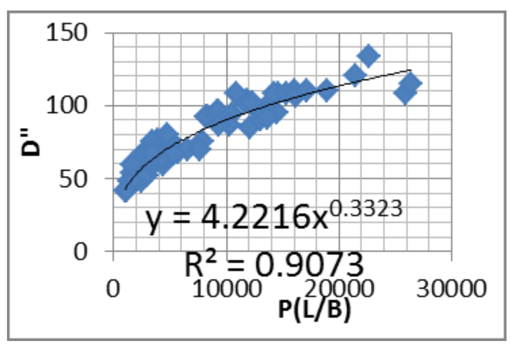

Fig.32 CORRELATION OF D"and PL/B (N=70)

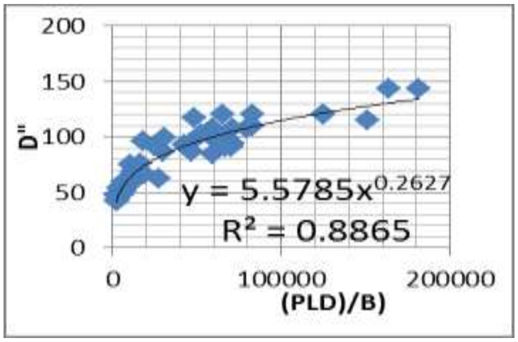

Fig.33 CORRELATION OF D"and PLD/B (N= 45)

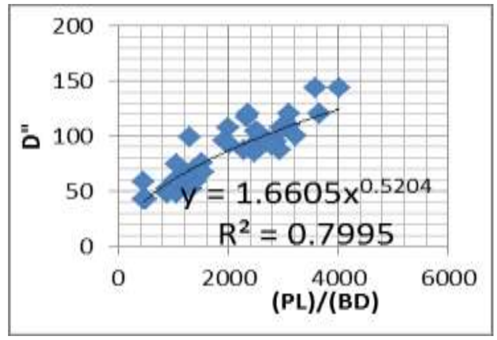

Fig.34 CORRELATION OF D"and (PL)/(BD) (N= 42)

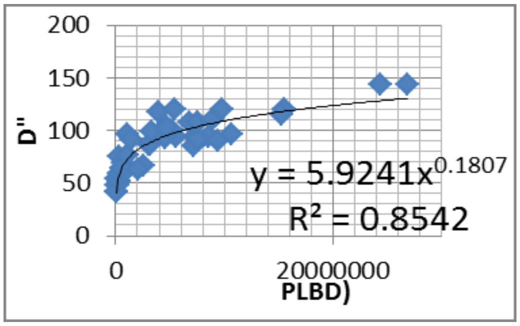

Fig.35 CORRELATION OF D"and PLBD (N= 45)

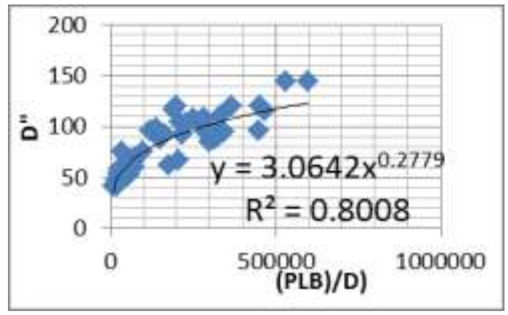

Fig.36 CORRELATION OF D"and PLB/D (N=45)

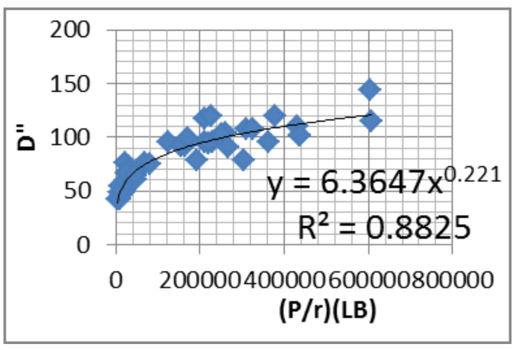

Fig.37 CORRELATION OF D"and (P/r)(LB) (N= 47)

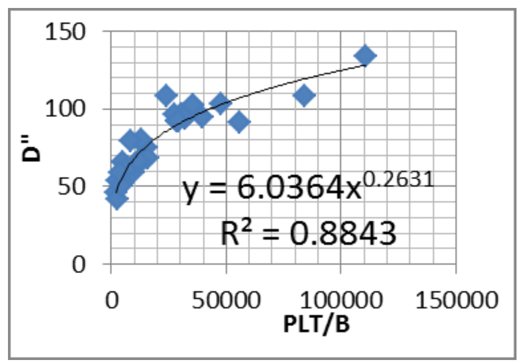

Fig.38 CORRELATION OF D"and PLT/B (N=36)

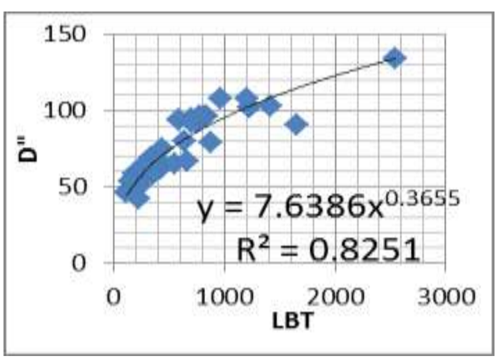

Fig.39 CORRELATION OF D"and LBT (N=36)

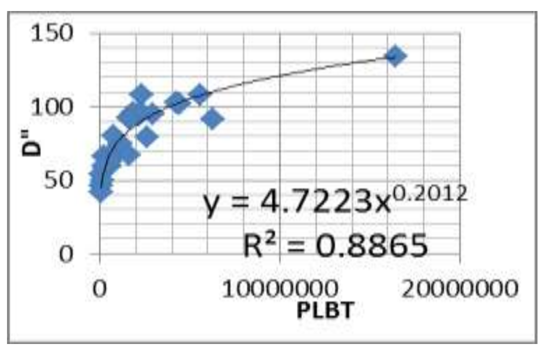

Fig.40 CORRELATION OF D"and PLBT (N= 36)

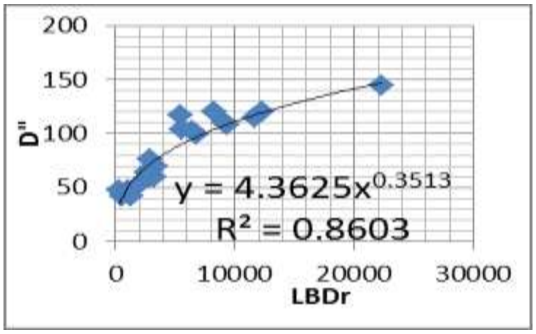

Fig.41 CORRELATION OF D"and LBDr (N= 19)

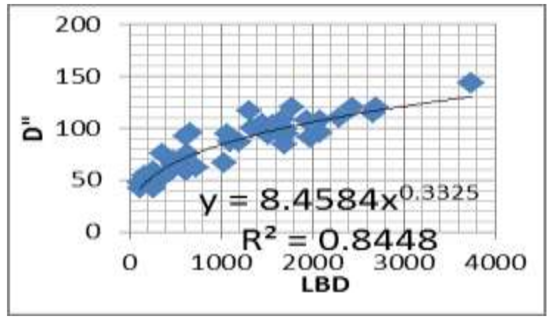

Fig.42 CORRELATION OF D"and LBD (N= 45)

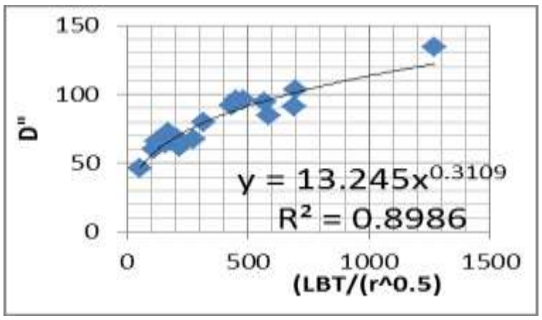

Fig.43 CORRELATION OF D"and LBT/√r (N=20)

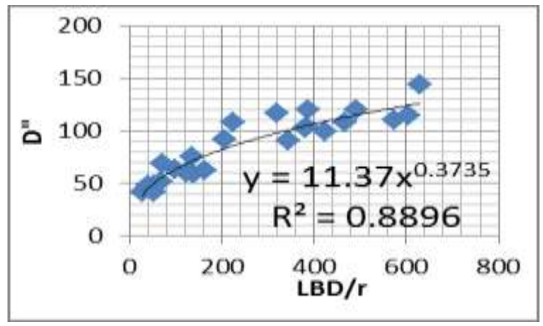

Fig.44 CORRELATION OF D"and LBD/r (N= 23)

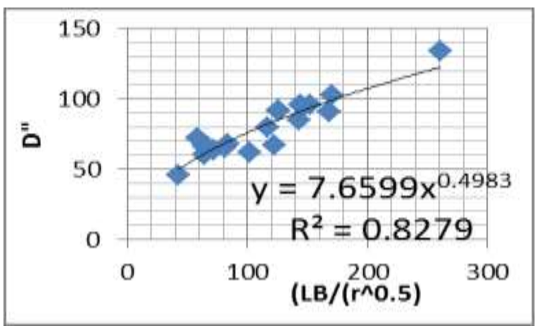

Fig.45 CORRELATION OF D"and LB/√r (N= 20)

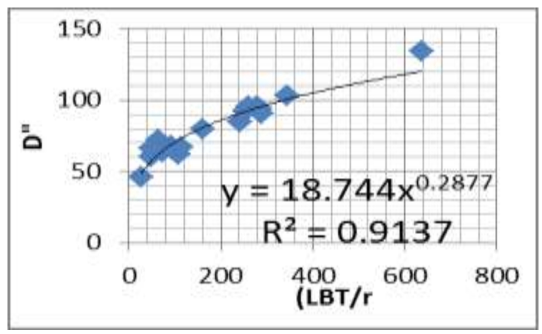

Fig.46 CORRELATION OF D"and LBT/r (N= 20)

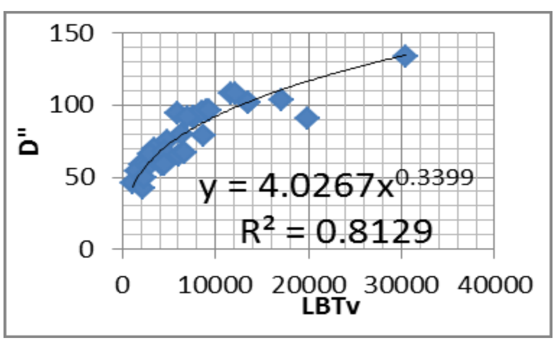

Fig.47 CORRELATION OF D"and LBT/v (N=36)

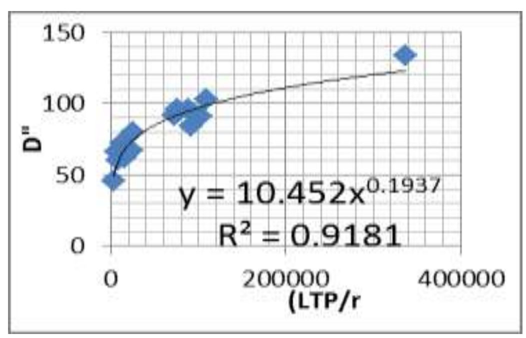

Fig.48 CORRELATION OF D"and LTP/r (N= 20)

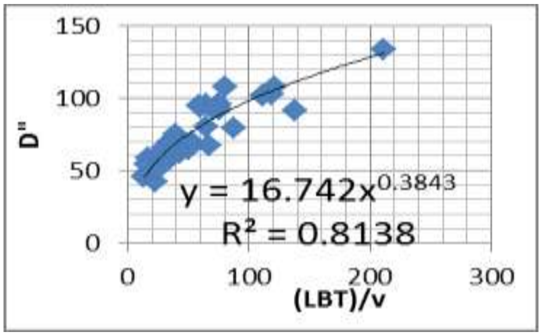

Fig.49 CORRELATION OF D"and LBT (N= 37)

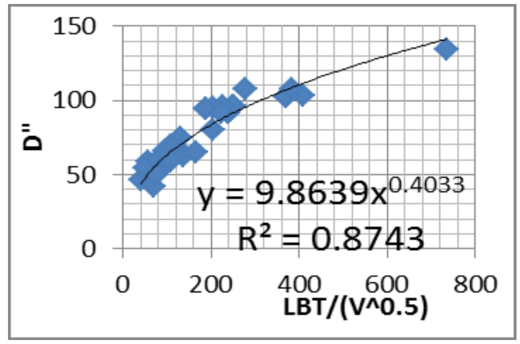

Fig.50 CORRELATION OF D"and PLBT (N= 33)

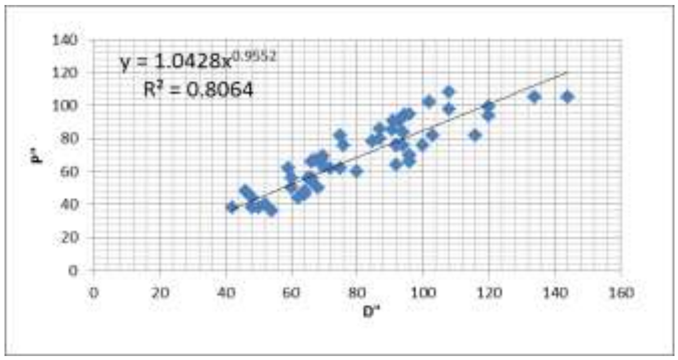

Fig.51 CORRELATION OF P"and D" (N=59)

TABLE 2 OPTIMUM PROPELLER DIAMETER COMPTATION EXAMPLE 1

	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	D" =	76.95	78.55	70.41	83.03	61.59	61.74	91.87	77.83
5	FORMULA	9	10	11	12	13	14	15	16
6	D" =	71.49	73.47	91.94	105.58	80.41	84.21	70.29	50.06
7	FORMULA	17	18	19	20	21	22	23	24
8	D" =	73.13	75.80	81.29	89.02	83.12	90.59	78.38	72.42
9	FORMULA	25	26	27	28	29	30	31	32
10	D" =	86.53	81.90	84.46	85.35	91.21	77.33	76.60	73.53
11	FORMULA	33	34	35	36	37	38	39	40
12	D" =	75.31	73.79	85.79	90.32	84.48	71.78	82.53	83.79
13	FORMULA	41	42	43	44	45	46	47	48
14	D" =	95.75	86.97	76.00	80.05	84.12	73.05	80.54	73.49
15	FORMULA	49	50						
16	D" =	84.38	85.68		D" = MEAN OF D"(1 - 50) =				79.96
17	P" =	68.511	predicted			ACTUAL D" = 67"			
18	ACTUAL P"= 67"			TUGBOAT NAME =			"151228VW" HOLLAND 2003		

TABLE 3 EXAMPLE2

	A	B	C	D	E	F	G	H	1
1	TUGBOAT	L=31.67m	B=10.97m	D = 4.88m	T = 4.11m	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	D" =	92.20	101.07	113.09	100.59	78.74	80.57	99.07	97.12
5	FORMULA		10	11	12	13	14	15	16
6	D" =	104.72	88.17	104.70	109.84	85.62	104.5	103.29	54.38
7	FORMULA	17	18	19	20	21	22	23	24
8	D" =	104.89	100.26	99.06	101.71	106.43	113.3	94.99	96.01
9	FORMULA	25	26	27	28	29	30	31	32
10	D" =	100.48	104.09	100.82	104.71	114.93	108.9	92.68	96.05
11	FORMULA	33	34	35	36	37	38	39	40
12	D" =	100.03	97.08	102.54	101.86	98.64	103.9	108.66	109.1
13	FORMULA	41	42	43	44	45	46	47	48
14	D" =	111.57	100.24	95.91	93.60	90.46	90.49	107.45	95.47
15	FORMULA	49	50						
16	D" =	108.63	113.85		D" = MEAN OF D"(1 - 50) =				99.73
17	P" =	84.62	Predicted			ACTUAL D" = 84.6"			
18	ACTUAL P"= 78.6"			BOAT NAME =		"CHALLENGER" USS ABS 2003			

TABLE 4 OPTIMUM PROPELLER DIAMETER COMPTATION EXAMPLE 3

	A	B	C	D	E	F	G	H	1
1	TUGBOAT	L = 23.71m	B= 8.0m	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	D" =	70.72	71.68	86.47	73.78	70.28	77.85	73.09	71.07
5	FORMULA	9	10	11	12	13	14	15	16
6	D" =	77.86	77.55	79.57	66.66	73.32	69.16	82.10	48.16
7	FORMULA	17	18	19	20	21	22	23	24
8	D" =	73.00	65.77	72.52	74.06	78.17	70.26	75.74	73.03
9	FORMULA	25	26	27	28	29	30	31	32
10	D" =	73.11	76.24	74.64	70.48	75.44	79.64	72.97	71.74
11	FORMULA	33	34	35	36	37	38	39	40
12	D" =	71.89	74.88	72.89	74.40	74.76	75.59	77.15	75.33
13	FORMULA	41	42	43	44	45	46	47	48
14	D" =	72.19	72.26	74.58	71.27	71.30	74.37	80.49	74.64
15	FORMULA	49	50						
16	D" =	73.29	76.67		MEAN OF D"(1 - 50) =				73.68
17	P" =	63.372701				ACTUAL D"= 76"			
18	ACTUAL P"= 76"			NAME OF BOAT = "BEN FOSS" BUILT IN USA 1980					