TRAWLING PULL EXERTED BY A TRAWLER - A METHOD OF ESTIMATION FROM PROPELLER DIMENSIONS AND ITS COMPARISON WITH SEA MEASUREMENTS

T. D. GOPINATHA KARTHA* AND R. L. ROY CHOUDHURY
Central Institute of Fisheries Technology, Ernakulam.

The proper matching of the pull exerted by a trawler and the size of trawl is important for maximising the catching efficiency. The available pull is more dependant on the propeller and its working conditions than the installed engine power. The normal practice is to directely connect net size to the installed power in the boat by formulae without reference to the propeller dimensions or the available trawling pull and this is not adequate to find out the optimum combination. By the method outlined in this paper, the accurate calculation of trawling pull is possible by taking into account only the propeller diameter, pitch and r. p. m. The predictions by the method are compared for trawlers with powers between 30 and 60 H. P. and agreement is found to be within $\pm$ 5%. The power absorbed by the propeller in trawling condition can also be calculated by this method for checking whether the engine is being overloaded.

INTRODUCTION

The proper matching of installed power in a trawler and the net size is important for maximising the efficiency of a trawler. This becomes more important in the case of small trawlers where relatively high installed powers can be justified if they are effectively utilised for fishing operations. Basically, this problem will mean estimation of the trawling pull which can be exerted by the trawler, so that, the net size can be designed to utilise this available pull effectively, or, if the net design for a particular set of conditions have been optimised by other considerations the trawling pull or in other words the required installed power can be determined. The state of loading of the engine and the trawling pull are largely dependant on the propeller dimensions and its conditions of working. Accurate estimation of these quantities are necessary to ensure optimum combination of net size and maximum utilisation of engine power and

*Now with Geological Survey of India, Hyderabad.

avoid overloading. Normally used formulae of the type S = 0.105 P + 4 (Miyamoto, 1959) and S = 0.095 P 0.56 (Koyama, 1962) where 'S' is the area of one otter board in ft.^{2} and 'P' is the installed horse power, are based on fitting regression lines to data collected from existing vessels. The net dimensions are related by a set of empirical relations based on dimensions of otter board. Such formulae, however, do not yield information about the power utilised during trawling, pull exerted and net resistance and so it is difficult to know whether they are matched properly. These can be calculated by considering only the diameter, pitch and r. p. m. of propeller in trawling condition (Roy Choudhury, 1962). In this paper, the method has been extended with some modifications, and the predictions compared with sea measurements.

Calculation Methods

Calculation of the thrust delivered and the horse power absorbed by a propeller will require considerations a set of parameters defining blade geometry and also propeller r. p. m., diameter, pitch (or pitch ratio), advance co-efficient ($J = \frac{v}{nd}$ where 'v' is the velocity, 'n' propeller revolutions/sec., 'd' diameter of propeller, all expressed in any consistent system of units). The possibility of reducing the number of these variables was examined (Roy Choudhury, 1962). It was found that effects of the changes of parameters of blade geometry were negligible for the small boat propellers, and Troost series 3.50 could be used for the calculations of other 3-bladed propellers. Further the analysis of data from fishing vessels (Table I) shows that J = 0.175 can satiafactorily describe the working conditions of the propeller while trawling. With thess simplications the number of variables are reduced to only the propeller r. p. m., diameter and pitch. Fig. 1. is prepared from Troost series 3.50 for simplifying calculations. The values of thrust and absorbed horse powers for 400 r. p. m. are readily available by entering this chart with propeller diameter and pitch ratio. For other r. p. m. the thrust and power values thus obtained are multiplied by a factor proportional to square and cube of ratio of r. p. m. to standard r. p. m. of 400. Fig. 2 gives these correction factors against r. p. m. The calculation method is shown in Appendix 'A'

The delivered thrust (T) thus obtained from the chart after applying r. p. m. correction is balanced as

$$T = R + 't_1' + \triangle T \quad (i)$$

where 'R' is resistance of vessel in trawling condition, 't_1' is the resistance of the gear (including warps) to forward motion and is actually the pull required to tow the gear. '$\triangle$ T' is a resistance augmentation of the vessel due to hull propeller interaction and generally is known as thrust deduction (instead of increase in resistance).

'R' values were estimated from model test results. The values are rather small and can be estimated by a co-efficient 4 lbs/ton of displacement of boat derived from these model results. In the calculations presented here, however, actual model test results have been used.

The condition of working of propellers of tugs are very similar to trawlers. A value of 0.10 for $\triangle$ T/T is taken on the basis of the results of tug propulsion investigations (Dawson and Parker 1962). The buttock flow form 'B' and 3 knots speed are nearest to the working conditions of fishing vessels. The actual value 0.07 is increased to 0.10 considering the rather wide sternposts of wooden fishing vessels.

In practice, the warp tensions are only measured. The warps are inclined to the direction of motion and as such the total warp tension (t) is greater than the gear resistance (t_1). This difference is analysed with reference to Fig. 3. AB is a small portion of one warp near the point of suspension 'A'. CD is the direction of forward motion parallel to X – axis. BC is parallel to the Y – axis (transverse direction). ACD is the vertical plane. Angle $\propto$ and β are explained in the figure. If the two warps are suspended from 'A' then angle 'β' is the half angle between the two warps at 'A'.

From the figure

$$t = \frac{t_1}{\text{Cos} \propto \text{Cos} \beta} \quad \text{(ii)}$$

From measurements 'β' is found to be around 3.50 ($2\beta = 7°$) and '$\propto$' varies from 15° to 30°. Substituting these numerical values in (ii)

$t = 1.03$ to $1.15\ t_1$ (iii)

for $\propto = 15°$ to $30°$ respectively.

This relationship is important because in practice 't' is only measured (without $\propto$ and β) and this relation shows the limits of accuracy to which the measured tension (t) and predicted pull (t_1) can be compared.

Measurements

The measurements were carried out in 8 boats in 3 size groups 30′, 32′ and 36′ shrimp trawlers. The reduction ratio, propeller diameter and pitch were noted in each case. The boats operated from Cochin and used shrimp trawls. The 30′ and 32′ boats operated generally in depths 6 to 12 fathoms and 36′ boats in 8 to 16 fathoms. The sea conditions were generally calm. During trawling operations, the tension in the warps, the r. p. m. of engine were measured and the trawling speeds were estimated. The tensions in the warps were measured by a portable tension meter, which could be clamped to the warp beyond the towing point. The tension in each warp was measured separately by the same instrument and the total tension obtained by addition. The time interval between the measurements on the two warps was kept to a minimum, about 2 to 3 minutes. The r. p. m. of the engine was measured on the forward end of the crankshaft by a tachometer two to three times during each of the trawling operations under observatian. In some cases however, the forward end of the crankshaft was not accessible and the disc attachment on the tachometer was used on the propeller shaft directly and speed measured by comparing the diameters of the disc and the shaft. The trawling speed was estimated roughly from the time taken by a floating object to pass along the length of the boat.

Results and Discussions

The particulars of boats, their reduction gears and propellers are given in Table I. The measured tension, propeller shaft r. p. m. and the estimated trawling speeds for the different boats are given in Table – II. As can be expected, for the same boat many of the measurements i. e. set of r. p. m. – tension – speed values are identical. From the table, it is seen that the estimated advance co-efficient (J) varies generally between 0.130 to 0.210, the mean being about 0.175. The trawling condition can thus be satisfactorily represented by J = 0.175. There are some advantages in reading the values corresponding to J = 0.175 from Troost series for the preparation of Fig. 1 and so J = 0.175 is chosen instead of the mean 0.170. The thrust and absorbed power vary $\pm$ 4 to 7 % for the above range of variation of J from 0.175.

Table III shows the calculated values of the pull exerted (t_1) and the power absorbed by the propeller by considering propeller dimensions of the different boats and the r. p. m. as presented in Table II. The calculations were carried out with the help of Fig. 1. and the steps shown in Appendix 'A'. The available s. h. p. of

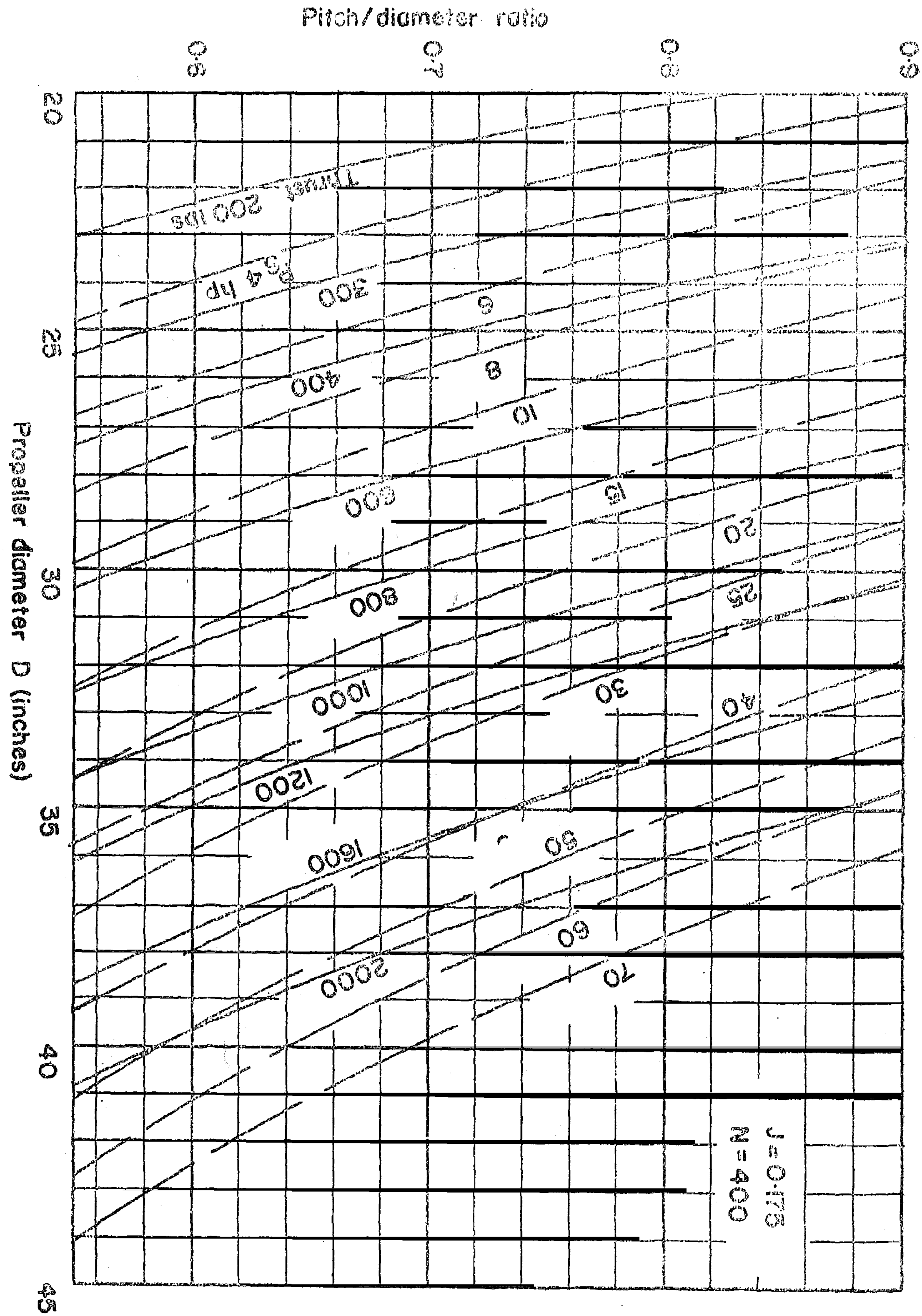

Fig. 1. Trawling thrust and S. H. P. Diagrams for 400 r. p. m.

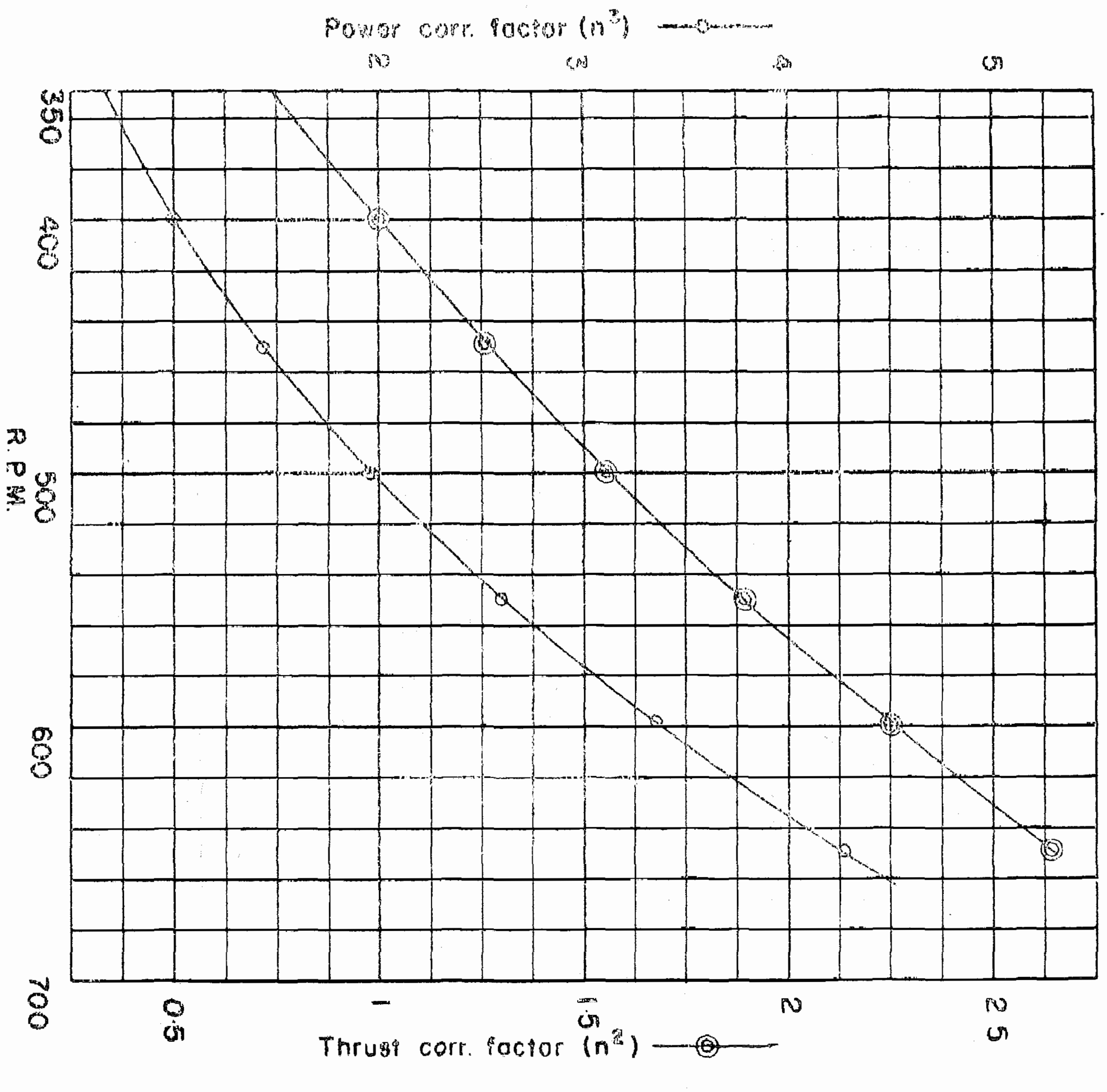

Fig. 2. Thurst and S. H. F. correction factors

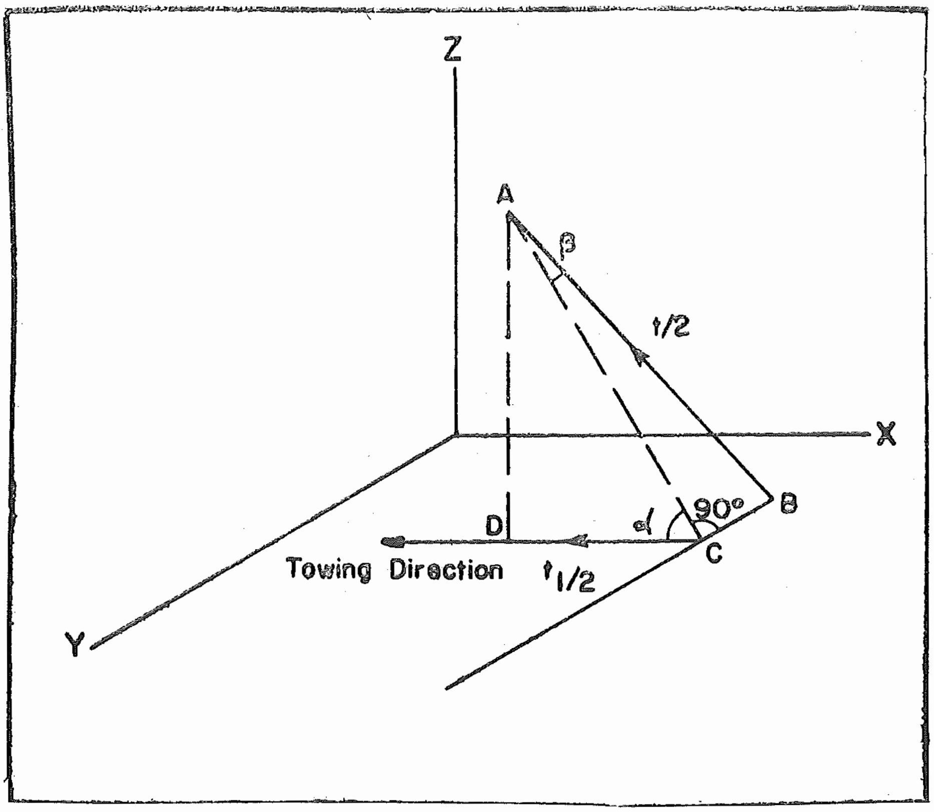

Fig. 3. Diagram showing the difference between warp tension (t/2) and resistence to forward motion (t_1 2)

TABLE I BOAT PARTICULARS

Boat No.	I	II	III	IV	V	VI	VII	VIII
Length	30′	32′	32′	32′	36′	36′	36′	36′
Breadth	9′—3″	9′—6″	9′—6″	9′—6″	11′—6″	11′—6″	11′—6″	11′—6″
Displacement (tons)	7	7.42	7.42	7.42	12.25	12.25	12.25	12.25
Max BHP / r. p. m.	33 / 1200	43.5 / 1500	43.5 / 1500	36 / 1500	62.5 / 1500	62.5 / 1500	62.5 / 1500	62.5 / 1500
Reduction ratio	1.61:1	2:1	2:1	2:1	3:1	3:1	3:1	3:1
Propeller Dia / Pitch (inches)	23 / 18	25.5 / 18	25.5 / 19.5	26 / 16	35.3 / 25.5	35.3 / 25.5	36 / 25.6	36 / 25.6
Pitch ratio P/D	0.782	0.706	0.765	0.615	0.722	0.722	0.711	0.711

TABLE II WARP TENSION AND R. P. M. MEASUREMENTS FROM THE BOATS

Boat No. Prop. dia. (in)		Prop. RPM (N)	Measured warp tension (t) lbs.	Estimated trawling speed v knots	J	Engine r. p. m. (n_1)
1		2	3	4	5	6
I	1.	670	792	2.04	0.161	1080
d = 23	2.	670	851	2.22	0.175	1080
	3.	663	834	2.02	0.161	1065
	4.	663	830	1.62	0.129	1065
	5.	645	792	1.87	0.153	1038
II	6.	552	845	1.58	0.136	1104
d = 25.5	7.	552	870	1.53	0.132	1104
	8.	563	880	1.58	0.134	1126
	9.	552	900	1.62	0.140	1104
III	10.	555	835	1.72	0.148	1110
d = 25.5	11.	555	835	1.89	0.163	1110
	12.	540	785	1.82	0.161	1080
IV	13.	550	710	1.80	0.153	1100
d=26	14.	550	710	1.80	0.153	1100
V	15.	342	1275	1.24	0.125	1026
d=35.3	16.	352	1223	2.52	0.246	1056
	17.	356	1192	2.49	0.241	1068
VI	18.	364	1135	2.22	0.210	1092
d=35.3	19.	362	1162	1.99	0.190	1086
	20.	356	1129	1.99	0.193	1068
	21.	362	1130	1,91	0.182	1086
VII	22.	356	1012	1.48	0.140	1068
d=36	23.	358	1019	1.42	0.134	1074
	24.	356	970	2.13	0.202	1068
	25.	347	1047	1.62	0.158	1041
VIII	26.	387	1107	2.27	0.204	1161
d=36	27.	366	1114	2.28	0.210	1098
	28.	382	1135	1.99	0.176	1046
	29.	370	1115	1.97	0.180	1110

$$J = 1217 \times \frac{V}{Nd}$$

n_1 = N (col.2) X Red. Ratio.

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Displacement (tons)	7	7.42	7.42	7.42	12.25	12.25	12.25	12.25
Max BHP / r. p. m.	33 / 1200	43.5 / 1500	43.5 / 1500	36 / 1500	62.5 / 1500	62.5 / 1500	62.5 / 1500	62.5 / 1500
Reduction ratio	1.61:1	2:1	2:1	2:1	3:1	3:1	3:1	3:1
Propeller Dia / Pitch (inches)	23 / 18	25.5 / 18	25.5 / 19.5	26 / 16	35.3 / 25.5	35.3 / 25.5	36 / 25.6	36 / 25 6
Pitch ratio P/D	0.782	0.706	0.765	0.615	0.722	0.722	0.711	0.711

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d = 25.5	7.	552	870	1.53	0.132	1104
	8.	563	880	1.58	0.134	1126
	9.	552	900	1.62	0.140	1104
III	10.	555	835	1.72	0.148	1110
d = 25.5	11.	555	835	1.89	0.163	1110
	12.	540	785	1.82	0.161	1080
IV	13.	550	710	1.80	0.153	1100
d=26	14.	550	710	1.80	0.153	1100
V	15.	342	1275	1.24	0.125	1026
d=35.3	16.	352	1223	2.52	0.246	1056
	17.	356	1192	2.49	0.241	1068
VI	18.	364	1135	2.22	0.210	1092
d=35.3	19.	362	1162	1.99	0.190	1086
	20.	356	1129	1.99	0.193	1068
	21.	362	1130	1,91	0.182	1086
VII	22.	356	1012	1.48	0.140	1068
d=36	23.	358	1019	1.42	0.134	1074
	24.	356	970	2.13	0.202	1068
	25.	347	1047	1.62	0.158	1041
VIII	26.	387	1107	2.27	0.204	1161
d=36	27.	366	1114	2.28	0.210	1098
	28.	382	1135	1.99	0.176	1046
	29.	370	1115	1.97	0.180	1110

$$J = 1217 \times \frac{V}{Nd}$$

n_1 = N (col.2) X Red. Ratio.

TABLE III CALCULATED VALUES OF POWER ABSORBED BY PROPELLER AND TRAWLING PULL

Boat s.h.p. max.	No.	Calculated pull (t_1) lbs.	Calculated s. h. p. (ab).	s. h. p. (n_1)
1		2	3	4
I	1.	806	27	27
30	2.	804	27	27
	3.	790	26	27
	4.	792	26	27
	5.	747	24	26
II	6.	788	24	26
	7.	789	24	26
39	8.	821	25	27
	9.	788	24	26
III	10.	796	24	26
39	11.	794	24	26
	12.	752	22	26
IV	13.	626	17	19
32.5	14.	626	17	19
V	15.	1033	25	38
56.2	16.	1062	28	40
	17.	1091	29	40
VI	18.	1149	31	41
56.2	19.	1141	30	41
	20.	1102	29	40
	21.	1143	30	41
VII	22.	1180	31	40
56.2	23.	1195	31	40
	24.	1164	31	40
	25.	1117	28	39
VIII	26.	1382	39	44
56.2	27.	1229	33	41
	28.	1352	38	43
	29.	1266	34	42

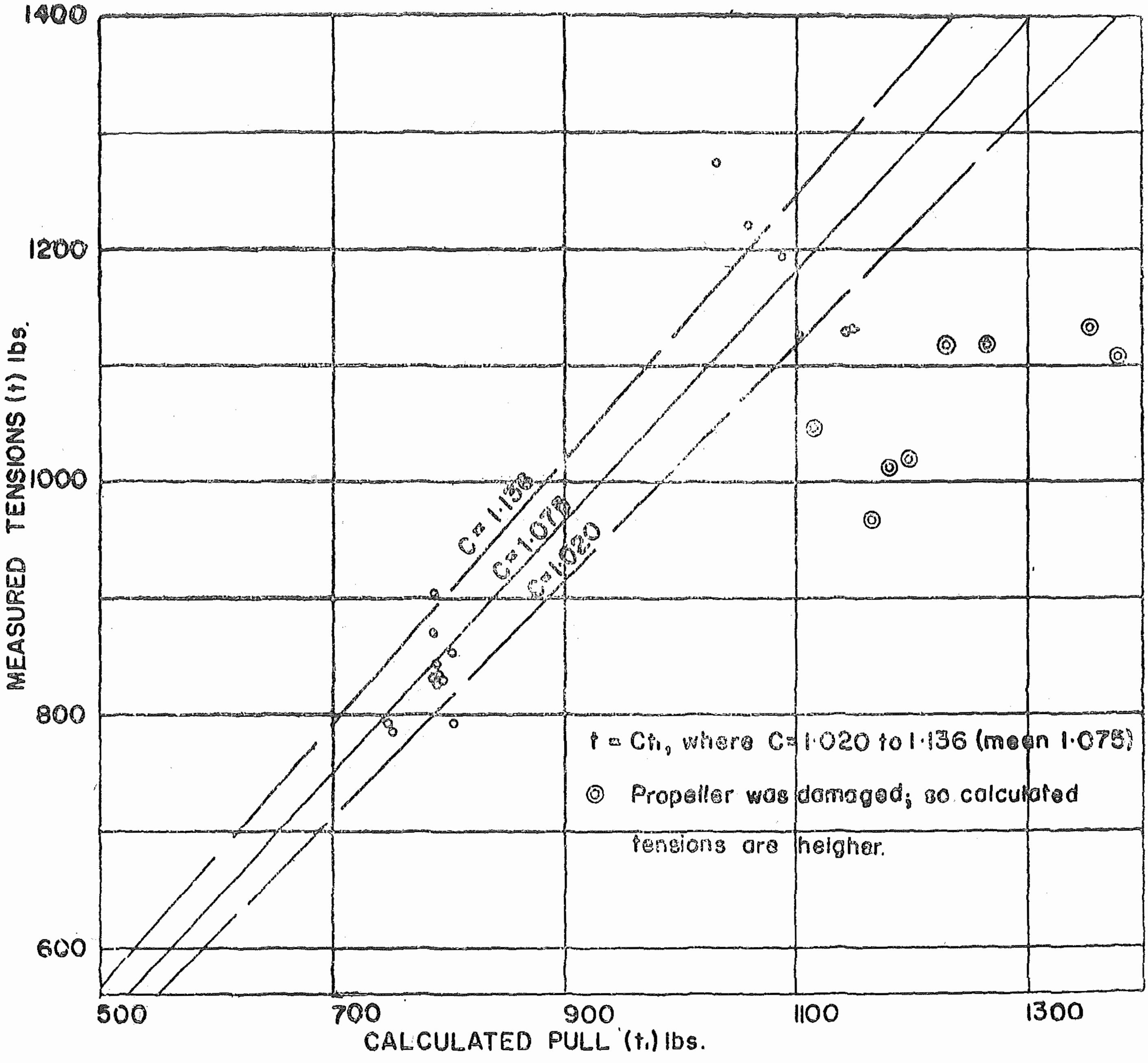

Fig. 4. Comparison of measured tension (t) and calculated pull (t_1)

the engine for the particular engine r. p. m. (Col. 4 of Table III) is estimated by assuming a constant torque i. e; s. h. p. (trawling) $= \frac{n_1}{N_1} X$ max. s. h. p.

'n_1' is trawling r. p. m. of engine from Col. 6 Table II.

'N_1' is continuous rated r. p. m. of engine from Table I

Max. s. h. p. $= 0.9$ X Max. BHP from Table I.

The s. h. p. absorbed by the propeller are calculated and shown in Table III (Col. 3). Comparison of Col. 3 & 4 shows whether the engine is overloaded or under-loaded and by how much. The differences between the available (Col. 4) and utilised i. e. absorbed s. h. p. (Col. 3) are small in the case of 30′ boats and very large in the case of 36′ boats. So possibilities exist for the 36′ boat to increase the catching efficiency by increasing net size, increasing speed of trawling if that is beneficial, using better net configuration (which may increase resistance) or even the use of two nets.

In Fig. 4, the measured tension (t) is plotted against calculated pull (t_1) and it is seen that most of the points lie within the lines $t = 1.020\ t_1$ and $t = 1.136\ t_1$. This is in good agreement with the relation $t = 1.030$ to $1.150\ t_1$ derived from equation (iii). However, some of the points marked speciallv, are completely outside the range and calculated values are too high. These are from two 36′ boats VII & VIII for which the propellers were severely damaged by erosion. The damages were not due to cavitation and later it was suspected due to stray current effects. 76% of the remaining points lie within the two lines mentioned above. The warp tension predicted by the mean time $t = 1.070\ t_1$ will have $+ 5\%$ accuracy. However, while designing the net, the gear resistance should be equated to pull (t_1) and not warp tension (t) as explained earlier.

Another factor affecting propeller performance is onset of cavitation. The calculation of the condition for cavitation cannot be simplified. But generally it is found in case of these small trawlers that if the propeller r. p. m. is around 400 to 500 corresponding to full rated r. p. m. of engine and if the propeller pitch - diameter ratio is between 0.6 to 0.8, the possibilities of cavitation and thrust break-down are negligible.

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REFFRENCES

Choudhury, R. L; 1962. 10th IPFC. Proc., Sec. III pp. 87–93.

Dawson, J. & Parker, M. N; 1962. *Trans. of Royal Inst. of Nav. Arch.,* London, pp. 252.

Koyama, T; 1962. *Bull Tokai Reg. Fish Res. Lab.* **33**: pp; 32.

Miyamoto, H. 1959. "Modern Fishing Gear of the World." Fishing News (Books) Ltd., London, E. C. 4. pp. 248–250.

APPENDIX 'A'

The method of calculation of the trawling pull (t_1), absorbed s. h. p. during trawling and available s. h. p. during trawling are illustrated by takihg observation No. 17 from boat No. V ref. Tables I & II.

From Table I Prop. dia. = 35.3 in. - (a)
Pitch ratio = 0.722 - (b)
Reduction ratio = 3:1
Displacement = 12.25 tons

From Table II Prop. r. p. m. while trawling = 356 – (c) (observation No. 17)

Corressponding engine r. p. m. (n_1) = 356 × 3 = 1068 — (d)

(where 3 is reduction ratio).

By entering Fig. 1 with prop. dia. (a) and pitch ratio (b) the absorbed s. h. p. and thrust for 400 r. p. m.

s. h. p. = 40.5

Thrust = 1610 lbs.

Actual prop. r. p. m. (c) is 356.

From Fig. 2 Thrust and s. h. p. correction factor for 356 r. p. m. are 0.792 and 0.705 respectively.

So for trawling condition

Thrust (T) = 0.792 × 1610 = 1270 lbs. Absorbed (utilised) s. h. p. = 0.705 × 40.5 = 28.6 — (f) Calculation of pull from Eqn. (i) $T = R + t_1 + \triangle T$ R (estimated at 4 lbs./ton of displacement) = 52 lbs. $\triangle T = 0.10\,T = 127$ lbs.

So t_1 = 1091 lbs.

Measured warp tension (t) = 1192 lbs. $t/t_1 = 1.09$

Calculation of available s. h. p.

From (d) Engine r. p. m. (n_1) in trawling condition = 1068

Full engine r. p. m. (N_1) from Table I = 1500

Full B. H. P. from Table I = 62.5

Full s. h. p. = 0.9 × 62.5 = 56.2

s. h. p. available at trawling condition =

$$\frac{n_1}{N_1} \times \text{full s. h. p.} = \frac{1068}{1500} \times 56.2 = 40$$

So % utilisation of available s. h. p.

$$\text{during trawling} = \frac{28.6}{40} \times 100 = 71.5\%$$

i. e. underloaded

Percentage utilisation of full s. h. p. =

$$\frac{28.6}{56.2} \times 100 = 51\%$$