Pertanika 7(3), 67–78 (1984)

A Simplified Method of Calculating Propeller Parameters for Small Trawlers.

JUHARI HUSIN and ZAINAL ASHIRIN SHAHARDIN
Department of Fishing Technology and Marine Science,
Universiti Pertanian Malaysia,
Mengabang Telipot Kuala Trengganu,
Terengganu,
Malaysia.

Key words : **Trawlers; simplified method of calculating propeller parameters.**

RINGKASAN

Adalah menjadi masalah biasa dimana kipas yang dipasang di sesebuah bot tunda tidak dapat mengadakan tujahan yang mencukupi menyebabkan ia tidak dapat menunda dengan kelajuan yang ditetapkan. Tindakan-tindakan segera yang biasa diambil ialah mengecilkan saiz pukat, menukar kipas baru ataupun menggunakan kuasa enjin yang lebih tinggi. Semua pilihan yang dinyatakan akan mendatangkan kesusahan kepada nelayan daripada segi kewangan. Oleh itu satu kaedah mudah untuk mengira bagi mendapatkan satu spektra parameter-parameter kipas seperti garis pusat, nisbah pic-garis pusat, kelajuan pusingan, pekali kuasa kerejangan dan pekali prestasi kipas untuk sesebuah jenama enjin telah dicipta, bagi mengelakkan kejadian tidak cukup kuasa tujah. Satu kombinasi parameter-parameter yang paling baik boleh didapati untuk memastikan bahawa kehendak-kehendak penundaan dipenuhi. Pada kebiasaannya kehendak-kehendak dinyatakan dalam bentuk tujahan kipas untuk mengatasi jumlah serek pukat dikelajuan penundaan yang telah ditentukan. Jumlah serek sesebuah pukat boleh didapati melalui ujian model atau pun model matematik. Tiga buah jenama enjin telah dikaji dan untuk setiap jenama nilai-nilai rejangan, pekali prestasi kipas dan pekali kuasa-kerejangan dikira. Nilai nisbah pic-garis pusat diperolehi daripada kelok prestasi kipas apabila pekali tork (μ) dan pekali mara hadapan (ϕ) *telah diketahui.*

SUMMARY

It is quite common to encounter a propeller installed on a trawl that does not develop adaquate thrust to pull the trawl at a specified trawling speed. The immediate actions usually taken are to reduce the size of a trawl, change to a new propeller or install a higher powered engine. All these alternatives will impose a financial strain on the fishermen. Therefore, a simple method of calculation is being suggested to obtain a spectrum of propeller parameters such as diameter, pitch- diameter ratio, speed, quasi-propulsive coefficient and propeller performance coefficient for a given engine model. The best combination of parameters can be obtained in order to satisfy a specific trawling requirement. Usually the requirement is stated in the form of thrust of propeller to overcome total gear drag at a specific trawling speed. Total gear drag can be determined by a model test or mathematical modelling. Three engine models have been studied and for each model values of thrusts, propeller performance coefficients and quasi- propulsive coefficient were calculated. Having known the values of torque coefficient (μ) *and advance coefficient* (ϕ) *the values of pitch- diameter ratios were obtained from propeller performance curve.*

INTRODUCTION

In West Malaysia small scale trawling is one of the major fishing activities, which is likely to remain important in the future. Though 97% of these trawlers have inboard engines of less than 50 shaft horse power (shp), trawler contribution in terms of fish landings for the year 1980 was about 44% of the total catch. Shrimp constitutes about 34% of the total trawl landings (Annual Fisheries Statistics, 1980).

Table 1, shows some principal particulars of typical shrimp trawlers operating in the state of Terengganu waters. The table indicates that the length ranges from 11m up to 13.4m and the

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Key to authors' names: J. Husin and Z. A. Shahardin

engine power varies from 16shp to 45 shp. The moulded depth of the boat's hull hardly exceeds 1m indicating that most of the boats have fairly low free board (about 0.4m at midship section) and low draught (0.5m to 0.7m). The low draught values explain the nature of port facilities for landing which is usually situated near the river mouth or near the coast.

The total trawling operation normally takes less than 12 hours and three-quarters of the operation time is spend on actual trawling. The remainder of the time is spend on cruising to and from fishing port and fishing ground (Hashim, 1980). The fishing grounds are usually not far away from the coast-about 5 to 12 miles. Thus, little time is actually wasted on searching suitable fishing grounds as they are predetermined prior to a trip.

Efficient trawling requires proper trawling speeds since the speed influences the overall perforamance of a trawl in the water. The performance of a trawl is normally stated in terms of net mouth height, not mouth area and sweeping area. Miyamoto (1960) and Eldered *et al.* (1968) recommended that a shrimpt trawl should have a wide-flat and low net mouth. This indicates that trawls having low values of net mouth height and net mouth area but a large sweeping area are preferable. In order to get the best performance, the trawl has to be towed at a specified speed and in the case of a shrimp trawl, a trawling speed of 2.0 knots has been found to be adequate (Shahardin *et al.,* 1983). For a trawler to achieve a specified trawling speed, say 2 knots, adequate effective horse power (ehp) has to be provided by the main engine via a propeller. Effective horse power is influenced by the total gear drag (consisting of warp, net and doors) and the hull resistance of the trawler. The greater the trawling speed, the greater will be the resistance from the trawl and hull. (Figure 2.). The ehp is provided by the propeller in the form of thrust and is the function of maximum torque available, propeller diameter and pitch to diameter ratio and gear reduction ratio which determines the speed of rotation of a propeller. A proper selection of propeller parameters is thus necessary to provide adequate thrust to overcome resistance from the trawl gear and hull for a given trawl speed. A comprehensive study on trawling gear-trawler interaction using mathematical models and extrapolations of propeller performance curves have been attempted by Kowalski *et al.* (1974). Unfortunately, the trawlers studied were comparatively large, having main engines ranging from 165 shp to 480 shp. The method of calculation is based on mathematical modelling that need the aid of a computer in solving suitably matched propeller parameters and boat hull resistance data. Thus, the method is not readily appreciated by users having inadequate mathematical knowledge. Therefore, a simplified method of calculation of trawl gear-trawler interaction needs to be formulated.

The nature of trawling operations in West Malaysia indicates that cruising speed is less important if compared to trawling speed. To satisfy both maximisation requirements at the same time for fixed blade propeller type is technically impossible. Therefore attempts should be concentrated on maximisation of propeller thrust at trawling rather than maximisation of propeller efficiency at cruising. Thus, the objective should be maximisation of propeller thrust at trawling, but simultaneously ensuring a reasonable level of propeller efficiency at trawling and cruising speeds. The level of maximisation of propeller thrust will depend on total gear resistance. There are two methods available for the determination of gear resistance. One is to use mathematical modelling with the aid of a computer as attempted by Kowalski *et al.* (1974) and the other is through experimental models using wind tunnel or water tank as has been attempted by Shahardin *et al.* (1983). Shahardin (1983) has carried out extensive studies on the performance of traditional shrimp trawl employed in West Malaysia and his results will be used as a basis for determining the required thrust that needs to be developed by the propeller.

METHODS AND MATERIALS

The estimation of the developed torque from the propeller can be determined from the following equations:

$$Q_{max} = \frac{746\ (shp_{MCR})}{2\pi\ (9.81)\eta} \qquad (1)$$

$$Q = \frac{\eta^2 \rho D^5}{\mu^2} \qquad (2)$$

where :

Q_{max} = maximum torque (kgm)

shp_{MCR} = shaft horse power of main engine at maximum rated engine rpm or maximum continuous rating (MCR)

η = Propeller speed (rps) (MCR)

ρ = mass density of sea water ($104.5\ kgs^2/m^4$)

μ = torque coefficient

D = diameter of a propeller (m)

Previously, Q_{max} was obtained at bollard condition by setting the advance coefficient (ϕ) on propeller performance curves equal to zero. This will give the corresponding value of torque coefficient (μ) at bollard condition, for a given pitch-diameter (P/D) ration. This in turn leads to an engine speed which is lower than the maximum rated rpm (Kowalski *et al.*. (1974). Now, instead, Q_{max} is calculated first as shown in equation (1) in order ascertain that value of Q used in equation (2) does not exceed the value of Q_{max} In orther words the value of (μ) is calculated once the value of Q_{max} has been set. In this manner, it can be ascertained that maximum thrust occurs at maximum rated engine speed.

Equation (3) shows that the value of Q_{max} will depend entirely on the speed of the propeller at a particular gear reduction ratio for a specific engine output power. The higher the gear reduction, the higher will be the Q_{max}. In the analysis, the gear ratios used are in the range of 3 : 1 to 7 : 1. It is anticipated that a gear ratio higher than 4 : 1 will require a large gear box and is not technically practical for the application of a small engine.

Three engine models having different maximum continuous rating (MCR) of shaft horse power have been selected. The choice of engine models are arbitrary but Model x has been chosen because it is a popular model especially in the East coast of Peninsular Malaysia (Husin *et al.*, 1983).

The next step is to determine the values of advance coefficient (ϕ) and torque coefficeint (μ) as given in Figure 1. In this analysis the advance speed has been specified to be at 2.0 knots.

$$\phi = V_A \sqrt{\frac{\rho D^3}{Q_{max}}} \qquad (3)$$

$$V_A = (1-w)\,V_s \qquad (4)$$

$$W = 0.5\,C_b - 0.05 \qquad (5)$$

where V_A = propeller advance velocity (m/s)

w = wake coefficient for single screw propeller

C_b = block coefficient which is assumed to be 0.5

V_s = trawling speed (m/s)

ϕ = advance coefficient

$$\mu = \eta \sqrt{\frac{\rho D^5}{Q_{max}}} \qquad (6)$$

ρ = mass density of sea water $104.5\ kgs^2/m^4$)

η = propeller rotational speed (rps)

μ = torque coefficient

Q_{max} = maximum torque (kgm)

The determined values of (ϕ) and (μ) are used to fix the value of thrust coefficient (δ) given in Figure 1. Hence the value of thrust (T) can be obtained.

$$T = \frac{\delta \times 2\pi \times Q_{max}}{D} \qquad (7)$$

where δ = thrust coefficient

T = thrust (kgf)

D = diameter of a propeller (m)

The value of pitch diameter ratio (P/D) and propeller open water efficiency (η_o) can also be determined from Figure 1., when the values of (ϕ) and (μ) are known. The quasi-propulsive coefficient (η_D) of a propeller which represents the actual efficiency of a propeller is baed on the following equation:

$$\eta_D = \frac{T\,VA}{2\pi Q\eta} \qquad (8)$$

T = thrust (kgf)

V_A = propeller advance speed (m/s)

Q = torque (kgm)

η = propeller revolution per second (rps)

Mathews (1964) suggests that at low speed of advance, propeller performance coefficient (e) involving thrust, delivering power and propeller diameter is more important than propeller efficiency. This is the same criteria used for tug boats.

$$e = \frac{T^{3/2}}{\rho^{1/2} P_D D} \qquad (9)$$

where e = propeller performance curve coefficient

T = thrust (kgf)

ρ = mass density of sea water ($104.5\ \mathrm{kgs^2/m^4}$)

P_D = $2\pi\eta Q_{max}$ (kgm/s)

D = diameter of a propeller (m)

The propeller performance curves as indicated in Figure 1. were supplied by the company concerned while information on engines of Model X was obtained from the local suppliers.

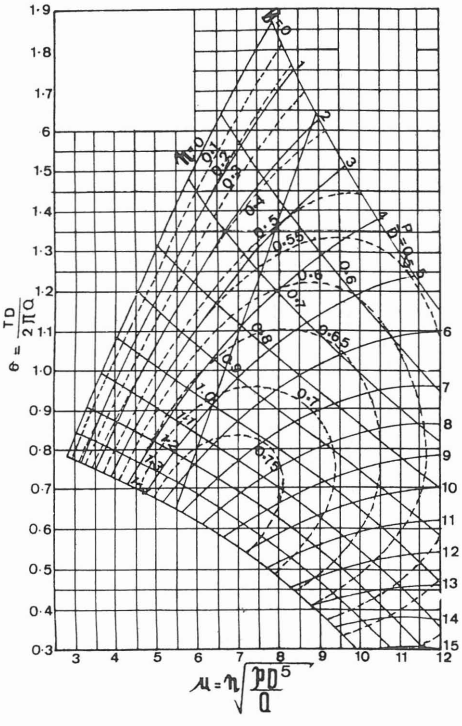

Fig. 1. Performance of a Three-Bladed Fixed Spiral Propeller having a developed surface ratio of 0.350.

RESULTS

The results of calculated values of thrusts (T), pitch to diameter ratios (P/D), quasi-propulsive coefficients (η_D) and propeller performance coefficients (e) for a series of gear reduction ratios (3 : 1 to 7 : 1) and variable propeller diameter for the three engine models (Model X 3SMGGE, Model X 3 KDGGGE and Model X 4KDGGGE) are shown in Tables 1, 2, 3 and 4 respectively.

DISCUSSION

Figure 2, shows the relationship between effective horse power (ehp) and the total gear drag force of a small trawl under towing conditions. At a speed of 2.0 knots the total drag and effective horse power of the trawl is about 860 kgf and 240 horse power respectively. Figure 3 shows the relationship between engine brake horse power and speed. At 2.0 knots, the shp required is about 2 shp which is equivalent to 0.4 ehp (Nomura *et al.,* 1976). Thus, the contribution of the hull resistance to the total effective horse power required to be supplied by the propeller is negligible. Hence, at low speed it is adequate to consider the total gear drag as the pulling force that needs to be overcome by thrust developed by propeller and can be used as a basis in finding the best combination of propeller parameters.

The assessment of shp for the boat hull at various speeds is based on the work of Anon[b] (1980). The principal particulars of the hypothetical boat are also shown in Figure 3.

The general trend of thrust calculated for a particular engine model shows that thrust increases with the increase in diameter and the decrease in propeller speed through reduction gear. However, a reduction gear of greater than 4 : 1 is anticipated to be too large for all the engine models considered. In fact the manufacturer's recomendation for gear reduction ratios for 3 SMGGE is 3.24 : 1 and for 3 KDGGGE and 4 KDGGGE is 3.29 : 1. Using standard manufacturer's reduction gear, it is obvious that boat having engines like the 3 SMGGE model, cannot pull the trawl at a speed of 2.0 knots since the maximum thrust obtained at 3 : 1 and 4 : 1 gear reduction is 693 kgf and 747 kgf respectively. This is less than 860 kgf as can be seen in Figure 2. Therefore, it is likely that most small trawlers currently operating in West Malaysia are trawling at a speed of less than 2.0 knots. This will contra-

TABLE 1

Principal particulars of small shrimp trawlers operating in the State of Terengganu.

Boat	1	2	3	4	5	6	7	8	9	10	11	12
Particulars												
Length (overall (L) (m)	11.03	11.25	11.70	12.00	12.30	12.50	12.75	12.80	12.90	11.21	13.30	Max 13.40
Beam moulded (B) (m)	2.67	Min 2.47	3.00	3.35	3.30	3.30	3.48	3.50	3.20	3.03	3.35	Max 3.90
Depth moulded (D) (m)	0.93	Min 0.83	1.05	1.00	0.90	1.10	1.10	0.95	1.10	Max 1.20	1.00	1.10
$\frac{L}{B}$	4.1	Max 4.6	3.9	3.6	3.7	3.8	3.7	3.7	4.0	4.4	4.0	Min 3.4
$\frac{B}{D}$	3.0	3.0	2.9	3.4	Max 3.7	3.0	3.2	3.6	2.9	Min 2.5	3.4	3.5
Engine Installed (shp)	16	Min 12	24	24	24	37	24	33	33	24	33	Max 45
Estimated cruising speed (knots)	6.5	Min 6.1	6.5	6.2	6.7	7.2	6.6	7.2	7.2	6.6	6.9	Max 7.5
Estimated displacement (tonnes)	8.8	Min 7.6	12.2	13.0	12.0	1.50	16.2	14.2	15.0	16.0	14.8	Max 19.0
Registered Tonnage	7.6	Min 4.2	10.4	12.0	10.3	19.8	15.0	12.0	14.0	12.4	12.4	Max 16.0

TABLE 2
Calculated propeller thrust (T) at 2 knots trawling speed for the three engine power output, propeller speed and diameter.

Engine model	Model X/ 3SMGGE, MCR-45shp/2200rpm					Model X/3KDGGGE, MCR-82shp/1450rpm					Model X/ 4KDGGGE, MCR-110shp/1450rpm				
Maximum Torque (kgm)	44.6	59.4	74.3	89.1	103.9	123.1	164.3	205.4	246.2	287.6	165.2	220.4	275.6	330.3	385.8
Propeller speed (rpm)	733	550	440	367	314	483	363	290	242	207	483	363	290	242	207
	Thrust, T (kgf)					Thrust, T (kgf)					Thrust, T (kgf)				
Propeller diameter (m)															
0.5	482	+	+	+	+	+	+	+	+	+	+	+	+	+	+
0.6	593	535	+	+	+	+	+	+	+	+	+	+	+	+	+
0.7	693	656	634	+	+	862	+	+	+	+	+	+	+	+	+
0.8	+	747	718	665	637	1015	+	+	+	+	+	+	+	+	+
0.9	+	+	794	765	725	1178	1090	+	+	+	1396	1246	+	+	+
1.0	+	+	+	868	816	1292	1218	1123	+	+	1547	1454	1351	+	+
1.1	+	+	+	891	890	+	1342	1256	1196	+	1680	1599	1480	1472	+
1.2	+	+	+	+	941	+	1454	1366	1302	1250	+	1743	1660	1591	1576
1.3	+	+	+	+	+	+	+	1499	1452	1390	+	1832	1798	1740	1641
1.4	+	+	+	+	+	+	+	1567	1547	1947	+	+	1930	1868	1749
1.5	+	+	+	+	+	+	+	+	1640	1615	+	+	2021	1979	1939
1.6	+	+	+	+	+	+	+	+	1682	1694	+	+	+	2102	2076
1.7	+	+	+	+	+	+	+	+	+	1754	+	+	+	+	2153
1.8	+	+	+	+	+	+	+	+	+	+	+	+	+	+	2236

+ = values out of range

TABLE 3

Propeller pitch- diameter ratio (P/D) at 2 knots trawling speed for variable engine power output, propeller speed and diameter.

Engine model	Model X/ 3SMGGE, MCR-45shp/ 2200rpm					Model X/ 3KDGGGE, MCR-82shp/1450rpm					Model X/ 4KDGGGE, MCR-110shp/1450rpm				
Maximum Torque (kgm)	44.6	59.4	74.5	89.1	103.9	123.1	164.3	205.4	246.2	287.6	165.2	220.4	275.6	330.3	385.8
Propeller speed (rpm)	733	550	440	367	314	483	363	290	242	207	483	363	290	242	207
	Pitch- diameter ratio (P/D)					Pitch- diameter ratio (P/D)					Pitch- diameter ratio (P/D)				
Propeller diameter (m)															
0.5	1.25	+	+	+	+	+	+	+	+	+	+	+	+	+	+
0.6	0.82	1.25	+	+	+	+	+	+	+	+	+	+	+	+	+
0.7	0.53	0.85	1.15	+	+	1.38	+	+	+	+	+	+	+	+	+
0.8	+	0.59	0.85	1.15	1.40	1.02	+	+	+	+	1.14	+	+	+	+
0.9	+	+	0.64	0.88	1.08	0.74	1.14	+	+	+	0.88	1.33	+	+	+
1.0	+	+	+	0.63	0.82	0.57	0.90	1.25	+	+	0.68	1.12	1.40	+	+
1.1	+	+	+	0.50	0.64	+	0.70	1.00	1.28	+	0.51	0.81	1.15	1.40	+
1.2	+	+	+	+	0.52	+	0.54	0.81	1.07	1.32	+	0.64	0.92	1.18	1.40
1.3	+	+	+	+	+	+	+	0.64	0.86	1.08	+	0.52	0.72	0.98	1.23
1.4	+	+	+	+	+	+	+	0.53	0.71	0.90	+	+	0.61	0.81	1.05
1.5	+	+	+	+	+	+	+	+	0.58	0.76	+	+	0.52	0.69	0.88
1.6	+	+	+	+	+	+	+	+	0.50	0.64	+	+	+	0.57	0.73
1.7	+	+	+	+	+	+	+	+	+	0.53	+	+	+	+	0.64
1.8	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0.54

+ = values out of range.

TABLE 4
Calculated quasi- propulsive coefficient (η_D) at 2 knots towing speed for variable engine power output, propeller speed and diameter.

Engine model	Model X/ 3SMGGE, MCR-45shp/ 2200rpm					Model X/ 3KDGGGE, MCR/82shp/1450rpm					Model X/ 4 KDGGGE, MCR-110shp/1450rpm				
Maximum torque (kgm)	44.6	59.4	74.3	89.1	103.9	123.1	164.3	205.4	246.2	287.6	165.2	220.4	275.6	330.3	385.8
Propeller speed (rpm	733	550	440	367	314	483	363	290	242	207	483	363	290	242	207
			(η_D)					(η_D)				(η_D)			
Propeller diameter (m)															
0.5	11.6	+	+	+	+	+	+	+	+	+	+	+	+	+	+
0.6	14.2	12.9	+	+	+	+	+	+	+	+	+	+	+	+	+
0.7	16.7	15.8	15.2	+	+	11.4	+	+	+	+	+	+	+	+	+
0.8	+	18.0	17.3	16.0	15.3	13.4	+	+	+	+	12.1	+	+	+	+
0.9	+	+	19.1	18.4	17.4	15.5	14.4	+	+	+	13.7	12.3	+	+	+
1.0	+	+	+	20.9	19.6	17.1	16.1	14.8	+	+	15.2	14.3	13.3	+	+
1.1	+	+	+	21.4	21.4	+	17.7	16.6	15.8	+	16.5	15.7	14.6	14.5	+
1.2	+	+	+	+	22.6	+	19.2	18.0	17.2	16.5	+	17.1	16.3	15.7	15.5
1.3	+	+	+	+	+	+	+	19.8	19.2	18.3	+	18.0	17.7	17.1	16.1
1.4	+	+	+	+	+	+	+	20.7	20.4	19.8	+	+	19.0	18.4	17.2
1.5	+	+	+	+	+	+	+	+	21.6	21.3	+	+	19.9	19.5	19.1
1.6	+	+	+	+	+	+	+	+	22.2	22.4	+	+	+	20.7	20.4
1.7	+	+	+	+	+	+	+	+	+	23.2	+	+	+	+	21.2
1.8	+	+	+	+	+	+	+	+	+	+	+	+	+	+	22.0

+ = values out of range.

TABLE 5

Calculated propeller performance coefficient (e) at 2 knots trawling speed for variable engine power output, propeller speed and diameter.

Engine model	Yanmar/ 3SMGGE, MCR-45shp/2200rpm					Yanmar/ 3KDGGGE, MCR-82shp/1450rpm					Yanmar/ 4KDGGGE, MCR-110shp/1450rpm				
Maximum torque (kgm)	44.6	59.4	74.3	89.1	103.9	123.1	164.3	205.4	246.2	287.6	165.2	220.4	275.6	330.3	385.8
Propeller speed (rpm)	733	550	440	367	314	483	363	290	242	207	483	363	290	242	207
			(e)					(e)					(e)		
Propeller diameter (m)															
0.5	0.605	+	+	+	+	+	+	+	+	+	+	+	+	+	+
0.6	0.688	0.590	+	+	+	+	+	+	+	+	+	+	+	+	+
0.7	0.745	0.686	0.652	+	+	0.567	+	+	+	+	+	+	+	+	+
0.8	+	0.730	0.687	0.613	0.574	0.634	+	+	+	+	0.633	+	+	+	+
0.9	+	+	0.711	0.672	0.620	0.705	0.627	+	+	+	0.678	0.571	+	+	+
1.0	+	+	+	0.731	0.666	0.728	0.667	0.590	+	+	0.712	0.648	0.581	+	+
1.1	+	+	+	0.691	0.690	+	0.701	0.635	0.590	+	0.732	0.680	0.605	0.600	+
1.2	+	+	+	+	0.688	+	0.725	0.660	0.614	0.578	+	0.709	0.659	0.618	0.610
1.3	+	+	+	+	+	+	+	0.700	0.668	0.625	+	0.705	0.686	0.653	0.598
1.4	+	+	+	+	+	+	+	0.695	0.682	0.649	+	+	0.708	0.674	0.611
1.5	+	+	+	+	+	+	+	+	0.695	0.679	+	+	0.708	0.686	0.666
1.6	+	+	+	+	+	+	+	+	0.676	0.684	+	+	0.704	0.704	0.691
1.7	+	+	+	+	+	+	+	+	+	0.678	+	+	+	+	0.687
1.8	+	+	+	+	+	+	+	+	+	+	+	+	+	+	0.687

+ = values out of range

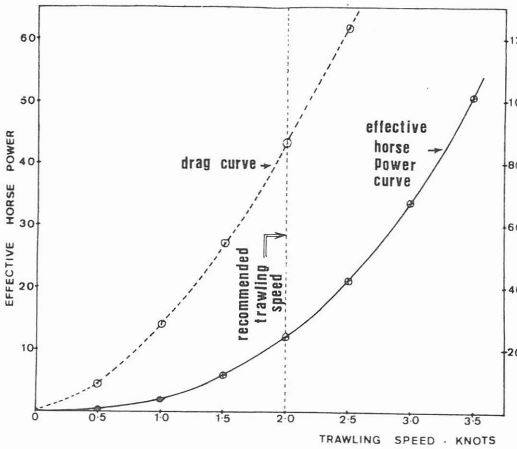

Fig. 2. Curves of Total Gear Drag (kgf) and required effective horse power (ehp) versus trawling speed (knots) of a typical small trawl.

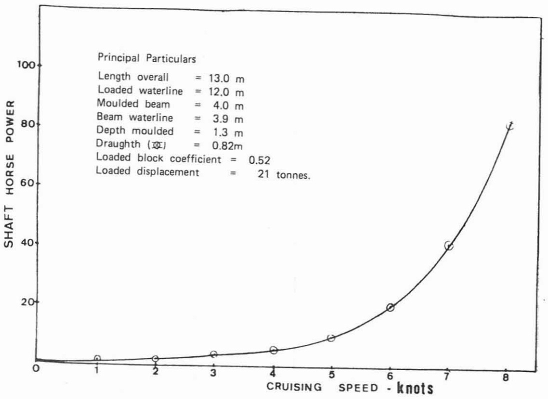

Fig. 3. Relationship between required engine Brake Horse Power (bhp) and cruising speed (knots) of a hypothetical small trawler.

dict with the general belief that small trawlers are trawling at speed of 2.0 knots. This is not possible unless if they are using small trawls or having engines of larger capacity such as 3 KDGGGE – 82shp or 4 KDGGGE – 110shp.

For a particular engine model the pitch-diameter ratio decreases with increasing propeller diameter. For a pitch diameter ratio range of 3 : 1, 4 : 1, the gear reduction is 1.25 to 0.53 and 1.25 to 0.59 respectively. A similar trend is shown by engine model 3 KDGGGE and 4 KDGGGE whereby the pitch-diameter ratio drops with increasing propeller diameter for a particular gear reduction ratio. The variation is 0.83 for 3 : 1 and 0.60 for 4 : 1 in the case of a 3 KDGGGE model and 0.63 for 3 : 1 and 0.81 for 4 : 1 in the case of a 4 KDGGGE model. The reduction in pitch-diameter ratio is associated with increasing thrust. This is an interesting relationship since it is possible to control the thrust by controlling the pitch of a propeller. A comprehensive study on the possibility of fitting a controllable pitch propeller (cpp) to a trawler for obtaining maximum efficiency and maximum thrust has been attempted by Kowalski *et al.* (1974).

For a particular engine model, the actual propeller efficiency or quasi-propulsive coefficient (η_D) increases with the increase in propeller diameter and gear reduction ratio. This is in agreement with the generally accepted idea that propeller quasi-propulsive coefficient (η_D) can be improved to a certain extent by increasing its diameter. The increase in quasi-propulsive coefficient (η_D) obtained by increasing propeller diameter for a gear reduction ratio is largely due to the increase in thrust. Similarly the rate of an increase in gear reduction ratio. However, for than the rate of increase of supplied power. Thus quasi-propulsive coefficient increases with increase in gear reduction ratio. However, for practical gear reduction ratio application, say 4 : 1, the maximum quasi-propulsive coefficient for engines 3 SMGGE, 3 KDGGGE and 4 KDGGGE are 18%, 19.2% and 18% respectively.

Table 2 shows the trend of propeller performance coefficient (e) at a trawling speed of 2.0 knots for 3 engine models considered. The table shows that for a given engine model and gear reduction, the performance coefficient (e) increases with the increase in propeller diameter. However, the maximum value of performance coefficient (e) is found to be decreasing with increasing gear ratio. These two trends are similar for all the engine models considered. The propeller performance curve at 4 : 1 gear reduction for 3 SMGGE, 3 KDGGGE and 4 KDGGGE are 73%, 72.5% and 70.5% respectively. Thus the values of propeller coefficient seems to depend to a large extent on propeller diameter and gear reduction ratio. Also from the comparison of 3 engine models, it is noticed that the coefficient seems to actually decrease with increasing engine output at a particular gear reduction ratio.

CONCLUSION

The metnod used in assessment of propeller thrust is simple and can be used as tool in inspecting the range of thrust available for a particular engine model having a specified (MCR) power output, by varying propeller diameter and reduction gear ratio. The selection of gear ratio to a large extent depends on its size. A large reduction ratio requires a large gear box. The gear ratio of up to 4 : 1 is normally available in the market and is suitable for small engine application. The quasi-propulsive efficiency (η_D) increases with the increase in propeller diameter and gear reduction ratio. As stated earlier the increase in diameter and gear ratio is usually constrained by physical limitations such as the size of propeller and the size of gear box.

As for quasi-propulsive efficiency, the propeller performance (e) increases with the increase in propeller diameter for a given reduction gear range. However, the maximum values of (e) obtained at a particular gear reduction decreases with gear reduction ratio increment. The best propeller performance coefficient is obtained at gear reduction of 3 : 1 for all engine models being considered.

The effective horse power required to overcome resistance of the boat hull of a typical small trawl at a trawling speed of 2.0 knots is found to be small. Thus at trawling, the assessment of effective horse power should only be based on the total gear drag of a small trawl. Total gear drag of a trawl under operation can be determined by conducting model experiments or mathematical modelling as has been suggested by Kowalski *et al.* (1974).

The results of thrust obtained indicate that most of the trawling operation carried out by small trawlers in West Malaysia is at a speed of less than 2.0 knots. However, this statement needs to be viewed cautiously since the total drag of gear used in the analysis is based on a single specification of a trawl used in the country. Therefore, trawling can still be done at 2.0 knots or more by using smaller scale gear. The conclusion that can be drawn here is that, small trawlers (engines less than 50 shp) having a trawl of the same specification as the one being tested will not be able to trawl at 2.0 knots.

It is expected that there will be a slight variation in the calculated values of thrusts, pitch-diameter ratios, quasi-propulsive coefficient (η_D) and propeller performance (e) obtained when the basic characteristics of the propeller used in the analysis are changed. Such basic characteristics will include developed surface ratio (blade area ratio) and number of blades. However, the error introduced in the overall calculation will be about 5% (Rawson *et al.*, 1967). Thus the method is suitable for use in preliminary design stages.

ACKNOWLEDGEMENTS

The authors are grateful to Ir. Kamarudin bin Mansor, a naval architect of Limbongan Timor Sdn. Bhd. for his help and useful comments during the preparation of the manuscript. Thanks are also due to Haji Umar bin Salleh, the Head of Station, Universiti Pertanian Malaysia, Kuala Trengganu for his cooperation and encouragement.

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(Received 12 December, 1983)