ENERGY SAVING IN TRAWLERS: PRACTICAL AND THEORETICAL APPROACHES

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SUMMARY

Due to a critical overfishing situation all over the Mediterranean waters, maintaining the productivity of a trawler at acceptable levels calls for technological interventions, mainly aimed at reducing the fuel costs.
In order to discuss on energy savings in fishing, a trawler is a very suitable example, since its management costs are strongly affected by the fuel consumed.
This paper tries to identify key areas to achieve fuel saving in fishing activities.
Many trawlers hulls request quite different powers to reach the same speed due to the fact that even small modifications to the hull shape could provide significant variations of its resistance by sea waters.
Some analyses on cruising speed, hull shape and propulsion systems will be worked out in the paper, on the base of some research results and experience based considerations, addressed to the hull and the propulsive apparatus as well.

1. INTRODUCTION

The productivity of a trawler could be expressed as a ratio between the fish catch value and the overall costs to achieve this catch. The present fuel cost, which concerns most fishing fleets, is claiming technical solutions for cheaper fishing vessel designs.
This paper is aiming at giving a contribution in this sense, offering some considerations mainly addressed to the aspects of management costs of a fishing vessel as sea-going vehicle.
Due to the clear impossibility to not fish more, maintaining this productivity at acceptable levels calls for technological interventions, mainly aimed at reducing the fuel costs. To discuss on energy savings in fishing, a trawler is a very suitable example, since the management costs of this type of vessel are strongly affected by fuel consumptions.
A fishing trip of a trawler consists of two fishing stages:

a) steaming from/to any fishing areas and
b) towing the fishing gear

The following worthwhile areas could be identified for investigation:

- steaming speed
- propulsion systems

While steaming to/from fishing grounds, the ship's hull is the main user of the engine power and fishing boats' features could be improved by applying to their hulls some rules of naval architecture, till now almost all neglected.

2. THE STEAMING SPEED

Let's firstly discuss on steaming speed. Fuel consumption is closely linked to the delivered engine power which, on turn, depends on ship's resistance and speed.
A typical feature of the vessel resistance curve is of moderate increase at low speed with increasing steepness in the higher speed regions. At the top of the speed range, the resistance increases with speed in the 6^{th} to 8^{th} power.
Very high speed-length ratios for displacement hulls (about 1.3), corresponding to high ship resistances, are peculiar to steaming. In order to reduce the resistance it would be enough to make the ship to operate at a lower speed/length ratio.
Two main factors determine the shape of the resistance curve for a vessel:

- vessel displacement
- vessel length

Ship resistance is roughly proportional to its displacement. Some investigations show a 35 ÷ 45% resistance increase for displacement increases by 50%.
The vessel length determines the steepness of the resistance curve at different speeds and, in practice, the maximum attainable speed of the vessel.
For a displacement type hull, there will be a practical upper speed limit which cannot be exceed, irrespective of the increase in power applied. Therefore, a reduction in speed when the ship is steaming from one fishing area to another and from there to the home port and vice versa, could allow a large fuel saving.
This could be accomplished by two different ways, i.e.:

- by lengthening the ship to realize as much length as possible, according to its requirements in terms of stability, seaworthiness and working efficiency;
- by reducing the speed.

The energy saving rising from a steaming speed reduction will be consider here.
Many steaming tests have been carried out, over a research fishing trip at different engine revolutions taking, as a starting and reference point, the fuel consumption to travel a given distance at a maximum speed of. 10.25 knots
Reducing the speed from 10.25 knots to 9.75 knots (i.e. by only half a knot) gives a fuel consumption decrease, of about 18%. Generally speaking, lowering by 10% the free running speed reduces by 30-40% the fuel consumed (per mile steamed).

Most of the fuel is consumed by applying the last rpm of the engine. When the rpm are increased from 80% to 100% fuel consumption is doubled.
A flow meter should be installed on board the trawlers so to make the fisherman to carefully monitor the fuel consumption and to practice more economic trawling trips.

3. IMPROVED HULL FORMS

Even though the speed of a trawler could not be increased, much could be done in order to highly reduce the hull resistance.
Fishing vessels are not equally power consuming and require highly spreading effective powers/displacement at the same relative speed. This is due to the fact that even small modifications to the hull shape could provide significant variations in its resistance and means that there is room to improve their performances from a powering point of view.
In order to give some quantitative indications on the relationship between the geometry and the resistance of the hull forms and to get to a merit rank, calculations have been made on a set of 8 commercial trawlers. Tables 1a and 1b show their characteristics.
For each ship, the total resistance has been calculated by the following methods: Van Oortmerssen, Darvin, Takagi, Inoi, Nakamura, Lap, Henschke, Taggart and Ridgely Nevitt.
The R_T (kg) values have been averaged and referred to the full load dispacement Δ [t] of the ship.

Table 1a. General characteristics of the fishing vessels

SHIP	L_{WL} [m]	L_{BP} [m]	B [m]	T [m]	D [m]	L/B [-]	B/T [-]	∇ [m^3]	Δ [kN]	S_{WS} [m^2]
A	27.12	23.80	7.40	2.96	3.50	3.216	2.500	237	2387	231.0
B	29.95	27.25	7.30	3.10	3.90	3.733	2.355	327	3287	305.3
C	27.14	23.80	7.00	3.06	3.60	3.400	2.288	276	2772	224.7
D	28.25	26.35	7.50	3.00	3.56	3.513	2.500	320	3220	256.0
E	29.30	27.30	6.80	2.98	3.50	4.015	2.286	288	2891	252.0
F	33.70	31.40	8.00	3.10	4.10	3.925	2.581	408	4098	255.1
G	27.71	24.50	8.00	2.77	4.00	3.063	2.890	304	3058	359.8
H	25.12	22.00	7.20	2.90	3.40	3.056	2.483	269	2701	217.2

Table 1b. General characteristics of the fishing vessels (*continued*)

SHIP	C_B [-]	C_P [-]	C_{WP} [-]	C_M [-]	A_{WP} [m^2]	A_M [m^2]	x_{CF} [*] [m]	x_{CB} [*] [m]	$L/\nabla^{1/3}$ [-]
A	0.459	0.568	0.701	0.807	123.4	17.9	-2.777	-0.920	3.844
B	0.529	0.612	0.765	0.862	193.3	21.3	1.627	0.274	3.956
C	0.541	0.787	0.927	0.687	154.4	14.7	-0.303	-0.503	3.657
D	0.540	0.646	0.815	0.836	161.0	18.8	-1.673	-0.530	3.851
E	0.523	0.693	0.829	0.755	152.8	15.3	-1.538	-0.023	4.136
F	0.519	0.612	0.776	0.849	154.1	16.7	-1.418	-0.181	4.235
G	0.560	0.670	0.787	0.836	151.8	17.8	-1.475	-0.975	3.643
H	0.583	0.696	0.863	0.837	136.5	17.8	-1.280	-0.490	3.412

NOTE : The (-) indicates that CF and CB lie astern the amidship

Table 2 -Values of R_T/Δ as a function of the relative speed $V/\sqrt{L}$

$V/\sqrt{L}$	A	B	C	D	E	F	G	H
0.2	0.19	0.20	0.18	0.19	0.22	0.20	0.18	0.18
0.4	0.76	0.82	0.70	0.73	0.86	0.78	0.68	0.68
1.0	5.61	5.77	7.95	5.58	7.27	6.00	6.14	6.53
1.2	11.70	11.12	18.30	10.66	13.47	11.04	15.25	16.37
1.4	23.02	20.70	43.31	20.07	25.32	20.90	29.87	32.91

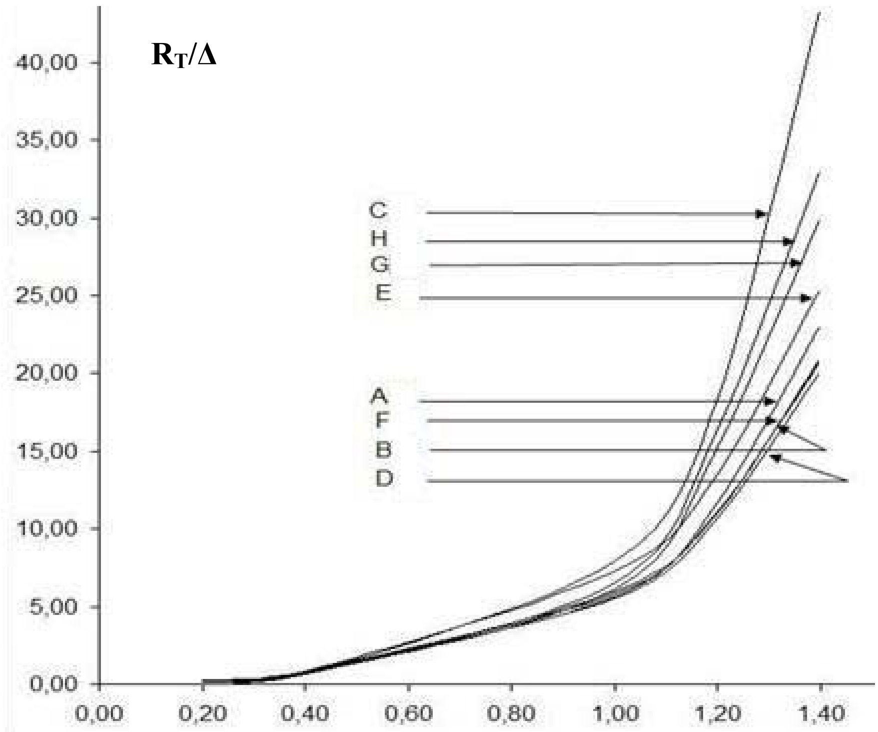

Figure 1 - Average values of specific resistance as a function of the relative speed

Fig. 1 shows that, for speed $V/\sqrt{L} < 1$, the hull forms C e E exhibit the highest specific resistance while the other hull forms exhibit the same specific resistance. For speeds $V/\sqrt{L} > 1$, the specific resistance is notably different for the hulls, with gaps more than about 100%. In the field of $V/\sqrt{L} = 1.25$, which is peculiar for fishing vessels, the hull D, is able to reach the best speed with lesser power. The results obtained from systematic model tests at naval towing tanks allow outlining some general rules, which could help a designer to draw a hull shape of higher efficiency. Among the parameters which influence the performance of a hull, the prismatic coefficient, the longitudinal position of the maximum sectional area, the centre of buoyancy, the half angle of entrance, the shape of bow and stern, are the most important ones.

The following further suggestions could be given for better fishing vessel designs:

- shifting afterwards the center of buoyancy gives good results. It should be placed at about $0{,}3L_{WL}$ astern the midship;
- the value of the block coefficient C_B should be around 0.52;
- the prismatic coefficient C_P is mostly affecting the resistance. Some results from studies on this coefficient allow to state that higher C_P give higher resistances. Its optimal value, for fishing vessels, seems to be around 0.58-0.60;
- an entrance angle i_E = 20° could be assumed for good performances;
- a transom stern seems better than a rounded stern.

Taking into account such considerations, a model of fishing vessel has been designed and tested in a naval tank. The fore body of this basic hull has been replaced by a bulbous bow.

This modified model was tank tested as well. Both the models represent a fishing vessel of the following features:

Length between perpendiculars	L_{BP} = 26.40 m
Load waterline length	L_{WL} = 8.00m
Beam	B = 6.75 m
Draft	D = 2.87 m
Prismatic coefficient	C_P = 0.59
Block coefficient	C_B = 0.447
Full load displacement	Δ = 249 t

Both towing and self propulsion results for the two models are reported in Table 3.

Fig. 2 shows that up to about 7.5 knots, the bulbous bow shows worse effective power characteristics than the basic hull but, in the same speed range, the bulbous bow is better as to the delivered power (fig. 3).

This confirms that:

- the bulb positively acts on the propulsive efficiency, in particular on the hull efficiency and therefore its performances are more efficient for any operating speed at least in this case.
- Both the basic and bulbous bow form showed lower power requests than a commercial vessel of same displacement.

TABLE 3 - Effective (P_E) and delivered (P_D) powers for both basic (1) and bulbous bow form (2) at speeds (V)

V [knots]	P_E [HP]			P_D [HP]		
	1	2	%	1	2	%
5	10	12	+ 20.00	23	19	- 21.00
6	18	21	+ 16.70	37	32	- 15.62
7	30	33	+ 10.00	59	53	- 11.32
8	50	46	- 8.70	93	85	- 9.41
9	77	67	- 14.92	137	125	- 9.60
10	112	97	- 15.46	197	170	- 15.88
11	179	169	- 5.91	299	260	- 15.00
12	343	321	- 6.85	543	492	- 10.36
13	674	582	- 15.80	1109	967	- 14.68
14	1203	1112	- 8.18	2153	1931	- 11.50

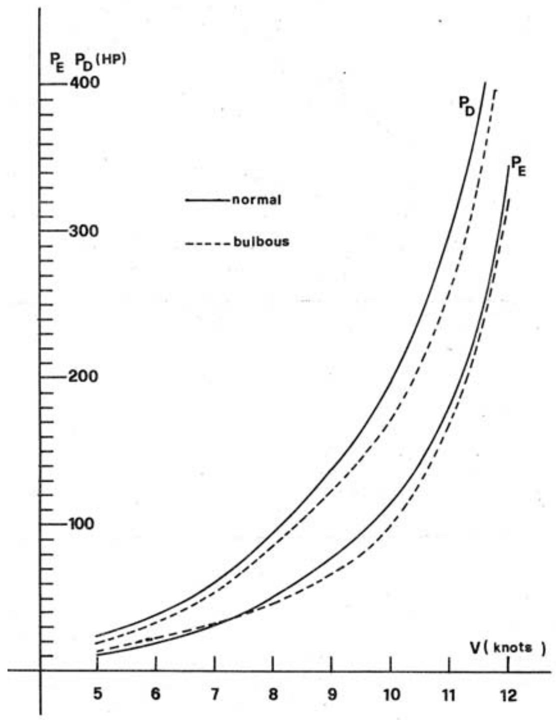

Fig. 2 – Effective (P_E) and delivered (P_D) power curves for a trawler with and without a bulbous bow

4 – IMPROVED PROPULSION SYSTEMS

The power plant of a trawler typically consists of a diesel engine driving a fixed blade propeller which exibits its best efficiency only at its designed point. Therefore, the efficiency of a fixed blade propeller, designed for steaming optimal performance, will drop when trawling.
The vice versa is as well true.
In order to improve the propulsive efficiency some effective devices could be suggested.

4.1 – DUCTED STERN

Such device (fig. 3) consists of a duct structure put ahead of the propeller. It will modify the ship's wake. Model tests with and without such device revealed energy savings (5-10%) due to lesser hull resistance.

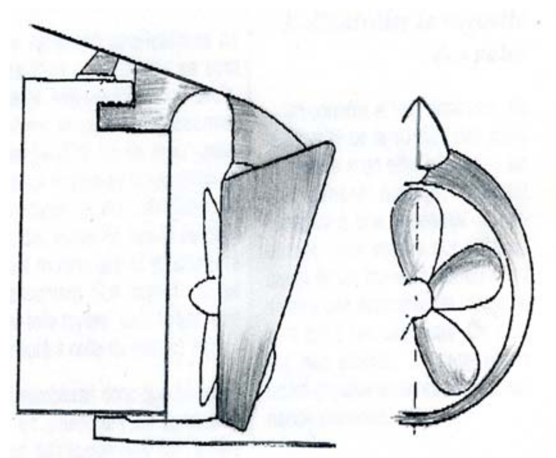

Fig. 3 – Ducted stern
(*source: Alain Le Duff, modified*)

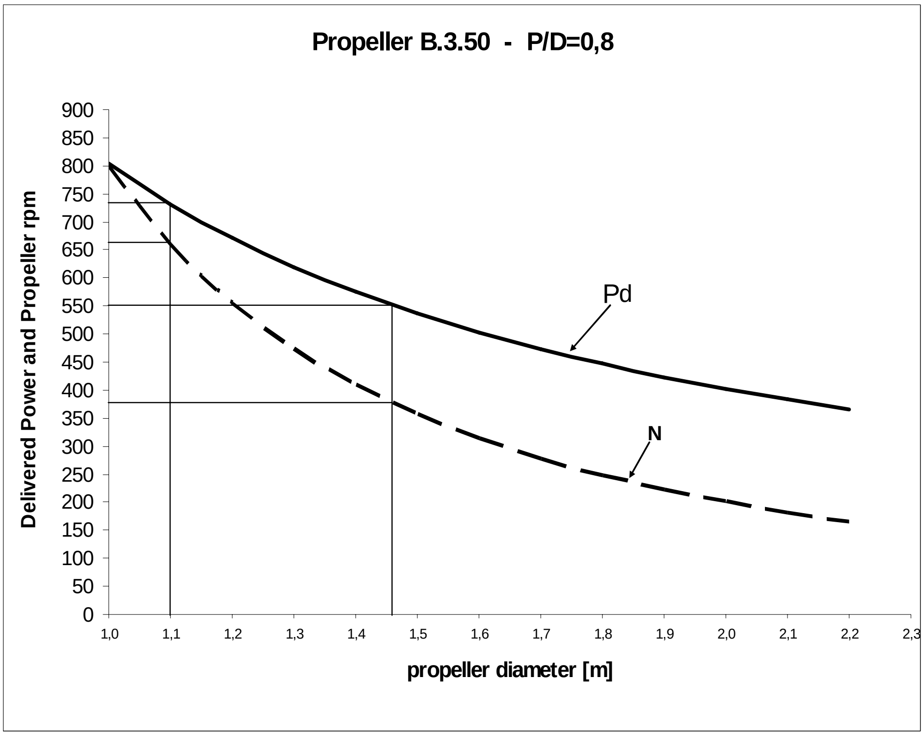

Fig. 5 – Relation between powers (P_D), revolutions (N) and propeller diameters (D) for the same thrust

4.2. STATOR

This structure, consists of putting some lifting flaps on the stern strut in order to reduce the loss of cinetic energy due to the rotation of the propeller wake. It could be applied together with a ducted stern, The efficiency could be improved by 2 ÷ 5%.

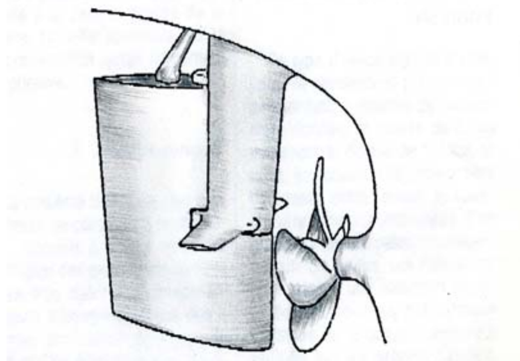

Fig. 4 – Stator
(*source: Alain Le Duff, modified*)

4.3. SLOWLY RUNNING PROPELLERS

Such propellers will gives an improved propulsive efficiency by increasing the amount of water through the propeller disc. The same thrust could be produced with lesser engine power by reducing rpm and increasing the propeller diameter.

The diagram of fig. 5 shows, for a particular propeller, how much power is requested at different rpm and propeller diameters, to produce a thrust of 6000 kg.
As a rule of thumb, when the propeller revolutions are halved and the diameter is increased by 1/3, the required power (and then the fuel consumed) will be reduced by ¼. Such indications are usually applied to new vessels.
but quite often some owners replace both the engine and the propeller even on their already working trawlers.
Further, a reduction of the blades number is effective to the fuel consumption.

4.4. DUCTED PROPELLERS

A ducted propeller, i.e. a propeller fitted around with a ring-shaped profile, will produce the same bollard pull with lesser engine power. For a trawler, the use of a ducted propeller will be power-saving.

Due to its smaller diameter, if compared with a conventional propeller, it could be installed also on already existing trawlers.
It could be said that, rpm being constant, a ducted propeller having a smaller diameter (-10%) than the conventional one, will produce a greater thrust (+25%).
Figure 6 shows a comparison between the powers required by a ducted (P_K) and a conventional propeller (P_C) to develop the same thrust.
The above statements are also supported by some bollard pull tests carried out on a trawler firstly equipped with a free propeller and then with a ducted one. Their performances are listed in Table 4.
The main engine was developing a maximum continuous power of 550 hp at 500 rpm.
For each engine rpm, both the corresponding pulls and the exhaust temperatures were taken.
The data reported in Tables 4 and 5, allow to say that a ducted propeller:

- compared to a free one, even of lesser diameter, running at the same rpm, gives a mean thrust increase of about 26%;
- the thrust being equal, the ducted propeller gives a mean power saving of about 32%.

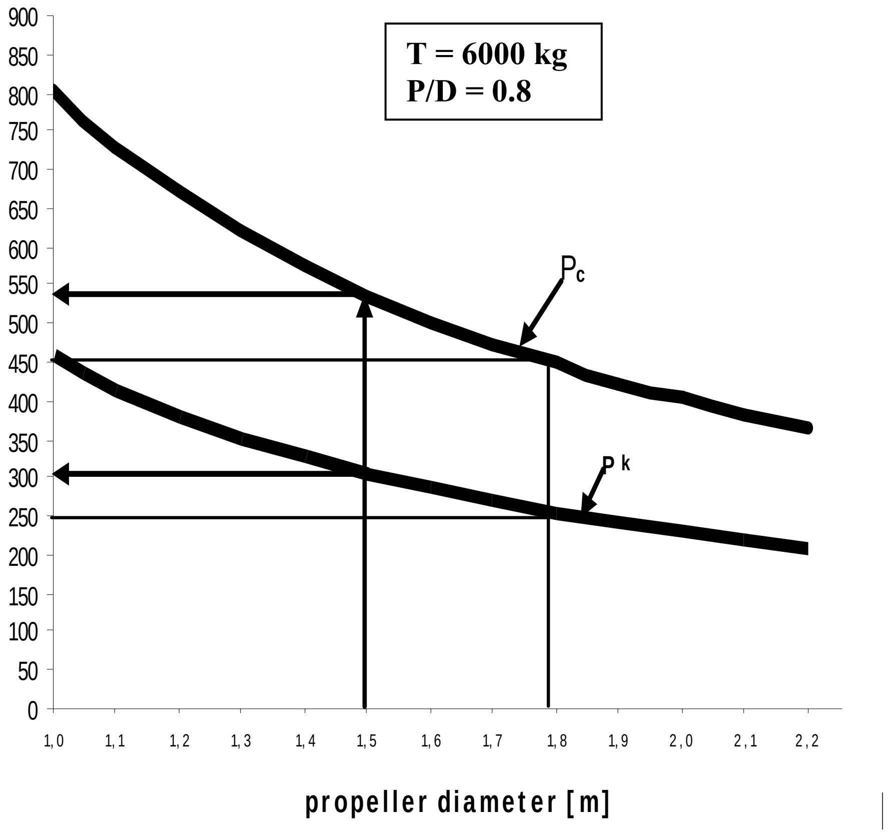

Fig. 6 - Power required by a ducted (P_K) and a conventional propeller (P_C) to develop the same thrust

TABLE 4 – Performances of the ducted and unducted propellers

		PROPELLER	
		unducted	**ducted**
Z	Number of blades	4	3
D	Propeller diameter	1600 mm	1500 mm
P	Propeller pitch	1040 mm	1350 mm
P/D	Pitch ratio	0.65	0.9

TABLE 5 – Comparison between the bollard pulls (T), delivered powers (P_D) and exhaust temperatures (S) at the same rpm (N) of an unducted (1) and a ducted (2) propeller

N [rpm]	**T [kg]**			**S [°C]**		**P_D [HP]**			**T/P_D**		
	1	**2**	**%**	**1**	**2**	**1**	**2**	**%**	**1**	**2**	**%**
385	3380	4240	25.44	360	338	180	170	- 5.55	9.66	12.11	25.36
400	3640	4600	26.37	375	360	200	192	- 4.00	10.40	13.14	26.35
415	3920	4950	26.27	420	383	225	215	- 4.44	11.20	14.14	26.25

TABLE 6 - Powers (P_D) and rpm (N) at the same bollard pull (T), for an unducted (1) and a ducted (2) propeller

T [kg]	**N [rpm]**		**P_D [HP]**		
	1	**2**	**1**	**2**	**%**
3500	392	350	189	128	- 32.27
4000	419	374	232	156	- 32.76

4.5. GRIM WHEEL

A Grim wheel is working as a waterturbine powered by the propeller wake. It is placed then in the slipstream of the propeller and can freely running around its own axis. Its diameter is about 20% larger than the propeller.
The exceed disc area works as a propulsor.
For an existing propeller, the revolutions number is fixed and the Grim wheel is an attractive way to virtually increase its diameter.

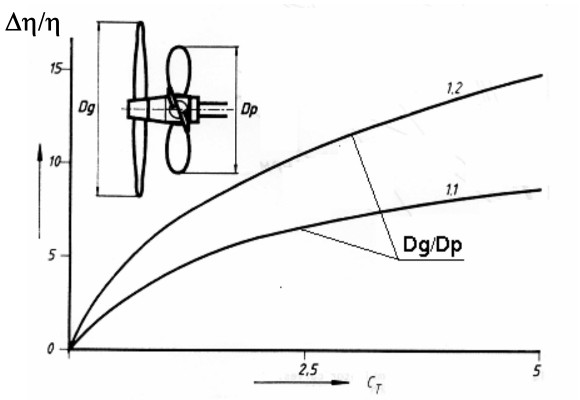

Fig. 7 – Efficiency improvement by a Grim wheel

The energy savings range from 5 to 12%. A Grim wheel could be applied either to new or to already existing propellers (fixed or c.p. type) when a proper room is available. Higher fuel savings could be obtained when a Grim wheel is used in association with heavily loaded propeller.
The improvement of efficiency [fig. 7] depends on the Dg/Dp ratio and on thrust loading C_T, given by

$$C_T = \frac{T}{k\rho Va^2 D^2}$$

where:

ρ	density of the water
D	propeller diameter
k	numerical factor (k = 0.3925)
Va	propeller advance speed
T	propeller thrust

The overall efficiency of a (Grim wheel/propeller) combination is comparable to a slow running propeller, whose diameter is equal to the vane-wheel.

The difference between both is the number of revolutions. The rpm of the Grim wheel/propeller combination is larger than the slow running propeller, resulting in a lower cost for machinary and shaftings.

CONCLUSIONS

Some results coming either from direct calculations or model tests, have been discussed in this paper. They allow to briefly conclude that:

- It seems convenient to reduce the steaming speed in order to achieve some fuel saving rate.
- It is possible to state a set of hull parameters, particularly suitable for a lesser fuel consumer fishing vessel;
- Trawlers should not have to be overpowered, hoping to realize higher steaming speeds. A displacement ship, like a trawler, could reach only a maximum speed imposed by its length; overpowers mean then wasted energy.
- For an useful evaluation of the fuel consumption a suitable fuel-meter should be placed on board the trawlers.
- To obtain substantial fuel savings, tank tests should be done because they are the most efficient mean to ascertain the hull performances.
- The practical results ratify the usefulness of nozzle propellers for trawlers.
- Reducing the number of blades will reduce fuel consumptions.
- High propeller diameters running at low rpm will better the efficiency.

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