

The Next Generation Stern Trawler

Birger Enerhaug¹, Roar Pedersen¹

¹ Fisheries technology, SINTEF Fisheries and aquaculture AS, Trondheim, Norway.

Abstract— In Norway, several projects concerning energy reduction of vessels and fishing gear have been carried out over the last years. In a 3-year R&D-project called “*The next generation Stern trawler*”, SINTEF Fisheries and aquaculture (SFH) investigated the energy saving potential of new solutions in hull design and propulsion, together with better utilisation of the energy in engines and general on-board consumption. In addition, the project also addressed the dangerous working conditions on trawl deck and proposed several new and safer ways of gear handling based on an extended use of mechanisation. The paper presents and discusses the influence of hull form and propulsion parameters on energy consumption, as well as a method for improving manoeuvrability and energy saving by transverse and longitudinal transfer of the trawl/towing blocks. The final results show that a total reduction of 25% in engine power can be achieved when towing in rough weather, compared to a conventional trawler under similar conditions.

Keywords-component; energy reduction; trawler; hull form;

I. INTRODUCTION

The project “The Next Generation Stern Trawler“ was initialized by Sintef Fisheries and aquaculture AS together with Rolls-Royce Marine AS and a reference group of eight ship owners with one or more stern trawlers in operation. The main objectives of the project were to develop new and improved technology in the trawler fleet in order to reduce the fuel consumption, and improve the safety and working conditions on the trawl deck.

The majority of the last generation of stern trawlers were built between 1986 and 1990. The installed main engine power in these vessels is between 3-4000 kW. Since then, fishing with double trawl and even triple trawl have become the common methods. To pull a double trawl at 4 knots in calm waters, the required thrust is approximate 37 tons, which correspond to a brake power of 2500 kW. In bad weather, however, with added resistance from waves and wind the required power will increase considerably. For a trawler, a vital part of the catch strategy, is to follow a certain path or course line. With

unfavourable cross currents, this may be a very demanding task that puts great efforts on both manoeuvrability and engine power capacity of the trawler. Several skippers in the reference group reported about incidents where they had to use rudder angles up to 30 degrees in order to compensate for current and environmental forces. Maximum power together with maximum rudder is a very unfavourable combination with respect to resistance. The induced speed from a heavy loaded propeller can amount to 3-4 times the towing speed, and thus give a rudder resistance of the same magnitude as the trawl. To overcome these problems, installed engine power has been steadily increased for the last decades. Reference [1] gives an overview of the changes in technical capacities of the largest Norwegian trawlers from 1974 to 2000. In this period the engine output and tonnage increased by 275%, and 209% respectively. The vessel length, however, increased by only 18%. This indicates that the larger trawlers have evolved from slender to chubbier vessels, at the same time as they are towing larger trawls. This development really came into focus during our last fuel crisis. The high fuel prices made it clear to everyone involved in design and operation of trawlers that the direction of development had to change. Suddenly, focus was on energy saving measures related to design and operation of the trawler and the trawl(s).

In this project, focus has been on improving the hull form and propulsion parameters with respect to energy consumption, as well as the possibilities for improving manoeuvrability and energy saving by transverse and longitudinal transfer of the trawl/towing blocks.

The next generation trawler was developed as a twin screw hull design with a slender bow shape, characterised by an almost vertical stem in combination with modest flare. The propeller size was optimised for best efficiency under heavy load, i.e. towing a large trawl in rough weather. To verify the properties of the final solutions, a series of model tests were conducted, both of the new twin screw hull design and for a comparable “state of the art” conventional single screw hull.

A. Notation

L_{PP}	Length between perpendiculars
FP	Forward perpendicular
AP	Aft perpendicular
V	Speed
VCG	Vertical centre of gravity
LCG	Longitudinal centre of gravity
$Fn = V/\sqrt{gL_{PP}}$	Froude number
ζ	Wave amplitude
$H = 2\zeta$	Wave height
λ	Wave length
H_S	Significant wave height
Th	Thrust
δ	Rudder angle
t	Thrust deduction fraction
w	Wake fraction
η_0	Propeller efficiency in open water
$\eta_H = (1-t)/(1-w)$	Hull efficiency
η_R	Relative rotative efficiency
$\eta_D = \eta_0 \eta_H \eta_R$	Quasi-propulsive coefficient
η_M	Mechanical efficiency
P_D	Delivered power
$P_B = P_D/\eta_M$	Brake power

II. EXPERIMENTAL METHODS

A. Models

For the experiments two ship models were used. One model had a hull form with one skeg, representing the “state of the art” of Norwegian stern trawlers, while the other had a hull form with two skegs representing our ideas of the next generation trawlers. Stern and bow profiles of the two models are shown in Figure 1 and 2. For simplicity they will be referred to in the text as the “single skeg” and the “twin skeg” model.

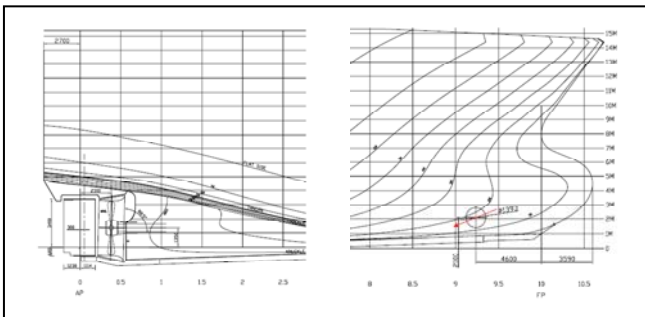


Figure 1 Stern and bow profile of a “state of the art” stern trawler

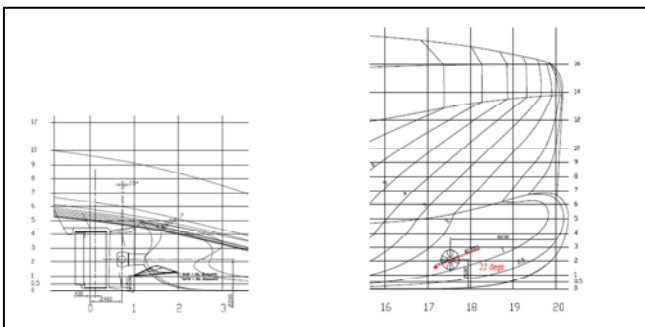


Figure 2 Stern and bow profile of next generation stern trawler

Both models were built in wood/divinycell to the linear scale of 1:19.656. The model of the next generation trawler is pictured in Figure 3. The characteristic bow shape with an almost vertical stem in combination with modest flare is clearly seen from the figure.

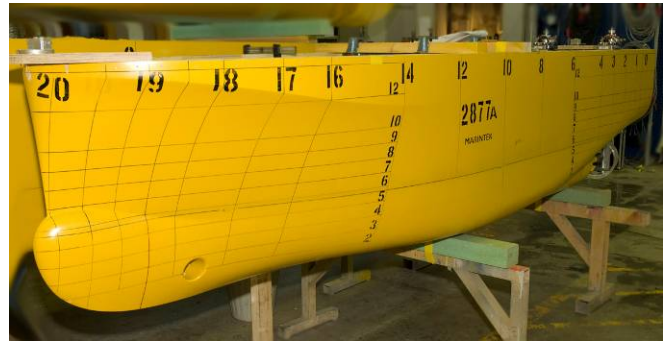


Figure 3 Next generation stern trawler (twin skeg hull)

Their main particulars of the two models are given in Table 1.

TABLE I. MAIN PARTICULARS OF MODELS

Parameters			Full scale values	
Denomination	Symbol	Unit	Single skeg	Twin skeg
Length over all	L_{OA}	m	67.11	70.00
Length in water line	L_{WL}	m	65.94	69.95
Length betw. perpendiculars	L_{PP}	m	60.20	66.40
Breadth in water line	B_{WL}	m	15.60	16.00
Draught at $L_{PP}/2$ (even keel)	T	m	5.70	5.70
Displacement volume	∇	m	3280	3393
Block coefficient (L_{WL})	C_B	-	0.56	0.53
Long. centre of gravity	LCG	m	28.70	31.00
Vert. centre of gravity	VCG	m	7.30	7.30
Long. radius of gyration	R_{55}	% L_{PP}	30	27
Rake of keel (over L_{PP})		m	2.00	0.00

The twin skeg model was equipped with two Rolls-Royce high lift rudders (Figure 4), and the single skeg model with one.

Both models were made with a side thruster tunnel in the fore body, with a dummy propeller mounted in the ship’s centre line.



Figure 4 Rudder arrangement on the twin skeg hull

B. Test programme

The test programme consisted of series of resistance and propulsion tests in calm water, propulsion tests in regular and irregular waves, and towing a simplified trawl model in irregular waves and calm water.

All tests were done in head seas in the MARINTEK towing tank in Trondheim. The tank has a total length of 260m, width 10.5m and depth 5.6/10m and is equipped with two towing carriages: One for high speed, and one for low speed applications.

1) Resistance and propulsion in calm water

In the resistance tests the model was towed by the towing carriage, and the resistance, sinkage and trim were measured at speeds ranging from 10 to 18 knots in full scale values.

In the propulsion tests the model was powered by an electric motor coupled to propeller through a dynamometer. The rate of revolution was regulated until the model was running with the same speed as the towing carriage. The speed range was from 10 to 18 knots in full scale values. To compensate for the scale effects in frictional resistance, an additional towing force was applied on the model. During the tests, the following parameters were recorded: Propeller thrust (T_h), propeller torque (Q), rate of revolution (n), model speed (V) and applied towing force (F_D).

Towing pull tests were performed with speeds corresponding to full scale speeds, $V_S = 0, 4$ and 7 knots.

2) Propulsion in waves

The test programmes in regular and irregular waves are shown in Table II. The same series of tests were carried out for both models.

The tests were run with two speeds in both regular and irregular waves, corresponding to the full scale speeds of $V_S = 4$ and 8 knots. In regular waves, the tests were carried out in waves with periods between 6 and 12 seconds and height-length ratio (H/λ) of 0.025.

In irregular waves, two wave spectra with the Pierson-Moskowitz energy distribution were chosen to represent two fully developed sea-states. The sea-states are described with their significant wave height (H_S) and spectral peak period (T_P).

TABLE II. PROPULSION TESTS IN WAVES

Speed	Regular waves		Irregular waves	
	H (m)	T (sec)	H_S (m)	T_P (sec)
4 & 8	1.41	6		
4 & 8	1.91	7		
4 & 8	2.50	8		
4 & 8	3.16	9		
4 & 8	3.91	10		
4 & 8	4.73	11		
4 & 8	5.62	12		
4 & 8			2.43	8.4
4 & 8			5.15	10.5

3) Trawling in calm water and waves

In addition to the standard propulsion tests, a series of tests were performed with the models towing a simplified model of a trawl system. A sketch of the trawling arrangement is shown in Figure 5.

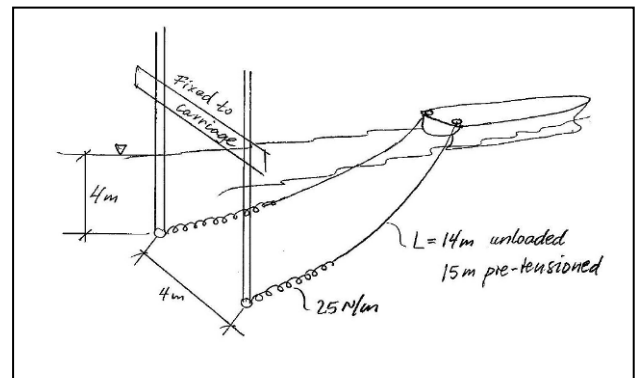


Figure 5 Trawling arrangement

As a trawler spends 60 – 70% of its operational time towing the trawl, it is of great importance to establish the performance under these conditions. In the planning stage of the tests various types of arrangements were considered, for instance rolling wheels as used by [2], or a model of complete trawl system as used by [3].

However, since all tests were done in head seas, the trawl system could be represented by a simple arrangement fixed to the towing carriage. Two springs were positioned 4 m below the surface and fixed to the carriage by two vertical poles at

4 m distance. The springs were connected to the model by two towing lines (“warps”) of 12 m length. The connection point on the model coincides with the position of the towing block on the full scale ship, and is referred to as the “towing point”. The stiffness and length of spring was chosen so as to represent the resistance and geometrical stiffness of the trawl, with approximate 1 m elongation. In pre-tensioned conditions during tests, the spring and towing line would together have a mean length of 15 m and represent the full scale resistance of 37 tons of a double trawl.

With this trawl arrangement, the power demand under towing/trawling was measured in calm water and irregular waves at a speed corresponding to 4 knots in full scale. Sea states are given in Table II.

This arrangement was also used for two additional series of tests:

-1. Measurements of the transverse hull force Y (+ to starboard) and yaw moment N (+ turning ship to starboard) for the 3 drift angles (+ bow to port) and 6 rudder angles (+ to port) given in Table III.

TABLE III. MEASUREMENTS OF HULL FORCES

Drift angle (degr.)	Speed (knots)	SB Towing point	Rudder angle (degr.)
0	4	1	-35, 0, 10, 20, 30, 35
7	4	1	--35, 0, 10, 20, 30, 35
15	4	1, 2, 3, 4	-35, 0, 10, 20, 30, 35

The drift angle is defined as the angle between the hull centre line and direction of the water flow relative to the hull. With water at rest, and the model moved in one direction, the drift and yaw angle will be the same. The model was fixed to the towing carriage with two jointed beams that allowed the model to surge, heave and pitch, but restricted it from yawing, swaying and rolling. The horizontal reaction forces between model and beams were measured and used to calculate the transverse hull force and yaw moment.

-2. Measure the effect on power consumption of transverse transfer of the starboard (SB) towing point from SB to port side at 15 degree drift angle.

The distance of the towing points from the ship centre line (in transverse direction) is given in Table IV. The distances are the same for both models. The longitudinal positions aft of AP are -2.75m for the twin skeg model, and -2.25m for single skeg.

TABLE IV. TOWING POINT COORDINATES I TRANSVERSE DIRECTION

No.	Towing points				
	5 (Port)	4	3	2	1 (SB)
Y(m) =	-5.00	-4.00	-1.00	2.00	5.00

The towing point arrangement with force transducers for the twin skeg model is shown in Figure 6. The SB towing point was moved step by step from point 1 on the SB side to point 4 on the port side.



Figure 6 Towing point arrangement

III. RESULTS

A. Resistance and propulsion in calm water

The effective power (P_E) and brake power (P_B) of the two hulls are shown in Figure 7. From the figure it is seen that both P_E and P_B values in general are higher for the twin skeg hull than for the single skeg hull in the speed range between 8 and 14 knots. The differences in resistance (P_E) between the hulls are 51% at 8 knots, 24% at the design speed of 12 knots and -10% at 16 knots. The difference in brake power (P_B) is 125% at 8 knots, 92% at the design speed 12 knots, and 33% at 16 knots. Thus the calm water resistance and propulsion test show poorer results for the twin skeg hull.

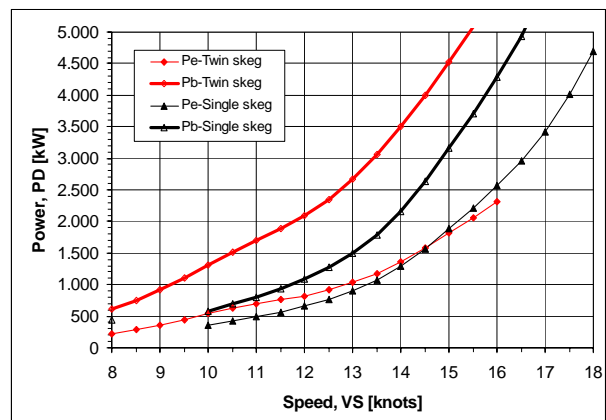


Figure 7 Towing resistance and brake power vs speed

The calculated quasi-propulsive coefficient $\eta_D = \eta_0 \eta_H \eta_R$ for the two hulls are shown in Figure 8. The single skeg ship has a mean value of $\eta_D = 0.62$, while the twin skeg hull has a considerable lower value of $\eta_D = 0.41$.

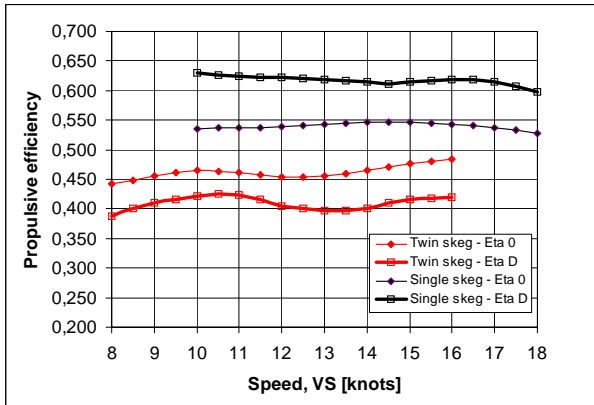


Figure 8 Propulsive coefficients, η_0 and η_D

B. Towing pull tests

In Figure 9 the towing pull achieved with both models in 4 knots are shown together with the necessary towing force (37 tons) of a double trawl.

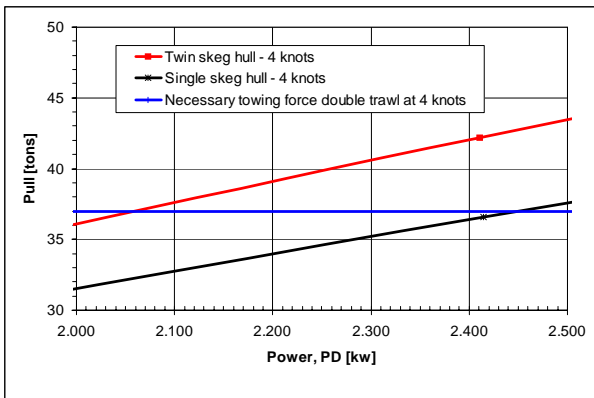


Figure 9 Towing pull and necessary towing force with double trawl

From Figure 9 it is seen that to achieve a towing force of 37 tons, the necessary delivered power (P_D) is 2450 kW for the single skeg hull, and 2060 kW for the twin skeg hull. The difference, 390 kW, correspond to 15.9% reduction of power to the benefit of the twin skeg hull.

C. Propulsion in regular waves - free running model

The propulsion tests in regular waves were run with two speeds, corresponding to 4 and 8 knots in full scale. When the period of encounter is similar to the natural period in pitch, maximum pitch and added resistance in waves are expected. As seen in Figure 10, the maximum delivered power (P_D) occurs at a wave period $T \approx 7.5$ sec. for 4 knots, and at $T \approx 8.0$ sec. for 8 knots.

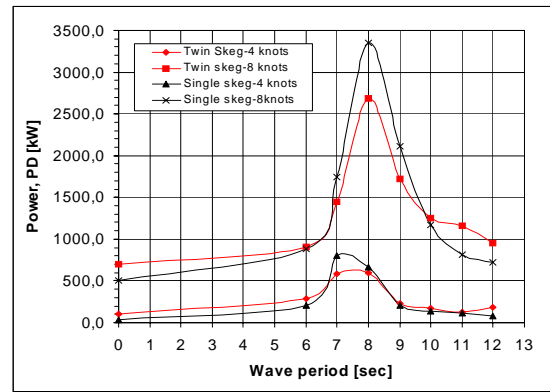


Figure 10 Delivered power (P_D) in regular waves

Despite of the poor calm water resistance and propulsion properties of the twin skeg hull, its delivered power is significant lower at resonance than that of the single skeg hull. The difference at 4 knots and $T = 7$ sec. is 26 % and at 8 knots and $T = 8$ sec. the difference is 20 %. The power reduction for the twin skeg hull can be explained by lower added resistance in waves due to the slender bow shape, and more favourable propulsive efficiency with increasing power/higher propeller loading.

D. Propulsion in irregular waves – free running model

The full scale results (4-8 knots) presented in Figure 11 are direct scaled, without friction scale compensating, and the divergences between the results from the reference calm water tests and the propulsion test results are illustrated in Figure 11. The calm water reference curves show that the twin skeg hull has as a higher power demand than the single skeg hull in calm water. However, the tests in irregular waves show that the tendency is rather that the twin skeg hull has the lowest power demand in irregular waves. At 8 knots and significant wave height $H_s = 5,1m$ the power reduction is approximate 12%. The reasons are as explained in Section C; lower resistance in waves and a more favourable propulsive efficiency.

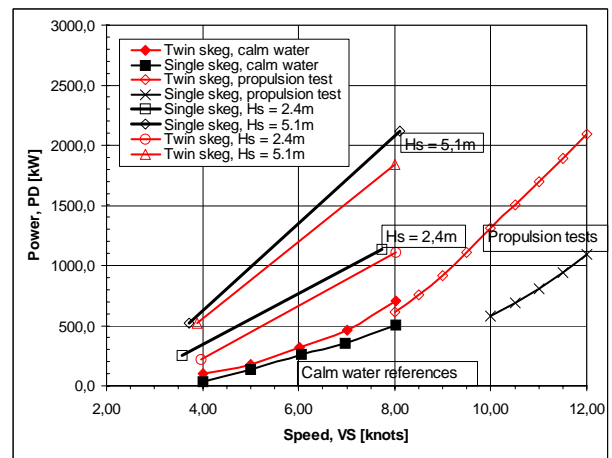


Figure 11 Power in irregular waves and calm water

E. Propulsion with trawl in irregular waves

The towing tests with the trawl model were performed in the same sea states as used in the propulsion tests with free models. The towing speed was 4 knots, and the mean towing force corresponding to a double trawl with 37 tons resistance. The measured mean values of delivered power (P_D) are shown in Table V.

TABLE V. TRAWLING IN CALM WATER AND IRREGULAR WAVES

Hull form	Mean delivered power (P_D) in [kW]		
	Calm water	$H_s = 2.43m$ $T_p = 8.4 s$	$H_s = 5.15m$, $T_p = 10.5 s$
Single skeg	2440	2905	3452
Twin skeg	2050	2280	2589

The test results show that the twin skeg hull has a significant lower power demand when trawling in waves. At 4 knots and significant wave height $H_s = 2.43m$, the difference is 21% (625 kW), and at 4 knots and significant wave height $H_s = 5.15m$, the difference is 25% (863 kW). From Figure 11 it is seen that in irregular waves without trawl in 4 knots the difference in delivered power (P_D) between the two models are only in the range of 50 - 100 kW. That shows that the better performance of the twin skeg hull is mainly due to improvements in propulsion efficiency when propeller loading is increased.

F. Trawling in calm water with variation in trawl block positions

When the measured yaw moment are zero, it means that the hydrodynamic forces on the hull is balancing the other "outer" forces acting on the model, which in this case is the moment from the trawl system. The yawing moment for the twin skeg hull is shown in Figure 12.

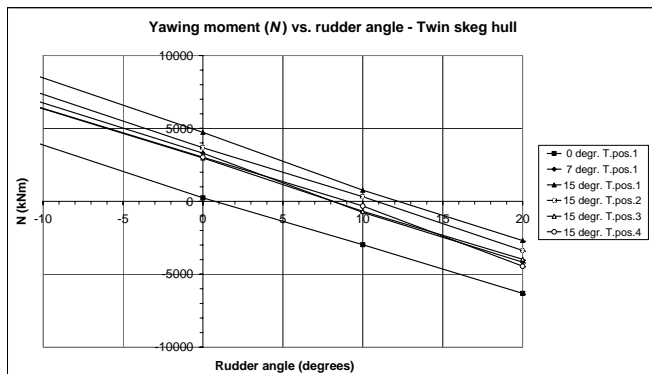


Figure 12 Yawing moments for twin skeg hull

From the figure it is seen that for 15 degree drift angle and SB towing point in position 1, a rudder angle of 12 degrees is needed to balance the trawl forces. Moving the towing point inwards to position 3, will reduce the necessary rudder angle to 8 degrees.

The reduction in delivered power can be found from Figure 13 which shows the delivered power for the tested drift and rudder angles. From the figure it is seen that moving the towing point from position 1 to position 3 at 15 degrees drift angle, the measured delivered power (P_D) is reduced from 2300 kW to 2100 kW.

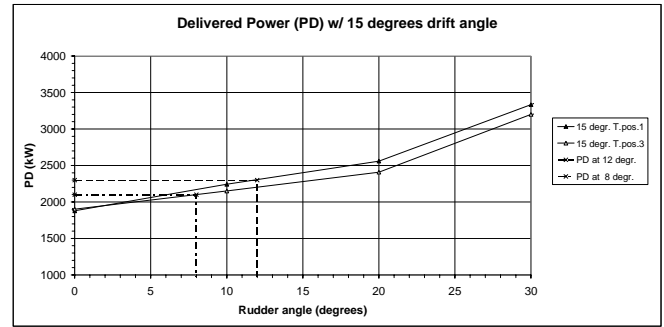


Figure 13 Delivered power (P_D) at 15 degrees drift angle - twin skeg hull

A reduction of 9% does not seem much, but it clearly demonstrates that the principle is effective.

The principle will, however, be more effective, the higher the loading of the propeller is. Theoretical calculations done in the early stages of the project, show that reductions in order of 20 - 25% can be obtained when maximum power is used under extreme conditions.

An accompanying effect of moving the trawl blocks sideways, is that manoeuvrability of the ship increases.

IV. CONCLUSIONS

There is a potential to improve the propulsive coefficients and the resistance of the twin skeg hull. The bulbous bow did not work properly in the low speed range and should be redesigned to be more optimal in the low speed range and at the normal steaming speed of 12 knots. The aft body hull form as well as the design of brackets influenced adversely on the propulsive coefficients such as relative rotative efficiency (η_R) and hull efficiency (η_H) which depend on thrust deduction (t) and wake fraction (w). With extreme propeller diameters as, chosen in this case, little can be done to improve the open water efficiency (η_0) in calm water and normal speeds. The open water efficiency is, however, increasing when trawling or in bad weather. Based on the experience with twin screwed anchor handling vessels there should be a potential to improve the quasi-propulsive coefficient $\eta_D = \eta_0 \eta_H \eta_R$ from 0.41 to approximate 0.5.

The fuel consumption for a whole year is calculated for both trawler concepts based on an assumed and simplified operating profile, rough weather statistics and results from tests. The factors that give lower fuel consumption for the twin screw/twin skeg model are better propulsive efficiency with two propellers in trawling conditions, lower resistance in waves due to a slender fore body and reduced drag on the rudders in demanding trawl operations in bad weather by moving trawl blocks to unload rudders. Fuel consumption in calm water steaming will increase due to higher resistance and lower propulsive coefficients compared to the single screw/single skeg model, but waves are normally present and therefore the power at steaming has not been increased with as much as 92% (calm water), but with 35% which is more representative. Less power installed will in average give a more favourable engine load with respect to the specific fuel consumption, and these effects are calculated. Some of the numbers in the TABLE IV are interpolated from test results, and some numbers are results of conservative assumptions based on experience.

According to the calculations in TABLE VI the “state of the art” trawler need an installed power of 5830 kW and the next generation trawler need an installed power of 4278 kW. Thus the reduction in installed power demand is 26.6%, and the average fuel reduction is calculated to be 14.2% on a whole year basis.

TABLE VI. TOTAL REDUCTION IN FUEL CONSUMPTION

		Typical operation profile stern trawlers, double trawl						
		Steaming to/from	Steaming at fish ground	Trawling good weather	Trawling normal weather	Trawling bad weather	Production normal weather	Trawling extreme load
Operating days	340	Hs<1m	Hs<1m	Hs<1m	Hs=1.5m	Hs=2.5m	Hs=1.5m	Hs=5.0m
Time consumed	100 %	11 %	7 %	25 %	36 %	10 %	10 %	1 %
Time consumed, days	340	37	24	85	122	34	34	3
Rudder resistance in percent of propulsion power		0 %	0 %	2 %	5 %	15 %	0 %	40 %
Speed	[knots]	12	12	4	4	4	2	4
“State of the art” trawler								
Average propulsion power demand	[kW]	1200	1200	2450	2600	2900	300	3450
Rudder resistance	[kW]	0	0	49	130	435	0	1380
Electric power demand	[kW]	300	400	450	500	550	500	1000
Total power	[kW]	1500	1600	2949	3230	3885	800	5830
Engine load	[%]	26 %	27 %	51 %	55 %	67 %	14 %	100 %
Fuel consumption	[tons]	256	174	1143	1803	802	124	90
Total fuel consumption per year	[tons]				Per day: 12,33	Per year: 4192		
Improvement next generation trawler								
Average propulsion power demand	[%]	-35 %	-35 %	16 %	18 %	21 %	0 %	25 %
Rudder resistance	[%]	0 %	0 %	80 %	70 %	60 %	0 %	50 %
Specific consumption	[%]	5,0 %	5,0 %	2,0 %	1,5 %	0,5 %	1,2 %	0,0 %
Heat recovery [% of power in use]	[%]	0 %	0 %	0 %	0 %	0 %	0 %	0 %
The next generation trawler								
Average propulsion power demand	[kW]	1620	1620	2058	2132	2291	300	2588
Rudder resistance	[kW]	0	0	10	39	174	0	690
Electric power demand	[kW]	300	400	450	500	550	500	1000
Heat recovery (12% of power in use)	[kW]	0	0	0	0	0	0	0
Total power	[kW]	1920	2020	2518	2671	3015	800	4278
Engine load	[%]	45 %	47 %	59 %	62 %	70 %	19 %	100 %
Fuel consumption	[tons]	311	208	956	1468	465	123	66
Total fuel consumption	[tons]				Per day: 10,58	Per year: 3598		
The next generation trawler								
Fuel reduction in average	14.2 %				Oil price	5,0	[NOK]	
Installed power reduction	26.6 %				Saved per year	2,969,597	[NOK]	
Specific fuel consumption	190 g/kWh				Saved every day	8,734	[NOK]	
Installed power “State of the art trawler”	5830 kW							
Installed power “Next generation trawler”	4278 kW							

ACKNOWLEDGMENT

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