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The Development of a “Green Trawler”

Dominic Rihan [1], Noel O’Regan [2], Barry Deakin[3]

1 An Bord Iascaigh Mhara, Crofton Road, Dun Laoghaire, Co. Dublin, Ireland
2 Promara Ltd, St Joseph’s Road, Mallow, Co. Cork, Ireland.
3 Wolfson Unit MTIA, University of Southampton, UK

***Abstract*—** As quota and fishing effort restrictions become tighter, and fuel costs spiral, it is likely that fishing time will further reduce and therefore the design pressure on fishing vessels of the future will be to improve efficiency when steaming and to retain optimum thrust when trawling. Rules and regulations have shaped our modern trawlers. The necessary fullness for carrying fish is accentuated by the imposition of restrictions in length. While it is generally accepted that there is a penalty in fuel consumption relating to this evolution this study sets out to quantify it.

This paper describes the development of a “green trawler” designed to incorporate the highest level of efficiency available in a practical form for use in the demersal fishing fleet. Results from field tests on existing trawlers and towing tank tests on the green trawler design are presented. Comparison is made between a typical demersal trawler, at sea and in the test tank, and the green trawler.

The model tests were designed to confirm that the design concept was fuel efficient; and to determine the potential for increased fuel efficiency if certain regulatory restrictions on fishing vessel design parameters were lifted. Savings of 30% on fuel consumption could be achieved with relatively modest length increases. Additional savings of 10 to 20% can be achieved by reducing the drag of hull appendages, for example, better alignment of bilge keels.

The study concludes by introducing the concept of “Green Tonnage” as an option that should be considered by the EU and Member States, whereby vessel owners would be allowed additional GT’s for new builds over and above existing limits without being penalized. This should be strictly on the basis that no increase in effective fishing effort results.

Keywords- Green Trawler; demersal; fuel efficiency; resistance; power; regulations, model test

I. INTRODUCTION

A typical trawler spends more than 20% of its time in transit to or from the fishing grounds and a similar portion of its time “dodging” in bad weather or moving fishing grounds at sea. Only 40% of its time is spent trawling (Curtis et al., 2006). As quota and fishing effort restrictions become more restrictive, and fuel costs spiral, it is likely that fishing time will further reduce and therefore the design of fishing vessels in the future must ensure that they are equally efficient when steaming as when trawling.

This study sets out to determine the inefficiency that occurs when the design brief for a new trawler is dominated by a single parameter. In this study we have focused on the recent trend in the Irish Fleet to build new vessels to a Registered Length of 19.8m, with the vessel size and carrying capacity maximised in all other respects. Further tests were carried out to determine the flow of water around the hull and the influence of the positioning of bilge keels.

The resistance of any displacement hull increases with speed. Low speeds require relatively little effort up to a “hull speed” above which the resistance rises steeply. This length of 19.8m gives us a hull-speed of around 9.0 knots.

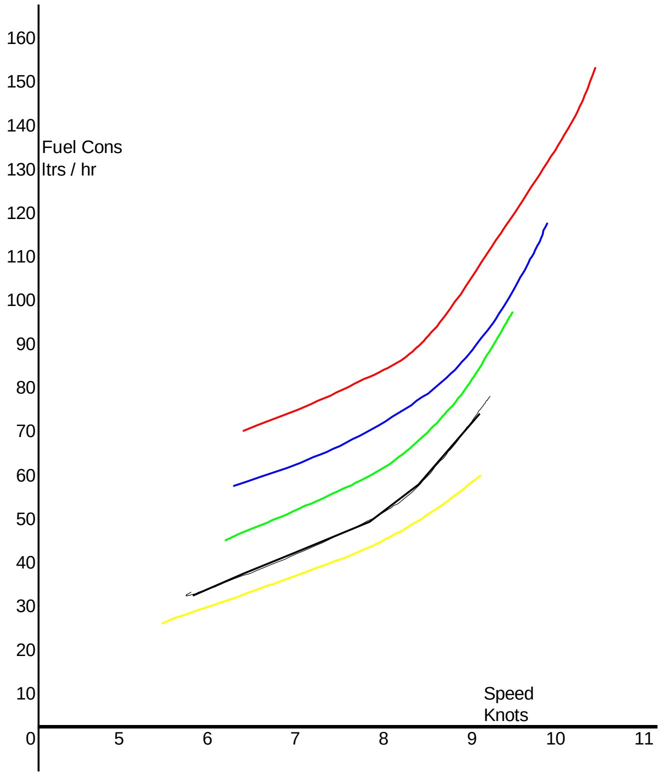
The hull shape and volume of the vessel determines the force required in achieving hull speed and the rate of increase in additional force required to accelerate beyond that hull speed. A more slender vessel would require less power to achieve hull speed and suffer less of a penalty to attain speeds above.

Taking cognisance of these factors a concept “Green trawler” has been designed based on the capabilities and carrying capacity of a typical Irish demersal trawler. This project was undertaken by Bord Iascaigh Mhara (BIM) in conjunction with Promara Ltd, and the Wolfson Unit based in the University of Southampton, who conducted the tank testing described in Section IV. The hull form was designed by Ian

Paton of Sc McAllister. The specifications of the green trawler are based on a 24 metre demersal trawler with 750kw installed, targeting traditional demersal species and nephrops, as well as pelagic species such as albacore tuna, mackerel, herring and sprat seasonally. It was compared with a reference vessel representative of those that form a large proportion of the newer Irish demersal fleet.

II. FIELD TESTS

Field tests were carried out on four vessels to optimise the existing propulsion equipment. Bollard pull and free running trials were carried out on all vessels. In addition to demonstrating the principle of hull speed, the best combination of propeller pitch and rpm for each vessel were determined. The different curves below relate to various combinations of propeller rpm & pitch which demonstrate the fuel saving possible by careful choice of operational settings. Each curve represents a range of propeller pitches at a fixed engine RPM. The highest curve was obtained at 1600 RPM and the lowest at 1200 RPM.



III. OUTLINE SPECIFICATIONS OF GREEN TRAWLER

As a first step a draft general arrangement and lines plan of the concept vessel were produced with the only restrictions imposed being installed power and hold size. The primary design objective was to develop a very efficient hull form using design principles to maximise fuel efficiency. This meant, by necessity, that the hull needed to be longer than current convention with a finer entry, narrower beam, shallower run aft and a bulbous bow. This would provide an easily driven hull that would reduce propulsion and fuel consumption and increase transit speed. A realistic approach was taken to weight estimates and stability restrictions. While a substantial reduction in beam appeared to be a prerequisite, the requirements of stability and the internal arrangement made a reduction below 8.0 metres impractical, even with a waterline length of 35m

At an early stage it was identified that to design such a vessel would require that it would not necessarily follow the design norms currently imposed by rules and regulations, both nationally and at EU level. In all likelihood, it would result in a vessel with increased Gross Tonnage (GT) compared to the standard equivalent trawler.

The hull shape was modelled with a round bilge construction and bulbous bow, narrow stern skeg, faired stem and non-immersed transom stern with very open flow to the propeller. The bow flare begins above the maximum design draft and is larger than normal for this size and type of vessel. The parallel mid-body is short and the aft section rises from a point close to the forward end of the engine room with the narrow skeg housing and a relatively long propeller shaft. The bottom of the transom is designed to be just immersed with the vessel in her light-ship depart-port trim.

The propeller aperture was designed to have an open flow of water with as little turbulent wake as possible. Below the main deck the hull was subdivided into five watertight compartments: forepeak, thrusters and sonar room, insulated fish hold, engine room and aft peak. Because of the increased length, the fish hold can be located to obtain the optimum trim. The main novel features of the concept vessel can be summarised as follows:

1. highly efficient hull shape with finer waterline entry and shallower, straighter, run aft
2. large propeller aperture with good flow to propeller
3. steering nozzle to minimise drag and maximise the length available to distribute the hull volume.

IV. MODEL TEST TECHNIQUES

In addition to the principal aim of addressing the length and form of the trawler hull design, to the tests needed to quantify the resistance penalties of badly designed and non-aligned bilge keels, and the lack of fairing to the bow thruster opening. The influence of sea-state on the resistance was also of interest.

A. Models and Their Keels

Models of the two hulls were constructed in wood and GRP, at a scale of 1:16. The vessels' principal dimensions are presented in Table 1, and the shape of the hull forms are shown in Figure 1 and Figure 2.

Figure 1 Hull form – Reference Trawler “Design A”

Figure 2 Hull form – Green Trawler “Design B”

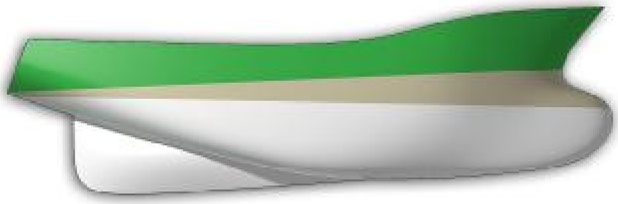


TABLE 1 PRINCIPAL DIMENSIONS

All dimensions in metres	Design A	Design B
Length overall	23.2	27.8
Length BP	18.7	24.0
Length registered	19.80	23.97
Moulded beam	8.2	8.0
Moulded depth	6.45	6.45

TABLE 2 LOADING CONDITIONS

	Design A		Design B	
	Depart port	*Depart grounds*	*Depart port*	*Depart grounds*
Draught amidships	3.808	4.769	3.887	4.793
Trim of keel	1. 500	0.130	0.554	-1.005
Displacement	403.7	539.6	428.67	564.61
LCG fwd of Fr 0	8.801	9.113	11.944	11.744

Bilge keels were fitted to Design A to model those on the existing vessel. They comprised a series of flat plates, set in a 60° V configuration, but with short plates fitted alternately on each side of the keel, rather than a more conventional single plate or solid V shaped bilge keel. The keel was fitted on a diagonal. Following flow visualisation tests, alternative bilge keels were fitted, at the same longitudinal location and of the same depth, and aligned to the local flow. These were of conventional solid 30° V section.

The green trawler “Design B” was fitted with conventional flat plate keels, of the same depth as those on Design A, with a length in proportion to the relative registered lengths. They were located on a diagonal drawn, on the body plan, though the 4.5m waterline at the centerline, at 40 degrees to the horizontal. Following flow visualization tests, solid V section keels were fitted at the same longitudinal location and of the same depth, and aligned to the local flow.

B. *Resistance Tests*

The tests were conducted in a towing tank 60m long, by 3.6m wide, by 1.8m deep. The models were towed using a single free to heave post, connected to the model by a fitting that enables freedom in trim. Measurements were made of resistance, heave and trim.

The tested loading conditions are presented in Table 2. They represent the actual conditions as presented in the stability booklet of the existing vessel, Design A, and realistic conditions calculated for the proposed vessel, Design B. It is evident that Design A has greater stern trim, and hence greater transom immersion, and this was one of the aspects that were addressed in planning the general arrangement of Design B.

Figure 3 Design A, Depart Port Condition at 9 knots

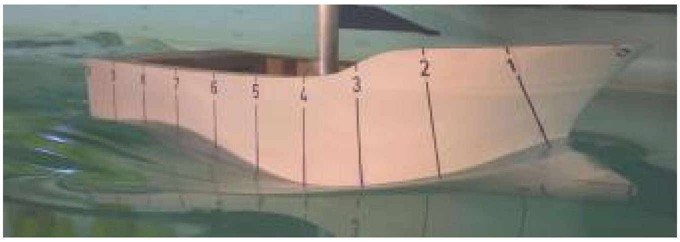
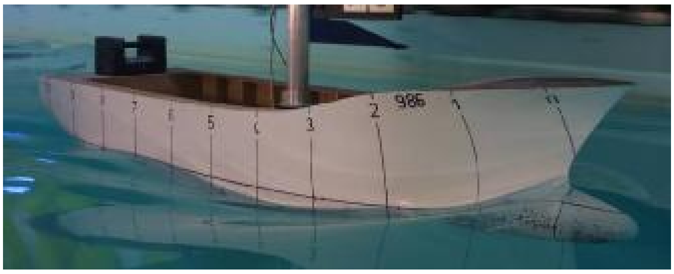


Figure 4 Design B, Depart Port Condition at 9 knots



C. *Flow Visualisation Tests*

Visualization of the flow over the hull was achieved using a paint and oil splatter technique, with a test run in the depart port condition at 10 knots. The paint streaks were analyzed to derive streamlines over the areas of the hull of interest, such as in way of the bilge keels and bow thruster.

D. *Seakeeping Tests*

Each model was tested briefly in head seas, in simulated JONSWAP spectra with a range of significant heights and periods. Most of the tests were conducted in sea states with a modal period of 6 seconds, representing steep waves such as may be generated over a relatively short fetch, and in some sea states of 7 and 8 seconds period.

Measurements were made of wave height, resistance, pitch and heave at the LCG.

V. MODEL TEST RESULTS

A. *Effects of Hull Form*

These vessels, being of very full form for their length, have relatively high resistance characteristics. This is principally due to high residuary resistance, and various aspects of this were demonstrated in these tests.

The photographs of the models under test show the extreme wave system that develops on both designs at the higher speeds. The waves are noticeably higher for Design A, reflecting the greater energy input required to overcome that component of the resistance.

Photographs of the flow at the stern of both models are presented for comparison in Figure 5 and Figure 6. The paint streaks which indicate the flow direction are not present at the stern, where there is a region of weak flow, or possibly separated flow.

Figure 5 Paint flow visualisation at the stern of Design A

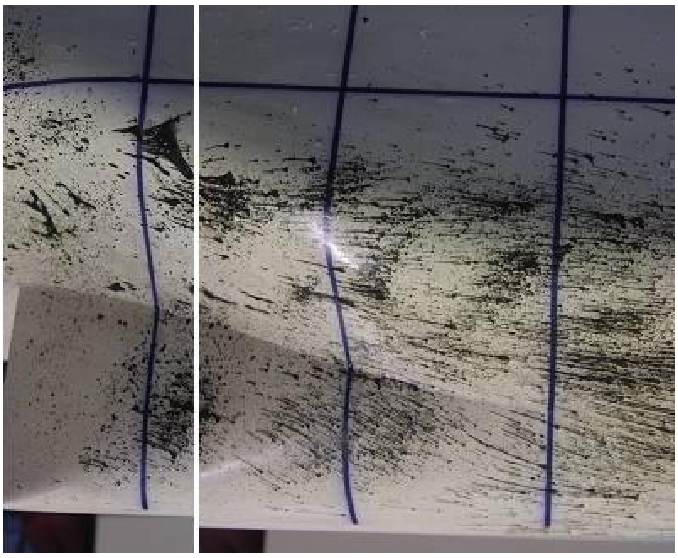
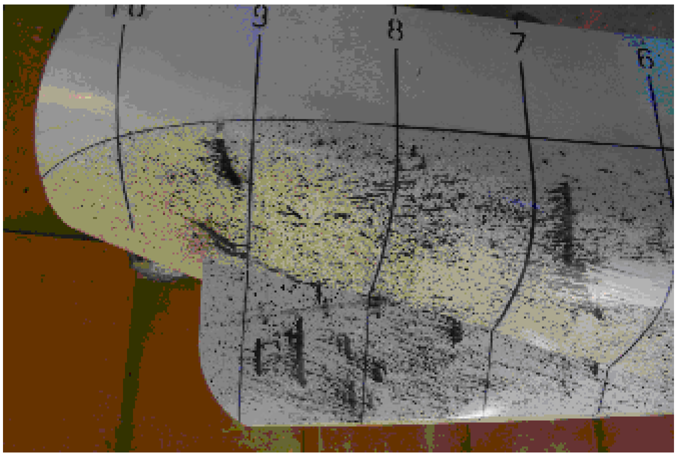


Figure 6 Paint flow visualisation at the stern of Design B

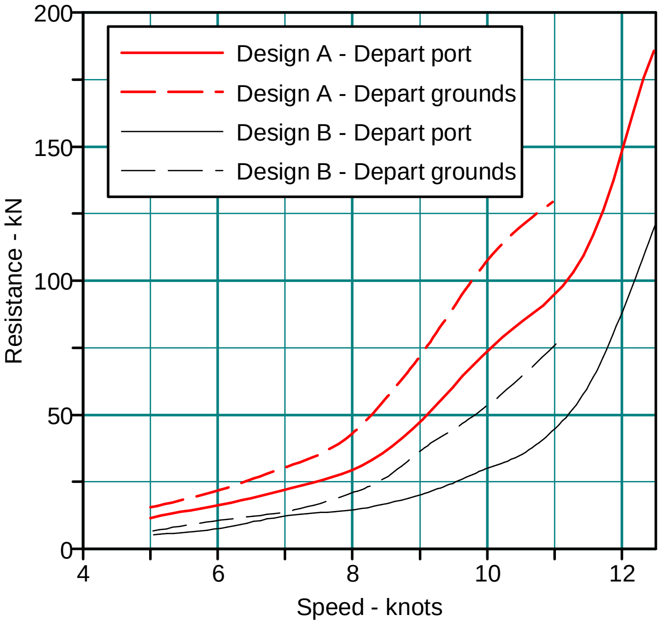


Although both models exhibited this undesirable feature, the area of poor flow was smaller on Design B and it is likely that the resistance penalty resulting from it was reduced significantly. There is no doubt though, that further improvements in the slenderness of the hull would help to strengthen the flow at the stern and reduce the resistance further.

Transom immersion adds significantly to the resistance, and this was a specific feature that was addressed by the designer.

All of these components of the resistance are lower for design B than for Design A, and a comparison of their total resistance is presented in Figure 7.

Figure 7 Comparison of the resistance of the naked hulls



For both designs, the resistance in the depart grounds condition was greater than in the depart port condition. This is consistent with the displacement, which is at least 30% higher in the depart grounds condition. The differences were considerable at the higher speeds. This may be due to less favourable LCG location and trim, and undoubtedly includes a penalty for greater transom immersion.

The effect of LCG variation was investigated for Design B in the depart grounds condition. Tests were conducted at 8 and 10 knots, for a range of LCG locations varying from the design location to 1.5 metres further aft. The optimum LCG proved to be about 1 metre aft of the design location for this displacement. The resistance penalty at 8 knots is small, but at 10 knots is 11.5%.

Both designs showed similar trim and heave behavior, although Design B heaved down a little less than Design A, indicating that the wave trough amidships was relatively smaller.

B. *Bilge Keel Effects*

For Design A, the streamlines in the region of the bilge keels are presented in terms of their position around the girth of the hull from the centerline in Figure 8. This method of presentation is similar to that of a shell expansion drawing. The locations are also shown of the different bilge keels tested.

Figure 8 Bilge keels and their relationshiop to the streamlines. Design A

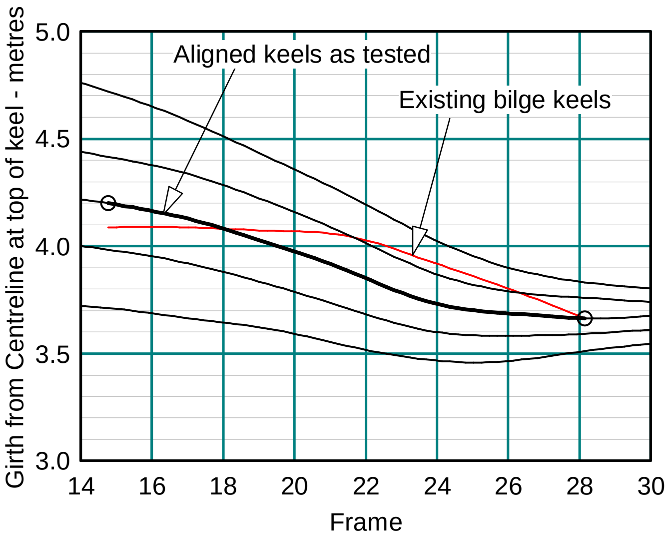
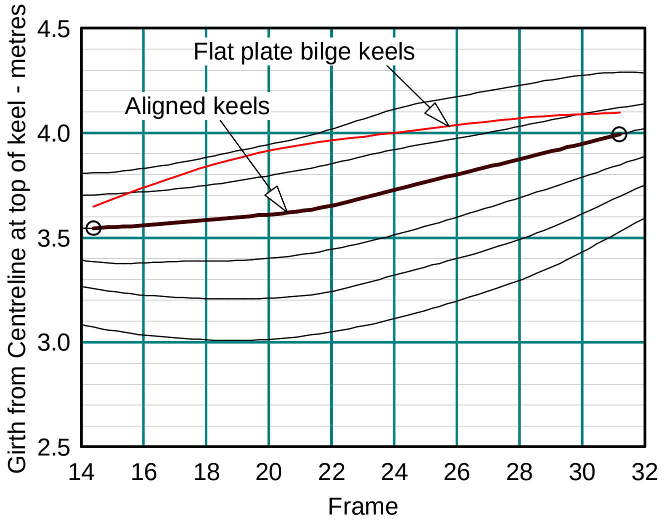


Figure 9 Bilge keels and their relationshiop to the streamlines. Design B



Design A, as built, had bilge keels which added significantly to the resistance, as shown in Figure 10. Their segmented configuration and poor alignment to the flow combined to add up to 15% to the naked hull resistance. The addition is variable because the alignment of the keels to the flow varies with speed. Figure 11 shows that the heave of the vessel (the vertical displacement relative to its position at rest) with these bilge keels fitted was negligible, although the naked hull heaved down 0.5 metre at 11 knots. The keels therefore generated considerable lift because of their alignment across the local flow, with an associated penalty of substantial induced drag. With the aligned keels fitted, the heave matched that of the naked hull.

Figure 10 Resistance of the bilge keels and bow thruster. Design A

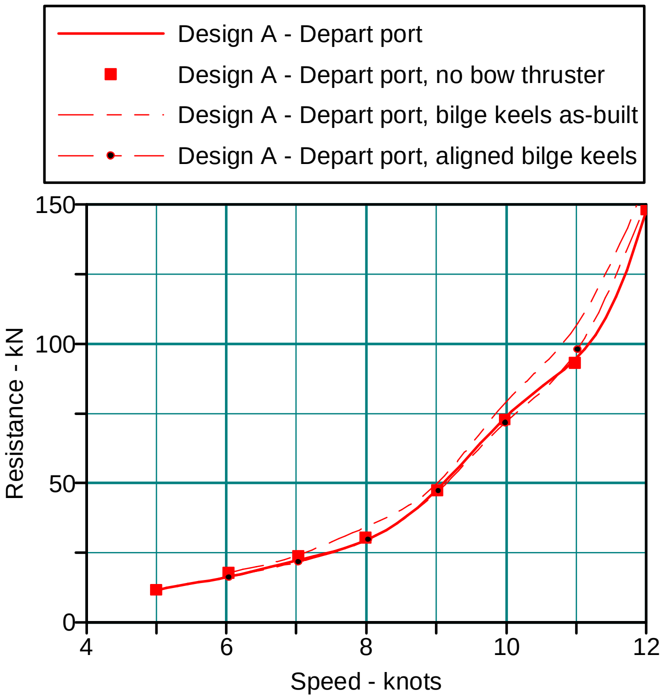
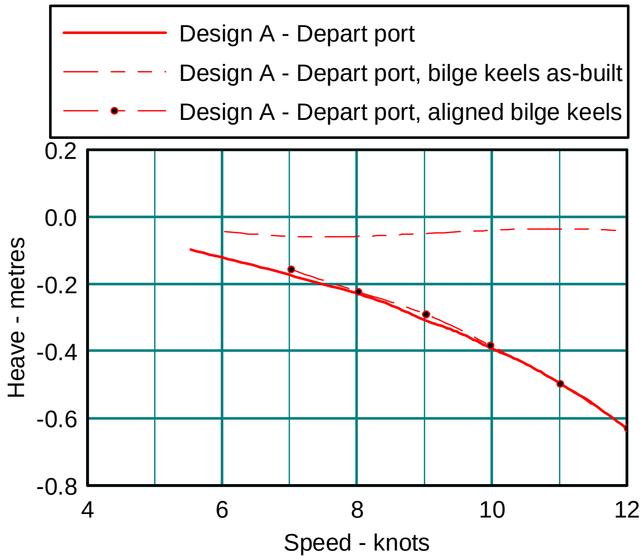
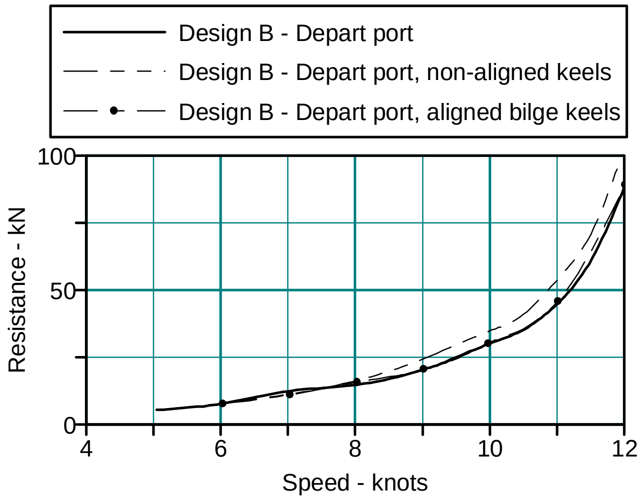


Figure 11 Heave with and without bilge keels. Design A



Design B was tested with conventional flat plate keels fitted along a diagonal. These added up to 20% to the naked hull resistance, as is evident in Figure 12. The keels increased the bow down trim of the model by almost 0.5 degree at 10 knots, and the study of LCG variation showed that such a trim change alone can account for over 10% increase in resistance. The remaining increase is due to the induced drag of the keels resulting from their misalignment, which is illustrated in Figure 9. Although the added resistance is a greater percentage of the naked hull resistance than for Design A, the actual increase in resistance was lower, 4.5kN at 10 knots for Design B compared with 5.5kN for Design A.

Figure 12 Resistance of the bilge keels. Design B



The tests with correctly aligned keels demonstrated that keels of equivalent size can be fitted with little or no resistance penalty. This fact was demonstrated on both models. On Design B, tests were also conducted in the depart grounds condition, where the keels would not have been precisely aligned, and the resistance penalty remained negligible. To align the keels accurately requires a flow visualization test on a model, but the fuel saving achieved over a modest period would justify the expense of such a model test.

C. Bow Thruster Effects

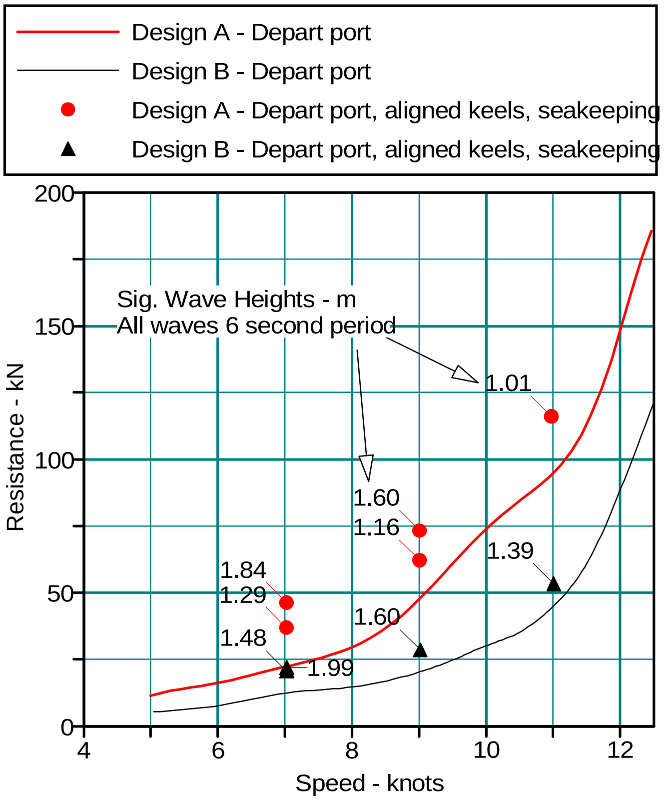
Tests on the bow thruster on Design A showed no significant resistance penalty. The data points are presented on Figure 10. In general they lie within the scatter of the experimental data. Whilst it is usual to measure a small resistance penalty with unfaired bow thruster orifices, the resistance of the hull is very high in this case, and any differences are negligible in comparison.

D. The Influence of Seastate

In the sea states tested, the added resistance was greater for Design A than Design B at all speeds, so the difference in their fuel consumption would be greater when operating in waves.

In all of the sea states, Design A exhibited substantially greater pitch motions than Design B, and in the sea states of 6 seconds period, the difference was approximately a factor of 2 at all speeds. This probably is the reason for the greater increase in resistance. In the longer waves the difference was less pronounced. The heave data show that neither model exhibited consistently greater heave than the other.

Figure 13 Added resistance in waves



VI. PROPELLER CALCULATIONS

Using the Wolfson Unit's Propeller Design Program, a suitable propeller pitch was calculated for each hull to investigate further the potential fuel savings or speed increase offered by the alternative design. The calculations were based on a controllable pitch Kaplan type nozzle propeller. An installed power of 750 kW and a propeller diameter of 2.5 meters were assumed in each case, with wake fraction and thrust deduction factors derived from the Wolfson Unit's Power Prediction Program.

The results are presented in Table 3. A number of cases were considered for comparison: Design A with keels as built, Design B with non-aligned keels, and Design B with aligned keels.

TABLE 3 PROPELLER DESIGN CALCULATION RESULTS

	Maximum speed with 725 kW	**Power required at**	**Power saving %**
Depart port		***10 knots***	
Design A, Keels as built	10.0 knots	725 kW	0%
Design B, Non-aligned keels	11.7 knots	310 kW	57%
Design B, Aligned keels	11.9 knots	275 kW	62%
Depart grounds		***9.3 knots***	
Design A, Keels as built	9.3 knots	725 kW	0%
Design B, Non-aligned keels	10.8 knots	375 kW	48%
Design B, Aligned keels	11.0 knots	335 kW	54%

VII. DISCUSSION OF RESULTS

The comparison of the resistance of the two hulls in Figure 7 reveals that extremely effective gains could be made in terms of fuel economy, if the regulatory constraints were relaxed to permit hulls similar to Design B. The naked hull resistance of Design B is 59% lower than that of design A at 10 knots in the depart port condition. The bilge keels as fitted to Design A further increase its resistance, and a comparison of Design B with correctly aligned keels reveals that its resistance is 62% lower than that of Design A with keels as built. To express this difference in terms of the penalty, Design A has more than twice the resistance of Design B, and will use more than twice the fuel, at 10 knots. At lower and higher speeds the differences are not quite so great, but remain large. Similar differences are maintained in the depart grounds condition, with Design A having twice the resistance of Design B at 10 knots.

These comparisons can be refined by considering the results of the propeller design calculations. In the first case the maximum speeds derived with the optimum propeller pitch were 10.0 and 9.3 knots for the two loading conditions tested. Design B could achieve speeds of 11.7 and 10.8 knots with non-aligned bilge keels, and speeds of 11.9 and 11.0 with aligned keels. These speed increases are quite modest because the resistance increases very rapidly with speed. The power reduction offered by design B is more dramatic, being in line with the resistance comparisons. Design B offers power savings of 57% and 48% in the two loading conditions, with non-aligned keels. With the keels correctly aligned these savings increase to 62% and 54%.

In the sea states tested, the added resistance was greater for Design A than Design B at all speeds, so the difference in their fuel consumption would be greater when operating in waves.

In all of the sea states, Design A exhibited substantially greater pitch motions than Design B, and in the sea states of 6 seconds period, the difference was approximately a factor of 2 at all speeds. This probably is the reason for the greater increase in resistance. In the longer waves the difference was less pronounced. The heave data show that neither model exhibited consistently greater heave than the other. Aside from the measured resistance benefits, the reduced pitch motions would be of great benefit in terms of reduced crew fatigue, and increased comfort and safety.

It is estimated that the Gross Tonnage of the Green Trawler will be 267 - 270 GT. The Gross Tonnage of the reference trawler (Design A) is 224 GT, a difference of 46GT for a vessel with the same KW and effective fishing power but with a higher degree of fuel efficiency as indicated. This indicates that many current fishing vessel designs constrained are not fuel efficient. In many cases this is due to the fact that fishermen have sacrificed fuel efficiency for carrying capacity but also due to constraints imposed by regulations.

The concept of “Green Tonnage” is felt something that should be considered by the EU and Member States whereby vessel owners would be allowed additional GTs for new builds over and above existing limits without being penalized. This would be strictly on the basis that the effective fishing power and carrying capacity are not altered. This is along the lines of the provisions of Article 8 of EU regulation No 1483/2003, which allows additional tonnage for safety on board, working conditions, hygiene and product quality. This obviously needs to explored further as there has been difficulties with the implementation of Article 8 but the work on the Green trawler indicates that to be more fuel efficient vessels should be less constricted by arbitrary rules that force them to be built as short boxy vessels and fishermen should be encouraged to look at general boat building principles, rather than fishing efficiency and carrying capacity.

VIII. CONCLUSIONS

From the tank testing it has been shown that very substantial fuel savings can be realized if the regulations which encourage designs of restricted length were relaxed. Savings of 50% on fuel consumption could be achieved with relatively modest length increases. To achieve these savings, however, would require an increase in tonnage of 18% and therefore additional building costs.

Further savings of 10 to 20% could be achieved by aligning the bilge keels on new vessels, or replacing non-aligned keels on existing vessels. This process will require model testing, but the costs of such experiments are likely to be recovered within a fraction of the life of the vessel.

Bow thruster fairings are unlikely to provide significant fuel savings on these types of vessel but subtle design changes to fairings over bow thrusters potentially will yield drag savings.

There is scope for further improvement in the hull design to improve attached water-flow and reduce turbulence. In addition the lessons learned in relation to bilge keel alignment and transom submersion can be applied to existing vessels to increase hydrodynamic efficiency and reduce fuel consumption

ACKNOWLEDGEMENTS

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