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The Inefficiencies of modern Trawler propulsion as a consequence of trends in hull form and length restrictions

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 demonstrate its extent.

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Bord Iascaigh Mhara
Irish Sea Fisheries Board

1. Introduction

Licensing and fishing effort of Trawlers are related to vessel size and power installed. These are expressed in terms of Gross Tonnage (GT) and Kilowatts (kW) respectively. Notwithstanding this the dominant parameter by which Irish vessels are segmented and/or restricted is length, either registered (L.reg) or overall (LOA). This causes bunching of vessel numbers immediately below the cut-off points set out below:

- 10.0m LOA re log book requirements
- 15.0m LOA re Code of Practice
- 18.0m LOA re capacity segment
- 19.8m L.reg re Pelagic entitlement
- 24.0m L.reg re Torremolinos Protocol
- 27.4m LOA re 3 mile exclusion zone

This research project arose from the activities of a working-group set up at Bord Iascaigh Mhara (BIM) to promote and develop fuel efficiency in the Fishing Fleet. Relevant work todate has involved measurement and adjustments for specific vessels and development of guidance for skippers on how to operate their vessel. The working-group comprises three BIM personnel, Dominic Rihan, Padraig Gordon and Geoff Long along with the author. This Green Trawler project is funded by the EU and BIM.

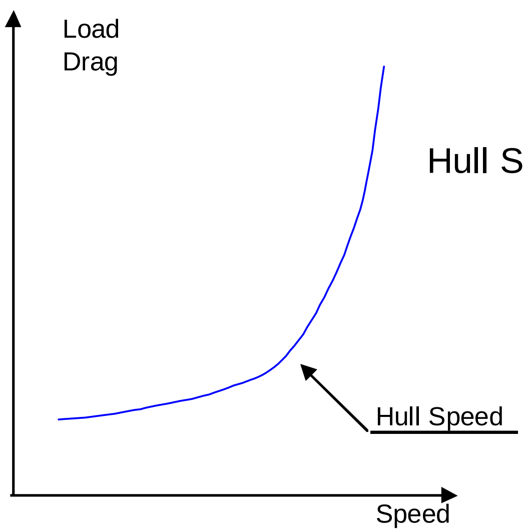
There are no surprises here for Naval Architects and designers except perhaps in the extent of the reduction in resistance. We have increased waterline length, removed the large flat transom dragging in the water, improved water-flow along the hull and to the propeller. We also show the advantages of proper alignment of Bilge keels. Few would have anticipated we would reduce resistance by 55 or 60%

2. Project Development

2.1 Objectives

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 case we have studied the recent trend in the Irish Fleet to build new vessels with 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 certain speed, known as "hull speed" above which the resistance rises steeply. This length of 19.8m gives us a hull-speed of c.9.0 knots.



$$\text{Hull Speed} = 1.1x\sqrt{\text{waterline (ft)}}$$

Fig 1. Hull Speed

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

2.2 Previous work

During Sea Trials on the vessel below, among others, we have demonstrated the principle of hull speed. The vessel has a waterline length of 20 mtrs and a hull speed of c.9 knots. The different curves relate to various combinations of propeller rpm & pitch.

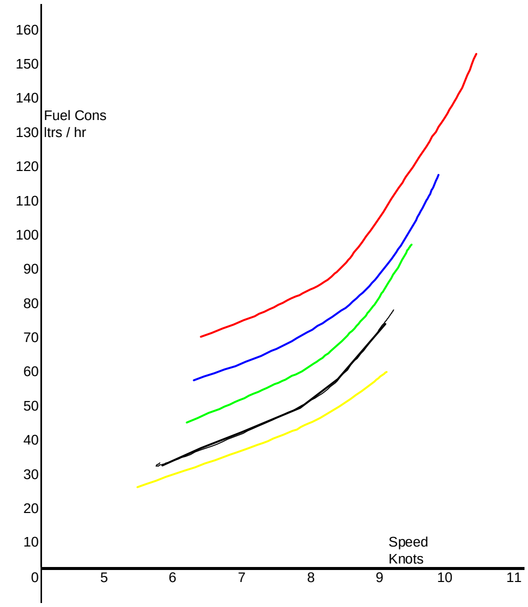


Fig 2 – previous work re Hull Speed

2.3 Participants

This research project arose from the activities of a working-group set up at Bord Iascaigh Mhara (BIM) to promote and develop fuel efficiency in the Irish Fishing Fleet. Funding was provided by the EU and BIM.

The Green Trawler concept was developed by the Author who coordinated the project throughout. The Lines-plan and stability study was developed by Ian Paton of S.C. McAllister. The Wolfson Unit of the University of Southampton was commissioned to build and then test the models at the towing tank of the Southampton Solent University

2.4 Theory

We set out to design a vessel with the same fishing capacity, in terms of Hold capacity & Kilowatts, as the 19.8m Trawler (Red Trawler) but with the length increased to 23.97m (Green Trawler). The beam was reduced to the minimum commensurate with stability requirements. Summary calculations were carried out for lengths of 26, 28 & 30m but no significant reduction in beam was achievable. Future developments may endeavor to lower the centre of gravity of the vessel to facilitate a reduction in beam

We also felt that gains are possible by correct alignment of Bilge Keels. It is not general practice to tank test Trawler hull designs. Positioning of bilge keels has always been a case of educated guesswork. The Red Trawler whose hull form and bilge keel position was used for these trials is universally acknowledged as well built and of admirable design.

The hull form of these recent vessels is inherently inefficient in calm water with inefficiency exaggerated in a seaway. We believed we could reduce drag and hence fuel costs by increasing waterline length and fairing the underwater shape. The proposition is that we could achieve considerable savings in fuel cost with a longer and fairer hull form. The two vessels are detailed below:

2.5 Vessel details

	Red Trawler	Green Trawler
Length Overall (m)	23.2	27.4
Length Registered (m)	19.8	23.97
Beam (m)	8.2	8.0
Depth (m)	6.45	6.45
Steering Nozzle / Propeller (mm)	2,500	2,500
Kilowatts (kW)	**745**	**745**
Hold capacity (M^3)	**120**	**120**
Gross Tonnage (GT)	220	267
Theoretical “hull speed” (knots)	8.9	9.8

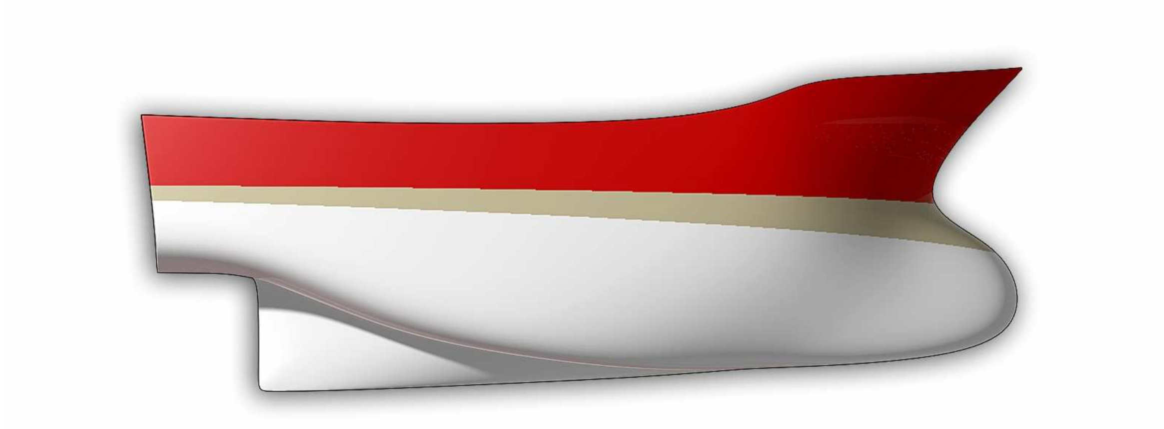


Fig 3 - Model of Red Trawler

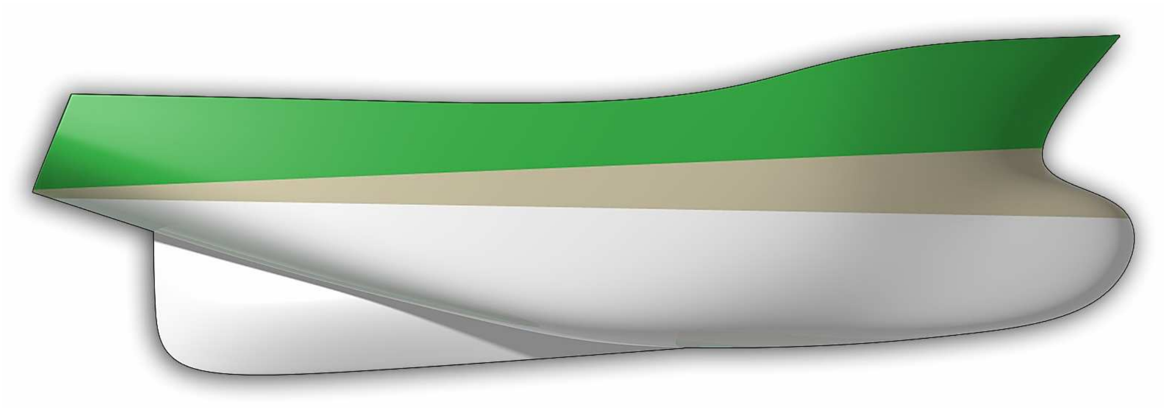


Fig 4 - Model of green trawler

2.6 Method

The Wolfson Unit of the University of Southampton was commissioned to build and then test the two models at the towing tank of the Southampton Solent University. This tank is 60m long by 3.6m wide by 1.8m deep and it is equipped with a wave maker capable of generating sea states patterns with waves of significant height up to 3.0m at a scale of 1:16. The towing mechanism and instrumentation were supplied and operated by the Wolfson Unit.

Fig 5 - Towing tank with red trawler in tow

2.7 Tow Test

The towing tests on two hull designs investigated their resistance and powering characteristics over a range of speeds. Each model was ballasted to its appropriate displacement and centre of gravity position, and towed from this point using a mechanism that allowed freedom to heave and pitch. The models did not include appendages other than bilge keels.

Bilge keels were first fitted on the Red Trawler to model the existing vessel. They comprised a series short flat plates alternately set in a 60°V configuration. Following flow visualization tests alternative bilge keels of solid 30°V section were fitted at the same longitudinal location & depth but aligned to local flow.

The Green Trawler was fitted with conventional flat plate keels, of equal depth to the Red Trawler, 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 45 degrees to horizontal. Following flow visualization tests, solid V section keels were fitted at the same longitudinal position & depth but aligned to local flow.

2.8 Flow Visualization

Visualization of the flow over each hull was achieved using a paint and oil splatter technique and a test run in the depart port condition at 10 knots. The model was removed from the tank and streamlines were drawn on the model in the region of the bilge keels. The resulting streamlines are presented in terms of their position around the girth of the hull, from the centerline. The locations of the various bilge keels tested are shown in figures 20 & 21

2.9 Sea-keeping 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 period of 6 seconds, representing steep waves such as may be generated over a relatively short fetch, and in some sea states with a period of 7 and 8 seconds. Measurements were made of wave height, resistance, pitch and heave at the Longitudinal Centre of Gravity (LCG).

3. Results

3.1 Red trawler as built

Heave is the lowering of a vessel bodily in the water as speed is increased. Trim generally changes with increasing speed. The Red Trawler, as built, has bilge keels which add significantly to the resistance, as shown in Figure 6 & 7. Their segmented configuration and poor alignment to the flow combine to add up to 15% to the naked hull resistance. The heave of the Red Trawler with these bilge keels fitted is negligible, although the naked hull heaved down 0.5m at 11 knots. The keels therefore generate considerable lift because of their alignment across the local flow, with an associated penalty of substantial induced drag. The unaligned keels generate enough lift to prevent Heave & this lift must be paid for in terms of power & fuel.

3.2 Green Trawler & unaligned keels

The Green Trawler was tested with conventional flat plate keels. These added up to 20% to the naked hull resistance, as is evident in Figure 9 & 10. The keels increased the bow down trim of the model by almost 0.5 degree at 10 knots, and reference to Figure 14 indicates that such a trim change alone can account for 10% increase in resistance. The remaining increase is due to the induced drag of the keels resulting from their misalignment. Although the added resistance is a greater percentage of the naked hull resistance than for the Red Trawler, the actual increase in resistance was lower, 4.5kN at 10 knots for the Green Trawler compared with 5.5kN for the Red Trawler.

3.3 Aligned Keels for Red & Green Trawlers

The tests with correctly aligned keels demonstrate that keels of equivalent size can be fitted with little or no resistance penalty. This fact was demonstrated on both models. Tests were also conducted in the depart grounds condition, where the keels would not have been precisely aligned, and the resistance penalty remained negligible.

3.4 Flow visualization

Flow visualization revealed that water flows over the bow area at a down angle of almost 45 degrees. This is a result of the volume and blunt shape of both vessels. The Red Trawler looses attachment of flow quickly as water flows over the keel aft of midships where the stern begins to rise. This indicates turbulent flow and increased drag. The model test differs from the real life vessel in that there is no propeller / nozzle drawing water. The action of the propeller in service will reduce the effect of this detachment and the penalty will be less in service.

The Green Trawler follows the same trends but the fairer hull form and less steep slope to the stern has retained attached flow further back. It is likely that in service the detachment would be less severe.

The accurate alignment of the keels 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.

3.5 Hull form comparison

Both designs, without bilge keels, showed similar trim and heave behavior, although the Green Trawler heaved down a little less than the Red Trawler, indicating that the wave trough amidships was relatively smaller. For both designs, the resistance in the depart grounds condition was greater than in the depart port condition. The differences were considerable at the higher speeds.

3.6 Changing Longitudinal Centre of Gravity (LCG)

The effect of LCG variation was investigated for the Green Trawler 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 1.5m further aft. The optimum LCG proved to be about 1.0m aft of the design location for this displacement. The resistance penalty at 8 knots is small, but at 10 knots is 11.5%. See figure 24 & 25.

3.7 Resistance comparison

The naked hull resistance of the Green Trawler is 59% lower than that of the Red Trawler at 10 knots in the depart port condition. The bilge keels as fitted to the Red Trawler further increase its resistance. To express this difference in terms of the penalty, the Red Trawler has almost 2½ times the resistance of the Green Trawler, and will use almost 2½ more fuel at 10 knots. At lower and higher speeds the differences are not quite so great, but remain very large. Similar differences are maintained in the depart grounds condition, with the Red Trawler having twice the resistance of the Green Trawler at 10 knots.

The Green Trawler 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 the Green Trawler is more dramatic, being in line with the resistance comparisons. The Green Trawler 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%.

	Maximum speed at 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%

Table 1 – comparison of power requirements

3.8 Sea state

In the sea states tested, the added resistance was greater for the Red Trawler than the Green Trawler at all speeds, so the difference in their fuel consumption would be greater when operating in waves. The towing tank is relatively short for sea-keeping tests, and the number of wave encounters therefore is less than would normally be used for precise predictions. Nevertheless, the data are adequate for the comparative purposes required in this project.

In all of the sea states, the Red Trawler exhibited substantially greater pitch motions than the Green Trawler, 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 a sea-way. In the longer waves the difference was less pronounced. The heave data show that neither model exhibited consistently greater heave than the other.

4. Conclusion

Our previous work has found that the operating profile of a typical whitefish trawler is as shown below. Trawlers in other sectors and activities such as Seining, Pelagic and Tuna spend less time, or no time towing heavy gear and so their potential savings are larger.

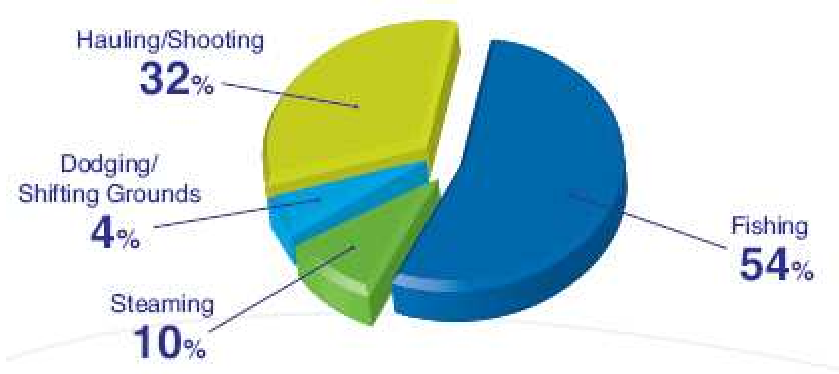


Table 2 – operating profile whitefish trawler

Both vessels have a very full form for their length and so they both have relatively high resistance characteristics. The photographs of the two models under test show the extreme wave system which develops at the higher speeds on both. Transom immersion adds significantly to the resistance. All of these aspects of the resistance are lower for the Green Trawler than for the Red Trawler.

The reduction in resistance and fuel savings relate to periods when the vessel is travelling to and from fishing grounds or steaming at reduced speeds. Vessels engaged in other activities may spend less time trawling and will benefit more. The power required to move a vessel through the water at trawling speed is small and the power required is directly related to drag by nets & doors. There will be a benefit when towing with the Green Trawler albeit at a reduced level due to improved water flow to the propeller and a longer waterline to provide a more stable platform.

New vessels must take into account the effects of hull form and length on fuel consumption. This will require increased gross Tonnage, increased build cost and a willingness by the licensing authority to think beyond the restrictions that have developed over time. Very substantial fuel savings could be realized if the regulations which encourage designs of restricted length were relaxed. Savings of 50% to 60% on fuel consumption might be achieved when steaming with relatively small length increases. This could translate to an overall fuel saving of 20% to 50% depending on the actual operating profile of the specific vessel.

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 investment in model testing and the installation cost will be increased by the presence of fuel tanks and insulated spaces, but the costs of such experiments and modifications are likely to be recovered within a fraction of the life of the vessel.

In 2007 & 2008 fuel costs rose to a level where most fishing activity struggled to provide an income for skippers & crew. Fuel cost rose to 40% of Gross landed value and more in some case. Much of the fleet would be unsustainable if these fuel price level return and so every effort must be made to make the fleet more fuel efficient.

Further research is required to further optimize the design of this vessel. The beam cannot be reduced without lowering the centre of gravity. It is also clear that there is a benefit in moving the LCG aft by 1.0m. These changes can be combined to gain even greater reductions in resistance and power for the vessel in transit.

There will be a considerable investment by owners to achieve these savings. Greatest benefits will be seen in transit where the cost of steaming to fishing grounds and the cost of carrying fish to market will be reduced hugely once they are caught. These reductions in cost do not lead to an increase in fishing effort as there is little saving during towing operation while the installed Kilowatts, and hold size are retained.

Noel O' Regan. MBA, AMIMarEST Chief Engineer
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Fig 6 - Red Trawler – Power & Speed

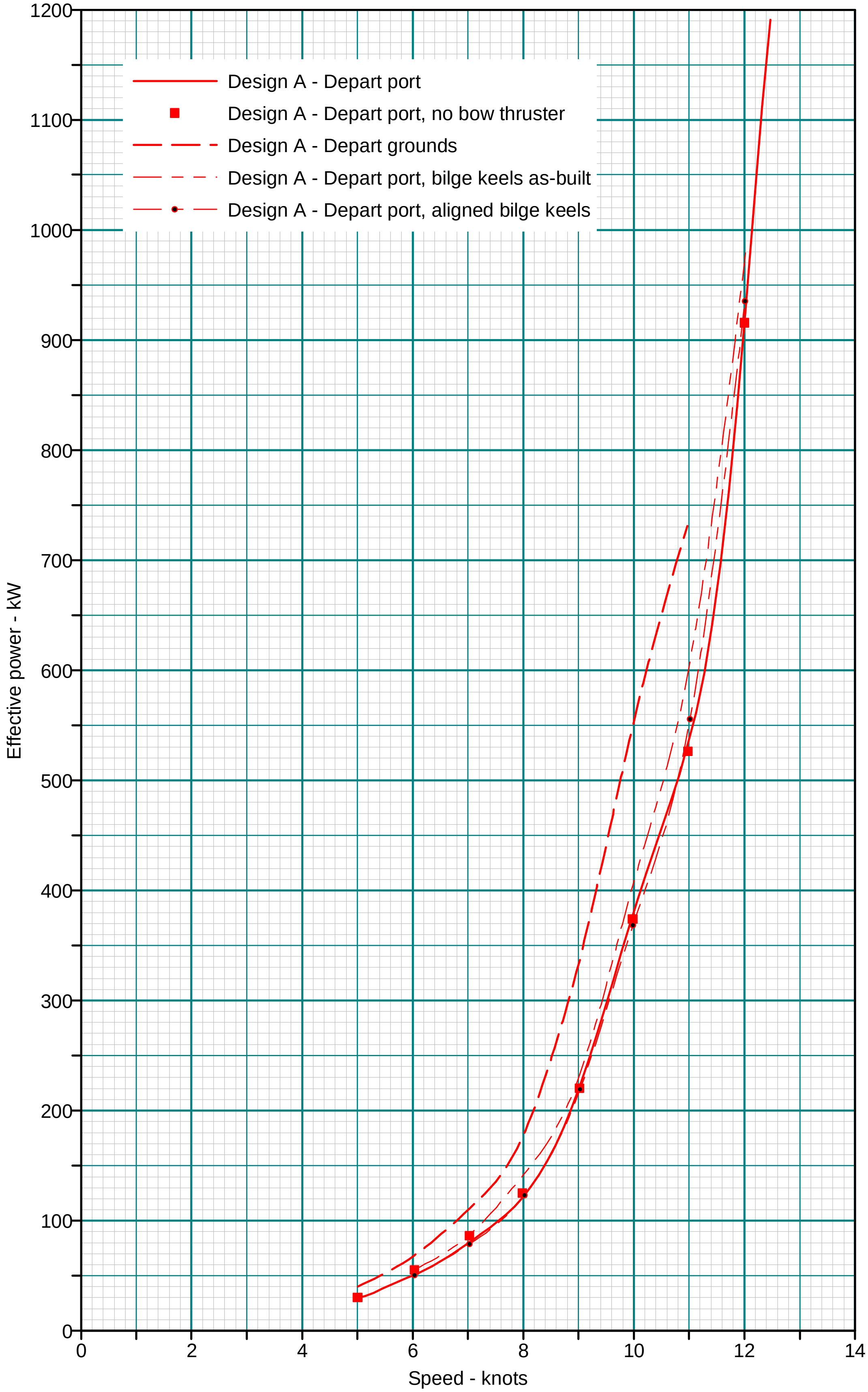


Fig 7 - Red Trawler – Resistance & Speed

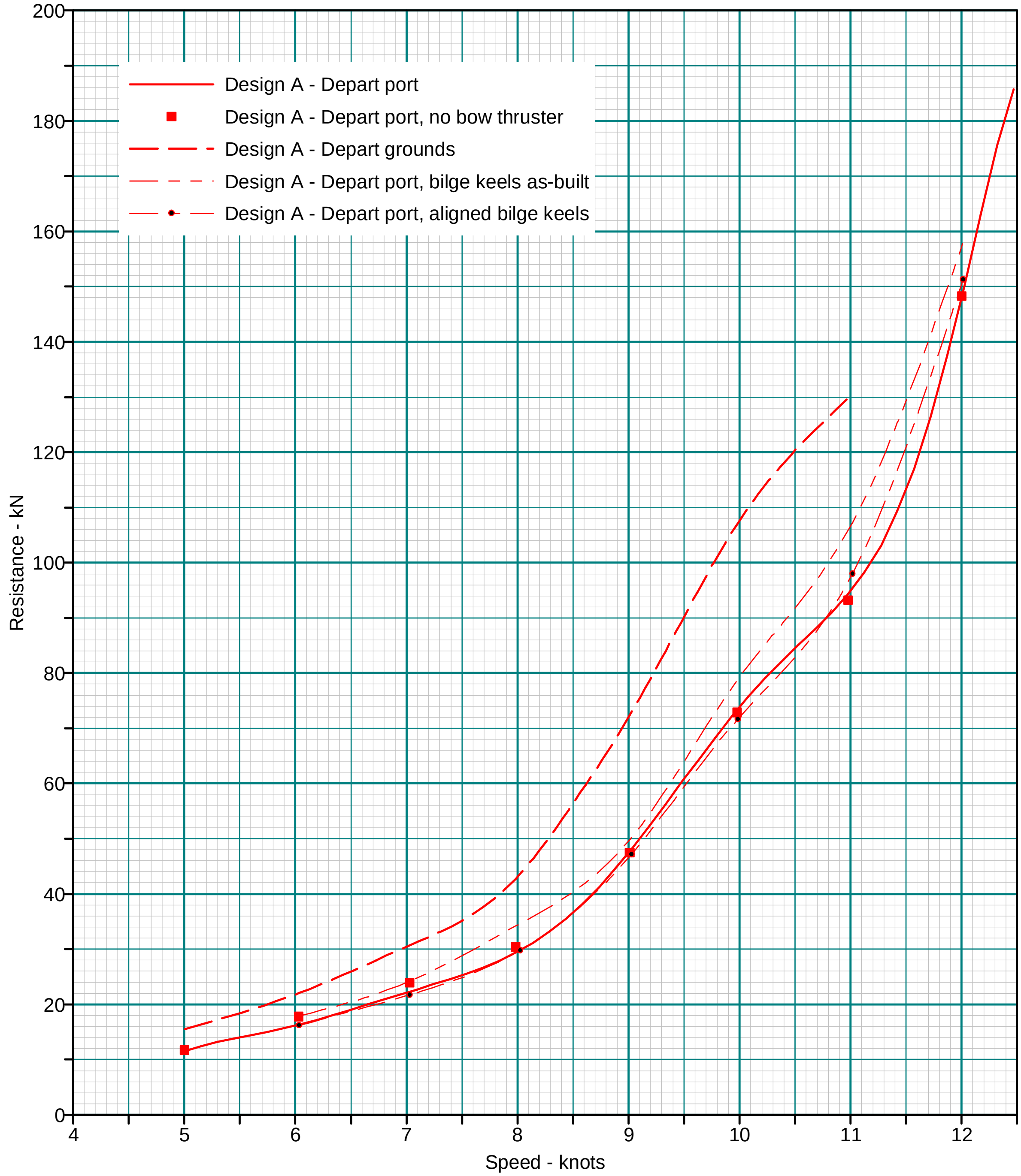


Fig 8 - Red Trawler – Heave & Trim with Speed

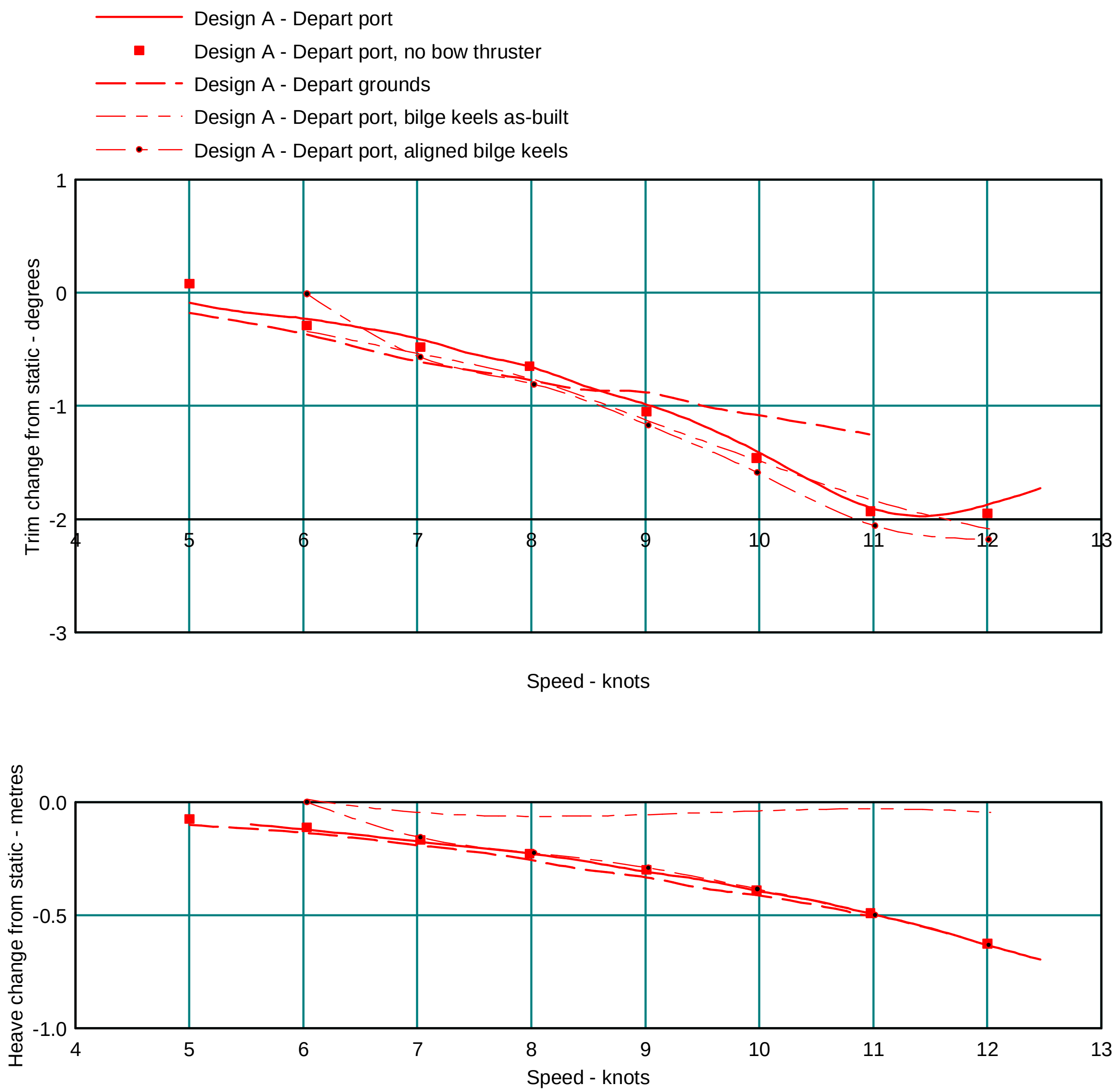


Fig 9 - Green Trawler – Power with Speed

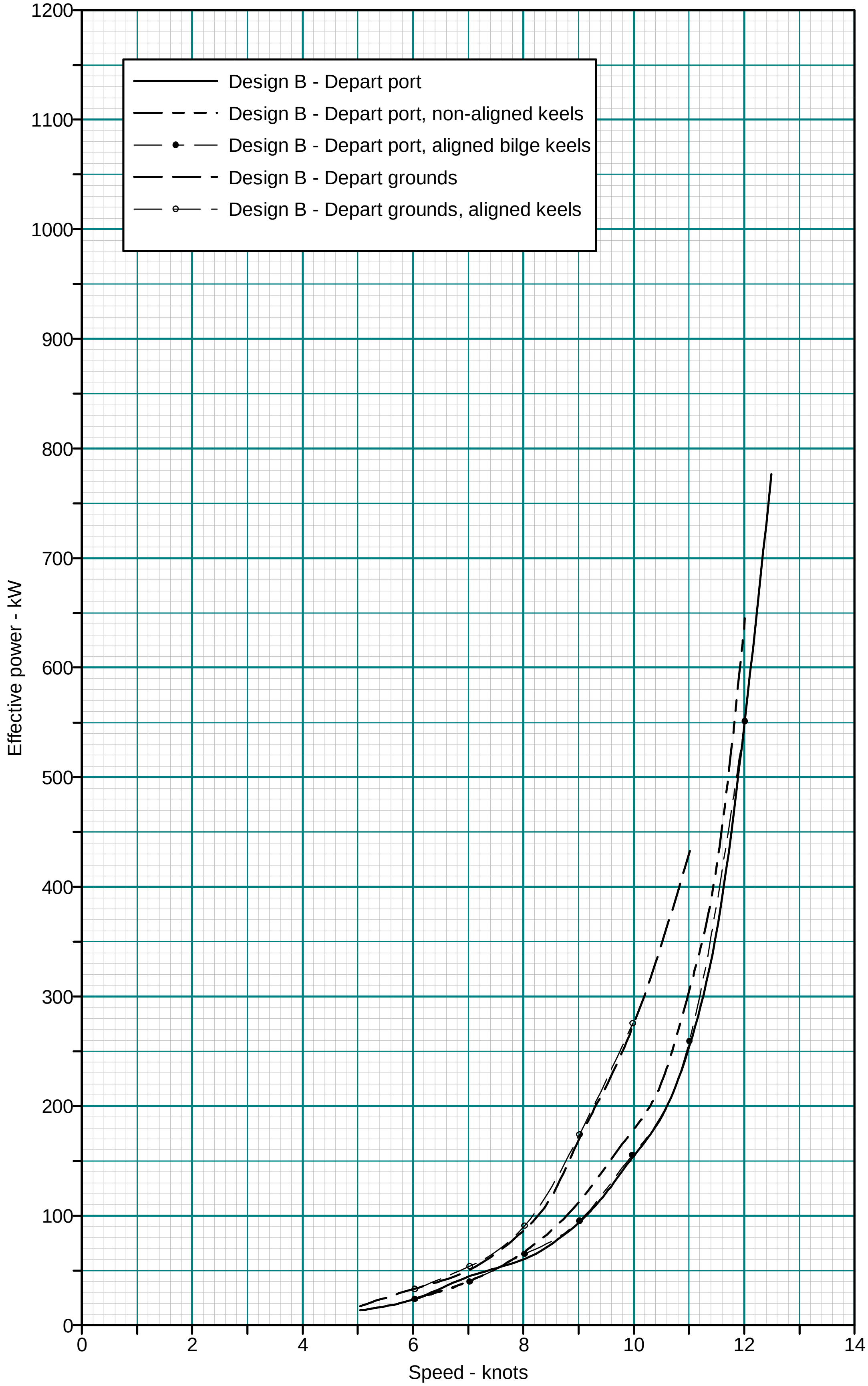


Fig 10 - Green Trawler – Resistance wit Speed

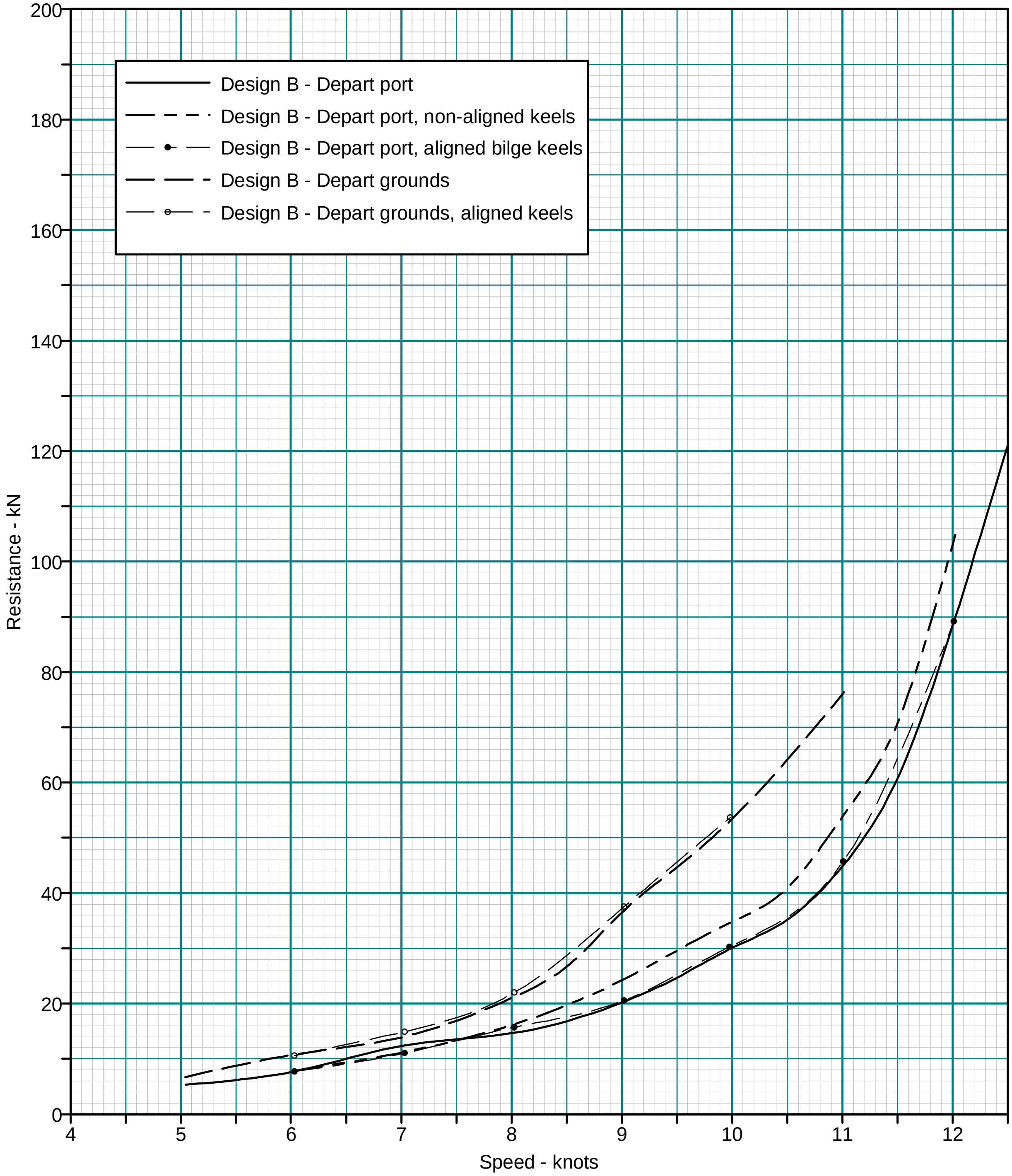


Fig 11 - Green Trawler – Heave & Trim with Speed

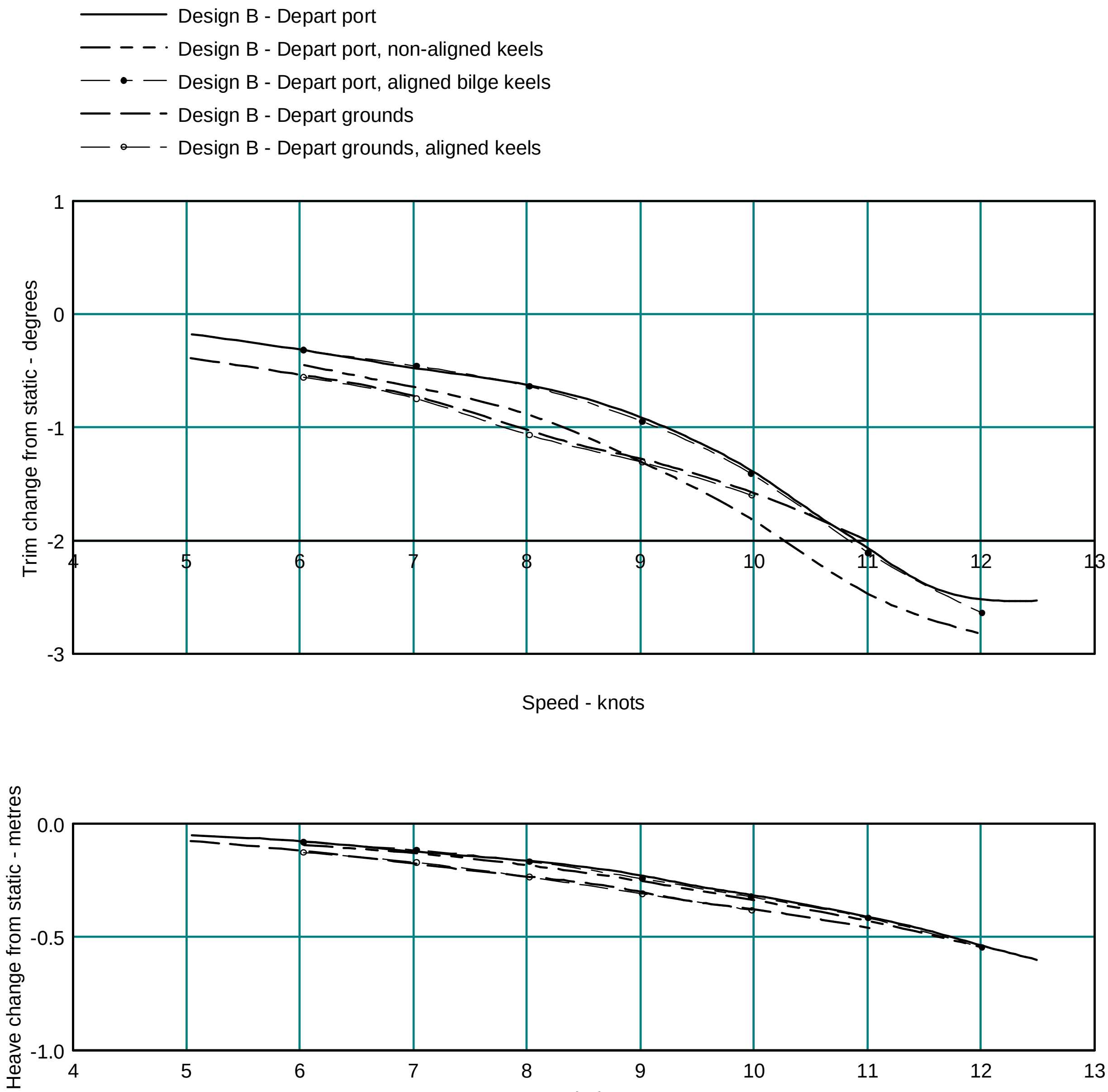


Fig 12 - Comparison of resistance with Speed – depart port

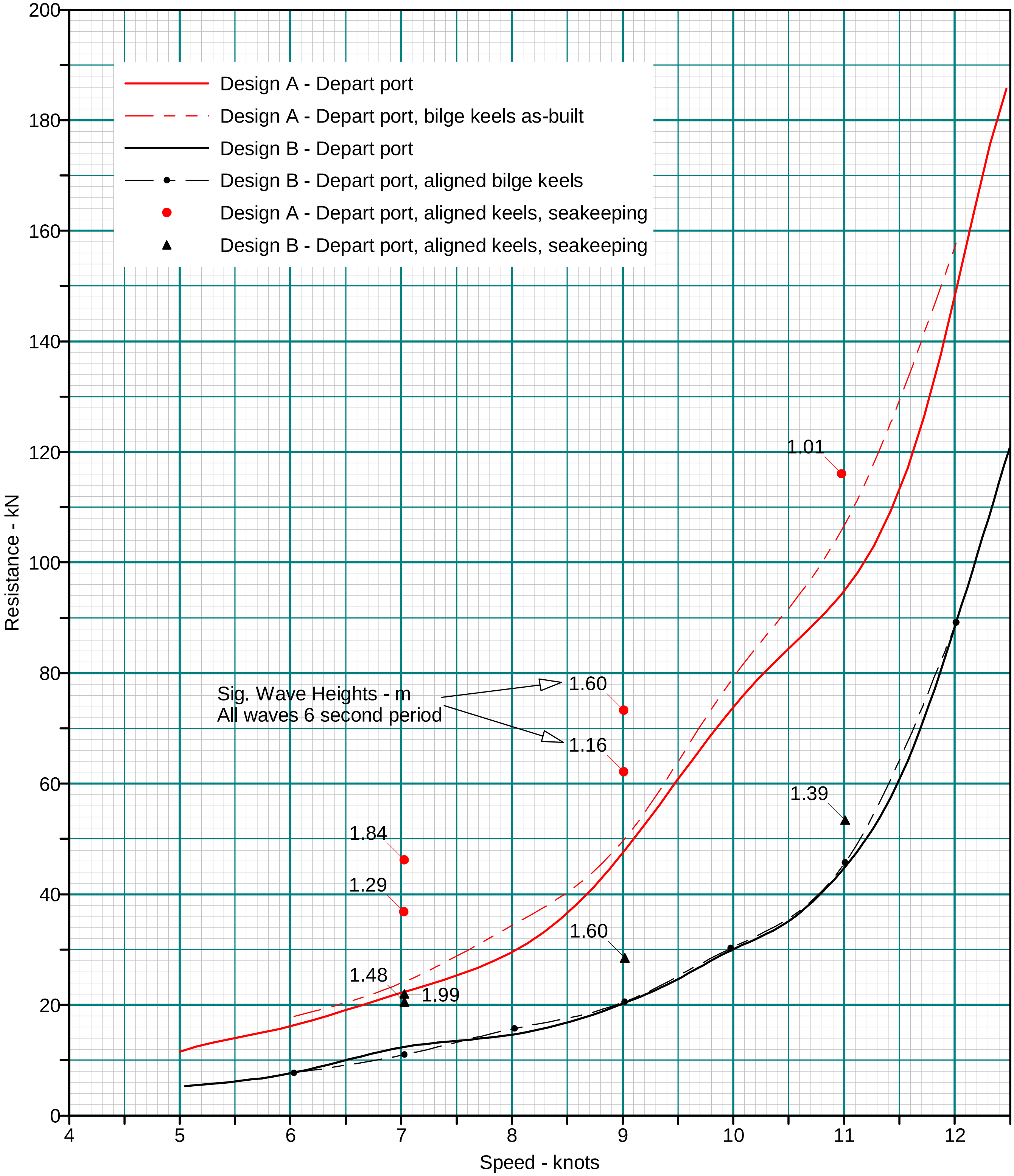


Fig 13 - Comparison of resistance with Speed – depart grounds

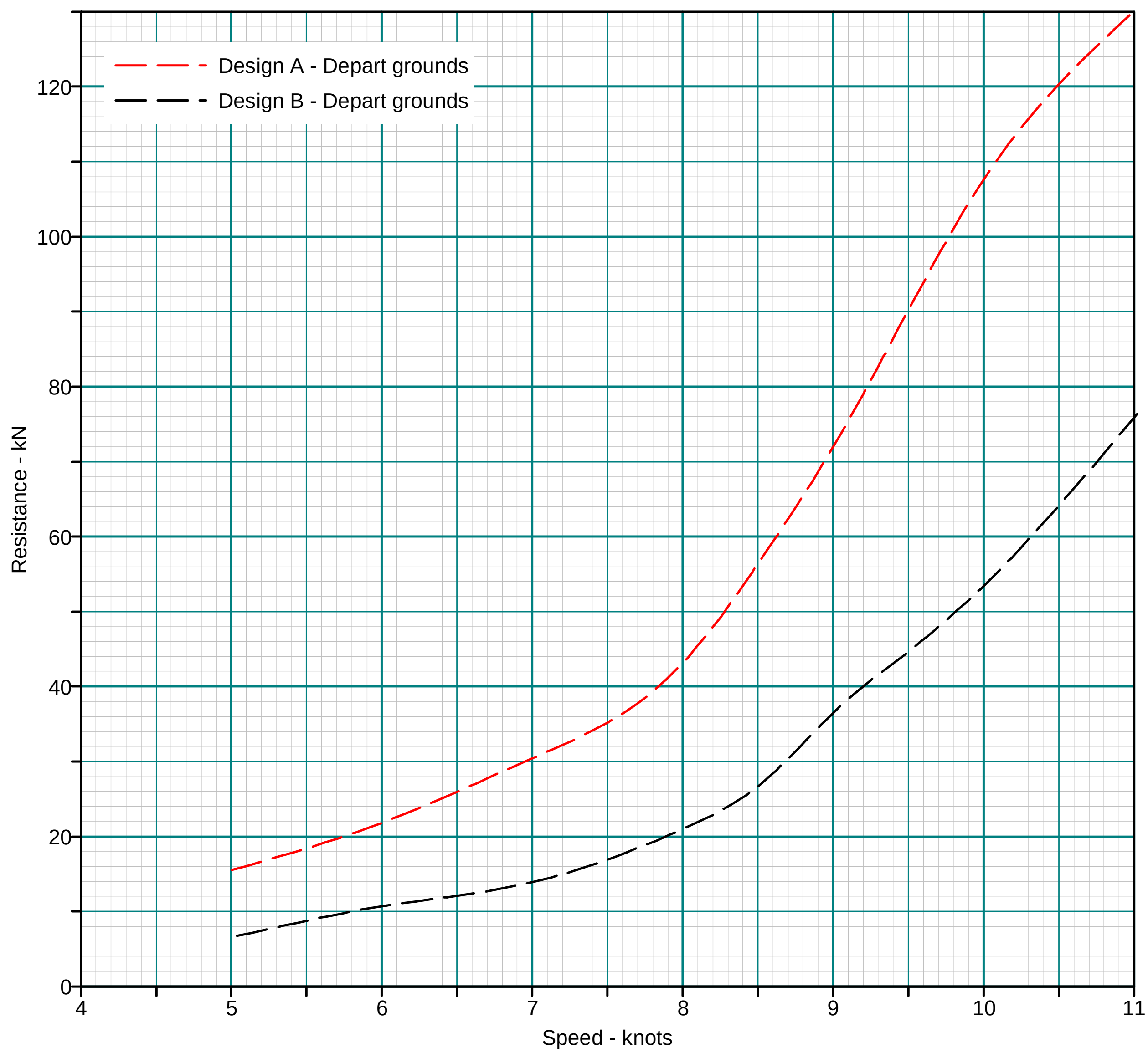


Fig 14 – Green Trawler depart grounds – Change of LCG

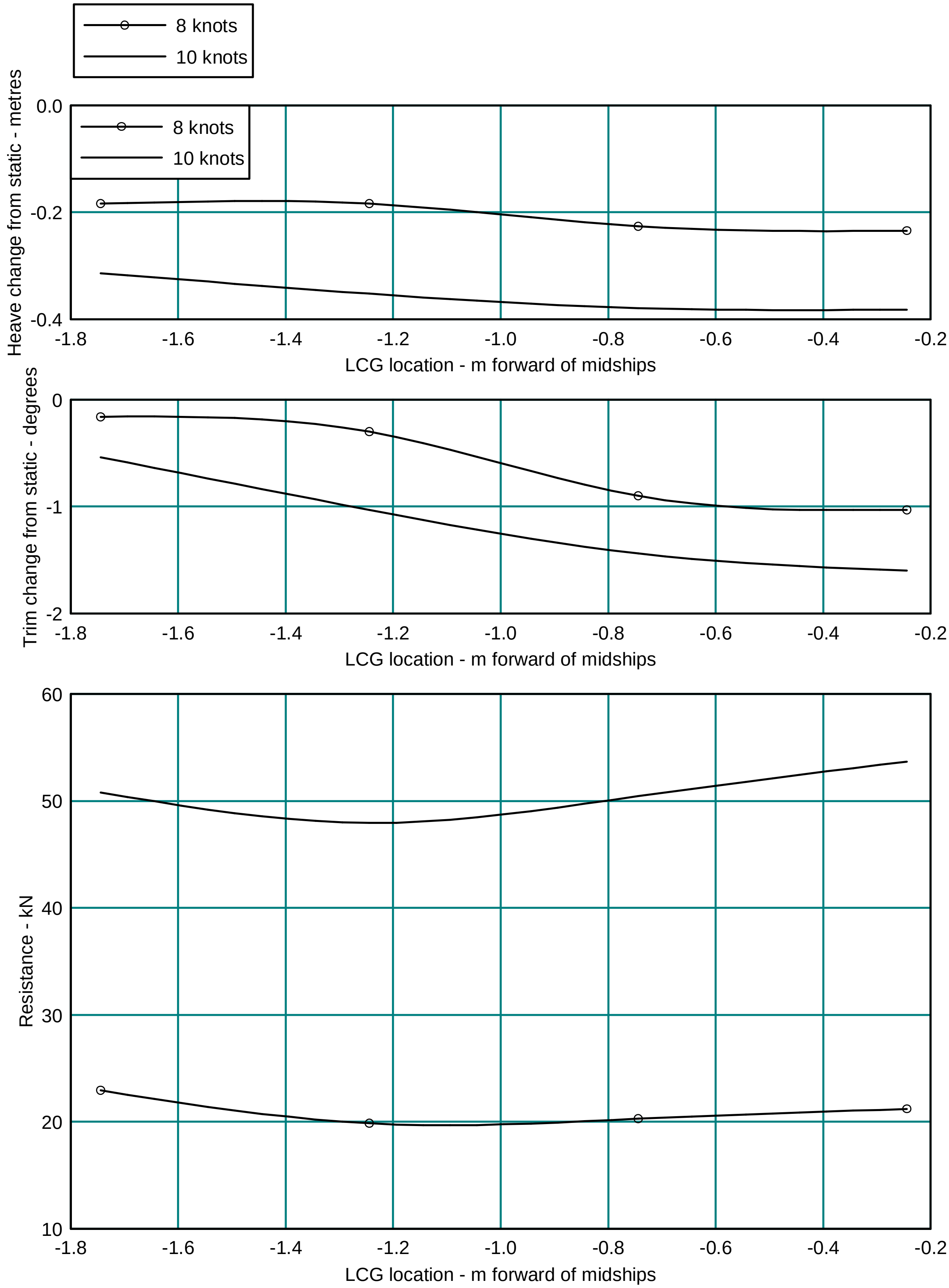
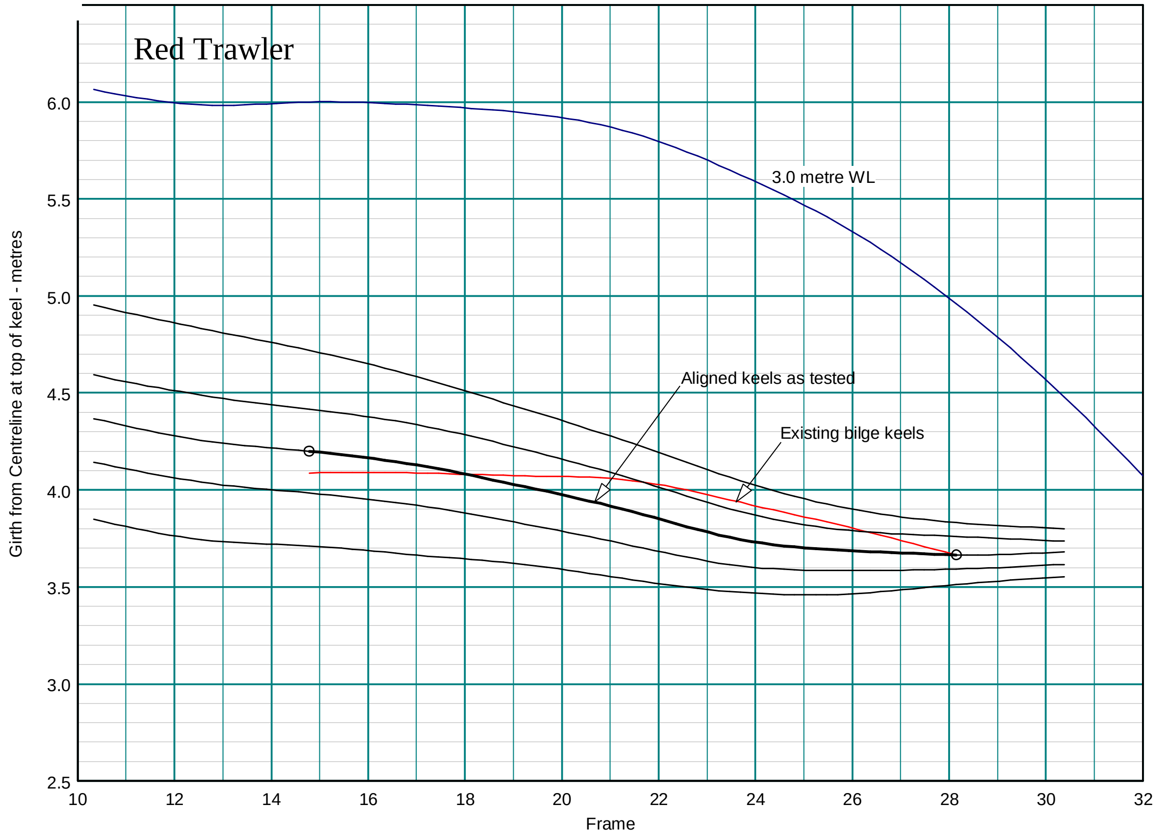


Fig 15 - Bilge Keel Location and Streamlines



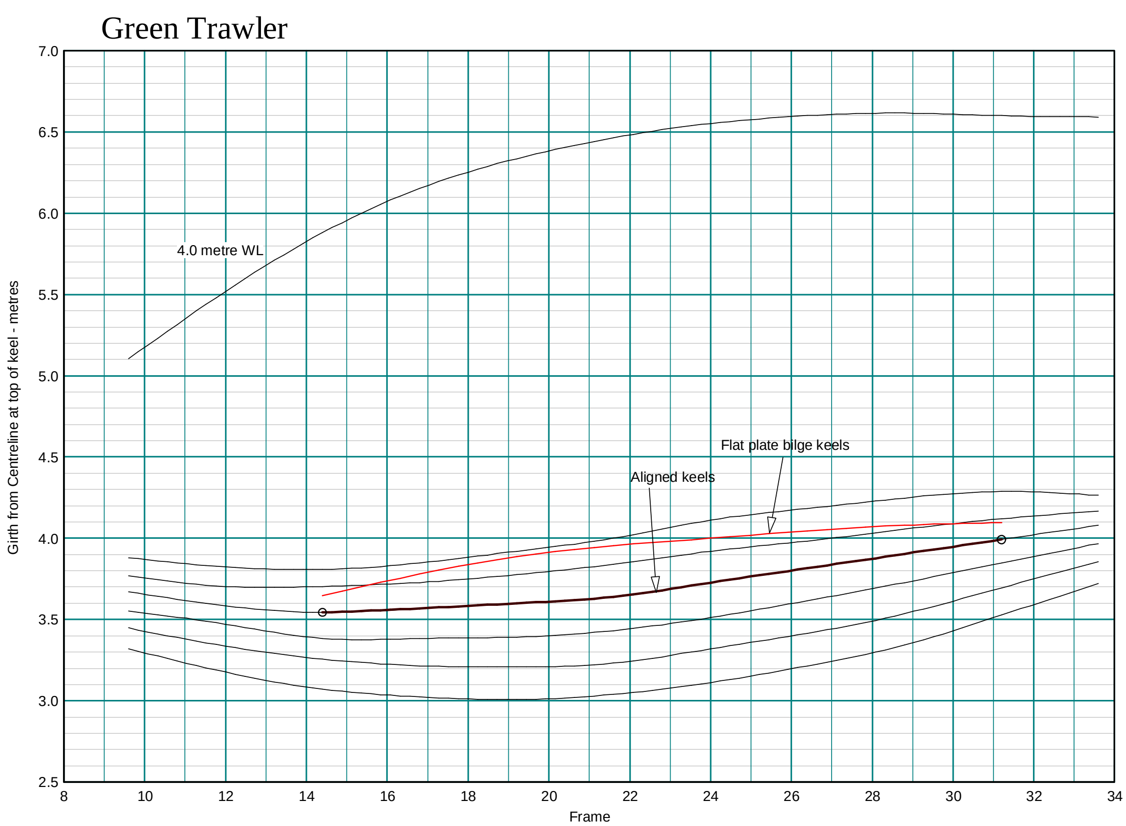
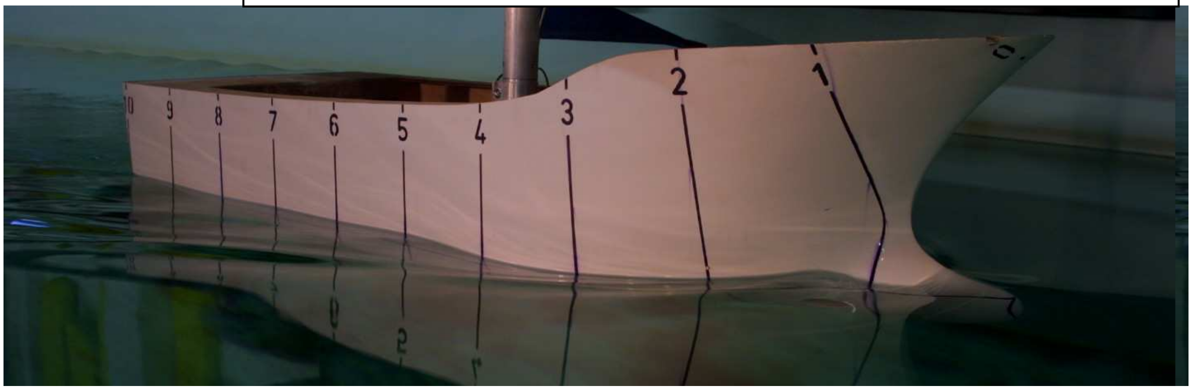
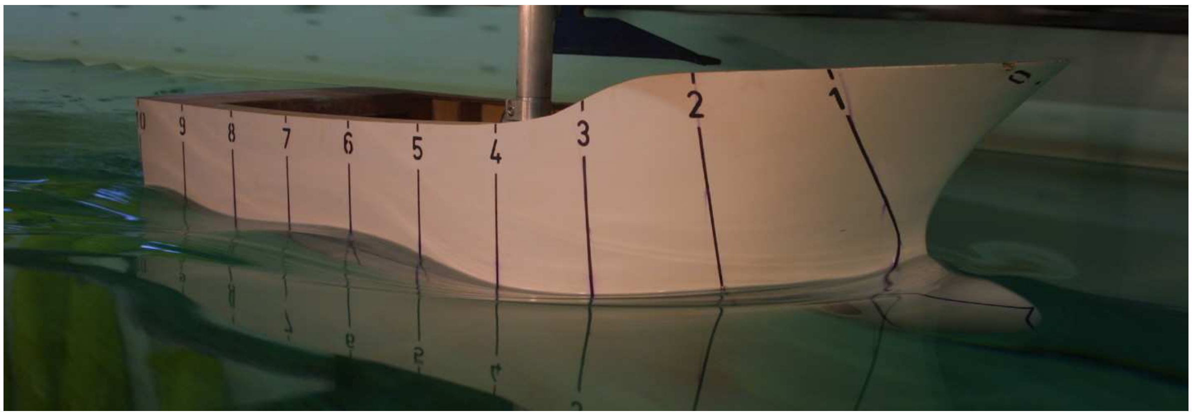


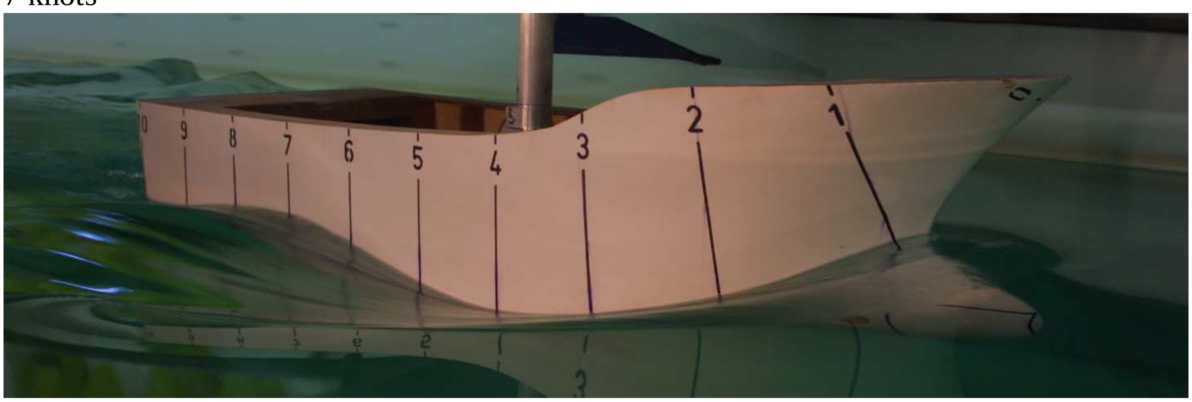
Fig 16 Red Trawler – Depart port



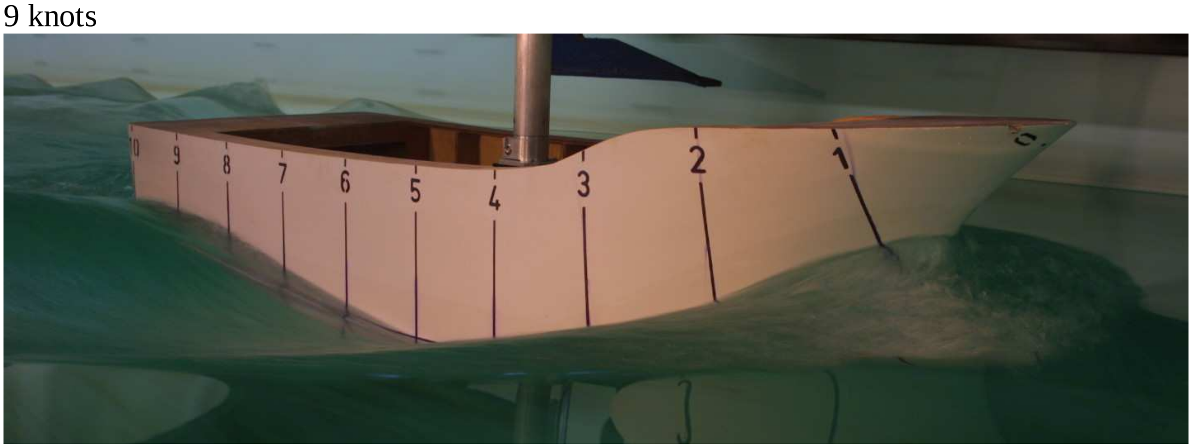
5 knots



7 knots

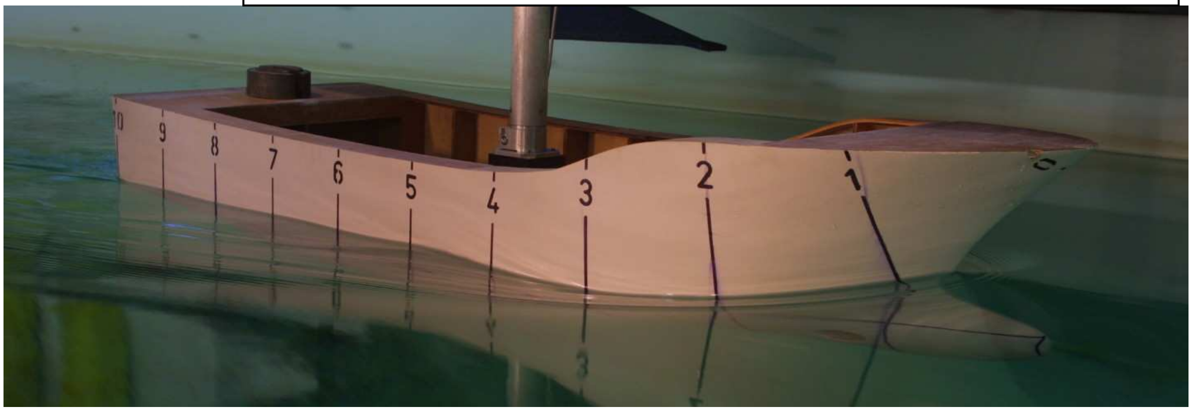


9 knots

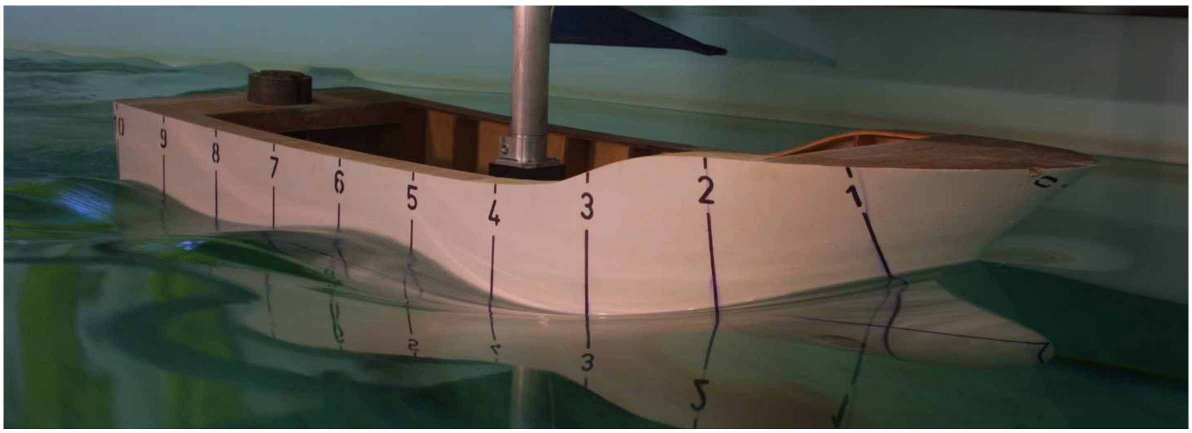


11 knots

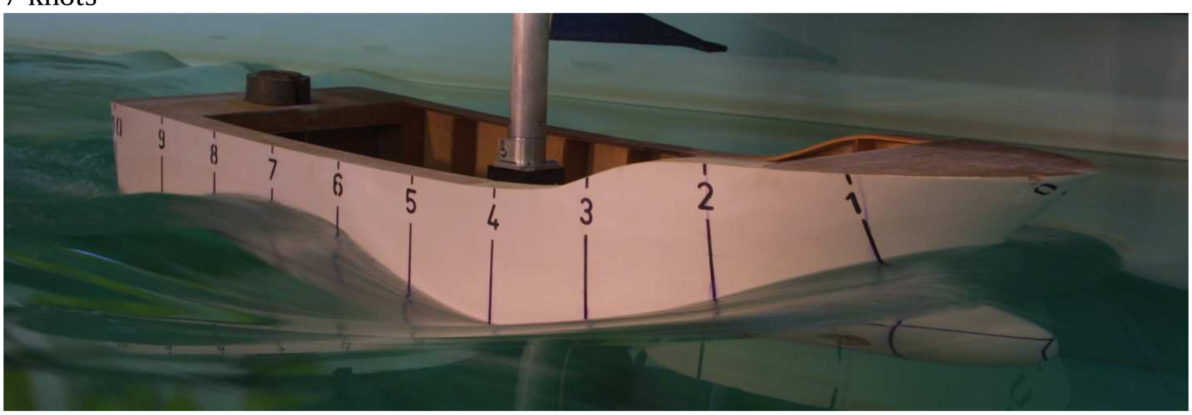
Fig 17 – Red Trawler Depart grounds



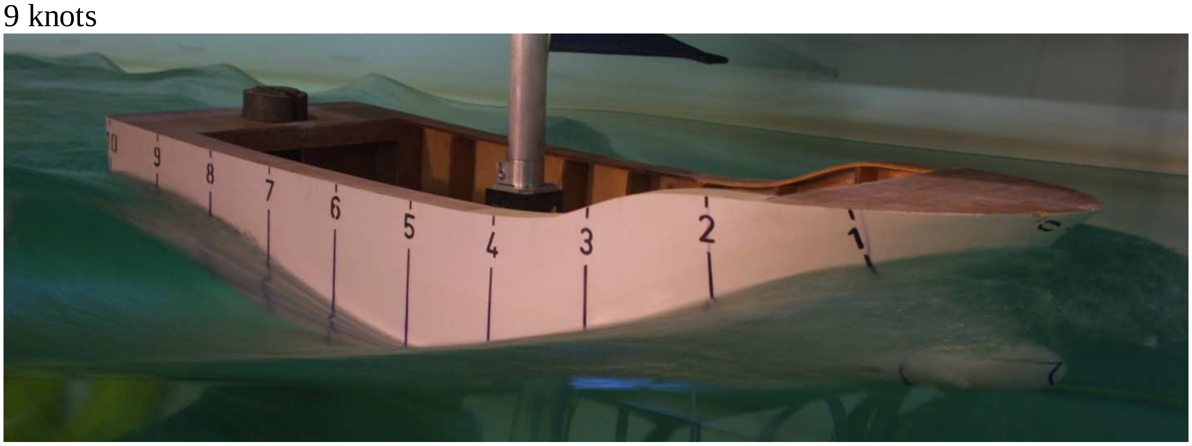
5 knots



7 knots

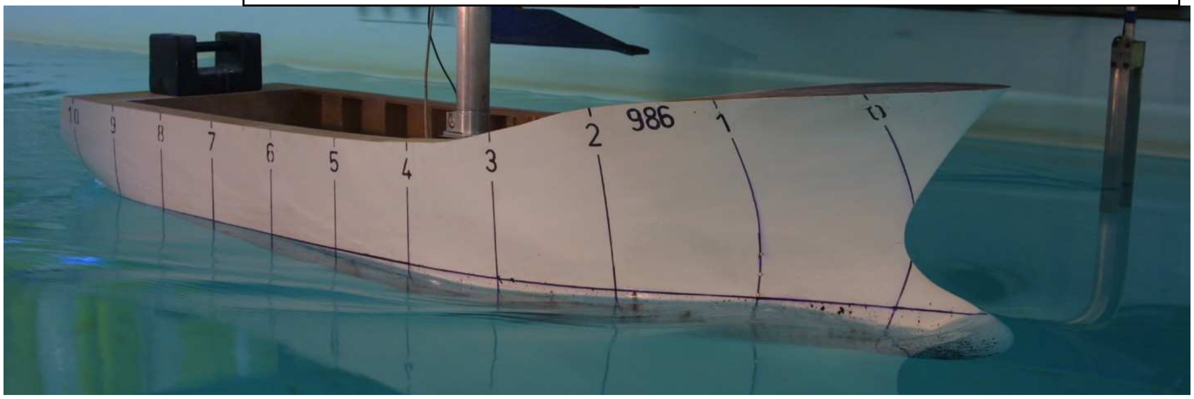


9 knots

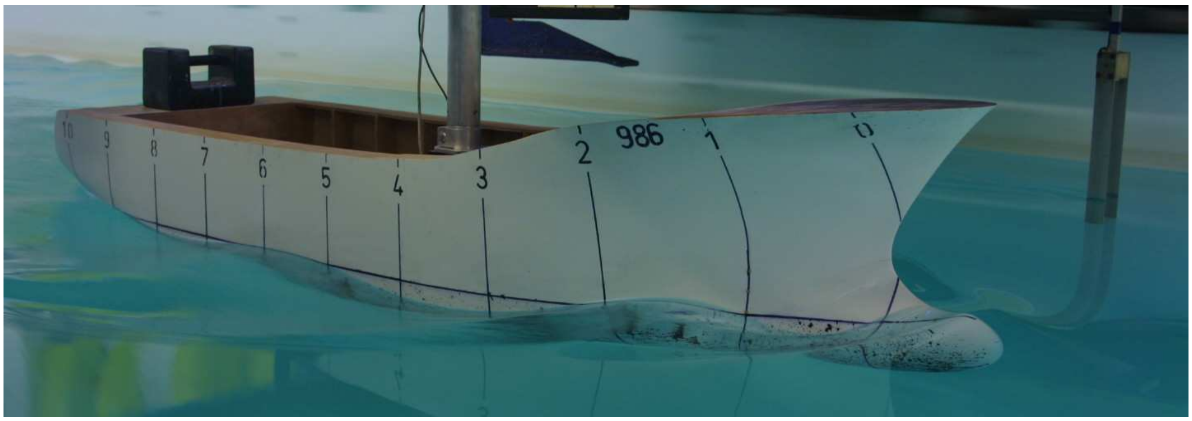


11 knots

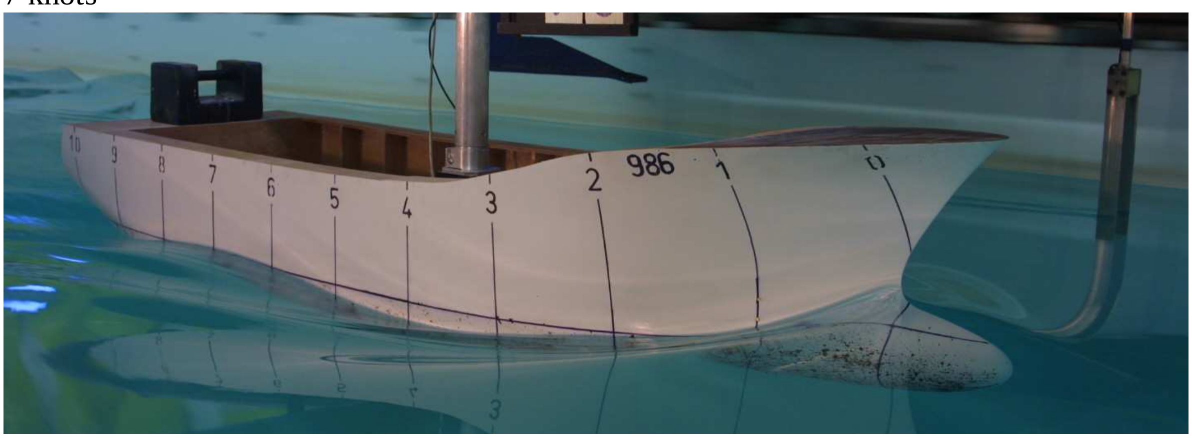
Fig 18 – Green Trawler Depart port



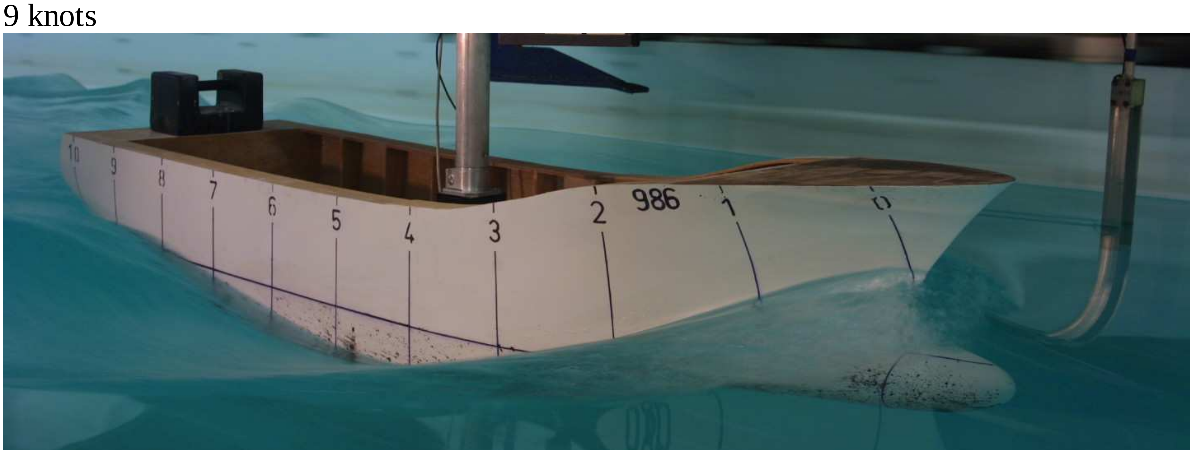
5 knots



7 knots

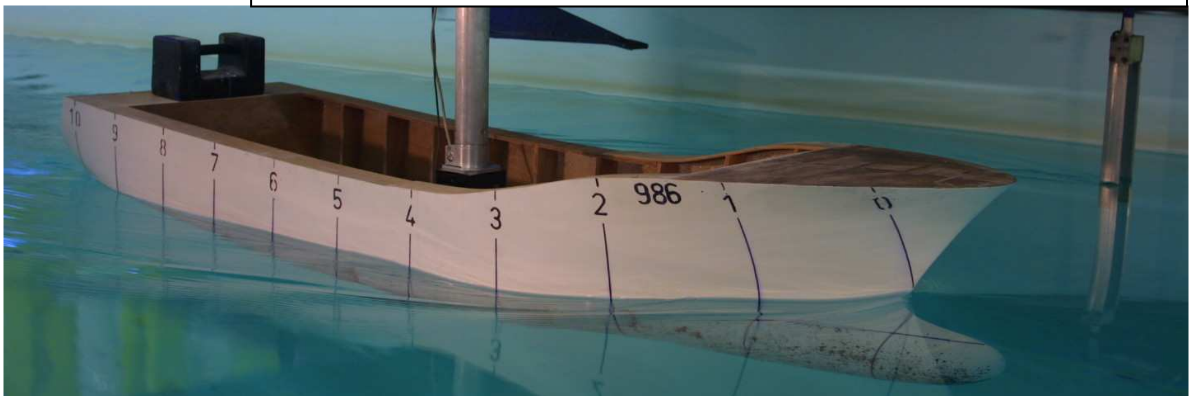


9 knots

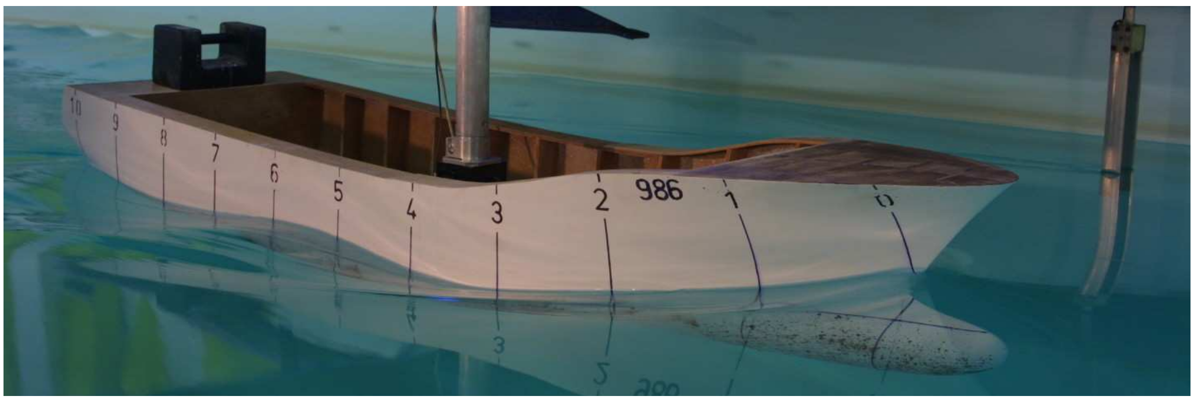


11 knots

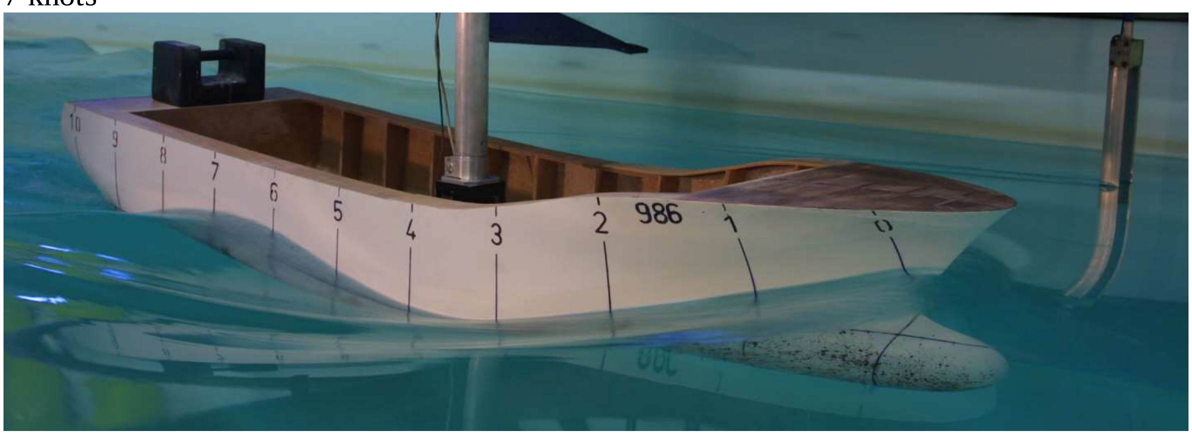
Fig 19 – Green Trawler – Depart grounds



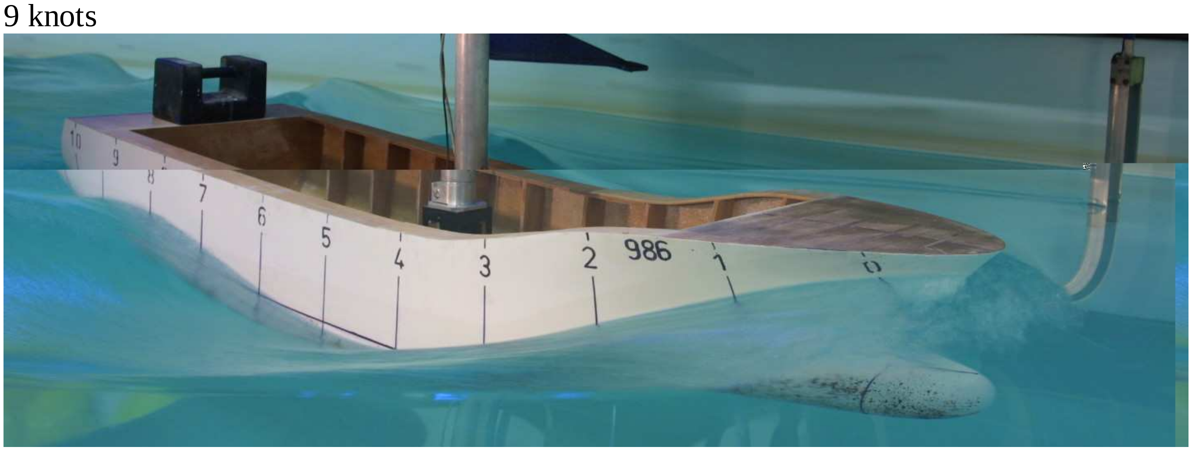
5 knots



7 knots

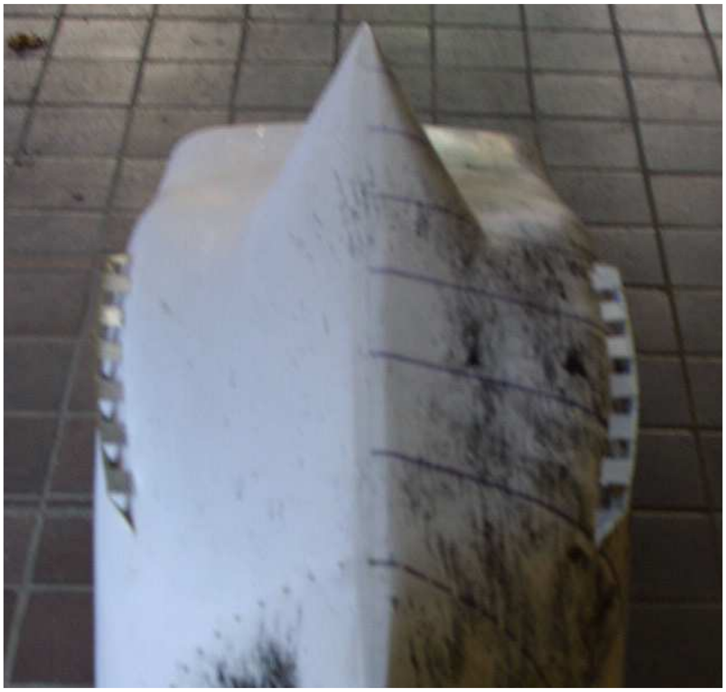


9 knots

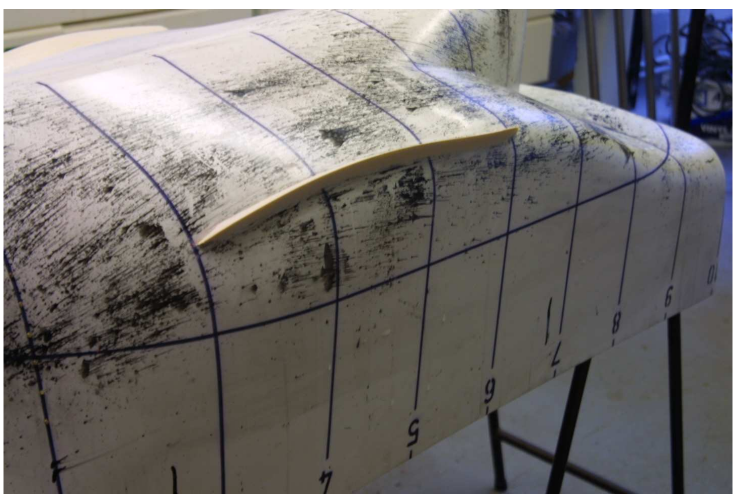


11 knots

Fig 20 - Red Trawler - Bilge Keels

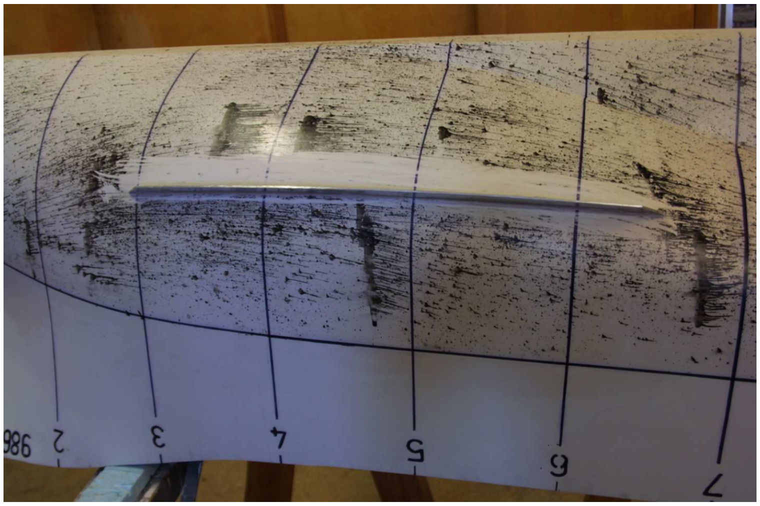


Red Trawler – as built



Red Trawler – Aligned keels

Fig 21 - Green Trawler – Bilge Keels


Green Trawler - Flat plate keels

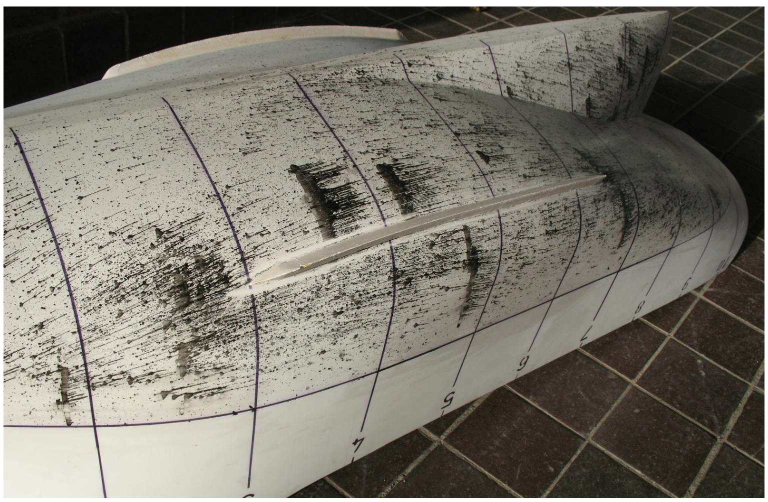
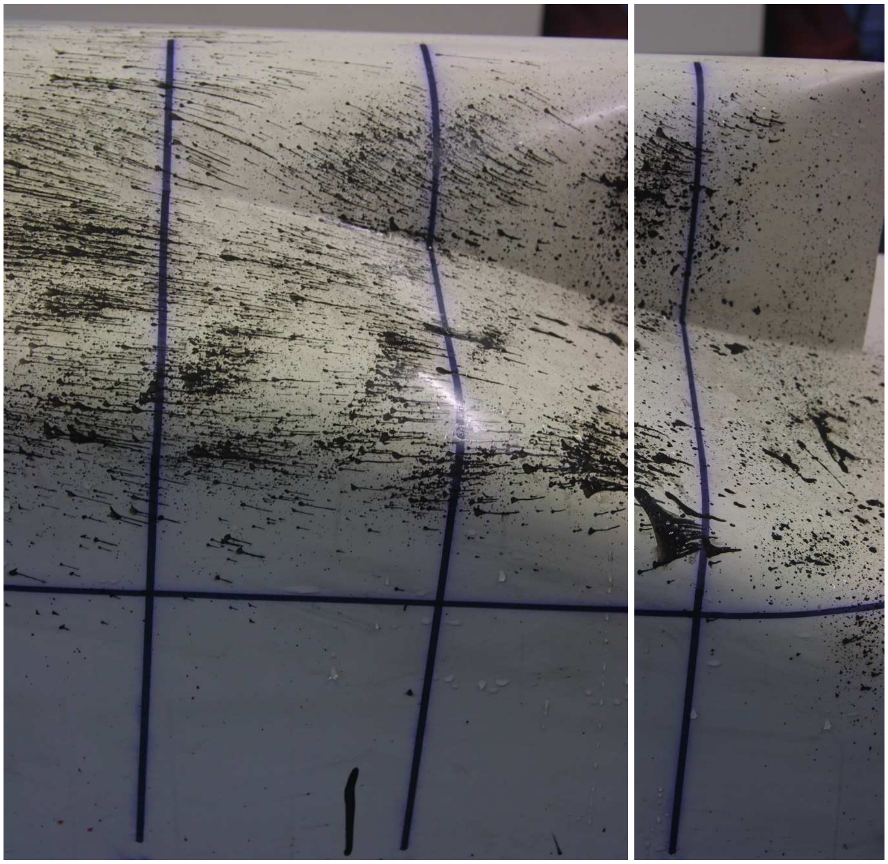
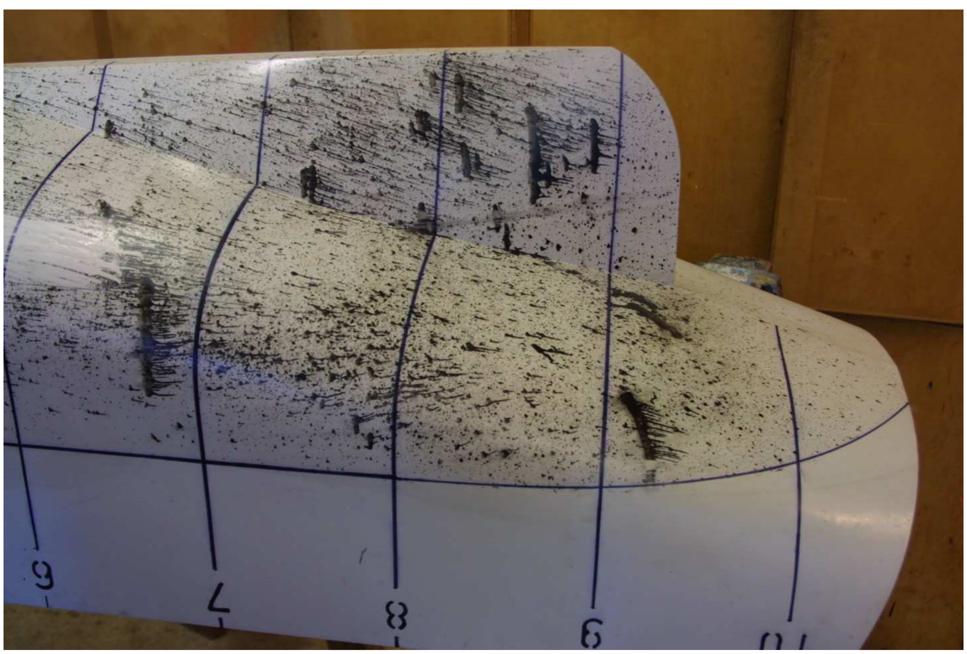

Green Trawler - Aligned keels

Fig 22 - Flow Visualisation at Stern

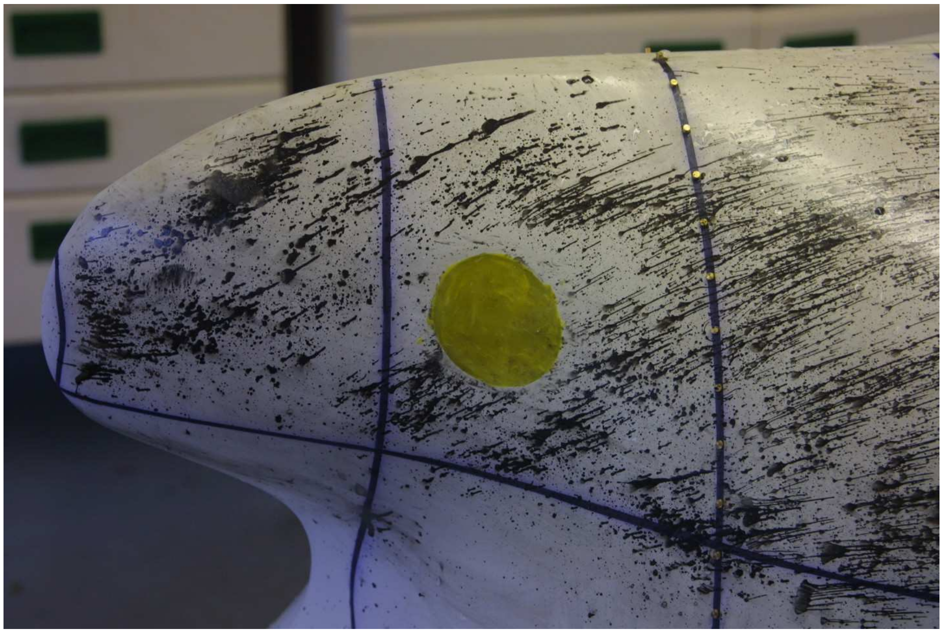


Red Trawler

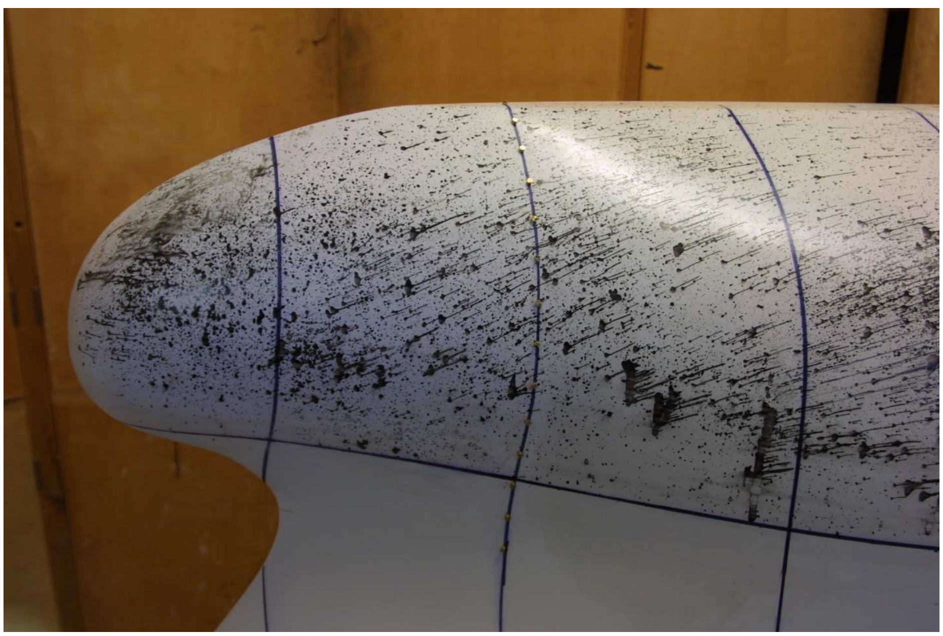


Green Trawler

Fig 23 - Flow Visualisation at Bow

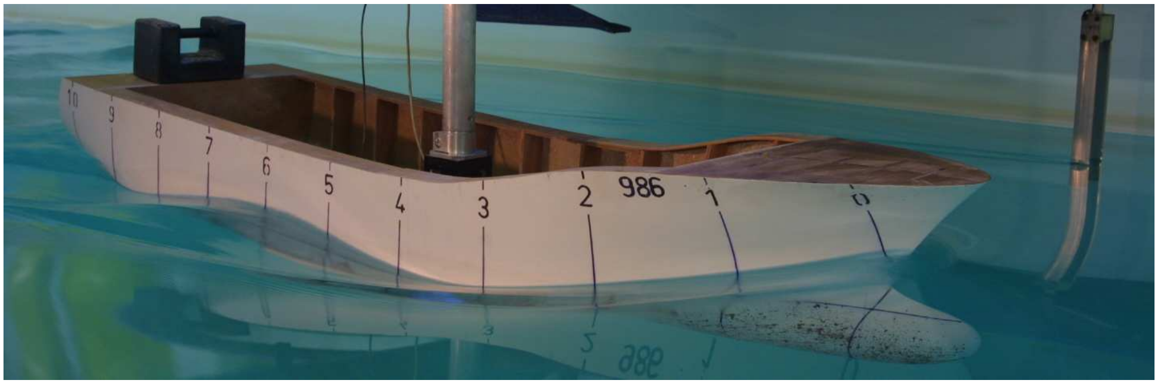


Red Trawler

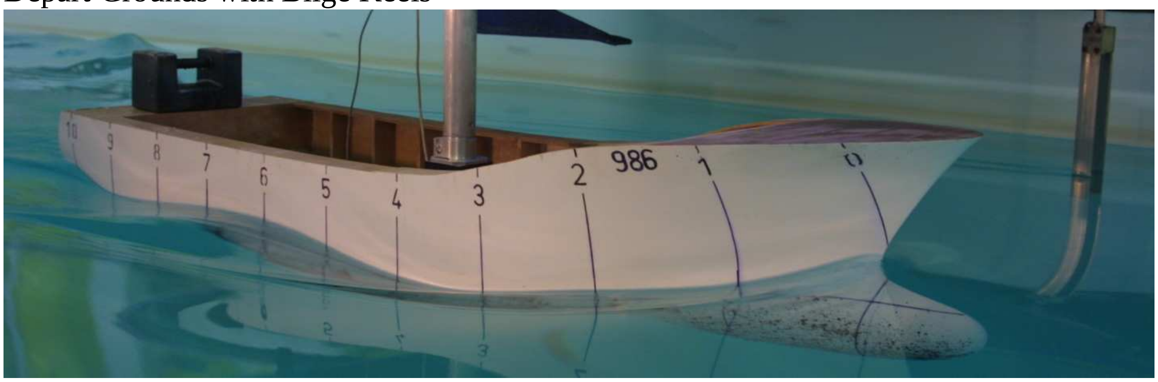


Green Trawler

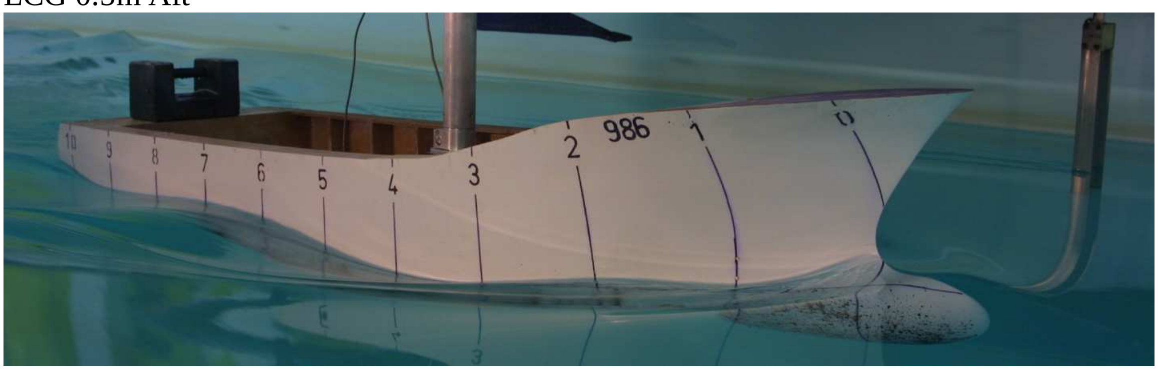
Fig 24 – Green Trawler – Depart grounds 8 Knots – Shift LCG



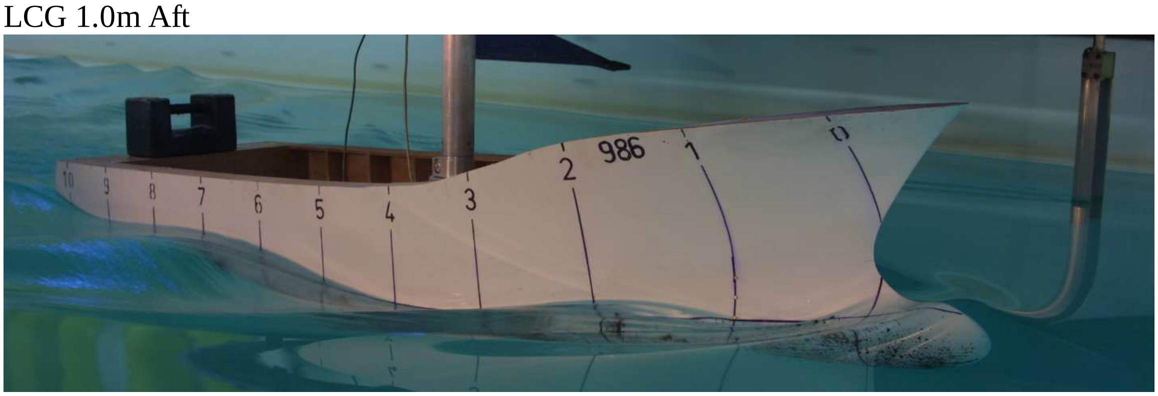
Depart Grounds with Bilge Keels



LCG 0.5m Aft

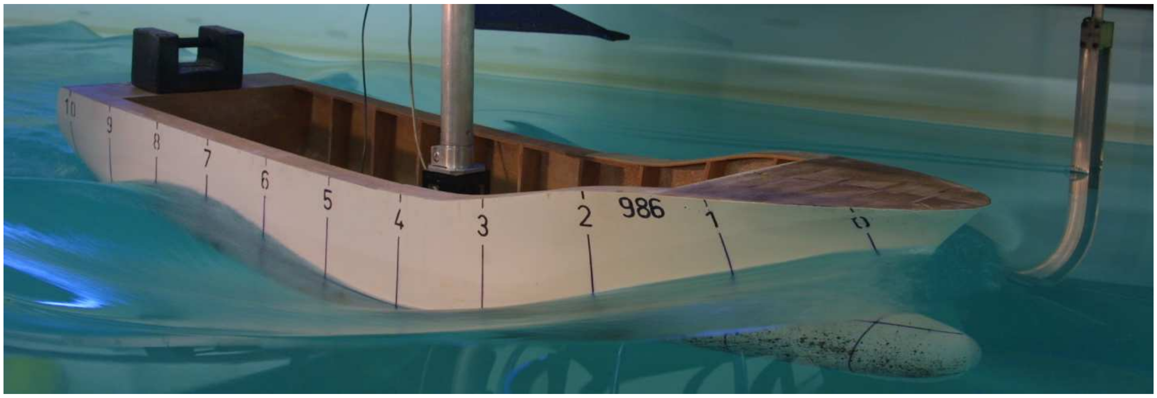


LCG 1.0m Aft

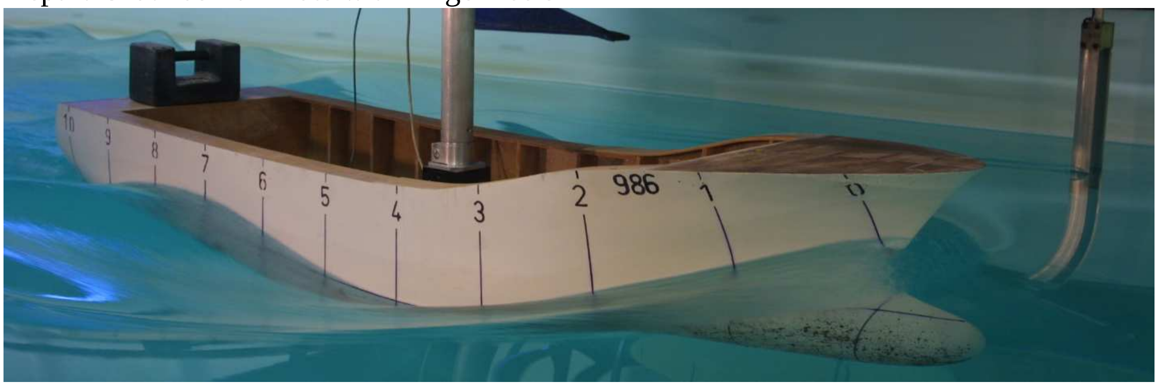


LCG 1.5m Aft

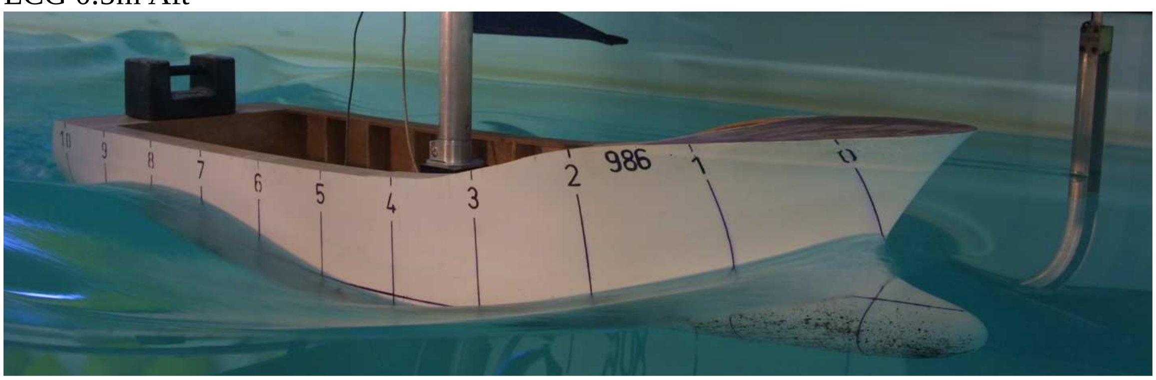
Fig 25 – Green Trawler – Depart grounds 10 Knots – Shift LCG



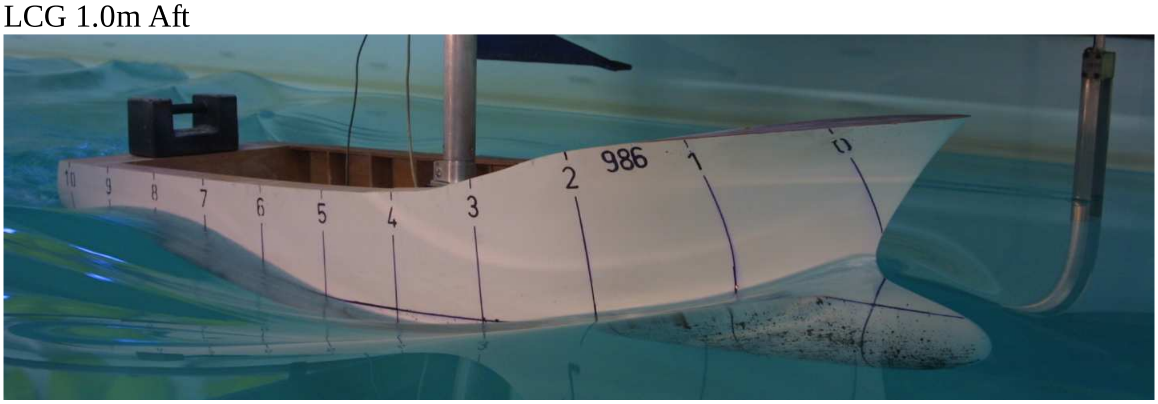
Depart Grounds 10 Knots with Bilge Keels



LCG 0.5m Aft



LCG 1.0m Aft



LCG 1.5m Aft