Energy Efficient Fishing: A 2006 review

PART B – Hull Characteristics and Efficiency

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Fisheries Research and Development Corporation

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Executive summary

Aims and objectives

The objectives of the review are to:

- examine the degree to which rising fuel costs have impacted on different fisheries
- examine new and existing technologies developed both within and outside Australia in the field of increased fishing efficiency through reduced energy usage and innovation
- examine opportunities for applying innovative solutions and developments that are most likely to produce the best return for the Australian fishing industry
- develop a publication that scopes potential innovations, whether they be existing or have the potential for development, that reduce energy usage
- provide advice on potential R&D that could assist industry in reducing energy usage.

This report contains part 2 of 3 of the review into energy efficient fishing. Of the entire subject space to be considered by the review, which is given in Appendix A, this report considers hull characteristics and efficiency. It is subdivided into two areas, hull drag and motion stabilisation. Notwithstanding the broad nature of the report, specific examples and data focus on displacement monohull forms rather than planing craft or multi-hulls.

The report contains two sets of recommendations – technical solutions that could be implemented immediately and longer term high priority research solutions. In both categories, all recommendations except optimisation of hull design are applicable as retro-fits to the existing fleet.

Hull drag

The bare hull of a vessel can be considered to have three main hydrodynamic resistance components when travelling in calm water:

Skin friction resistance: The effect of viscous friction between the water and the ship's hull.

Viscous pressure resistance: The result of the distribution of pressure around the hull that is related to the thickness of the boundary layer and wake (separated flow) in the flow pattern. It is often called form drag.

Wavemaking resistance: Is caused by water pressure on the hull, and is associated with generating a pattern of waves on the water surface as a vessel moves along. The resistance is due to the energy required to create these waves.

At low speeds, the waves made by a vessel are very small and the resistance is almost wholly viscous. As speed is increased the viscous resistance increases moderately with speed. However, the wavemaking resistance increases greatly with speed.

Planing craft such as crayboats travel faster than hull speed by having a light hull that generates fewer waves. With speed, these boats are lifted out of the water by the pressure generated on the bottom of the hull, reducing the immersed volume of the hull and the making of waves. At planing speeds frictional resistance is again the dominant resistance component and pressure drag is also significant, particularly if the vessel operates at a non-optimum trim.

The single most important method of reducing fuel bills for vessels that spend a significant proportion of their time travelling to and from their fishing grounds is to reduce speed. e.g., for a typical 15m long displacement hull, the power required to travel at 10 knots can be about 205kw. However, if steaming speed is reduced to 9 knots the power would only be 115kw, a reduction of more than 40%.

Adding 2% weight on the example 15m vessel at 9 knots, would increase the required power by about 2%.

A fairly typical paint roughness of 250 microns will increase the friction by about 2.5% compared to a perfectly smooth hull. The effect on engine power is typically a 1% increase. Excessive weed or barnacles that are allowed to grow on the hull will easily cause friction to increase by 50%.

A bulbous bow can yield a significant reduction in drag (> 10%) on displacement craft moving at Froude number greater than 0.3. For a 15m vessel this corresponds to >7 knots.

Excessive form drag often occurs if a vessel with a transom stern is trimmed by the stern. Proper trim adjustment is important, even extra weight (ballast) in the bow to achieve level trim might reduce total drag. Trim tabs or stern wedges can be beneficial at higher speed (Froude number > 0.35) by modifying trim.

All vessels have additions to the underwater hull (appendages), like the rudder, bilge keels, transducer mounts and cooling water pipes etc. The total appendage drag can easily add up to 20% of the total hull drag. Where the design of appendages has focused on simplicity, low capital cost and robustness, excessive drag may exist. For a typical 15m vessel travelling at 10knots, an aerofoil rudder consumes nearly 6kW (4%) less engine power than a flat plate rudder. If the rudder is turned to 10 degrees, the aerofoil rudder consumes about 4kW (3%) less than the flat plate rudder. Similarly, it is estimated that cooling pipes consume about 2-3% of the total engine power generated. Using a different method to cool the engine water could remove this drag component.

When a fishing vessel is exposed to side currents or wind, the effective resistance to forward motion is increased; rudder drag increases due to the application of rudder to produce the necessary angle of leeway and angled flow onto the hull to resist the side loads, hull drag is increased because it is travelling at an angle of attack (leeway) and lastly, because of the misalignment of the flow into the propeller, the thrust force is slightly reduced. Adjustments to the vessel that can reduce the amount of rudder and/or leeway required for these situations could produce a significant improvement in fuel efficiency. Slow moving vessels (e.g. trawlers) are vulnerable to significant problems in this area, particularly those using trawl systems that are a continuous unit towed equally from a wire on each side of the vessel.

Alternative hull designs, like catamaran, SWATH, cathedral, and M hull, might produce substantial benefits in some fishing applications where their distinct technical qualities are appropriately married to the particular operational circumstances. For example, catamaran and SWATH vessels have improved sea-keeping properties in moderate sea states, but can be worse in severe weather. They have greater deck area for a given vessel length and good high speed performance. These craft can be more fuel efficient than planing vessels in many instances.

Regulatory constraints on hull form have resulted in vessels with poor fuel efficiency. The optimum fishing vessel should be one that earns the maximum in its lifetime and therefore its form needs to match the conditions in which it operates. Minimum resistance and large hold capacity are conflicting objectives and a compromise solution is required for the maximum earning ability. An appropriate optimisation tool such as the Decision Support Problem (DSP) technique (Pal, 2006), could identify optimum hull forms for specific Australian conditions and also explore the impact of regulatory constraints.

Immediate solutions summary

Reduce speed

Maintain hull smoothness

Trim monitoring

Cooling water pipe drag

Change of rudder section

☑ *Vessel motion stabilisation*

The pitch, roll, heave and yaw motions of a vessel travelling in ocean waves decrease economic efficiency for several reasons; most importantly, the motions of the vessel cause extra hydrodynamic drag, further, the motions cause non optimal conditions (for example, incorrect trim and incorrect flow into the propeller), drag from various pieces of equipment used to reduce motions (paravanes, bilge keels etc), reduced task progress rates and sea sickness due to boat motion.

In fishing, specific devices and strategies for reducing vessel motion exist principally for the reduction of roll. Roll is generally the motion of greatest magnitude, since it is very sensitive to wave period and is lightly damped. The range of devices employed to reduce roll focus on either one of these aspects of the roll problem:

- paravanes, bilge keels, sails active fins, anti-roll tanks, gyroscopes

The design principles and associated practical implications for many of these devices has not been extensively studied and documented. There is considerable scope for optimising existing anti-roll systems and in the first instance establishing an adequate technical description of current industry best practice. The most popular approach to reduce roll currently is to increase damping, which typically also involves significantly increasing resistance to forward motion. Non-drag devices such as anti-roll tanks and gyros offer alternative solutions that have much lower running costs.

Other vessel motions, particularly pitch and yaw, underlie significant efficiency problems for fishing vessels. Ideas are emerging as to the structure of these problems and mitigating technical solutions.

Immediate solutions summary

Comparison of existing roll stabiliser devices

☑ *Conclusions and research questions*

Hull drag

Dominating the hull drag discussion are two issues; the large increase in wave making resistance at higher speed (for displacement vessels) and the highly variable drag component, pressure drag, which can become a significant factor in the high running costs of a fishing vessel through bad design of hull and appendages or bad operating practice (e.g. incorrect trim).

The following research questions and project themes should underpin initiatives in this area:

1. Retro-fit bulbous bows

Bulbous bow seems worthwhile for displacement vessels that spend a significant portion of time at steaming speed.

- Optimum bulb design for smaller vessels not certain.

- Are simple retrofit bulbs beneficial?

2. Stern wedges

Most applicable for planing vessels.

- Research required to identify range of application that returns an acceptable benefit.

3. Improved estimate of cooling water pipe drag

- Consider issue's sensitivity to Reynolds number and shadowing effects to establish most cost effective research approach.

- Model or full-scale tests to indicate scale of drag increase associated with keel pipes.

4. Optimum trawler design

- Formal design/optimisation exercise for test case desirable to establish range of benefits possible; a typical scenario might involve situation where regulations restrict the use of optimum hull shape.

Vessel motion stabilisation

Devices that are commonly used for reducing vessel motions contribute substantially to drag and fuel costs. A very low understanding of the dynamics of these motion stabilisers exists within industry and with technologists – most device installations are based on tradition.

Research questions and recommended tasks in this area are:

1. Optimisation of paravanes for minimum drag

- Review current designs to identify/document design principles and performance features.

- Numerically evaluate performance and practical benefits of devices to fishers.

- Short term sea trials of vessel-specific modifications and retrofits to quantify/confirm performance benefits.

- Test new innovative designs concepts.

2. Drag reduction using roll gyros

- Instrumented trials of fishing vessel fitted with a roll gyro (off the shelf) to determine motion reduction and fuel efficiency effects for various sea states.

3. Reduction of pitch motion using retro-fit bulbous bows or bow fins

- Tank testing model fishing vessels to establish the practical benefits of bulbous bows and bow fins in the reduction of pitching motion and fuel consumption.

- Based on tank tests and computer simulation propose optimum bulb/bowfin design that could maximise performance benefits to fishing vessels.

4. Minimising yaw drag using DGPS

- Consider for fishing vessels the relationship between directional stability, manoeuvrability and fuel efficiency to determine guiding design principles and field techniques to establish the status of existing fishing vessels.

- Determine retrofit options to improve the fuel efficiency of fishing vessels during autopilot controlled voyages, including the use of DGPS.

1 Hull drag

1.1 Introduction

For the purposes of this document, resistance and drag are the same thing. They are the force in the direction of travel, generated as a consequence of moving the boat forwards. Effective power is the ship resistance times the ship speed. Engine power (shaft power) is about twice the effective power because of efficiency losses (mainly in the propeller) i.e. overall propulsive efficiency is typically 50%

The bare hull of a vessel can be considered to have three main hydrodynamic resistance components when travelling in calm water [1] [2]:

Skin friction resistance: This is the component of resistance obtained by summing up the tangential forces over the hull surface. In other words, it is simply the effect of viscous friction between the water and the ship's hull.

Viscous pressure resistance: This is the component of resistance obtained by summing up pressures due to the thickness of the boundary layer and wake. It is essentially a drag due to viscosity other than skin friction (i.e. form drag).

Wavemaking resistance: When a vessel moves along the surface of the water it creates a pattern of waves. Energy is required to create these waves and the wavemaking resistance is the component of resistance associated with the expenditure of this energy.

At low speeds, the waves made by a vessel are very small and the resistance is almost wholly viscous friction (see Figure 1). As speed is increased the viscous resistance increases moderately with speed. However, the wavemaking resistance increases greatly with speed with a very steep increase occurring when the ship is travelling at the speed of a wave of its own length. In this case there will be a large crest at the bow and the stern with a deep trough amidships. This speed is sometimes known as maximum hull speed because of the power required to exceed it. The maximum hull speed in knots is approximately 1.4 times the square root of the waterline length in feet. e.g. for a 15m (49ft) length vessel the hull speed is 1.4 times square root of 49, which is 9.8kn.

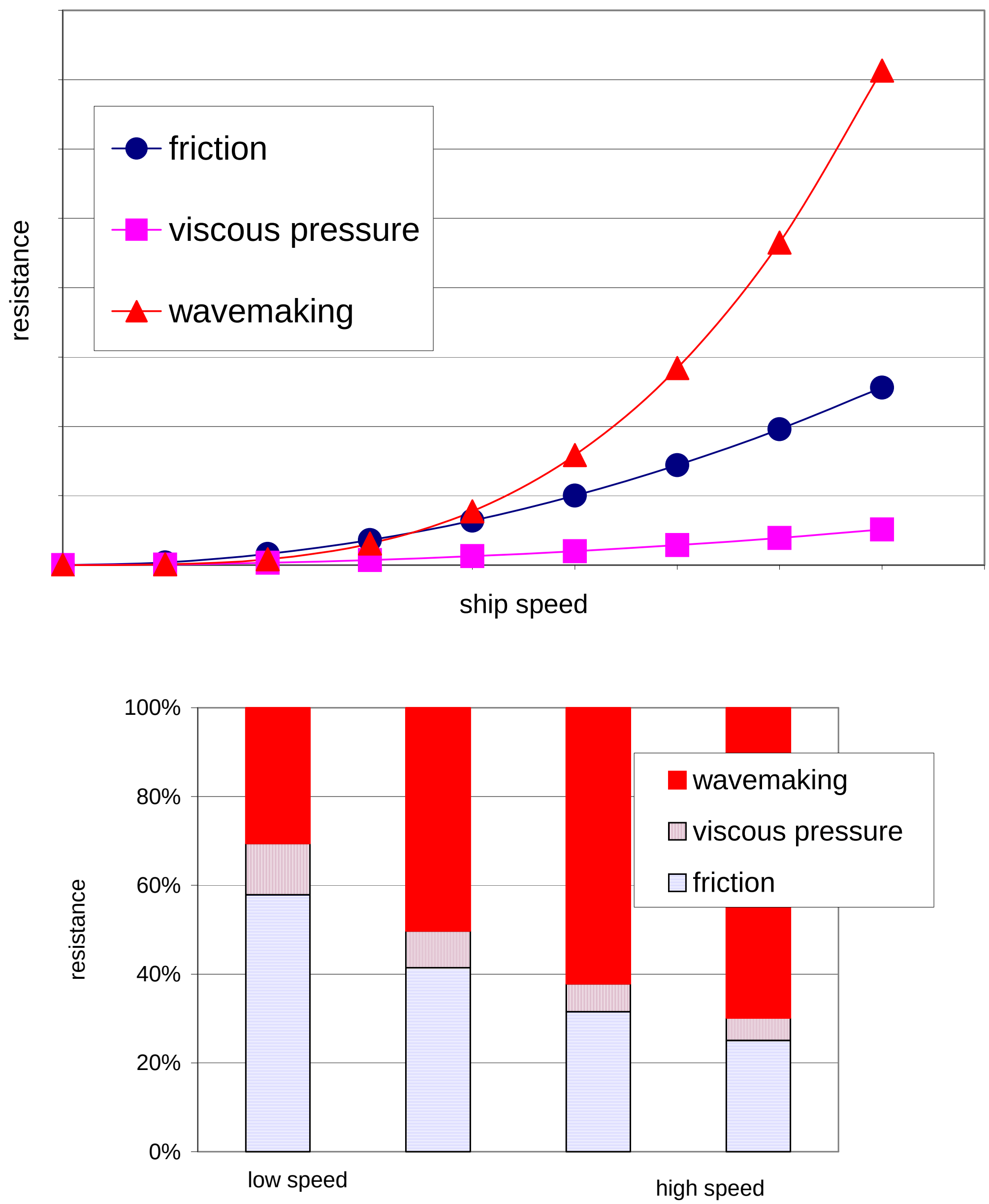


Figure 1. Breakdown of vessel drag for various operating speeds

Planing craft such as crayboats travel faster than this hull speed by having a light hull that generates fewer waves. Once the boat is travelling faster than hull speed it starts to lift out of the water, reducing the immersed volume of the hull and hence reducing the wave making (Figure 2). This is called planing. At these higher speeds, frictional resistance starts to become more important again. An additional component of drag is created as a consequence generating the planing lift force, called trim drag. If the vessel operates at a non-optimum trim at planing speeds, there can be a severe drag penalty and consequent increase in fuel consumption.

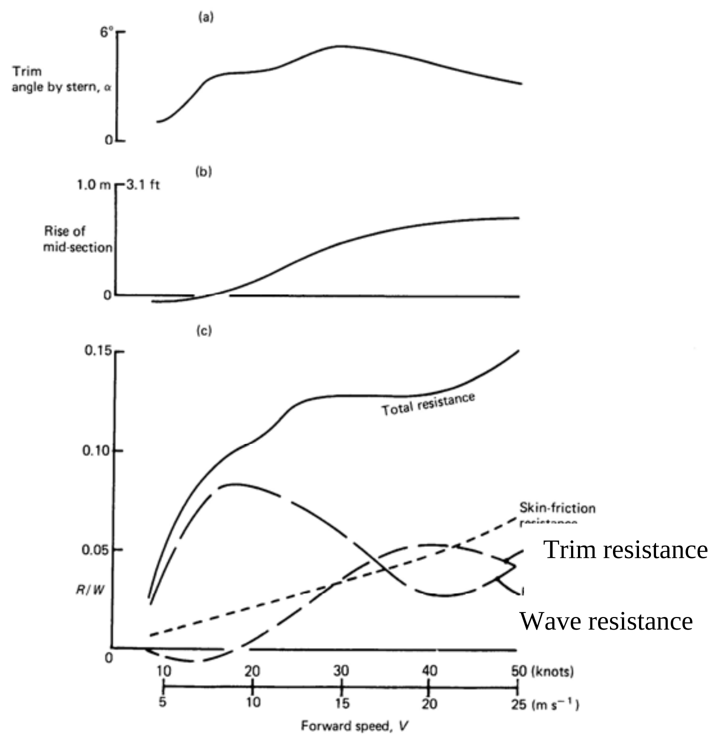


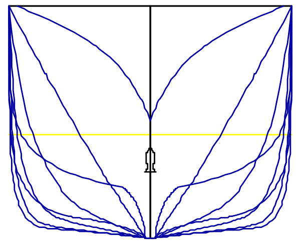
Figure 2. Breakdown of drag for planing hull over its range of operating speeds [3]

Immediate solution: reduce speed

Consider a trawler of 15m waterline length with the characteristics given in the table below.

Displacement kg	56125
Draft at FP m	1.500
Draft at AP m	1.500
Draft at LCF m	1.500
Trim (+ve by stern) m	0.000
WL Length m	15.000
WL Beam m	4.068
Wetted Area m^2	75.650
Waterpl. Area m^2	52.100
Prismatic Coeff.	0.661
Block Coeff.	0.598
Midship Area Coeff.	0.908
Waterpl. Area Coeff.	0.854
LCB from zero pt. (+ve fwd) m	0.282
LCF from zero pt. (+ve fwd) m	-0.386
Propulsive efficiency	50%

The resistance of the bare hull in calm water with no appendages or deployed trawl gear can be calculated using standard series data (the results of model tank tests of a series of geometrically similar hull forms). The resulting graph of engine power against speed is shown in Figure 3.



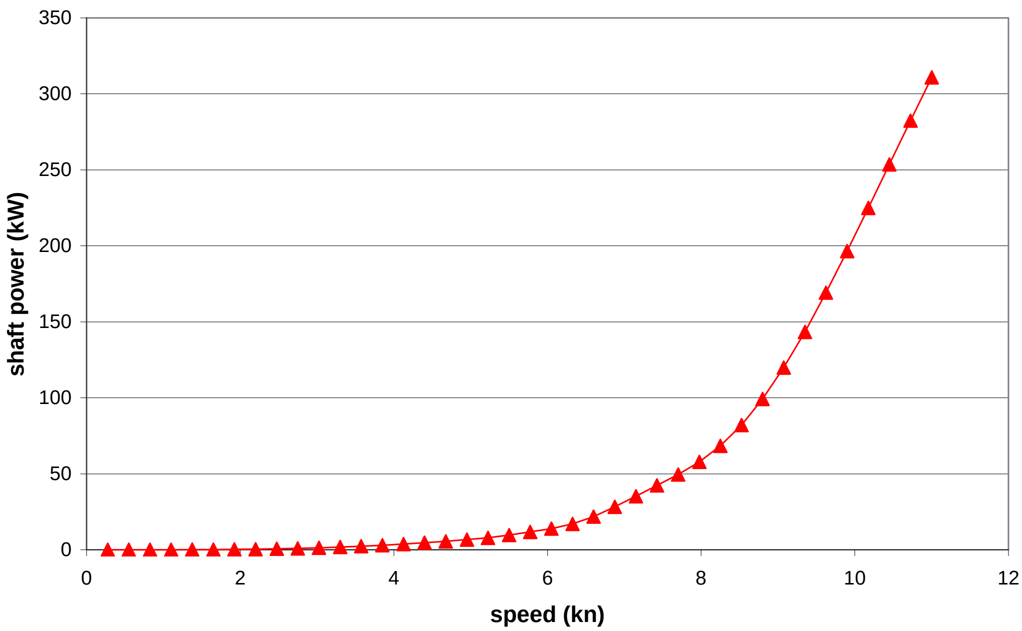


Figure 3. Required shaft power versus speed for 15m displacement fishing vessels (Hullspeed, 2006)

The most striking feature of this curve is its steepness at high speeds. If the vessel usually steams at 10kn, the power required is about 205kw. However, if steaming speed is reduced to 9kn the power is only 115kw, a reduction of more than 40%. This is probably the single most important method of reducing fuel bills for vessels that spend a significant proportion of their time travelling to and from their fishing grounds. It is also the easiest to implement. Offset against a steaming speed reduction must be considered the cost of extra time spent at sea.

1.2 Effect of increasing vessel weight

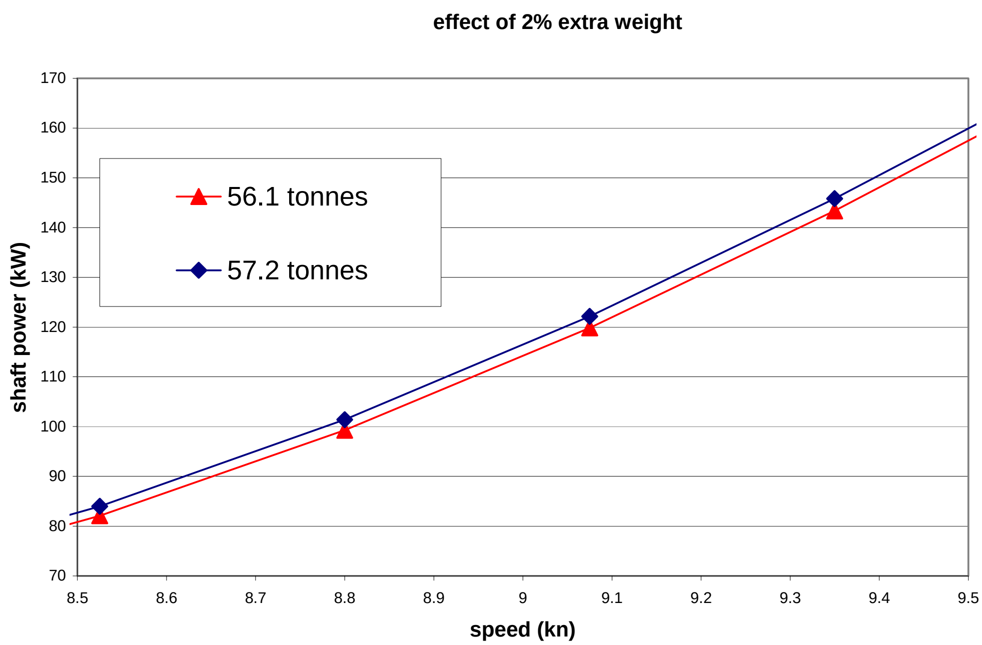


Figure 4 Effect of adding weight on required engine power

The effect of adding weight on required power for the example 15m vessel is illustrated in Figure 4 above. For example, at 9kn, an extra 2% weight (1.1 tonnes) increases the required power by about 2%.

1.3 Friction/paint systems

When water flows past the hull, as shown in Figure 5 below, the water nearest the hull surface tends to stick to it and will therefore have zero velocity.

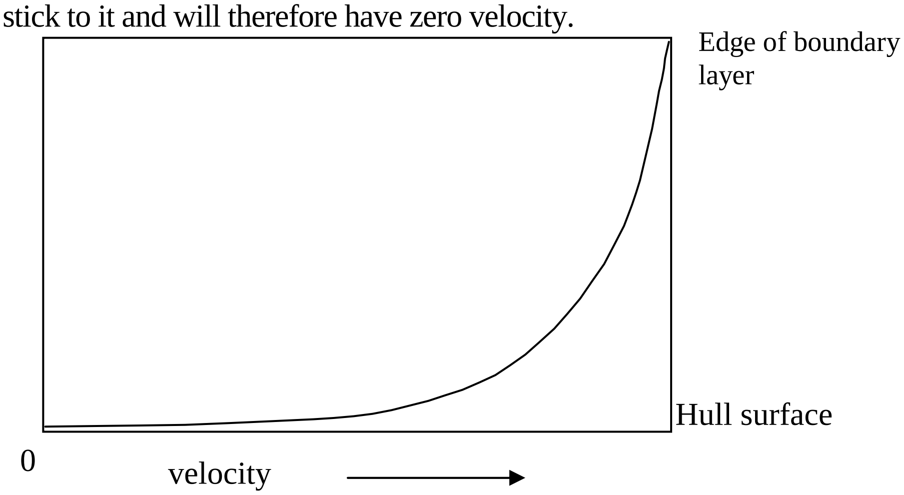


Figure 5. Speed of water flow against hull as a result of friction and boundary layer affect

With increasing distance from the surface the velocity approaches that of the ship speed. The region of slowed down water is called the boundary layer. It increases with thickness from the bow to the stern, but even at the stern it is only about 10-20mm thick.

The flow within the boundary layer over a fishing boat hull is turbulent (remember that this is at a very small scale, not really visible to the naked eye). However, very close to the hull this turbulence must die out (the turbulent motion hits the hull and flattens out), generating a smooth inner layer called the laminar sub-layer. This laminar sublayer is about 0.2mm thick (i.e. 200 microns), but it is very important for fuel efficiency. If the paint surface has a roughness which is large enough to protrude through the laminar sublayer into the main part of the boundary layer, then the frictional drag will increase. A typical marine paint finish roughness is between 200 and 400 microns height, so even if there is no marine growth, there will be an increase in friction drag compared with an ideally smooth hull surface. As an approximate guide, any roughness thicker than a human hair will generate some increase in friction drag.

A fairly typical paint roughness of 250 microns will increase the friction by about 2.5% [4]. The effect on engine power depends on what proportion of total drag is taken up by friction (which in turn depends on ship speed, hull shape etc.), but it might typically represent a 1% increase in required power.

If marine organisms such as weed or barnacles are allowed to grow this will cause a large increase in roughness, hence increasing frictional resistance. A barnacle is about 5000 microns high, so frictional drag can easily increase by 50% if the paint system is not well maintained.

Immediate solution: maintain hull surface smoothness

It is important to maintain a smooth paint system, and especially important not to allow marine organisms to grow. Pay particular attention to obtaining a smooth paint finish when applying antifouling, and clean the hull regularly – perhaps every 3 to 6 months – in order to minimise the friction increase due to marine growth.

1.4 ☑ Wave making resistance

The importance of wavemaking resistance has already been illustrated in the introduction of Section 1.1. The two biggest factors influencing wavemaking resistance are:

- Vessel speed. As a very rough guide, a 10% increase in speed results in a 40% increase in wavemaking resistance for displacement vessels such as trawlers.
- Vessel mass (displacement). Other things being equal, wavemaking resistance is directly proportional to displacement e.g. if the vessel mass is increased by 10%, then the wavemaking resistance will increase by 10%. In practice it will probably increase more than this, because the extra sinkage due to the mass increase may result in a non-optimum hull shape. The increased sinkage will also increase frictional resistance (more wetted surface area) and viscous pressure resistance (more separated flow from the immersed stern shape). See also section 1.2.

Research option: bulbous bows

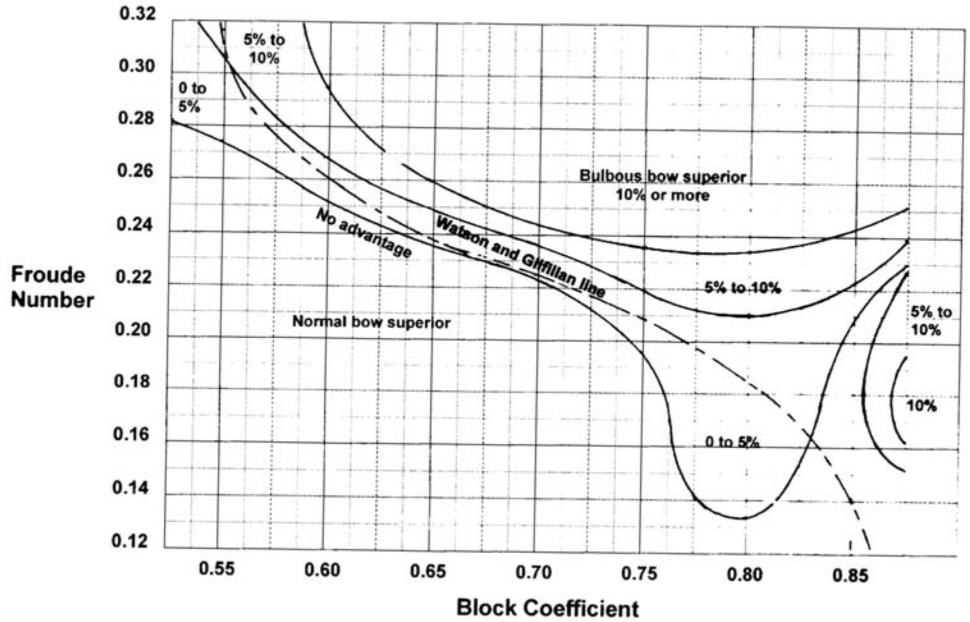


Fig. 8.1. The combination of Froude number and block coefficient at which a bulbous bow is likely to be advantageous.

([4])

The above diagram is a generalisation of the effect of a bulbous bow for different hull shapes (block coefficient on the x axis) at different ship speeds (Froude no on the y-axis). Most fishing vessels have a low block coefficient (around 0.5), so it is the left hand side of the graph that is of interest. It shows that a bulbous bow starts to have a drag advantage at Froude number greater than about 0.3. For a 15m LWL vessel this corresponds to a speed of about 7 knots. Therefore a bulbous bow is worth considering if the vessel spends a significant portion of its time at steaming speed. However, it should be noted that these calculations assume the ocean is calm. See Section 2.3

Research option: - stern wedges

Wedges and trim tabs work by altering the pressure distribution around the aft end of the hull. This results in a trim change, which itself alters the drag of the boat. If the wedge or tab does not alter the trim, it is unlikely to have a beneficial effect on drag, and could make it worse. The graph in Figure 6 shows that a tab starts to take effect at a Froude number of 0.35, which corresponds to a speed of 8.3kn for a 15m LWL. So there could be beneficial effects for a trawler at steaming speed, or a planing crayboat. However, wedges are usually at their most effective when correcting the trim of a vessel that is operating at the wrong (non-optimum) trim, either due to bad design or change in LCG from the design condition. The effectiveness of a wedge or tab on a vessel already operating at optimum trim angle is very dependent on hull shape and speed. Tank tests would be required for a variety of hull shapes and wedge sizes to find the best solution.

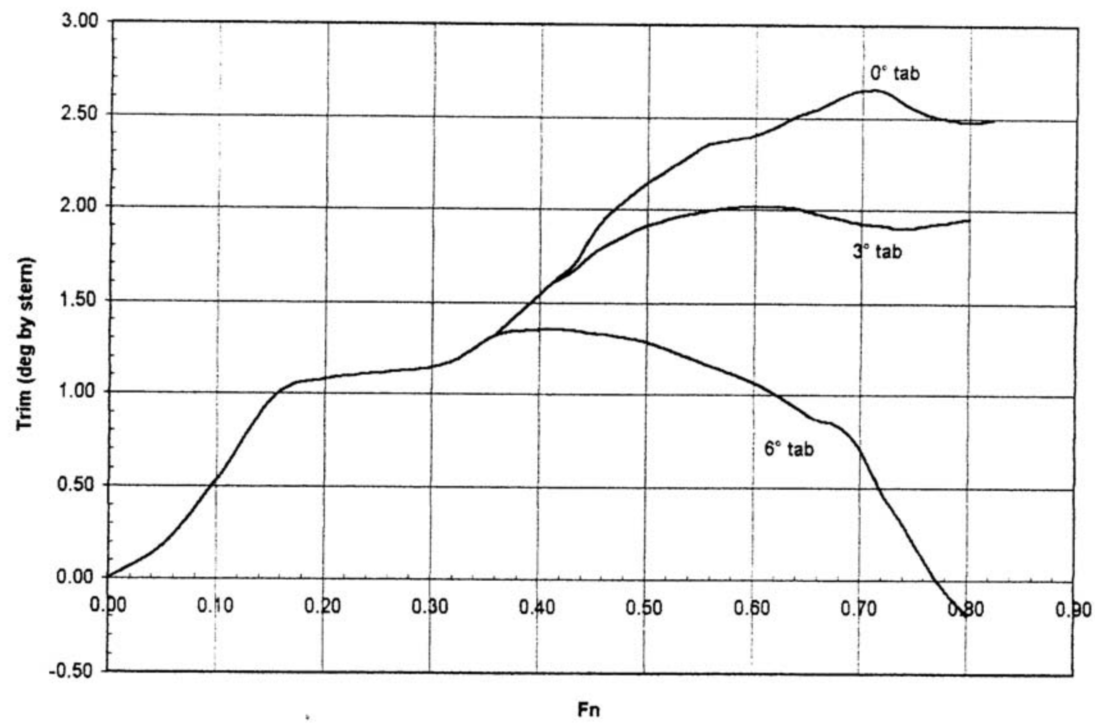


Figure 6. Effect of stern wedge in correcting vessel trim AMECRC

1.5 ☑ Form drag

Form drag is also called viscous pressure drag, pressure form drag, separation drag and eddy-making drag. It is mainly due to the boundary layer (see Section 1.3) separating or peeling away from the hull, leaving a void of water to be filled by back-eddies, which require a lot of energy to generate (hence a lot of resistance). Form drag of a well-designed hull is usually only about 5-15% of the friction drag, so about 1-5% of total drag. However, for a poorly designed hull, or one which is heavily trimmed, it may increase to 10-15% of total drag. The form drag tends to increase with the fullness of the hull. There is a trade-off here because a fuller hull allows for more cargo (fish hold) within a given vessel length. Therefore a high form drag might be acceptable if it increases overall cargo-carrying efficiency.

Immediate solution: trim monitoring

Beware of increased form drag if a vessel with a wide or a transom stern is trimmed by the stern. The stern was not designed to be immersed (except perhaps on planing craft), so dragging the stern will incur a severe form drag penalty. It might even be worth the extra weight (hence increased wave drag) of adding ballast in the bow to bring the boat back to level trim.

1.6 ☑ Appendage drag – keel, rudder, keel pipes

The drag of the basic hull is only part of the total drag. All vessels have additions to the underwater hull, which the naval architects classify as appendages. These include bilge keels, transducer mounts, cooling water pipes and the rudder itself is usually considered an appendage. The total drag of these appendages can easily add up to 20% of the bare hull drag. In many instances the appendage is retro-fitted, with little thought or understanding of the impact on drag, the emphasis being on simplicity, low capital cost and robustness. Examples are:

- Fitting a flat plate rudder instead of an aerofoil section rudder
- Adding external cooling water pipes.

Immediate solution – change of rudder section

Consider the same fishing vessel as in the cooling pipe example, with a rudder of chord 1m and span 1m. Compare a flat plate rudder to an aerofoil shape. This is difficult to do because a flat plate rudder would usually have the stock protruding outside the plate thickness, a shape for which there is no drag data. Instead we can reasonably compare a 5cm thick plate rudder with a 15cm thick aerofoil shape. Whilst this is thicker than a typical plate rudder, it allows for some of the extra drag of the stock. For the vessel travelling at 10knots, the aerofoil rudder consumes nearly 6kW (4%) less engine power than the flat plate rudder. If the rudders are turned to 10 degrees, the aerofoil rudder consumes about 4kW (3%) less than the flat plate rudder. An interesting aside from this analysis is that turning the rudder by about 10 degrees results in an additional 3kW (2%) engine power required. So minimising rudder angles can have a measurable effect on fuel economy (see also Section 2.4). Refs:[5] [1, 6] [7]

Immediate solution – example of cooling water pipe drag

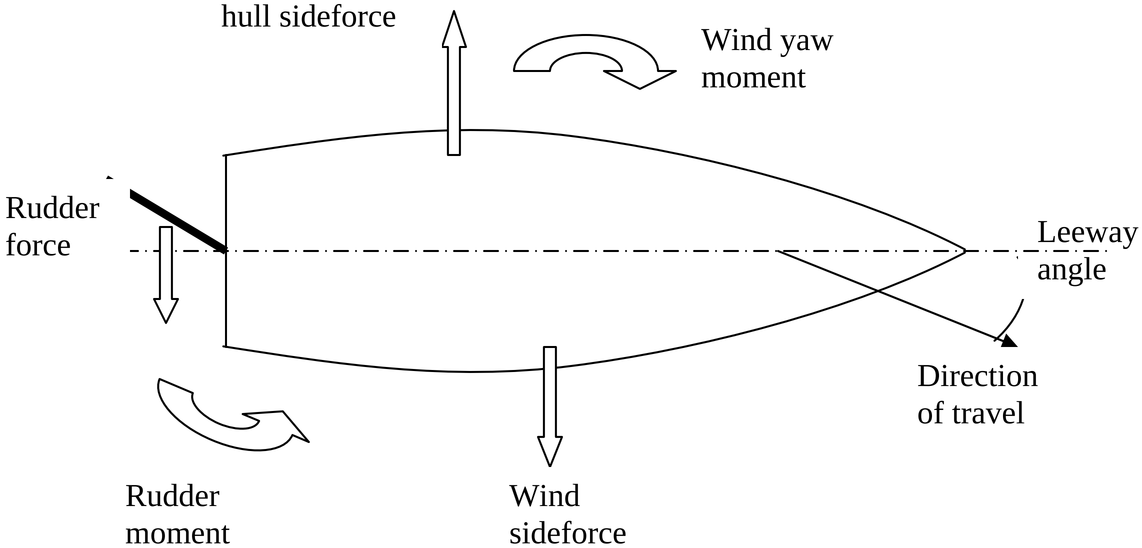
Consider a 15m fishing vessel with installed power 300kW steaming at 10kn. It has a cooling water pipe fitted along 6m of the hull. The pipe has three sections, each of 35 mm diameter. The friction drag of the pipes is 62N and the viscous pressure drag about 138N [5]. The likelihood is that the pipes will not be exactly aligned with the flow, which adds a further 40N, and will be fouled by marine growth to some extent, which adds another 140N. Total drag is approximately 380N so the installed engine power required to overcome the drag of these pipes is about 4kW. Now the total installed power is 300kW, but only about half this is used whilst at steaming speed. Therefore the pipes are consuming about 2-3% of the total engine power generated. Using a different method to cool the engine water would remove this drag component.

Research option: Improved estimate of pipe drag

The above calculations rely on assumptions about pipe alignment to the flow, shadowing effects between pipes, hull boundary layer influences and marine growth rates. There is no directly applicable data to validate the assumptions made. A research program to generate such data would enable optimum design of external cooling water pipes and would also contribute to an accurate cost-benefit analysis for internal v external pipe options. Such a research program would require a combination of wind tunnel tests and CFD, preferably supported by full scale trials comparisons.

1.7 ☑ Induced drag due to side winds/currents

When a fishing vessel is exposed to side currents or wind it is able to resist the applied side force by travelling at a drift or leeway angle. The angled flow onto the hull generates a side force that balances the side force applied by the wind. The resulting sideforce usually generates a yaw (turning) moment that must be opposed by applying a rudder angle.



As a result of this process extra resistance is generated in a number of ways:

1. The angle of the rudder causes extra drag ("induced drag"). The lift force on the rudder holds the hull at an angle of attack to the direction of motion. Unfortunately this lift force is also in the same direction as the wind side load, which means that the balancing side force from the hull has to match both the applied side force from the wind and the lift force from the rudder.

2. There is increased drag on the hull because it is travelling at an angle of attack to the direction of motion (leeway). This is probably the largest component of extra resistance for a fishing vessel, because the hull is not designed to generate sideforce efficiently.

3. The hull is at an angle of leeway so the propeller force is not aligned with the direction of motion. This misalignment of the flow means that the thrust force is slightly reduced because the propeller is designed to operate at its maximum efficiency with flow coming from directly ahead.

The above effects are greatest when the vessel is travelling at slow speed, because the hydrodynamic forces are proportional (approximately) to speed squared and leeway angle. So for a given sideforce generated by the wind, the vessel has to adopt a much larger leeway angle at slow vessel speed as compared with at high vessel speed. The vessel will then generate much greater hydrodynamic drag at this larger leeway angle. This situation is made worse if the trawl gear towed is a single unit towed with two wires (eg. Single prawn trawl, single fish trawl, triple rig, five rig). A trawler operating at a leeway angle using this type of gear will incur increased warp tension of the lee side compared to the windward side. This will require even larger rudder angles to hold the vessel on course. This detrimental effect can be compensated for by using a slight difference in port and starboard warp lengths to turn the boat (instead of the rudder). This would allow the vessel to travel in a straight line using a smaller rudder angle (thus reducing one source of increased resistance) and also ensuring that the nets are fishing square.

The problem of drag in a side wind is similar to the condition of a sail-assisted vessel, where the sail sideforce has to be opposed by a matching hull sideforce generated by adopting an angle of leeway (see Review-Part A Section 2.2.2).

1.8 ☑ Hull design options

The principles described above and the resulting recommendations apply mostly to retrofits for existing vessels of conventional hull form. There is a wide range of new hull forms that may yield considerable fuel savings if applied to fishing vessels. Such hull forms include:

- Catamaran
- SWATH
- Cathedral
- M hull

However, their impact on the overall operation of the vessel must be evaluated, including such issues as safety, manoeuvrability, carrying capacity, performance in rough water, cost and so on For example, if we consider the advantages and disadvantages of catamarans and SWATHs (Small Waterplane Twin Hull). SWATHs may be generalised as forming a subset of catamarans. Compared with conventional displacement monohulls, these vessels tend to exhibit improved seakeeping properties in moderate sea states, but worse in sever weather. They have greater deck area for a given vessel length, with consequent improvements in operational efficiency. If high speed performance is important e.g. for the crayfish industry, catamarans can require less power than planing craft in many instances, with lower fuel costs resulting. Catamaran resistance and seakeeping is sensitive to cargo load – SWATHs are especially sensitive owing to their low waterplane area yielding large draft increase for small mass increase. Catamarans often have shallower draft than an equivalent monohull, enabling them to work in shallow waters more effectively.

The importance of these various characteristics is overshadowed by the typeforming effect of vessel size regulations. .Many existing hull forms have been designed to maximise capacity within regulatory constraints. These vessels are often hydrodynamically very inefficient. Consideration of hydrodynamic effects in regulations could result in significant savings in fuel costs. For example, the use of length as a primary regulatory measure encourages abnormally beamy boats, which exhibit very high wavemaking resistance and viscous pressure resistance. Decreasing length-beam ratio from 3 to 2 can result in fuel costs increase by over 150% [8].

Research option: Optimal prawn trawler design

(This project could be applied to any fishing vessel type; prawn trawlers have been selected as an example)

Trawler hull forms may not be optimum for the conditions in which they operate. The optimum trawler should be one that earns her maximum in the lifetime. The form should be such that it offers minimum resistance and thus consumes least fuel. The optimum vessel is determined by comparing a large number of alternatives for a fixed set of requirements i.e. operating port and fishing ground particulars. This is made possible by applying a suitable optimization technique. The propeller to be fitted should operate in the running condition with maximum efficiency and develop maximum thrust while trawling. The form of the vessel will be finer for the minimum resistance and at the same time the earning capacity will be a maximum when the vessel is fuller. Therefore, the objectives are of conflicting nature and a compromise solution is required for the maximum earning. Using an optimisation tool such as the Decision Support Problem (DSP) technique [9] could yield a much improved hull form designed for specific Australian conditions. Such tools can also be used to explore the impact of regulatory constraints.

2 Vessel motion stabilisation

2.1 Introduction

The pitch, roll, heave and yaw motions of a vessel travelling in ocean waves decrease economic efficiency for several reasons:

- The motions cause changes to the incoming waves and they also generate their own waves, all of which requires energy, which in turn comes from the engine having to operate at a higher load.
- The various pieces of equipment used to reduce motions (paravanes, bilge keels etc) generate their own drag, which uses up fuel.
- The motions of the boat will result in an unsteady flow of water around the propeller, reducing its efficiency.
- Whilst not directly affecting fuel costs, sea sickness and injuries due to boat motion affect overall economic efficiency of the vessel.

2.2 Roll

Roll is usually the motion of greatest magnitude, because it is inherently very lightly damped. A review of roll stabilization devices is provided in [10]. There are several ways of reducing roll motion of an existing vessel:

- Paravanes
- Bilge keels
- Active fins
- Anti-roll tanks
- Sails
- Gyroscopes

Paravanes

The most popular method of reducing roll motion on fishing vessels is probably paravanes [11]. They are reasonably effective at medium to high vessel speeds but not at slow speeds, because they rely on the vessel speed to generate enough water flow to create the required roll moment A slow speed version of them, often called flopper stoppers, is also available [12, 13]. Model tests (Bass, 1998) have shown that roll reduction from paravanes is 30-35% in small (0.6m high) waves at zero vessel speed, reducing to 20-25% in larger waves. During full scale trials 45% roll reduction was the highest achieved, at steaming speed. The main disadvantages of paravanes are the significant hydrodynamic drag (hence fuel use) and complexity of deployment and recovery. Their weight also adds drag to the vessel.

The drag associated with a paravane is not easy to calculate, as it depends not only on the paravane shape and vessel speed, but also on the rolling motion of the vessel.

There are three paravane types. Most paravanes used in fishing operate in a relatively "free" kite like fashion by being towed at the end of a flexible chain. These are easy to deploy, but operate at an angle of attack at all times thus producing a significant amount of drag - especially when the vessel is moving at high speed (steaming). Easy deployment means that these paravanes can easily be stowed when sea conditions are fair or while steaming for large distances and when roll stabilisation is of lower priority. A second paravane type has the damping plate fixed to a freely swinging pole. This increases the control over the angle of attack of the plate and there is the possibility of increasing the effectiveness of the device when vessel speed is very slow or zero (at anchor) because the pole is able to push against the plate in situations where a chain system would go slack. Potentially this arrangement has less drag and is more effective, but this has not been studied and documented. The third paravane type has the plate fixed normal to the axis of the pole and a number of restraining wires are used to fix the pole in a vertical orientation. This ensures the plate is at zero angle of attack to the direction of steady state motion and essentially reduces drag to that of the pole, which is usually streamlined. For this arrangement the plate works to resist rolling very effectively in both directions, however due to the more complex fixing system the arrangement is usually operated at all times the vessel is at sea irrespective of the wave conditions, therefore creating drag even when the vessel is not rolling.

Bilge keels

Bilge keels can dampen roll motion by typically 20% whilst at trawling speeds, more at steaming speed [14, 15]. They have the advantage of being "fit-and-forget" technology. Their main drawback is the hydrodynamic drag, which is always present even when roll reduction is not required. In recent years a number of vessels have been fitted with short, almost square bilge keels, looking similar to fixed fins. This was largely a result of research described in [16], indicating that roll reduction of 60% is achievable with suitably large keels.

Active fins

Active roll stabiliser fins have been used in large ships (particularly passenger liners) for over 50 years. They are only effective at steaming speeds, though some progress has been made in using them at zero vessel speed by oscillating the fins at high frequency [17, 18]. Active fins are relatively expensive, prone to damage unless retractable (even more expensive) and the zero speed operation requires large amounts of energy. They also incur a hydrodynamic drag penalty.

Sails

Fishers have used sails for centuries to provide roll damping, though their effectiveness has only recently been quantified [19, 20]. They can provide considerable roll reduction, though there are operational constraints on deck space etc. (see also Review-Part A Section 2.2.2)

Anti-roll tanks

Anti-roll tanks have been used for over a century with some success. There are two main types – passive tanks with no control system, and active tanks that control the flow of water in the tank.

Passive tanks [21] are relatively inexpensive but they are heavy, take up cargo space and can cause stability problems – GM reduction due to tank free surface alone is 20-40%, in addition to the shift in VCG due to the extra weight. They incur a hydrodynamic drag penalty only through their weight increasing the immersed volume of the vessel (see section 1.2). The tank will weigh typically 1.5-2.5% of displacement [22]. A significant disadvantage of passive anti-roll tanks is that they have to be tuned to work at a particular wave period (usually the natural roll period of the vessel), so they are not very effective at reducing roll in waves of any other period.

Active anti-roll tanks have a mechanism for regulating the flow of water as the vessel rolls. This might for example be a valve through which water must flow when sloshing from side to side. This allows the tank to be effective over a wider range of wave conditions compared with a passive tank, but the control system adds complexity and expense.

Roll reduction from passive tanks is roughly comparable with that achieved by paravanes at steaming speed, and more effective at trawling speed.

Gyro-stabilisation

Gyro stabilisation of roll motion has been used for over 70 years, though it fell out of favour in the 1960s and only recently reappeared. The principle is simple – the roll motion of a suitably gimballed gyro causes a precession which in turn creates an anti-roll moment. Roll motion reductions greater than 50% are readily achievable [23]. They are effective at all vessel speeds, but are most useful when trawling. There is no hydrodynamic drag, they are small and easily installed – almost "fit–and-forget" technology – and they are energy efficient when running. They are more expensive and slightly heavier than bilge keels or paravanes (about 1-2% of displacement),. Mitsubishi make them http://www.marinemaxarg.com/ and more recently a device has been developed at Curtin University, Perth which is sold by Sea Gyro Pty Ltd http://www.webace.com.au/~sea_gyro/ http://www.abc.net.au/newinventors/txt/s1415189.htm

The only drag penalty is due to the extra vessel weight and there are opportunities for reduction of drag through optimal coupling of vessel motions and reduced added resistance in waves.

Immediate solutions - comparison of existing roll reducing devices

A cost benefit analysis on the use of non-drag devices such as gyros, compared with conventional paravanes and bilge keels would provide operators with information for selecting the best roll reduction device for a set of prescribed operating conditions. However, there is currently insufficient information to include comprehensive drag reduction calculations in the analysis; this would require a separate investigation (see below)

Research option: Optimisation of paravanes for minimum resistance

There is considerable scope for optimising existing anti-roll systems for improved fuel efficiency, especially paravanes and bilge keels. In the first instance it might be appropriate to review current designs to identify/document design principles and performance features along with a theoretical evaluation of their overall benefits to fishers. This could be augmented by short term sea trials on vessel-specific modifications and retrofits, or longer term efficiency comparisons and/or testing of innovative new designs.

Research option: Drag reduction from using roll gyros

The drag reduction potential from optimising roll stabilisation devices is twofold:

- The absence of any device in the water.
- The reduction in rolling motion itself reduces the hydrodynamic drag of the hull.

The former requires the measurement of drag for the various roll reduction devices currently in use and proposed. Whilst some information is already available, further model tests and full scale trials would be required to fill the knowledge gaps.

The latter is more readily assessed, for instance by instrumenting a vessel fitted with a gyro, then comparing the engine power with the gyro turned on and turned off. Sea Gyro have expressed an interest in this project and have a gyro-stabilised vessel available for trials.

2.3 ☑ Pitch

Pitching motion, which occurs in combination with heave, increases resistance in waves therefore requiring additional engine power and more fuel. Pitching motion is a very limiting factor in trawling, especially for smaller vessels. The pitching characteristics of a vessel are mainly a function of its hull form and distribution of masses on the vessel. The main area of opportunities for reducing pitch motion of existing vessels is the retro-fitting of bulbous bows (see 1.4) and the use of anti-pitching fins.

Active anti-pitching fins and flaps

Active systems have been used in the high speed ferry industry for approximately 20 years ([24] There is very little data on the effect of active control surfaces on drag. The hydrodynamic drag of the fins is offset to some extent by the reduced added resistance in waves. Fins and flaps are only effective when the vessel speed is high enough for the fins to generate useful lifting force – typically15kn.

Passive bowfins – fixed and flexible

Fixed fins attached near the bow can alter the pitch motion through increased damping and inertia. If designed carefully, they could reduce the pitching motion for some hull forms. There is much discussion and some research on the use of fins that are allowed to flap or flex with the vessel motion, the fins themselves creating useful thrust – the “whale-tail” propulsion concept [25].

Research option – reduction of pitch motion using retrofit bulbous bow or bow fins

There may be scope to gain benefits through the use of passive fixed or flexible bowfins or bulbous bows. Potentially such bowfins will make trawlers much more comfortable to work, maintain forward propeller thrust to a greater extent in pitching seas and possibly provide augmented thrust through their own action. If the vessel is pitching in waves, a bulbous bow might, if designed carefully, reduce the pitching motion and also reduce the added drag due to the pitching. A program of tank testing and full scale trials validation would be required.

2.4 ☑ Yaw

No vessel steers an entirely straight course, even in calm water. The autopilot is required to make course adjustments through the steering system. The amount of course change affects fuel use in three ways:

- The autopilot requires power to run; the more course corrections required, the greater the power used.
- The vessel travels further because of its meanderings, compared with the straight-line distance
- As the vessel meanders, the hydrodynamic drag increases for two reasons: firstly, the rudder is being set at an angle which creates extra drag; secondly the entire hull will adopt a slight angle to the flow during these small turns, further increasing hull induced drag. There is also the varying inflow angle to the prop affecting its ability to generate thrust efficiently.

Research option: Minimising yaw drag by using DGPS

The use of the rudder to maintain course increases drag and uses fuel. The rudder angles applied are a function of the autopilot controls, which in turn rely on input of vessel actual heading and required heading. Most autopilots use GPS input, older models relying solely on a magnetic compass and a user-input desired heading. The optimum control is obtained by applying course corrections that maximise the speed over the ground for minimum energy input. If the accuracy of the information used by the autopilot were increased, there could be a reduction in rudder angles used and an increase in velocity made good over the ground – hence reduced steaming time at a given engine revs. The use of Differential GPS (DGPS) increases positional and heading accuracy by an order of magnitude compared with conventional GPS. A research project is proposed whereby a vessel autopilot is connected to a DGPS input, the DGPS capability is turned on and off for suitable time periods, the resulting differences in distance made good at constant engine revs providing a measure of fuel saving. A provider of DGPS services, Omnistar Pty Ltd www.omnistar.com.au has expressed interest in contributing to such a project.

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4 Appendix A. Road map for the Energy Efficient Fishing Review