Optimising a novel prawn trawl design for minimum drag and maximum eco-efficiency

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8 August 2014

FRDC Project No **2011/209**

ISBN 978-1-86295-768-8

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2014

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Executive Summary

This report presents work aimed at generating knowledge about factors responsible for the engineering efficiency of Australian commercial prawn trawling gear, and the subsequent development/testing of a prototype ‘W’ trawl system for significant drag reduction. The work was undertaken by researchers at the Australian Maritime College (AMC), an institute of the University of Tasmania, and Sterling Trawl Gear Services over the period from December 2011 to February 2014. Much of the work utilised the AMC flume tank located at Beauty Point, Tasmania for evaluation of trawl models. In the final stages of the project field trials were conducted on model and full-scale gear from a prawn trawler in Moreton Bay, Queensland.

Background

Trawl net design is an exceedingly difficult research area because of the coupling of the complex mechanics of the apparatus and its operation in a harsh environment. For these reasons the traditional trial and error approach cannot achieve a high level of optimisation and refinement in a short time frame. As a consequence, the prawn trawling industry has not been able to deal quickly and effectively with the mounting challenges over the last three decades in respect to the need for improved energy efficiency and environmental performance of its trawl gear.

A key approach to improving the energy efficiency of trawling and raising the productivity of fishing per litre of fuel consumed is through drag reduction of the trawl system. A concurrent FRDC project, #2011/010, is systematically investigating the effects of anterior modifications to prawn-trawl systems on drag and catch/by-catch. That work seeks to understand the broad catch/drag “mechanics” of prawn trawl systems through evaluating the effects of the wide range of existing gear variants. In the final stages of that project some innovative ideas for trawl-system improvement will be trailed within the context of optimal configurations of existing gear – including the outcomes of this project, if applicable.

In this project, the investigators specifically propose a new trawl concept, named the ‘‘W’ trawl’. This is an innovative idea for a more fuel efficient trawl based on the current understanding of the engineering characteristics of prawn trawl systems. The ‘W’ trawl has a ‘double-tongue’ format (tongue in both the headline and footline), and features to enhance the transfer of drag from the body of the trawl to the tongues rather than to the wings. It is envisaged that the reduction of drag transfer to the wings will make the trawl substantially easier to spread and result in smaller otter boards being required and subsequently reduced overall drag of the trawl system.

Aims/objectives

To assist the industry and academia in the understanding of drag generation and reduction in the context of prawn fishing in Australia, the following three main objectives were specified:

1. Systematically breakdown and understand the technical issues connected with the generation of drag by prawn trawls and the needs of industry, to establish practical trawl improvements based on existing and new trawl design principles.
2. To optimise the shape and netting characteristics of a novel trawl design for prawn trawling with respect to lower drag and maximum eco-efficiency.
3. To predict the drag of prawn trawls based on net plan parameters and towing speed, accounting for twine orientation and the operational shape of the trawl.

Methodology

A series of systematic trials in the flume tank and in the field were conducted during the project.

The experimental program in the flume tank comprised frame-line tension measurements for several systematic series of prawn trawl models over various flow speeds. The trawl-plan variables of body taper and mesh orientation in the wings were investigated for a typical Florida Flyer design and the sensitivity of the results to horizontal spread and vertical opening was established.

As groundwork for the development of the 'W' trawl, the effect of alternate implementation T0 (diamond mesh orientation) and T45 (square mesh orientation) netting in the main body and side sections of trawl models on frame-line tensions was measured. The aim was to establish an optimal combination of mesh orientation for the principal parts of the 'W' trawl.

The conventional and 'W' trawls tested were ¼ scale models of 8-fathom (14.63m) headline length trawls. The trawl-development work led to an investigation of the benefits of enhanced strain transfer to the tongues through variant bracing rope techniques applied to the centre line of the 'W' trawl. A small commercial 'W' trawl, with 2-fathom headline length, was compared to a standard trawl (Florida Flyer) of the same size in the flume tank over a range of spreads and speeds as refinements to the "bracing rope" technology were implemented. Following the flume tank work the small trawls (two-fathom headline) were tested in the field (Moreton Bay Trawl Fishery) to establish their relative engineering and catching performance in a commercial fishing context.

Subsequently a full-size 4-fathom 'W' trawl was tested against a comparable Florida Flyer in the Moreton Bay Trawl Fishery to establish comparative performance, as further design refinements were implemented to the novel trawl and system tunning occurred to improve catching performance.

Results/key findings

A series of drag prediction equations and tables have been developed to quantify the extent that trawl body taper, vertical wing mesh count, spread ratio, vertical opening and towing speed affect drag.

Whilst alternation of mesh orientation (T0 vs. T45) in the principal parts of the trawl was demonstrated to have a very small drag benefit in a conventional prawn trawl, it was of no practical significance.

The developed small prototype 'W' trawl effectively redistributed 64% of netting-drag off the wings and onto the centre tongues, which resulted in drag savings of ~19% for the associated 'W' trawl/otter-board/sled system compared to the traditional trawl/otter-board arrangement in a single trawl or twin rig configuration. Furthermore, based on previously published data, the new system is expected to provide approximately ~11 % drag reduction compared to quad rig. The 'W' trawl system also has benefits over quad rig in regards to the reduced number of cod-end/BRD devices to be installed and maintained.

Implications for relevant stakeholders

The developed equations and tables for drag estimation of the netting part of prawn trawls will enable refinement of the existing prawn-trawl drag prediction model (named the Industry Trend Trawl Model that is a central component to the Prawn Trawl Performance Prediction Model (PTPM) (Sterling, 2005). The PTPM is used extensively by researchers of prawn trawl systems to design experimental equipment/procedures and managers of prawn fisheries to design and plan management measures.

The new 'W' trawl technology is a relatively simple and low cost change for a trawling operation that potentially reduces fuel consumption by 10%-20%. When the potential of the new technology is fully realised (through further gear refinement to improve the catch rate), the trawl's usage will directly reduce production costs of typical Australian prawn fisher by $15,000-20,000 per annum. This equates to about $6M per year for QLD East Coast Fishery. Similar benefits will occur for all prawn fisheries in Australia.

Recommendations

Given the superior engineering performance of the new prawn trawl system and the catch rate being below expectations, the catching performance of the 'W' trawl system requires further investigation. Future field work should involve the use of underwater video cameras to ensure the gear is working at maximum efficiency. Arrangements for work extension in this regard are currently in progress.

STERLING, D. 2005. Modelling the physics of prawn trawling for fisheries management. Doctor of Philosophy thesis, School of Applied Physics, Curtin University of Technology, Perth, 268 pp.

Keywords

Prawn trawl, energy efficiency, drag reduction, mesh orientation, T0 vs. T45, catch comparison

Acknowledgments

The authors are very thankful to the people who provided substantial assistance to the project, namely: Morgan Behrel for his tireless and excellent research assistance during the preparation and execution of the 2-fathom trawl sea-trials in Moreton Bay; Rowan Frost and Allan Faulkner from the Australian Maritime College for their flume tank testing expertise and very generous assistance with associated experiments; David Box for facilitating the provision of Scanmar trawl sensors and load cells from the Australian Maritime College, including rising to the challenge of professional refurbishing the Scanmar spread sensors to as new condition after their very inconvenient failure; Mike Wood and Wayne Till, for turning their fine FVs, Mark-Twain and Remark, into very effective gear-research vessels. Also Matt Broadhurst for his genuine interest in the research outcomes, and instigation in taking the outcomes to a next stage (beyond the project) – field trials of W-trawl V3 (10 fathom) incorporated in triple rig for trawlers based at Yamba NSW.

Introduction

In lieu of high-level research input, fishers have had to largely apply a trial and error approach to the development of better trawling systems. Trawl net design is an exceedingly complex research area because of the coupled problems of complex hydro-mechanics, flexible systems and a harsh operating environment. Due to the complexity of the design space, a trial and error approach cannot achieve a high level of optimisation and refinement. As a consequence, the prawn trawling industry has not been able to deal quickly and effectively with the mounting challenges over the last three decades in respect to the need for improved energy efficiency and environmental performance of its trawl gear.

The need for more progressive work was highlighted by the results of recent FRDC funded energy audits of prawn trawlers. The 1st International Symposium on Energy Efficiency in Fishing was held in Vigo, Spain (May 2010) and clearly emphasised the need for strategic R&D in this area.

Energy efficiency is a vital issue for Australian Fisheries, with the prawn trawling industry being marginally profitable given present fuel prices. Further increases in fuel prices will cause many prawn trawling operators to become commercially unviable. For prawn trawling operations, 60% of the fuel consumed is whilst trawling (FRDC 2006/229), and the netting of the trawls is responsible for 60-80% of the towing drag (FRDC 2005/239).

To assist the industry and academia in the understanding of drag generation and reduction in the context of prawn fishing in Australia, the following four phases of the project were undertaken:

- Drag characterisation for the netting part of a conventional prawn trawl. The necessary data was collected through flume tank experiments to quantify the extent that trawl body taper, vertical wing mesh count, spread ratio, vertical opening and towing speed affect drag and in-pull.
- Determination of the effect on frame-line tensions from alternate implementation of square and diamond mesh in the main body and side sections of trawl models of conventional and ‘W’ configuration, with the aim to establish an optimal combination of mesh orientation for the principle parts of the trawl.
- Implementation of the optimal solution for maximum drag reduction in the novel ‘W’ trawl compared to the conventional trawl based on flume tank and field experiments with 2-fathom ‘try-gear’ trawls.

- Design modifications to the 'W' trawl to refine catching performance in the context of full size 4-fathom commercial trawls operated in Moreton Bay, QLD.

The methods, results, discussion and conclusions for each of these four phases are presented in four chapters below, followed by discussion of the overall project conclusions.

Objectives

1. Systematically breakdown and understand the technical issues connected with the generation of drag by prawn trawls and the needs of industry, to establish practical trawl improvements based on existing and new trawl design principles.
2. To optimise the shape and netting characteristics of a novel trawl design for prawn trawling with respect to lower drag and maximum eco-efficiency.
3. To predict the drag of prawn trawls based on net plan parameters and towing speed, accounting for twine orientation and the operational shape of the trawl.

Chapter 1 – Drag characterisation for the netting part of a typical prawn trawl

1.1 Introduction

The drag of the netting part of the prawn trawl can be mainly characterised by four design and three operational parameters. The design parameters that effectively determine the amount of netting in the trawl are body taper, gape, vertical wing mesh count and netting solidity (area of mesh material/area covered by mesh) (Fig. 1.1).

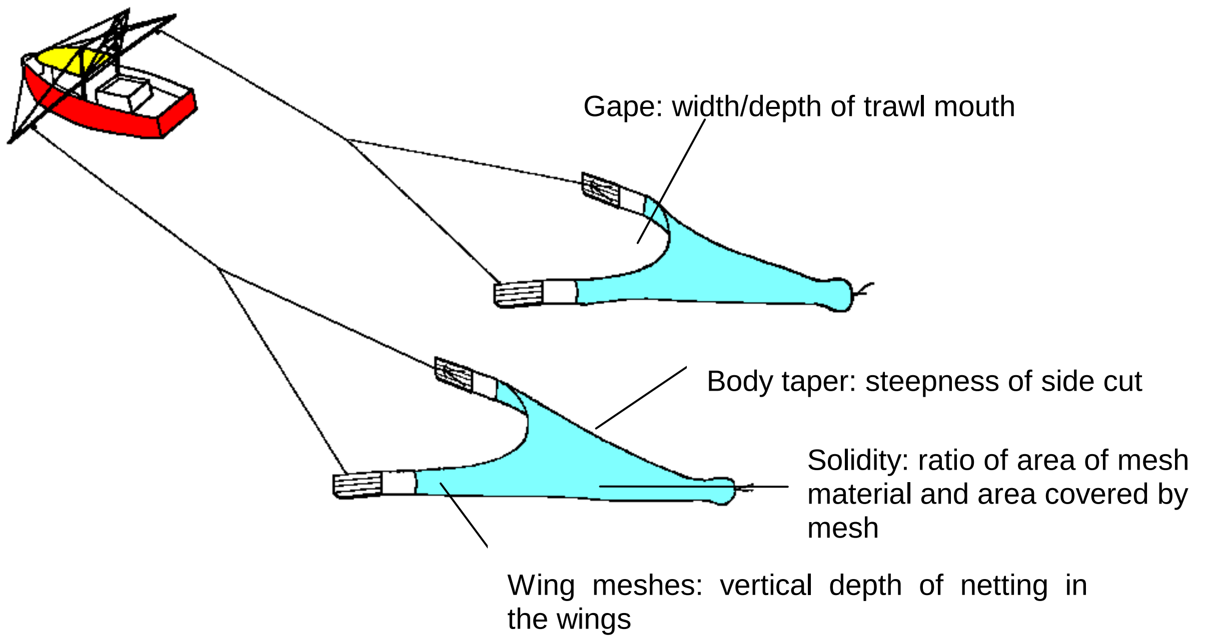


Fig. 1.1 Design parameters of the netting part of a prawn trawl

The operational parameters are towing speed, horizontal spread and vertical opening – these determine the extent the netting is exposed to flow. The effects of netting solidity on drag in quasi-static flow has been quantified by a number of authors: Tsukrov et al. (2011) provide a comparative review of these existing formulae. Wakeford (1994) conducted flume tank tests on a systematic series of models to measure the effects of gape on drag, where gape determines the general character of the frame-line tapers and is the ratio of the number of meshes between the wing-ends to the mesh-depth of the trawl mouth). Subsequently Sterling (2005) developed a drag-prediction equation with respect to gape, based on the data.

In the present work, the effects of other important parameters affecting the netting drag of a typical prawn trawl were investigated, namely: body taper, vertical wing mesh count, horizontal spread and vertical opening. The developed prediction equations are to be integrated into the existing prawn trawl drag prediction model described by Sterling (2005).

1.2 Methods

Fig. 1.2 shows a net plan for a standard Australian prawn trawl. The model represents a ¼ scale 8-fathom Florida flyer. Overall, five models were built with varying body tapers and meshes in the wing as shown in Table 1.1. The baseline (reference) model was also tested for three sets of vertical heights (medium, low and high), whilst the vertical height was kept constant (at the medium setting) for the other models. All models and height settings were tested at the spread ratios of 70, 80 and 90% and flow speed of 1.0, 1.2, 1.4 and 1.6 m/s. The reference model was tested over a wider range of spread ratios from 65 to 95% with 5% increments.

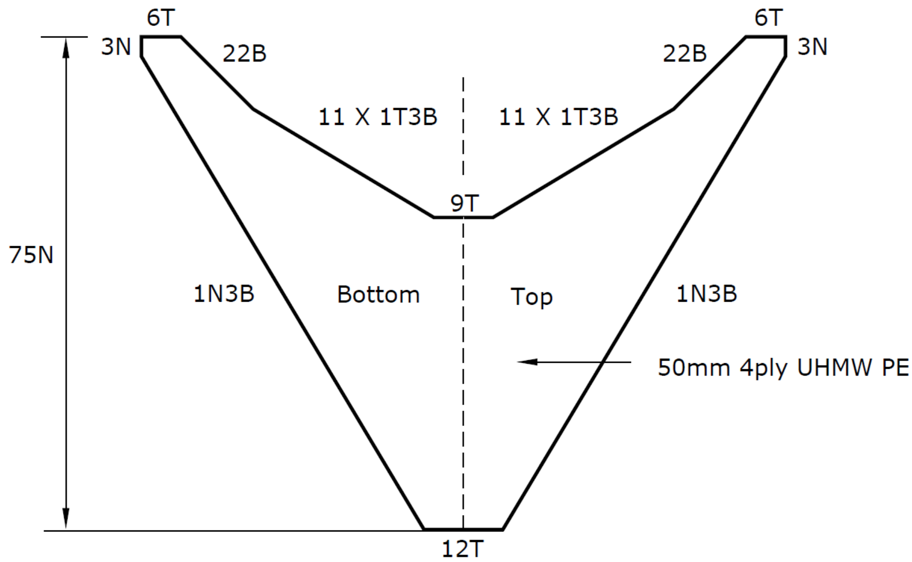


Fig. 1.2 Net plan for ¼ scale 8-fathom Florida flyer. Taper sequences are on the left side of the plan, and numbers of meshes corresponding to these tapers are on the right. Top and bottom panels are identical. N – normal, T – transversal, B – bar

Table 1.1 Testing matrix for drag characterisation

Model #	Body Taper	Vertical Wing Mesh Count	Vertical height, mm	Spread ratio, %	Flow speed, m/s
1	1P3B	12	225 (medium)	65, 70, 75, 80, 85, 90, 95	1.0, 1.2, 1.4, 1.6
2	1P2B	12	225 (medium)	70, 80, 90	
3	1P4B	12	225 (medium)		
4	1P3B	6	225 (medium)		
5	1P3B	18	225 (medium)		
1	1P3B	18	175 (low)		
1	1P3B	18	275 (high)		

All models were built from 50mm 4ply (1mm twine diameter) Ultracross Dyneema© (Ultra High Molecular Weight Polyethylene), a high strength material that is used for full-scale prawn trawl construction and can be advantageously used in model experimentation for the following reasons: (1) use of full-scale material ensures a representative Reynolds number (ratio of inertia and viscous forces) occurs, and (2) hydrodynamic forces continue to dominate netting mechanical forces at model-scale due to the very low twine stiffness of the multifilament material.

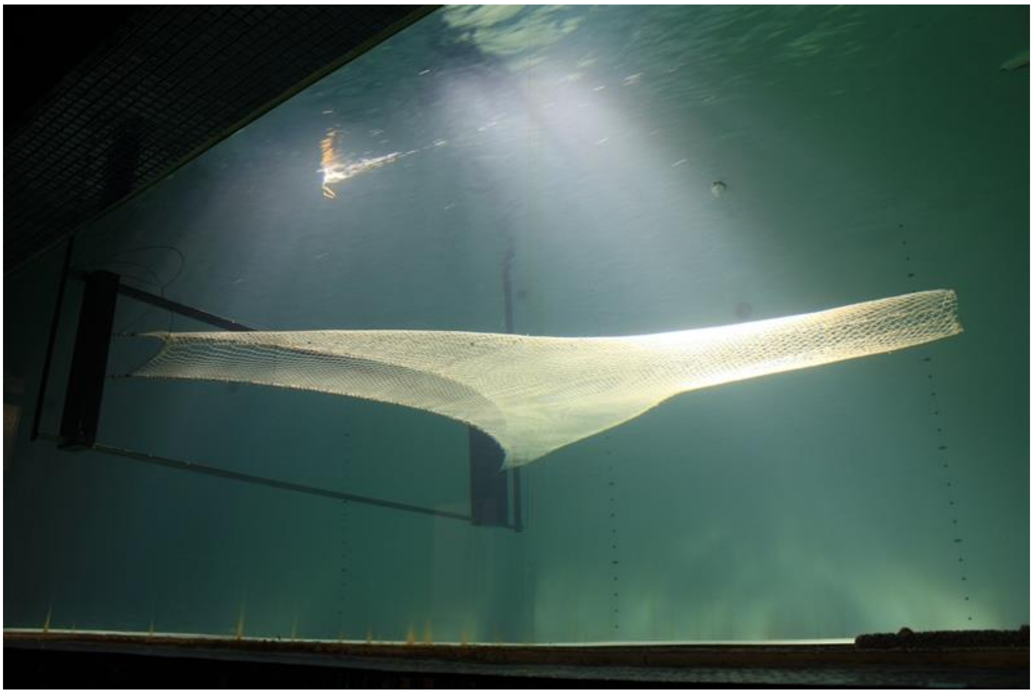


Fig. 1.3 Trawl model attached to the Trawl Evaluation Rig and tested in the mid-stream of the flume tank

The experiments were conducted in the flume tank at the Australian Maritime College, Beauty Point, Tasmania, Australia. The test section of the flume tank is 17.2 m long, 5 m wide and 2.5 m deep, and as a whole contains approximately 700,000 litres of fresh water. The flow is circulated with four impellers, each driven by a variable speed drive.

During prawn-trawl fishing, the horizontal opening of the trawl is maintained by otter boards and is therefore not precisely fixed. For controlled testing in the flume tank the model trawls were attached by the four end points of the upper and lower frame lines to a trawl evaluation rig (TER) - Fig. 1.3. The TER was an aluminium rectangular frame where the two vertical sides can slide laterally along upper and lower streamlined beams, and be firmly fixed at any desired spread. Each trawl-connection point contained a load cell so that the frame-line tensions at all connection points were measured for each case.

The sum of the two measured tensions for each wing-end give T_1 (starboard wing tension) and T_2 (port wing tension), and are composed of vector contributions from the in-pull force of the trawl F_{in} (this force must be overcome by the otter boards to maintain the open trawl) and drag force. The sum of the drag components from the combined tensions in each wing is the total drag of the trawl, F_d. As shown in Fig. 1.4, the relationship between the force contributions and the sum of tensions is determined by an angle θ between the frame line and flow direction at the wing end. The drag force F_d and the in-pull force F_{in} were derived as shown in eqs. (1.1) and (1.2) respectively. The angle of the frame-lines (at the connection points) relative to the flow direction was measured with a bevel gauge referenced to an unsubmerged beam on the TER that was transverse to the flow direction.

$$F_d = (T_1+T_2) \cos \theta \quad (1.1)$$

$$F_{in} = ((T_1+T_2)/2) \sin \theta \quad (1.2)$$

A ground chain was not attached to the model trawls as it would cause the lower half to become unacceptably out of shape when tested in mid-water. In addition, the chain would produce a constant drag increase across all models that would need to be subtracted from the total in order to ascertain netting drag.

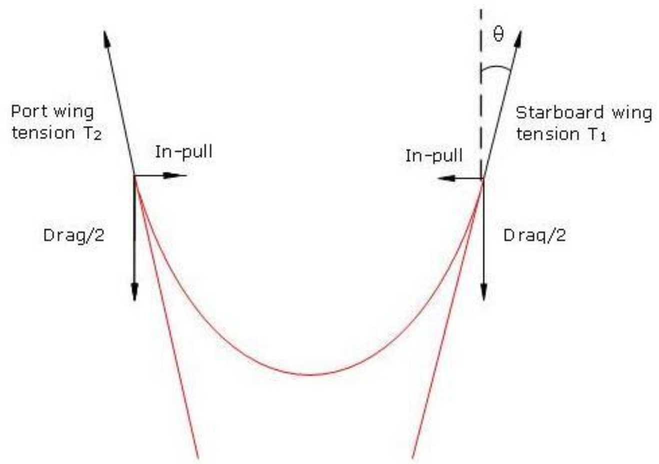


Fig. 1.4 Force vector breakdown at the wing-ends for a prawn trawl

1.3 Results and Discussion

For each velocity, the drag of each trawl was plotted as a function of the spread ratio and presented in Fig. 1.5 (for the velocity of 1.2m/s). The linearity for each trawl is very high. Moreover, all straight lines seem parallel. To verify this first impression, the difference of drag between an arbitrarily chosen reference trawl and all other kinds of trawl were calculated for each spread ratio, according to eq. (1.3). The reference trawl chosen was the 1P3B-12M. These relative differences are in Table 1.2 for a velocity of 1.2 m/s. It is clear that the differences for the 3 spread ratio are not constant, but they are close enough to try to use only an average of these 3 values, in order to simplify the final formula. Similarly, the average values obtained for the three other sets of speed, and the results are in Table 1.3.

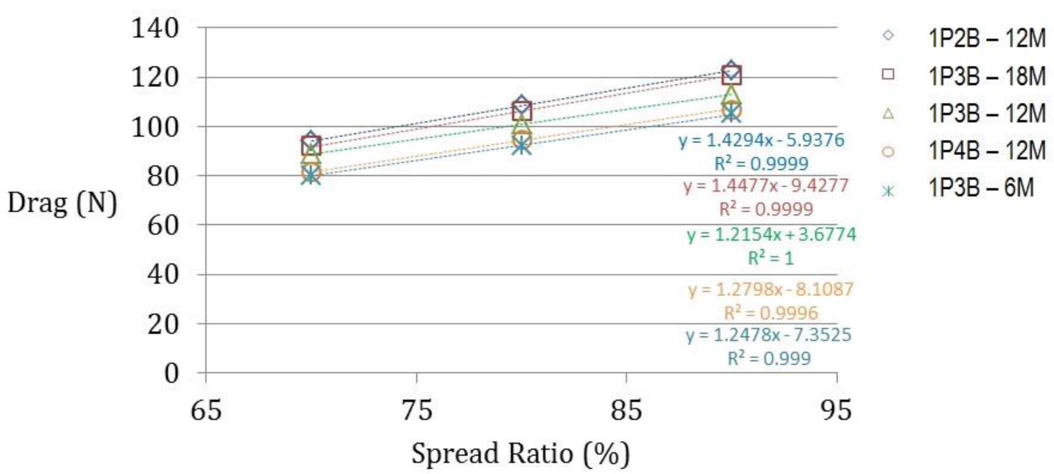


Fig. 1.5 Drag vs. spread ratio for at the speed of 1.2 m/s

$$Relative\ Difference_{net}(SR,V) = \frac{Drag_{1P3B-12M}(SR,V) - Drag_{net}(SR,V)}{Drag_{1P3B-12M}(SR,V)} \quad (1.3)$$

Table 1.2 Relative drag difference between the reference net 1P3B-12M and the other nets at 1.2m/s for each spread ratio

Spread Ratio (SR)	**70%**	**80%**	**90%**	**Average**
1P2B - 12M	0.060	0.075	0.085	0.073
1P3B - 6M	-0.096	-0.089	-0.069	-0.085
1P3B - 12M	0	0	0	0
1P3B - 18M	0.037	0.052	0.070	0.053
1P4B - 12M	-0.083	-0.063	-0.054	-0.067

Table 1.3 Averaged relative drag difference between the reference net 1P3B-12M and the other nets for each tested speed

Velocity	**1.6 m/s**	**1.4 m/s**	**1.2 m/s**	**1 m/s**	**Global**
SR	Average	Average	Average	Average	**Average**
1P2B-12M	0.070	0.070	0.073	0.069	0.071
1P3B-6M	-0.083	-0.085	-0.085	-0.094	-0.087
1P3B-12M	0.000	0.000	0.000	0.000	0
1P3B-18M	0.051	0.055	0.053	0.043	0.051
1P4B-12M	-0.067	-0.067	-0.067	-0.076	-0.069

Now, the drag of each kind of trawl can be calculated with only the drag of the reference trawl (1P3B-12M) and a factor depending on the body taper and the wing-meshes of the trawl. Subsequently, this factor is called *k*. The value of *k* for each trawl case is given in Table 1.4. The formula giving the drag of the trawl is:

$$D_n = D_n^{1P3B-12M}(V,SR) * (1+k) \quad (1.4)$$

Table 1.4 Factor k for each kind of net

	6M	12M	18M
1P2B		0.071	
1P3B	-0.087	0	0.051
1P4B		-0.069	

For each set of speed the value of $D_n^{1P3B-12M}$ is linked linearly to the value of the Spread Ratio SR.

Assuming that for each body taper the relative difference is the same between the different wing meshes, missing factors can be extrapolated from the existing factors (Table 1.4). For instance, naming the *k* factors matrix coefficients, the drag of a 1P2B-6M can be expressed as:

$$D_{1P2B-6M} = (1 + k_{12}) * D_{1P2B-12M} \tag{1.5}$$

$$D_{1P2B-6M} = (1 + k_{12})(1 + k_{21}) D_{1P3B-12M} \tag{1.6}$$

$$D_{1P2B-6M} = (1 + k_{12} + k_{21} + k_{12}k_{21}) * D_{1P2B-12M} \tag{1.7}$$

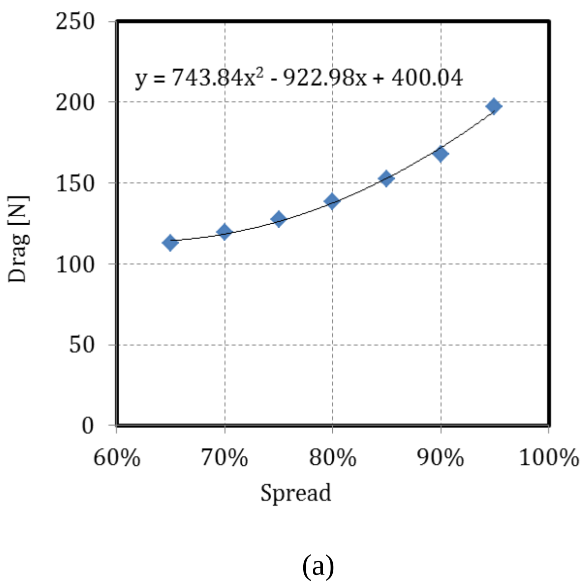
Therefore, the missing coefficient is:

$$k_{11} = k_{12} + k_{21} + k_{12}k_{21} \tag{1.8}$$

The calculated values are given in Table 1.5.

Fig. 1.6 presents the results for the drag values due to spread ratio. A reference point is set to the spread ratio of 65%.

Table 1.6 provide the drag ratios to be used for estimating the drag due to change in the vertical height. To enable the generic usage of the results, the vertical height is presented as a ratio of the length of the meshes in the wing when stretched vertically to square mesh. Similarly in Table 1.5, the number of meshes in the wings is generalised through a relative length (when stretch to square mesh) to the headline length and the Table 1.5 shows the effect of this on drag through the k factor.



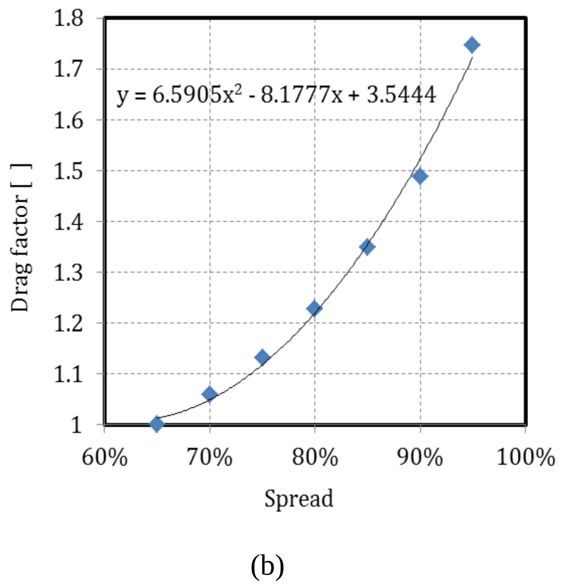


Fig. 1.6 Drag due to spread: (a) raw experimental data and (b) non-dimensional drag factor with a reference to 0.65 spread ratio

Table 1.5 Factor *k* for each known nets, and the extrapolation for the unknown nets (blue cells)

Number of meshes in one panel	6M	12M	18M
MR, (total number of meshes in the wing x mesh size x 0.707) / headline length	0.058	0.116	0.174
1P2B	-0.022	0.071	0.125
1P3B	-0.087	0	0.051
1P4B	-0.150	-0.069	-0.022

Table 1.6 Relative drag due to vertical height

Vertical height, mm	175	225	275
MT, headline height / (total number of meshes in the wing x mesh size x 0.707)	0.41	0.53	0.65
70%	0.941	1.0	1.094
80%	0.922	1.0	1.087
90%	0.917	1.0	1.076

For the purposes of interpolation and extrapolation, the following expressions (eq. (1.9)) was obtained by least-squared-error regression and can be used to determine the drag 'k factor' for any value of MR and MT.

$$k = \frac{4.989 + 19.116MR\ e^{1.1149MT}}{9.192} \qquad (1.9)$$

1.4 Conclusions

The effects of key netting drag parameters of a typical prawn trawl were assessed, namely: body taper, vertical wing mesh count, horizontal spread and vertical opening. The developed drag-prediction equations and tables are to be integrated into the existing prawn trawl performance model (PTPM V3) described by Sterling (2005), as a refinement of that prediction tool.

Further work should also include comparison of the drag results obtained in the controlled environment of the flume tank with the extensive field data obtained from FRDC 2011/010. While flume tank data allows precise scrutiny of specific parameters for their effect on drag, the field data includes the effects of performance-factor interaction and the environment (including the accumulation of catch). A detailed analysis of both sets of data will improve the state of art of understanding prawn-trawling mechanics, and allow this to be subsequently incorporated into the PTPM to make a more accurate/useful tool for drag and geometry prediction of prawn-trawl systems.

References

STERLING, D. 2005. Modelling the physics of prawn trawling for fisheries management. Doctor of Philosophy thesis, School of Applied Physics, Curtin University of Technology, Perth, 268 pp.

STERLING, D. & EAYRS, S. 2010. Trawl-gear Innovations to Improve the Energy Efficiency of Australian Prawn Trawling. *1st International Symposium on Fishing Vessel Energy Efficiency.* Vigo, Spain.

TSUKROV, I., DRACH, A., DECEW, J., ROBINSON SWIFT, M. & CELIKKOL, B. 2011. Characterization of geometry and normal drag coefficients of copper nets. *Ocean Engineering,* 38**,** 1979-1988.

WAKEFORD, J. 1994. The Effect of Frameline Tapers on the Engineering Perfomance of Prawn Trawl Systems. Launceston: Australian Maritime College.

Chapter 2 – Mesh orientation effects on drag and its application to a novel prawn trawl

This Chapter explores the effect on frame-line tensions from the implementation of square and diamond mesh in the main body and side sections of trawl models of a conventional trawl and novel 'W' configuration, with the aim to establish an optimal combination of mesh orientation for the principle parts of the trawl.

2.1 Introduction

In Australia, a fundamental part of the historical progression of prawn-trawl gear included the wide implementation of multi-net systems in the 1980's. The driving principle was to reduce the twine area of large single trawl systems by replacing each with a number of smaller sized trawls that had a combined catching span equal or greater than the original. Broadhurst et al. (2013) experimentally estimated that by increasing the number of nets towed simultaneously in a prawn trawling system, the fuel consumption of the system for a given swept area can be reduced by up to 23% due to a reduction of both otter board and twine area.

A more recent innovation to significantly reduce drag has been the use of Ultra High Molecular Weight Polyethylene (UHMW PE) netting materials that allows the use of thinner twine compared to traditional materials. Small diameter UHMW PE twine are of similar or greater breaking strength to traditional material, but the thinner twine (by ~ 40%) results in decreased drag (by ~ 27%) (Lowe, 1996).

Another possibility for improving the engineering performance of prawn trawls is through design modification that makes the trawl easier to spread and consequently requires smaller otter boards. The Danish Fisheries Technology Institute [DFTI] (1989), proposed a Y-design fish-trawl that allowed a higher headline height as an inadvertent side effect of installing an innovative seam down the centreline of the trawl such that the wings consist of T45 (square) mesh. The developers of the Y-design trawl identified benefits from catching and selectivity perspectives: a wider mesh opening down the wings and sides allows small fish to escape, and overall larger vertical and horizontal trawl openings produce a greater cross-section area. Following the Y-design concept, Ripon (1991) considered the engineering performance of a so-called pleated-panel prawn-trawl with T45 netting along the wings and sides achieved by installing tapered-seams down the centrelines of the top and bottom panels. The pleated-panel trawl required less force to spread as the netting drag was transferred more directly to the otter boards by high tension along the T45 bars in the sides as opposed to a conventional T0 trawl where the netting tension runs towards the bosom of the trawl and then to the otter boards along the frame lines and along bars that are at a steeper angle to the direction of tow. Despite the pleated-panel trawl generating less in-pull force and having less twine area, overall drag was found to be higher compared to a conventional trawl. The increased drag of the pleated trawl was not conclusively explained but was thought to possibly be a result of the greater number of netting bars oriented perpendicular to the flow.

Since the performance benefits of the pleated-panel trawl were negated by the concomitant drag disadvantages, the pleated-panel trawl was not developed any further. However, Sterling & Eayrs (2010) suggested the double-tongue trawl might be a design that similarly has low in-pull forces, and it would not be subject to high-drag side sections with exposed bars perpendicular to the water flow. The proposed double-tongue design had T45 mesh orientation in the upper and lower panels which would enhance drag transfer to the tongues as the bars are aligned to the direction of the transfer and will not allow the trawl to stretch in this direction. In the side sections of this double-tongue trawl the netting would be T0 orientation relative to the length-direction of the side, as the square-mesh (T45) in the top and bottom panels fold around the sides of the elliptical, 45° cone-shaped, body of the trawl.

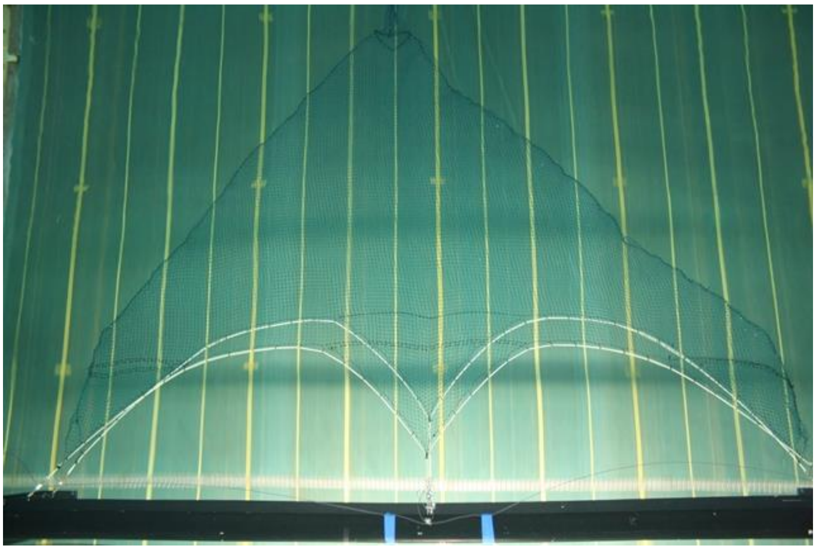


Fig. 2.1 A model double-tongue trawl built from knotted polyethylene netting and hung on the square mesh– the model is asymmetric about the centre-line due to different mesh lengths in the lateral and longitudinal directions caused by knots

Fig. 2.1 shows a photo of the double-tongue trawl suggested by Sterling & Eayrs (2010), in the form of a model being tested in the Australian Maritime College flume tank. The model double-tongue trawl streamed in the flume in Fig. 2.1 was asymmetric because this T45 trawl was constructed from knotted netting. The arrangement in this case produced netting of T90 orientation down the starboard side and T0 orientation down the port side (with reference to the direction of tow). Since knotted netting has a shorter stretched mesh-length in the T90 compared to T0 direction, it caused the port side of the trawl to have loose netting and the cod-end to be pulled to the starboard side of the centre line. One way to remove this distortion is to use knotless netting which is of the equal stretch-mesh length in the transverse and longitudinal directions.

The relation between mesh orientation (T0 vs. T45) and drag has not been comprehensively studied. Many papers on this subject refer to T0 and T45 mesh as ‘diamond’ and ‘square’ respectively. While ‘diamond’ and ‘square’ terminology may appear more intuitive and self-explanatory, ‘square’ mesh technically occurs wherever mesh opening is at a hanging coefficient of 0.707 and this can occur for T0 netting in many circumstances. Hence, some trawl makers have started using the T0 and T45 terminology such that it defines the orientation of the principle mesh-axis relative to a stated reference direction (usually the direction of tow). This latter terminology/definition is adopted by the authors of this report, but ‘square’ and ‘diamond’ are also used if that is the preferred terminology used in a sited reference. Zhan et al. (2006) analytically derived formulae for the drag force acting on T45 and T0 netting sheets (called by the authors square mesh and square-diamond mesh respectively) as a function of the angle of incidence. The analytical formula were calibrated by adjusting the pressure and friction force coefficients used in the formula such that drag predictions agreed with minimum error with experimental data for ‘square-diamond’ (T0) netting over a range of netting solidities and angles of incidence to the flow. The experimental work did not include cases of square mesh (T45) netting and did not investigate the difference in drag for panels with square (T45) and square-diamond (T0) mesh orientations. Calculations by the authors here using the published empirical formula for pressure and friction coefficients in both the proposed analytical formulae for square-diamond (T0) and square mesh (T45) panels suggest that there is a significant drag difference between the two mesh types.

Fig. 2.2 shows the result of drag ratio estimations for angles of incidence between 0° and 90° to the flow and a flow velocity of 1.6m/s. As can be expected mesh orientation has no effect on drag when the panel is normal to the flow. However, as the panel progressively tilts towards becoming parallel to the flow, the predicted drag for the T0 (diamond) panel reduces more rapidly compared to T45 (square) mesh. For incidence angles typically found in prawn trawls, 0° – 45°, T45 mesh is predicted to have 40 to 50% more drag for the same twine area. Stewart & Ferro (1987) investigated the drag of square (T45) and diamond (T0) mesh cod-ends and found that the drag was significantly higher for a square (T45) mesh cod-end. The authors believed that friction drag was greater for the square (T45) mesh cod-end where the netting was parallel to the flow compared to the diamond mesh (T0) cod-end, which was of a 'trumpet' shape, because the square (T45) cod-end had substantially more open meshes. The authors reached the conclusion that cod-end drag was related to the surface area of the cod-end. In this respect the study did not investigate the difference in drag that might occur between T45 (square) mesh and T0 (diamond) mesh in a situation where the surface area or mesh opening of the cod-ends were similar.

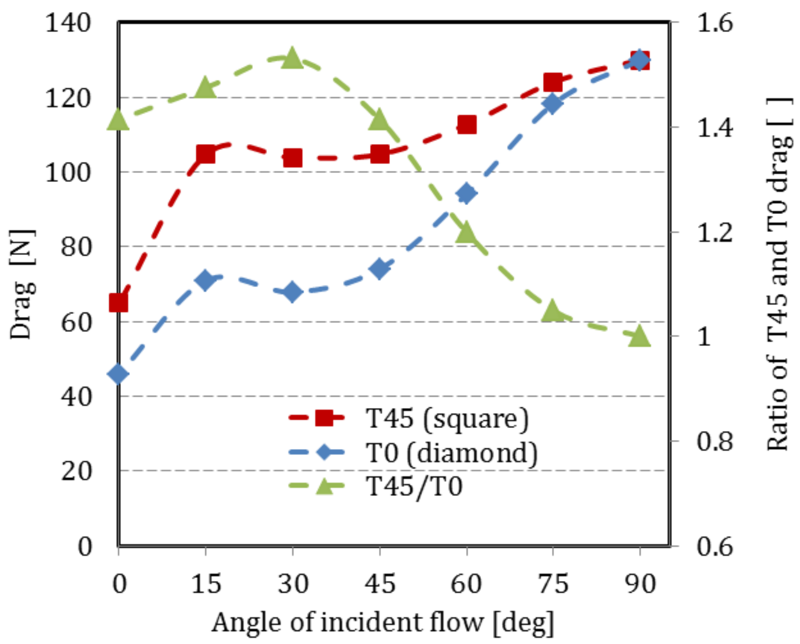


Fig. 2.2 Drag prediction for a trawl section (T45 and T0) based on the formulae developed by Zhan et al. (2006)

A number of other authors studied the drag for net panels that were of various mesh patterns. Even though the effect of mesh pattern was out of their work scope, some conclusions were reached on the potential effect of mesh pattern on drag. Tsukrov et al. (2011) compared the drag of copper and nylon nets positioned normal to steady flow, and detected significant differences in drag coefficient for a given solidity. The authors noted that while the copper and nylon samples were of diamond (T0) and rectangular (T45) mesh orientation respectively, the most likely cause for the drag differences for netting normal to the flow were the higher roughness of the nylon netting giving rise to a higher effective twine diameter. Gansel et al. (2012) studied the effects that flow speed and angle of attack (between 15° and 90°) had on netting of high and low bending stiffness. While the studied netting were of various mesh shapes (diamond, square and hexagonal), the paper did not explore their effect on drag or draw conclusions in that respect. The major theme of the paper was to compare measurements with prediction formulas that quantified the effect of angle of attack and solidity on drag.

In this Chapter, the authors investigated the drag variation of conventional and double-tongue, named 'W', prawn trawls due to T0 (diamond) and T45 (square) mesh alteration in the main body and side sections of the trawls, with the aim to propose a minimum drag solution for a 'W' prawn trawl. The performance indicators of interest were both the drag and in-pull of trawl models so that consideration of design features could be based on comparing the total drag of the trawl system (including predictions of otter board drag).

2.2 Methods

The experimental program in the flume tank comprised frame-line tension measurements for two groups of prawn trawl models over a range of flow speeds. The first set of models was based on ¼ scale 8-fathom Florida flyer prawn trawls that are commonly used by Australian prawn trawler operators (similar to the flat and balloon shrimp trawls used in the USA and described by Watson et al. (1984)). Within this group: Model A [T0 mesh body with T45 sides] was a conventional two seam trawl, meshes hung at the bosom at E=0.71, with T45 mesh side-sections achieved inherently by applying an all-bar side taper cut; Model B [T0 body with T0 sides] was a four seam trawl, meshes hung at the bosom at E=0.71, with T0 side panels sown to the all-bar side tapers at a hanging ratio of E=0.75; and Model C [T45 body with T0 sides] was a two seam trawl, bars hung tight at the bosom, with T0 side-sections achieved by applying an all-mesh side taper cut. The net plans for models A, B and C are shown in Fig. 2.3. The hanging lengths for all tapers connected to the upper and lower frame lines were calculated such that the netting was fully open to squares irrespective of mesh orientation. The models were simplified (short) versions of commercial trawls in that 45° side tapers were always selected (i.e. either B or N/T) instead of the more gradual body reduction achieved by typically using a 1N3B side taper in a commercial trawl. For the models, the amount of twine in the upper and lower (body) sections were minimised to sensitise the results to the drag-effects of mesh-orientation in the side sections. The second set of models contained adaptations of models A and C to form 'W' trawls, namely TA and TC (Fig. 2.4).

All models had equal frame-line length and each set had similar number of meshes (Table 2.1) so the effect of mesh orientation on drag could be quantified with minimal standardisation for twine area.

Table 2.1 Number of meshes and twine area for each model trawl

Model	**Number of meshes**	**Twine area (m^2)**
A	2219.5	0.22195
B	2211.5	0.22115
C	2268	0.22680
TA	3419	0.34190
TC	3642	0.36420

Twine area A_{twine} was calculated as shown in eq. (2.1):

$$A_{twine} = 2ldn \qquad (2.1)$$

where d is twine thickness (1mm), l is mesh size (50mm), n is number of meshes in the trawl. The resulting twine areas for the model trawls are presented in Table 2.1.

The experiments were conducted in the flume tank at the Australian Maritime College, Beauty Point, Tasmania, Australia.

The flow profile in the flume tank is not ideally uniform, so the measurement of average flow-speed through the trawl is difficult to achieve. To obtain highly precise drag comparisons from the flume tank, a series of paired comparisons were conducted for this set of tests. Each model was therefore tested at the top and bottom of the TER as shown in Fig. 2.5, and in a sequence as specified in Table 2.2. Generalised Linear Models (GLM) of the data were statistically analysed using SPSS software to estimate the effects of trawl position (top vs. bottom), speed setting in the tank, and trawl type on drag-loading and in-pull of the trawls.

The last test-combination shown in Table 2.2 involved a modified version of model TA, denoted MTA, which had bracing-ropes sown from the tongues down the centre lines of the diamond mesh body to investigate the potential to increase the stain transfer within the trawl to the tongues.

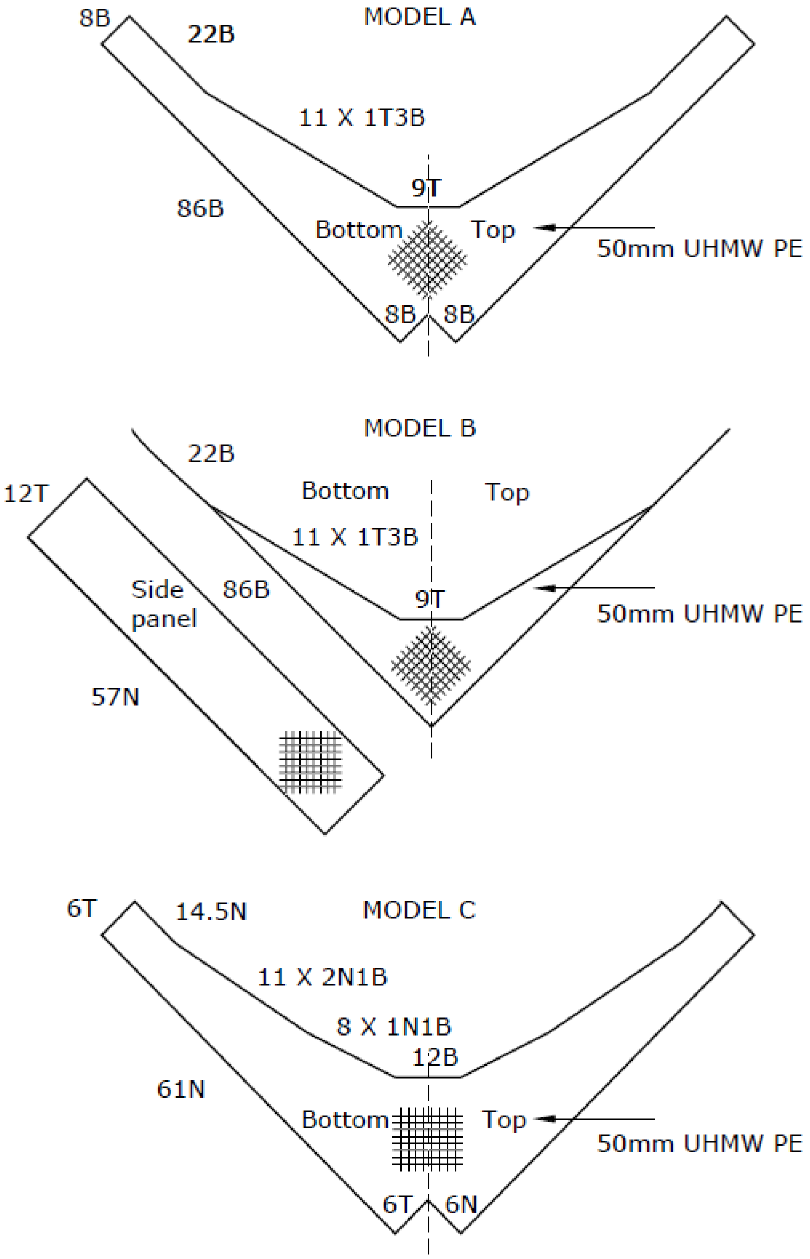


Fig. 2.3 Net plans for Standard trawls: Model A [T0 body with T45 sides], Model B [T0 body with T0 sides], and Model C [T45 body with T0 sides]. N – normal, T – transversal, B – bar. Hanging ratio: E=0.71 for meshes on frame-lines and E=0.75 for side panel meshes to body taper of trawl B

As can be seen from the net plans in Fig. 2.3 and Fig. 2.4, the top and bottom panels were identical within each model and produced a symmetric trawl about the central horizontal plane. This situation of no lead-ahead allowed the vertical opening around the frame-lines to be fixed by attaching four equally spaced 3mm-diameter fibre-glass struts. This methodology standardised the vertical opening of the mouths of the trawls against the effect of varying vertical netting-forces between the models. The horizontal spread was set to 82.5% of the frame line length. The distance between the lower and upper connection points on the TER (vertical mouth opening), and the length of the struts, was equal to 226 mm.

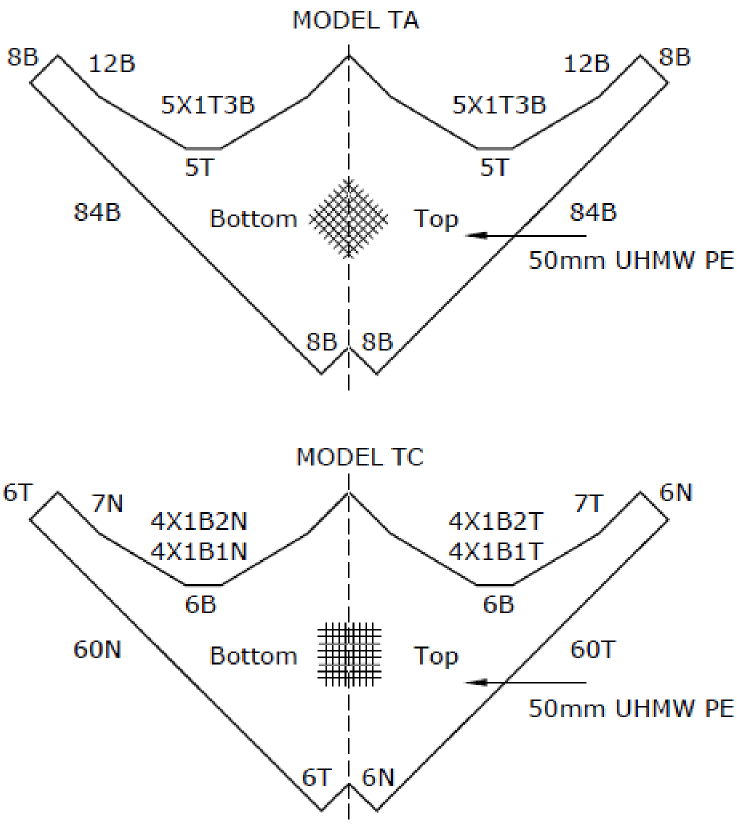


Fig. 2.4 Net plans for 'W' trawls models - TA [T0] and TC [T45]. Hanging ratio: E=0.71 for frame-line

Table 2.2 Testing sequence of the model trawls on the Trawl Evaluation Rig. For each combination, every model was tested in the top and bottom locations of the Trawl Evaluation Rig

Test run	Top net	Bottom net
1a	A	B
1b	B	A
2a	B	C
2b	C	B
3a	A	C
3b	C	A
4a	TA	TC
4b	TC	TA
5a	A	TA
5b	TA	A
6a	C	TC
6b	TC	C
7a	MTA	TC
7b	TC	MTA

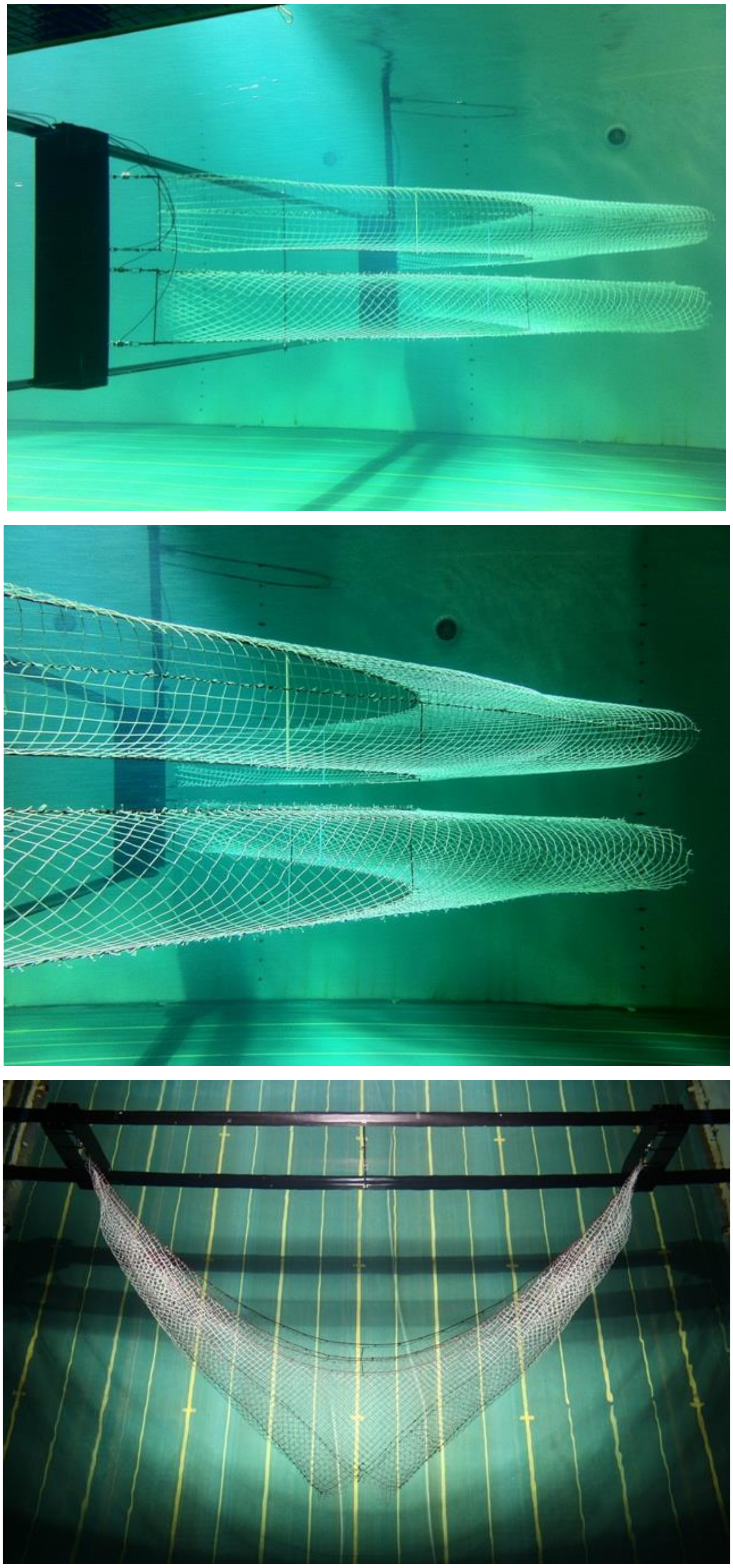


Fig. 2.5 Two model trawls (A on top and B on bottom) attached to the Trawl Evaluation Rig in the middle section of the flume tank

The flow speed was recorded with an electro-magnetic probe located upstream of the model, 1.25 m below the free surface on the centre line of the test section. The tensions at the tow points of the model were measured with four load cells of 20 kgf capacity each. The load cells were calibrated at the beginning of the test program and zeroed before each test run. Data was sampled at 1 Hz for 30 sec. For each trawl-net scenario the flume tank impellers were set sequentially to four operating conditions as shown in Table 2.3.

Table 2.3 Tested flow speed conditions

Impellers rotation (rpm)	Approximate flow speed (m/s)
125	1.0
150	1.2
175	1.4
200	1.6

The drag force F_d and the in-pull force F_{in} were derived as shown in eqs. (1.1) and (1.2) respectively for the conventional trawl. The angle of the frame-lines (at the connection points) relative to the flow direction was measured with a bevel gauge referenced to an unsubmerged beam on the TER that was transverse to the flow direction.

From these performance indicators of the trawl models the total drag of the trawl system (including predictions of otter board drag) can be estimated from eq. (2.2).

$$Total\ Drag = F_d + 2\frac{F_{in}}{L/D} \tag{2.2}$$

where, F_d is netting drag, F_{in} is in-pull of the net, L/D is a lift-to-drag ratio of the otter board (assumed to be 1).

2.3 Results

Fig. 2.6 shows the estimated effect of mesh orientation, as set in models A, B and C, on drag along with 95% confidence intervals from the GLM analysis of paired-comparisons (test runs 1 through 3 in Table 2.2). For each speed case the drag of model C is set as the reference (with a value of 1). The percentage drag difference between model B and model C is consistently 0.5% less, although it is shown not to be statistically significant. There was no statistical difference in drag between models A, B and C at the slowest speeds while model A exhibited 3.5% less drag than model B and C at the highest speed.

Fig. 2.6 shows the effects of twine orientation on the drag for models A, B, and C as it could be practically implemented in models. However, as shown in Table 2.1, the twine area for the models slightly varied, and in order to evaluate the effects of mesh orientation on the netting drag from a general perspective, the drag values were also standardised by twine area (Fig. 2.7). The drag standardised by twine area (drag twine-area^{-1}) for model B was consistently estimated to be significantly higher than for model C by about 2.0%. There was no statistical difference in standardised drag between models A and B at the slowest speeds while model A produced less standardised drag than model B at the higher speeds; by about 3.5%. It appears that model A produced progressively less standardised drag compared to models B and C. Model A had 1.5% higher drag twine-area^{-1} than model C at the lowest speed and 1.5% lower drag twine-area^{-1} at the highest speed.

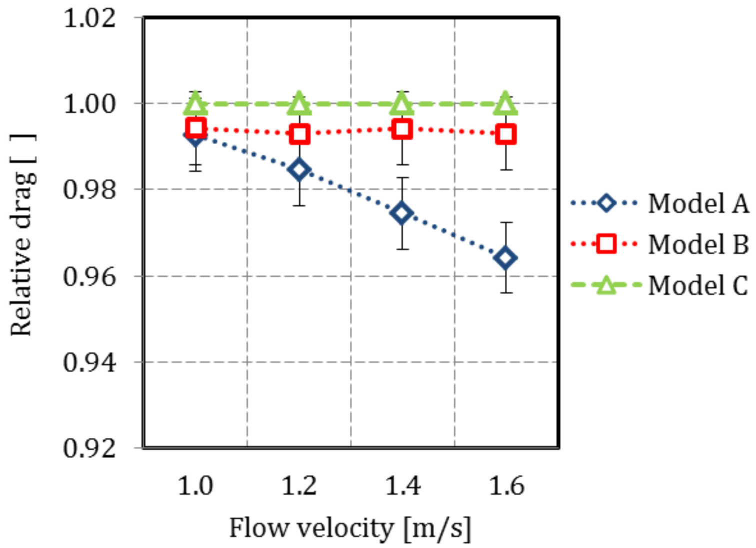


Fig. 2.6 Relative drag for standard model trawls with model C being a bench mark [Model A: T0 body and T45 sides; Model B: T0 body and T45 side-panels; Model C: T45 body and T0 sides]

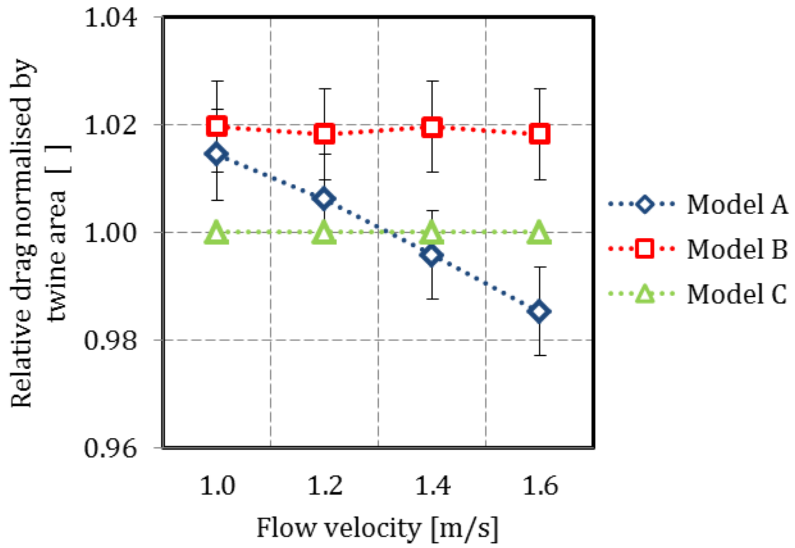


Fig. 2.7 Relative drag standardised with twine area; with model C being a bench mark [Model A: T0 body and T45 sides; Model B: T0 body and T45 side-panels; Model C: T45 body and T0 sides]

The results for the ’W’ trawl implementation of models A and C, namely TA and TC, are shown in Fig. 2.8. Model TA showed an 8.4% lower drag compared to TC, which is mainly due to twine area difference. However, TA produced significantly less drag transfer through the tongues, which implies higher strain on the otter boards - TA and TC exhibited 40% and 59% drag transfer to the tongues respectively. The introduction of the bracing-ropes to model TA, shown as MTA, lead to a significant increase in drag-loading of the tongues, from 40% to 50%, though the model’s drag slightly increased due to the additional drag of the ropes. Model MTA had 6% less drag than TC.

Fig. 2.9 contains predicted in-pull force for all trawl models, and it shows that models MTA and TC would require similar size otter boards that would be approximately half the size of those required by models A and C.

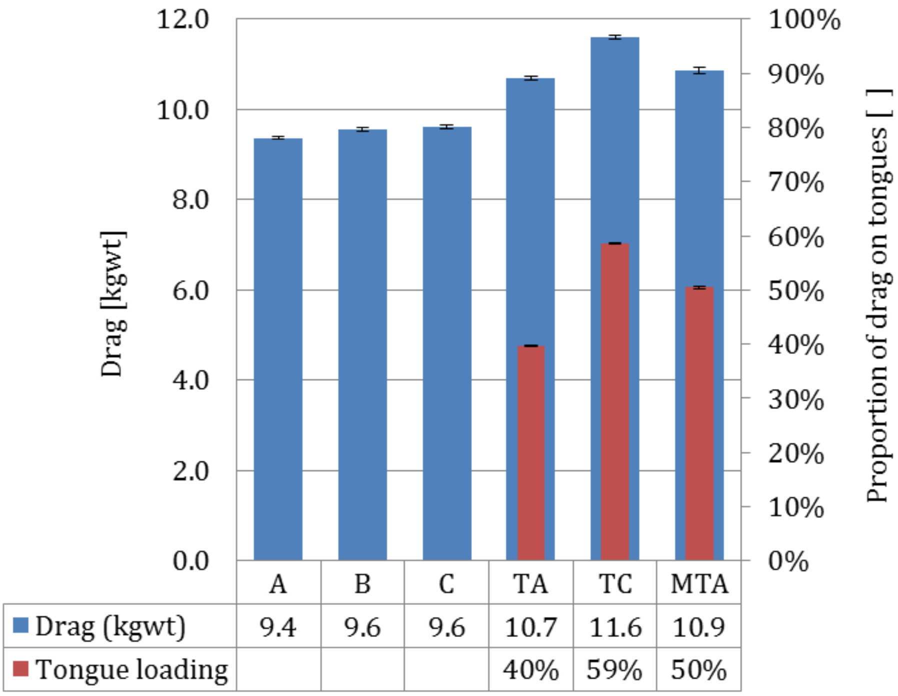


Fig. 2.8 Drag comparison for all tested trawl models. Estimated marginal mean drag from GLM and proportion of total drag transferred to tongues for each trawl (with 95% confidence intervals)

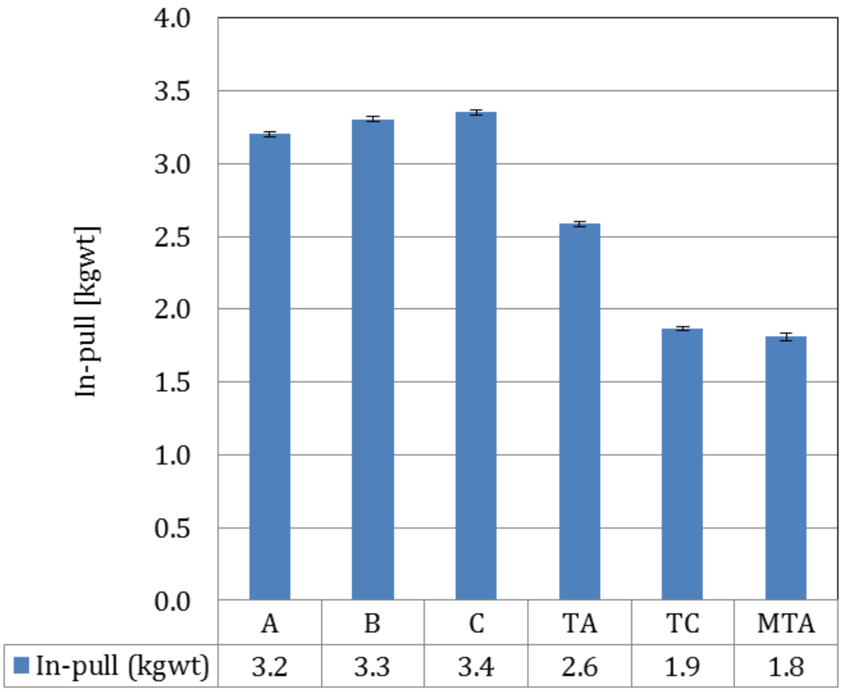


Fig. 2.9 Expected otter board loading for all models

2.4 Discussion

Models B and C comprise main body sections (nearly parallel to the flow) that have T0 and T45 netting orientation respectively, while the side sections for both models are of T0 orientation. Given that Model B exhibited 2% higher drag twine-area^{-1} than model C, it suggests that T0 in the upper and lower sections had slightly more drag than T45 mesh. Alternatively, the explanation could be that model B produced a higher drag due to the four side-seams that connected the main body sections to side panels of the trawl; and additionally, the seams for model B are bar-to-mesh joins and bulky compared to the two mesh-to-mesh joins for model C.

Model A is fundamentally different to models B and C in respect to the orientation of meshes in the side sections of the trawl (T45 vs. T0), and identical to model B in respect to the configuration of the upper and lower body panels, so it appears that T45 mesh in side sections at 45° to the flow produces progressively lower drag compared to T0 with speed. The reduction in T45 drag relative to T0 as flow speed (and corresponding Reynolds number) increased is consistent with the general understanding that higher Reynolds number can ameliorate the separation of flow around an object and lower its drag coefficient. This effect might be more significant for T45 netting, which contains twine elements that are normal to the flow, compared to T0 where all twine elements are oblique to the flow, and therefore more streamlined in cross-section. It could be that the drag for both orientations is similar at certain speeds; however, it is evident that the drag coefficient for T45 at 45° reduces as water speed increases relative to the drag coefficient for T0 netting at 45°.

Table 2.4 presents the estimated total drag loadings from the trawl and otter boards combined for all models as per eq. (2.2).

Model A exhibited 3.0% (± 0.4%, p=0.05) less drag than the other standard trawls on average, and had similar drag to its ‘W’ counterpart, model TA. For the model TA implementation of the ‘W’ trawl concept, the drag penalty of the extra twine area in the tongues cancelled the rather moderate drag benefits associated with the transference of netting drag through the tongues and away from the wings and otter boards.

For the ‘W’ trawl, model TC, there was 4% less total drag than for the TA trawl system. This improvement was caused by the way that model TC had much higher transfer of netting drag to the tongues than model TA. However, the introduction of the bracing ropes along the centre lines of the T0 body panels of model TA (presented as MTA) led to (1) an increase of the strain transfer to the tongues: from 40% to 50%, and (2) a decrease of the trawl’s wing-end angle, and made model MTA the best performer of all trawls tested.

Table 2.4 Estimated total drag (trawl and otter boards) for all trawl model cases including 95% confidence intervals

Trawl	A	B	C	TA	TC	MTA
Predicted total drag (kgf)	15.8 ± 0.05	16.2 ± 0.06	16.3 ± 0.05	15.9 ± 0.06	15.3 ± 0.05	14.5 ± 0.09

Model TC, which has bars hung on the bosum, requires the use of more expensive knotless netting (Ultracross) to avoid distortion of the trawl that occurs with conventional knotted netting, due to its difference in stretched length in the lateral and longitudinal directions. Ultracross knotless netting also provides the advantage that it will sustain much higher loads along the line of the bars without local distortion of the mesh shape (Sterling & Eayrs, 2010). Models TA and MTA have T0 mesh orientation in the main body of the trawl and as a result conventional knotted netting can be used without causing distortion of the trawl, but it has been demonstrated that the T0 ‘W’ trawl (model TA) requires bracing ropes attached down the centrelines of the top and bottom sections to improve strain transfer within the trawl to the tongues and to achieve any overall drag-benefit. The implementation of bracing ropes adds cost to the construction of the trawl, but results in a trawl with superior performance to model TC.

The comparison of drag performance between the conventional trawls (models A and C) and ‘W’ trawls (models TA and TC) (Fig. 2.8) shows that the total netting drag is not proportional to twine area. This is because the additional twine area in models TA and TC is exposed to the flow at a low angle. The double tongue and conventional trawls comprise equal side-panels (for A and TA, and C and TC), while the overall trawl twine area is greater for the ‘W’ trawls due to the addition of the two tongues to the main body (54.0% greater for TA compared to A; and 60.6% greater for TC compared to C). Despite the significant addition of twine area in the 'W' models, the overall drag only increased by 14.1% and 20.6% for TA and TC respectively. The low effect on total drag of a relatively large increase in netting at a low angle of attack is consistent with the hypothesis of the twine 'shadow' effect suggested by Goudey (1992) and illustrated by Enerhaug et al. (2012).

In the present work, the conventional trawl models were designed to have a low amount of twine in the main body compared to industry practice in order to increase the sensitivity (statistical power) of the experiment to detect the effect of mesh orientation in the side sections on drag. In practice, substantially longer trawls than the tested models would be required. Models of such trawls would have significantly more twine area generally and the difference in twine area, and associated drag, between the conventional trawls and the 'W' trawls would be much less significant in percentage terms.

Overall, 7.6 – 8.9% (p=0.05) less drag is estimated for a trawl system based on 'W' trawl, model MTA, compared to conventional trawl, model A. This represents the demonstrated benefits of the 'W' trawl concept as tested in the present study. In the field, higher relative drag benefits can be expected for commercial trawl gear because the detrimental drag effect of adding tongues will be subdued by the generally higher twine area of the commercial trawls.

2.5 Conclusions

The study presented in this Chapter investigated drag saving potential of a novel design concept for prawn trawls called the 'W' trawl, based on drag tests of simplified trawl models. The innovation is characterised by the redirection of drag loading from the wings to the centreline connection points of the 'W' trawl in order to reduce the amount of in-pull force applied to the otter boards and give an overall drag reduction of the system, because smaller otter boards can be used. The work also investigated the drag implications of using T45 vs. T0 netting orientation in various sections of a prawn trawl in order to identify low-drag cases. In order to increase the sensitivity of the experiment, the work reported in this Chapter utilised very short trawl models of generally low twine area that are not directly applicable to commercial operations . Due to this the results are a conservative assessment of the 'W' trawl's potential for drag reduction. Below are the main conclusions:

(i) At a very low angle of attack (where netting is near parallel to the flow), T0 mesh may produce a slightly higher drag compared to T45. At higher angle of attack (where the netting was subjected to the flow at an angle of about 45°), T45 mesh exhibited a progressively reducing drag compared to T0 as flow speed increased.
(ii) In the 'W' trawl design, drag was better redirected through the centreline to the tongues for T45 mesh body sections compared to T0: 59% and 40% of the total drag was transferred respectively.
(iii) The introduction of bracing ropes along the upper and lower centrelines of the T0 mesh body sections at a hanging coefficient E=0.71 improved the strain transfer to the tongues from 40% to 50% of the total drag, and reduced the trawls dynamic wing-end angle. Potential exists to enhance strain transfer to the tongues and achieve further performance improvement of the 'W' trawl through optimising of the hanging ratio used to attach the bracing-ropes.
(iv) The best 'W' trawl design tested to date indicated an 8.3% (± 0.6%, p=0.05) drag benefit for industry compared to a conventional trawl. In the field, higher drag benefits for commercial trawl gear can be expected because the measured detrimental drag effect of adding tongues to the model trawls will be subdued by the general increase in twine area of the commercial trawls.
(v) Further work is required to investigate the application of 'W' trawl technology to specific commercial prawn-trawling contexts and its associated drag saving potential.

References

DFTI 1989. Y-design - A new concept for trawl design from DFTI. Hirtshals, Denmark Danish Fisheries Technology Institute.

ENERHAUG, B., FØRE, M., ENDRESEN, P. C., MADSEN, N. & HANSEN, K. 2012. Current Loads on Net Panels with Rhombic Meshes. *31st International Conference on Ocean, Offshore and Arctic Engineering.* Rio de Janeiro, Brazil.

GANSEL, L. C., JENSEN, Ø., E. LIEN, E. & ENDRESEN, P. C. 2012. Forces on Nets With Bending Stiffness: An Experimental Study on the Effects of Flow Speed and Angle of Attack. *31st International Conference on Ocean, Offshore and Arctic Engineering.* Rio de Janeiro, Brazil.

LOWE, T. 1996. *An Analysis of the Gains in Engineering Performance Achieved by Constructing Australian Prawn Trawls from Spectra Netting.* B.Sc., Australian Maritime College.

RIPON, M. 1991. *The pleated trawl: An analysis and comparison of the engineering performance of a new construction style of prawn trawl net.* Bach. App. Sci. (Fisheries) Australian Maritime College.

STERLING & EAYRS 2010. Trawl-gear Innovations to Improve the Energy Efficiency of Australian Prawn Trawling. *1st International Symposium in Fishing Vessel Energy Efficiency.* Vigo, Spain.

STEWART, P. A. M. & FERRO, R. S. T. 1987. Four Experiments Investigating Cod-end. *Fisheries Research,* 5**,** 349-358.

TSUKROV, I., DRACH, A., DECEW, J., ROBINSON SWIFT, M. & CELIKKOL, B. 2011. Characterization of geometry and normal drag coefficients of copper nets. *Ocean Engineering,* 38**,** 1979-1988.

WATSON, J. W., WORKMAN, I. K., TAYLOR, C. W. & SERRA, A. F. 1984. Configurations and Relative Efficiencies of Shrimp Trawls Employed in Southern United States Waters. National Maritime Fisheries Services, NOAA.

ZHAN, J. M., JIA, X. P., LI, Y. S., SUN, M. G., GUO, G. X. & HU, Y. Z. 2006. Analytical and experimental investigation of drag on nets of fish cages. *Aquacultural Engineering,* 35**,** 91-101.

Chapter 3 - 'W' trawl design with emphasised strain transfer

The work presented in this Chapter investigated the potential of redistributing the drag-strain within prawn trawls away from the wings and the otter boards to the centre line of the trawl, where top and bottom tongues have been installed, with an aim to minimise the loading/size of the otter boards required to spread the trawl. To establish the extent of strain redistribution to the centre-line tongues and the relative drag benefits of the new design, conventional and 'W' trawls of two-fathom (3.66m) headline length were tested firstly over a range of spread ratios in flume tank and subsequently at optimum spread ratio in the field.

3.1 Introduction

In prawn trawling practise, significant drag reduction is obtained through use of multiple-net rigs, which replace a single net with a number of smaller size nets. The drag reduction occurs because: (1) a smaller amount of netting is used in the system, (2) smaller otter boards are required to spread the smaller nets, and (3) drag savings occur when nets are joined together due to reduced number of otter boards per trawl. Fig. 3.1 is a comparative display of some multiple-net prawn-trawl systems used in Australia: single (a), twin (b), triple (c) and quad (d) configurations. Sterling & Eayrs (2010) showed a simplistic prediction of drag reduction from using multiple nets based on flume tank drag data for model Australian prawn trawls of various sizes. This assessment indicated that triple- and quad-rig trawl-systems have less than half the drag of a single-net system with the same total headline length. Broadhurst et al. (2013) measured the drag of single, twin, triple and quad rigs in the field and demonstrated fuel savings of up to 26% from using the high-order multiple net rigs. It should be noted, however, that a negative side-effect of employing multiple nets is the added practical difficulty of emptying multiple cod-ends each shot and the high cost to purchase and maintain a larger number of approved By-catch Reduction Devices (BRD) and Turtle Exclusion Devices (TED), which are compulsory for all prawn trawl nets used in Australia.

To counter what was perceived to be low ground-chain pressure for the ‘W’ trawl, close attention was directed to the shape of the wing-ends, which are a bar-to-bar cut in the wings of the ‘W’ trawl as opposed to a mesh-to-mesh cut in the Florida flyer. This tailoring of the netting in the wing-end removed a lot of loose netting that is typically found in traditional trawls, however the resulting strain on the log rope and the observation that it tended to be mainly applied to the lower end of the logline produced a perception that it could be lifting the fishing line and ground chain in the wings of the ‘W’ trawl during the trawling process. To resolve this issue, the wing-end bars were secured evenly along the log rope to ensure that the strain in the wing-ends was being applied in a balanced way to both the upper and lower frame line. The average catch rates over the subsequent 13 hauls demonstrated a substantial improvement (TB3 in Fig. 4.5), such that there was no statistically significant difference in either the average mass of prawns caught each shot or the average size of individual prawns (there was however an observed reduction in catch and prawn size for the “W” trawl).

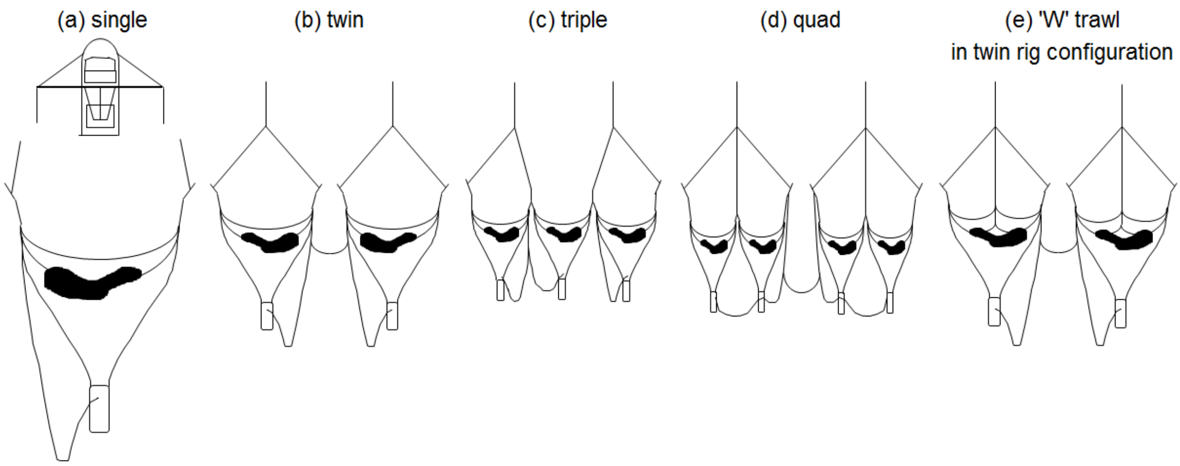


Fig. 3.1 Multiple net configurations: engineering efficiency is progressively increased with an addition of smaller size nets. The proposed ‘W’ trawl in twin rig configuration (e) is hypothesised to be a progressive development beyond the quad rig (d)

Looking forward, the authors of this project report propose a new technology for further drag reduction of prawn trawl systems, called the ‘W’ trawl. The principle behind the proposal, as outlined originally by Sterling & Eayrs (2010), is that a large portion of netting drag can be transferred to a central towing wire via a trawl sled connected to upper and lower tongues, as opposed to putting load on the otter boards through the wings of the trawl (Fig. 3.1e). The new technology should provide superior drag performance compared to a single trawl configuration due to reduced otter board size requirements, and similarly two ‘W’ trawls could be used instead of standard twin rig for the same performance benefits. Furthermore, the ‘W’ trawl concept would alleviate the operational issue of additional cod-ends, TEDs and BRDs intrinsic to four net systems (quad rig), if the two adjacent nets were replaced by ‘W’ trawls. Potentially the twin ‘W’ trawl system could out-perform quad rig, from an engineering perspective, depending on the extent that the ‘W’ trawl can direct netting-drag generated within the trawl to the centre bridle.

Chapter 3 showed that alternation of mesh pattern (diamond – T0 and square – T45) in the upper/lower and side sections of standard and 'W' trawl models did not substantially affect their drag. However, for the ‘W’ trawl, T45 mesh in the upper/lower sections of the trawl was shown to produce a higher strain transfer forward to the tongues compared to T0 mesh (40% for T0 and 59% for T45). Conversely, the authors concluded that T0 mesh provided an overall more-favourable solution for the following two reasons: (1) strain transfer to the tongues for the T0 case could be increased through installing bracing ropes down the centrelines of the upper and lower panels of the trawl and (2) the ‘W’ trawl had a significantly asymmetrical (distorted) shape when hung on the square (T45) unless expensive ultra-cross knotless netting is used; standard netting can be used for the ‘W’ trawl with T0 mesh orientation.

The work in this Chapter investigated the potential of further strain transfer to the tongues through variant bracing rope techniques applied to the centre line of the ‘W’ trawl. Standard (Florida flyer) and ‘W’ trawls of 3.65m headline length (2-fathom) were tested in the flume tank over a range of spread ratios to compare their engineering performance and monitor performance improvements for the ‘W’ trawl as refinements to the design were implemented. Following the flume tank sessions, the trawls were tested at sea to establish their relative engineering and catching performance in a commercial fishing situation.

3.2 Methods

Net plans for the small standard and ‘W’ trawls are shown in Fig. 3.2. Trawls of this 2-fathom size are commonly used as try-gear, a small net to regularly sample catch rates while the main gear is operated uninterrupted over a longer time period. Both the trawls were built from Hampidjan Dynex material – 50mm mesh size and 1.1mm twine thickness.

3.2.1 Flume tank experiments

The work in the flume tank aimed to:

(i) Improve the strain transfer to the tongues through implementation of an optimal bracing rope technology along the upper and lower centrelines of the body section.

(ii) Obtain drag and in-pull measurements for the standard and ‘W’ trawls over a range of spread ratios so that the drag benefits of the new system and optimal otter board size could be estimated.

The experiments were conducted in the flume tank at the AMC – University of Tasmania in Beauty Point, Tasmania, Australia. The trawls, without ground gear, were attached one at a time to an aluminium rectangular frame (Trawl Evaluation Rig – TER) by the four end points of the upper and lower frame lines, and an additional two points for the ‘W’ trawl, being at the upper and lower tongues (Fig. 3.3). Each trawl-connection point contained a load cell so that the frame-line tensions at all connection points were measured for each case. Otter boards and ground chain were not attached to the trawls in these flume tank sessions. The spread ratio was adjusted on the TER by moving the two vertical sides to the desired location and firmly fixing them in place. The tensions at the tow points of the model were measured with load cells of 20 kgf capacity each. To isolate drag and in-pull components from the frame line tensions, the angles of the frame-lines (at the connection points) relative to the flow direction were measured with a bevel gauge.

To investigate the proportion of drag-strain transferred to the tongues, the following two applications of bracing ropes to the centre line of the trawl were tested with the trawl spread set to 80% of its headline length:

(i) 3 x 12mm polyethylene (PE) ropes fitted down the centre line; these ropes were not sewn to the trawl, but were threaded through adjacent meshes to completely fill the open mesh and therefore to prevent them from closing.

(ii) Stretched netting was sewn down the centre-line of the trawl. The mesh size for the stretched netting was selected such that the position of each knot corresponds to the position of the connection-lashings to the trawl in that a hanging ratio of 0.707 was achieved (Fig. 3.4).

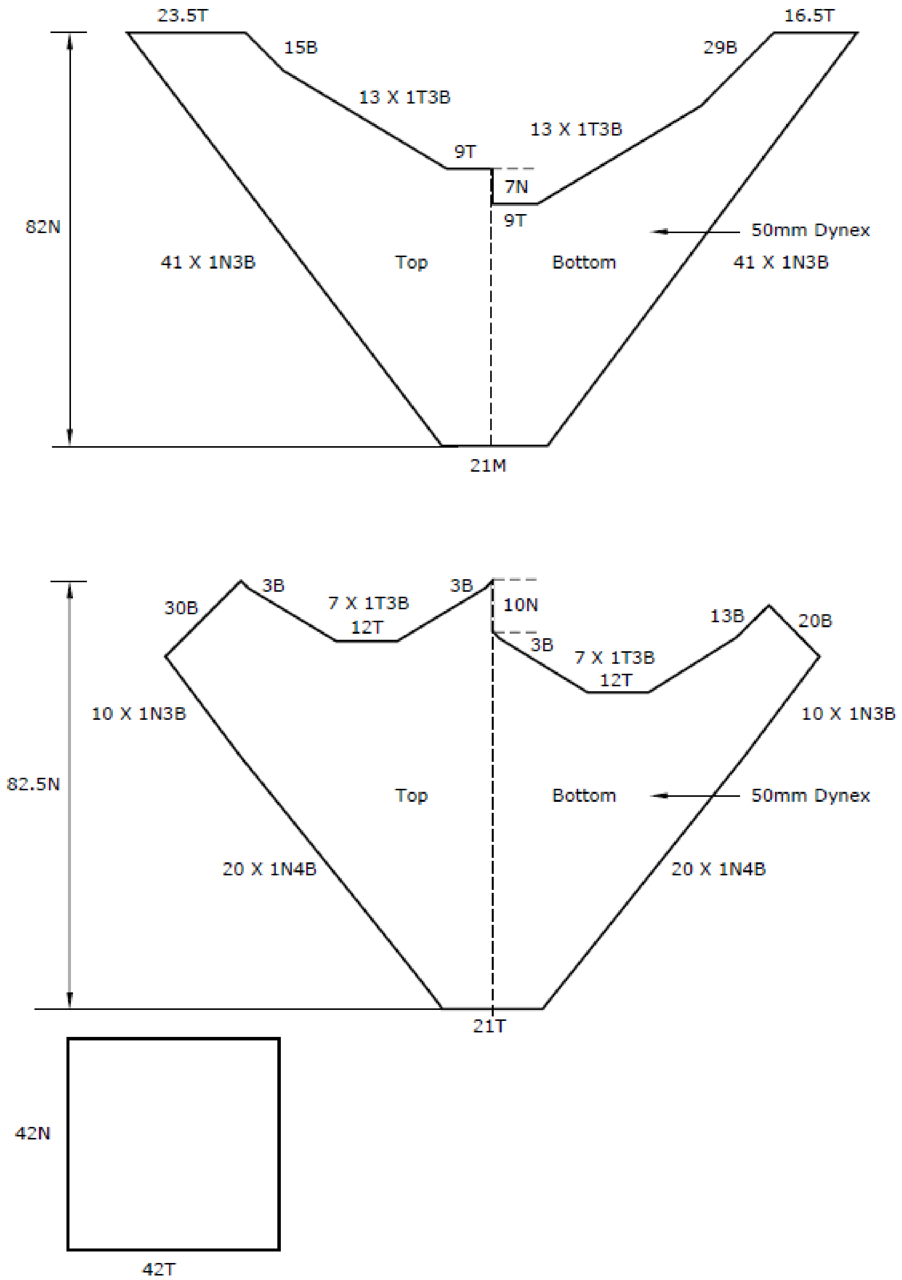


Fig. 3.2 Net plans for Florida flyer (top) and 'W' (bottom) trawls

Table 3.1 Tested conditions for flume tank sessions

Bracing rope application	**Trawl spread ratio [%]**
3 x 12mm PE ropes	80
Stretched netting	80
Optimal solution	70
	80
	90

Table 3.2 Flow speeds tested

Tank impellers rotation [rpm]	**Approximate flow speed [m/s]**
120	0.96
140	1.12
160	1.28
180	1.44

The optimal bracing rope solution was selected based on the highest strain transfer achieved without distorting the operational shape of the trawl. The selected solution was implemented for a subsequent set of comparative tests between the standard and 'W' trawls over spread ratios of 70, 80 and 90% and four water speeds as specified in Tables 3.1 and 3.2. For each data set, a linear model was fitted to the force vs. velocity squared, and a single standardised drag force was obtained corresponding to the tank flow setting of 150rpm (~1.2m/s).

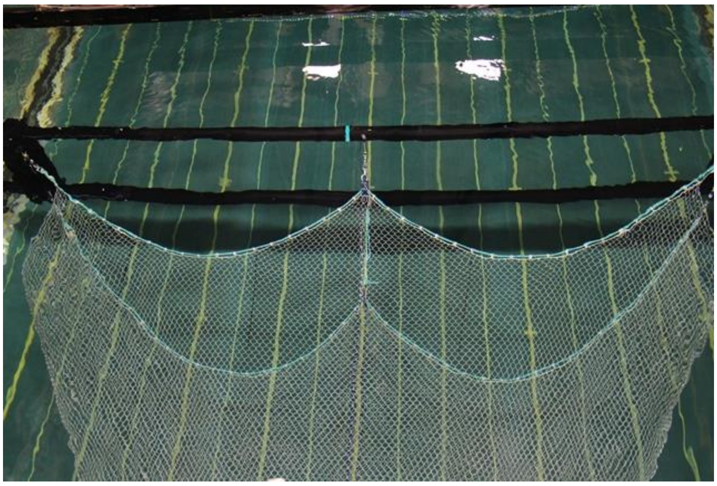


Fig. 3.3 'W' trawl attached to the Trawl Evaluation Rig (TER) and placed in the mid-stream section of the flume tank

Fig. 3.4 Stretched netting sewn down the centre line with a hanging ratio of 0.707

3.2.2 Field experiments

The objective of the field experiments was to obtain comparative system drag and spread measurements, and catch data, for a preliminary assessment of the energy efficiency of the new 'W' trawl system compared to the standard arrangement. The 'W' trawl was tested with a bracing rope fitted as per Fig. 3.4

The trials occurred in Moreton Bay, Queensland, Australia in September 2013. The experiments occurred before the main prawn season, but this was not a point of concern as catches would be sufficient to gauge the relative effectiveness of the gear. Data collection in respect to catch involved weighing the various catch components during the normal flow of material in the production process.

(a) (b) (c)

Fig. 3.5 Otter boards and sled used with the try-nets; (a) Florida flyer board, (b) 'W' trawl board, (c) 'W' trawl sled

Table 3.3 Otter board and sled particulars

	Overall length x height dimensions [mm]	**Effective panel area [m^2]**	**Weight [kg]**
Florida flyer board	914 x 559	0.464	41
'W' trawl board	610 X 483	0.232	17
'W' trawl sled	914 x 483	in line with flow	34

The two trawl systems were towed simultaneously in a double rig configuration: The Florida flyer was positioned on the starboard side of the vessel and the 'W' trawl on the port side. 35 shots were undertaken over four days and the duration of each shot was 20 min. A load cell of 4 tonne capacity was attached using wire grips to the warp on each side of the vessel after the gear was deployed. The towing speed was approximately 3 knots. Scanmar® sensors were attached on the end points of the frame lines to record the horizontal spread of the trawls. The boat was 12 m long and had a 150 Hp engine. General particulars for otter board and sled are presented in Fig. 3.5 and Table 3.3, and ground chain specifications are in Fig. 3.6. Fig. 3.7 and 3.8 demonstrate gear set up on both sides of the trawler and a process of sorting the catch and by-catch.

A Generalised Linear Model (GLM) was developed with the aid of SPSS, statistical analysis software, to standardise the drag and spread measurements for each shot with respect to trawl speed and the ratio of deployed warp-bridle length to water depth, and establish the effect of trawl system on these engineering performance measures. GLMs were also used to analyse the log of catch rates.

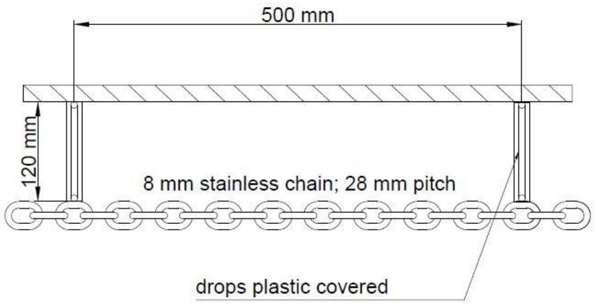


Fig. 3.6 Ground-chain specification (inside plastic droppers: 5 links of 6mm for Florida flyer and 7 links of 4mm for 'W' trawl)

(a) (b) (c)

Fig. 3.7 Trawl gear set-up; (a) 'W' trawl system at end of the boom on the port side, (b) Load cell attached to starboard warp by a wire grip, (c) Florida flyer with two Scanmar® sensors at the boom-end on the starboard side

During the first 2 days of trials there were difficulties with the 'W' trawl system during the shooting away process. It was evident that the otter boards were not providing strong spreading forces during this phase of the operation. It was concluded that this was due to the characteristics of the trawl system and that the traditional flat otter board would need to be modified in order for the system to operate in a practical way. The mechanism behind the poor otter board performance during shooting away centres on the divergence angle of the 2m sweeps included between the wing-end of the 'W' trawl and the connection point for the trawl to the otter board (see fig. 3.9). When the trawl is closed the longitudinal distance of these sweeps becomes much longer than the longitudinal distance of the sweep/sled combination along the centreline of the system, because the divergence angle of the 2m sweeps becomes zero. In this state the wings of the 'W' trawl carry no tension and the otter boards dangle loosely into the water during the initial part of the shooting away process. After day 2 of the trials a number of changes were made to improve the situation:

(i) The length of the sweeps behind the otter boards were halved in length to 1m and the system was retuned by appropriately shortening the centreline sweeps as well (Fig. 3.9).

(ii) The general arrangement of weight in the flat rectangular otter boards was redistributed such that the centre of gravity was moved forward and in board as much as possible. This made the otter board enter the water at a sensible orientation relying on tension in the wing-end of the trawl attached to its aft edge.

Subsequent to these modifications the operation of the 'W' trawl system during shooting away was vastly improved and made it more practical.

Fig. 3.8 Sorting the catch and by-catch into species groups

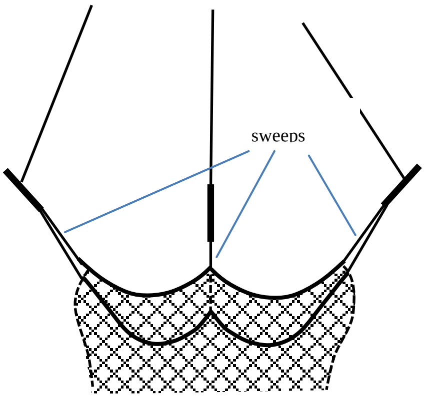


Fig. 3.9 Sweep lengths being tuned for proper trawl geometry

3.4 Results and Discussion

3.4.1 Engineering performance in the flume tank

For the case of fitting 3 x 12mm PE ropes down the centre line of the 'W' trawl, a large drag-transfer of 72% to the tongues was recorded. However, it was found that the rope fitting process through the meshes did not easily give a consistent and desired restriction of mesh elongation, and caused excessive trawl-shape distortion.

A significant practical improvement was achieved with the subsequent lashed attachment of stretched netting down the centrelines of the upper and lower panels. A 64% drag transfer to the tongues was obtained, while the shape of the trawl was smooth and undistorted.

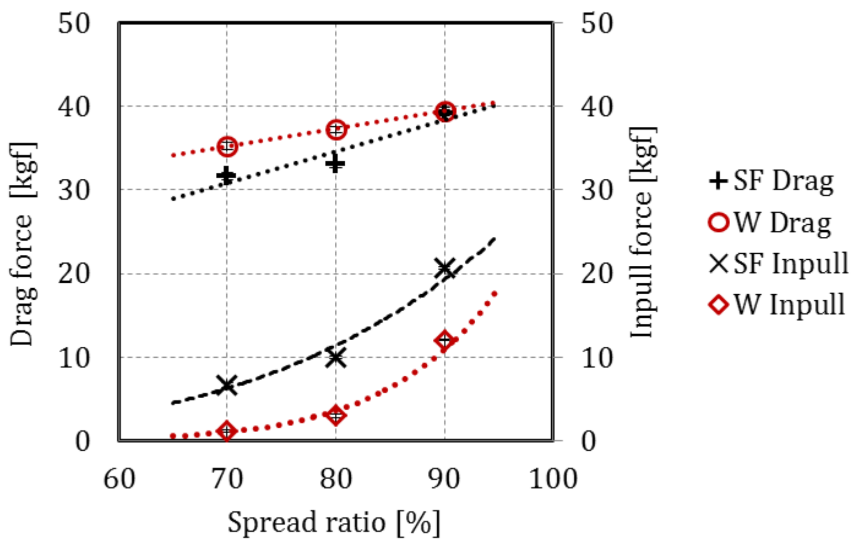


Fig. 3.10 Drag and in-pull for standard flyer (SF) and 'W' trawls with respect to spread ratio

Fig. 3.10 shows standardised data collected from the trawl evaluation rig in the flume tank for the two trawls over a range of spread ratios – drag and in-pull components of the load cell tensions for the standard flyer (SF) and 'W' trawl with the stretched netting bracing rope hung to the centre line with E=0.707. The 'W' trawl generally exhibited a higher drag compared to the standard trawl. However, the difference reduced as spread ratio increased. Conversely, the in-pull force that would be applied to the otter boards was substantially less than that for the standard trawl (by about 65% on average), which was due to the drag-transfer to the tongues and away from the wings of the trawl. As shown in Fig. 3.11, the proportion of drag-transfer to the tongues decreased as the trawl spread became wider.

Fig. 3.12 shows predictions of the total drag (trawl and otter board drag) for the three measured spread ratios – the drag difference between the trawl systems increased from 17.3% to 18.5% for the spread ratio range of 70% to 90%.

Whilst total drag of the trawl systems increased with the spread ratio, swept area rate (SAR) also increased proportionally, because spread ratio linearly drives SAR. To obtain drag measures that are standardised by SAR, drag divided by spread ratio is plotted in Fig. 3.13 to account for the countervailing effects of spread ratio on trawling efficiency.

Based on the flume tank results, the optimal spread ratio, where the drag per unit of spread is minimum, appears to be around 75% for both SF and 'W' trawls (Fig. 3.13). This is surprising as one would expect the optimum spread ratio (SR) for the 'W' trawl system to be higher than for the standard trawl because the 'W' trawl requires smaller otter boards. In hindsight we can see that the reason for the premature minimum in drag/unit spread for the 'W' trawl is because of the way that the proportion of trawl drag transferred to the tongues drops steeply with increasing spread ratio (as shown in Fig. 3.11). This characteristic of the 'W' trawl data is a result of the applied methodology in that the fore/aft position of the tongue relative to the wings was set for 80% SR and not subsequently readjusted for the 70% and 90% cases. The implication of this assumption is that the relative performance result for the 'W' trawl at 80% is correct, but the results across the SR range are distorted. A correction can be applied to the results by assuming that the proportion of trawl drag through the centre line would be fixed at 64.2%, rather than drop from 71.8% at 70% SR to only 35.1% at 90% SR, if the tongue position was correctly adjusted for each SR. Fig. 3.13 also shows 'adjusted' standardised total drag results, which indicates that the practical optimum spread ratio for the 'W' trawl is about 80%, which is higher than for the standard trawl (75%).

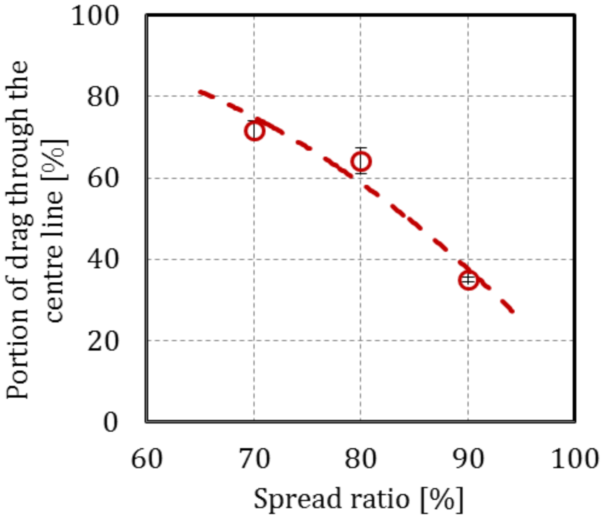


Fig. 3.11 The proportion of drag-transfer through the centre line of the ‘W’ trawl with respect to spread ratio

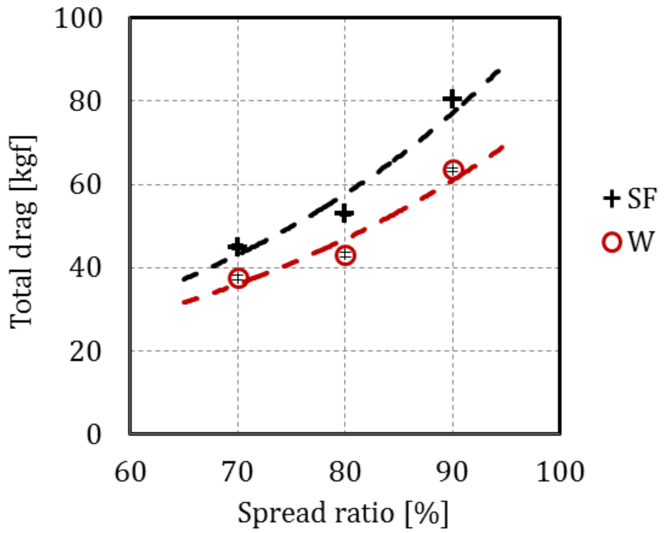


Fig. 3.12 Predicted total load including trawl and otter board drag for standard flyer (SF) and ‘W’ trawls [flume tank data]

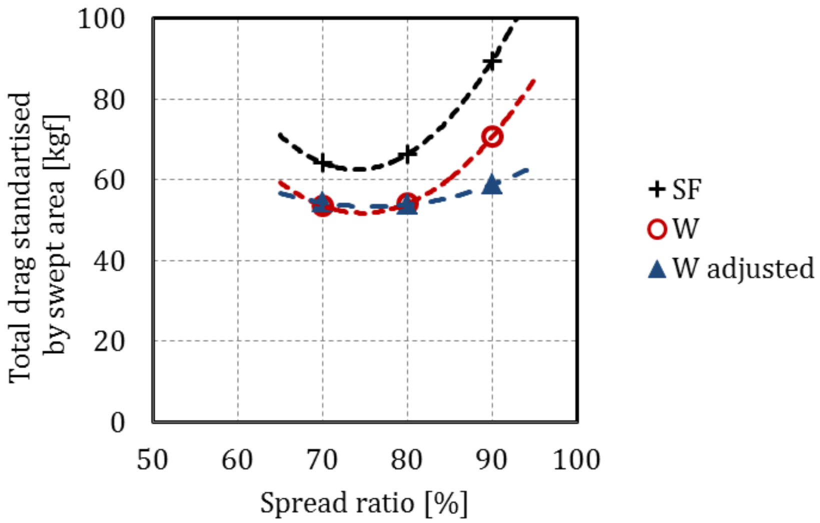


Fig. 3.13 Total drag load (including drag of net and otter boards) standardised by swept area for standard flyer (SF) and ‘W’ trawls [flume tank data]. ‘W’ adjusted shows data corrected for the fore/aft position of the tongue relative to the wings

3.4.2 Engineering and catch performance at sea

Fig. 3.14 and Fig. 3.15 present the GLM-determined total drag and spread ratio for the standard flyer and 'W' trawl systems in the field. The 'W' trawl had 16.0% less drag, which was statistically significant ($p<0.05$), while the spread ratio was 81.0% for the 'W' trawl and 77.7% for the flyer. Table 3.4 summarises the relative engineering performance of the 'W' trawl and shows that the new system provides 19% drag saving when standardised by swept area rate. There was good agreement between flume tank and sea trial data in regards to the measurement of the drag benefit of the 'W' trawl concept; being 17.9% and 19% respectively.

In absolute terms though, the measured drag of the trawl systems in the field was substantially higher than the drag predictions for the netting part and otter boards from the flume tank. This is due to the following reasons: (1) the flume tank estimation did not include ground chain forces or the effect of bridle in-pull forces, (2) drag due to field-material caught in the netting, (3) drag due to the accumulating catch in the cod-end, and (4) drag of lazy lines (used for cod-end retrieval). In the 'W' trawl system, a significant portion of these drag additions will have been redistributed onto the centre line tongues, and hence the relative drag difference between the two systems is consistent between the flume tank and sea data.

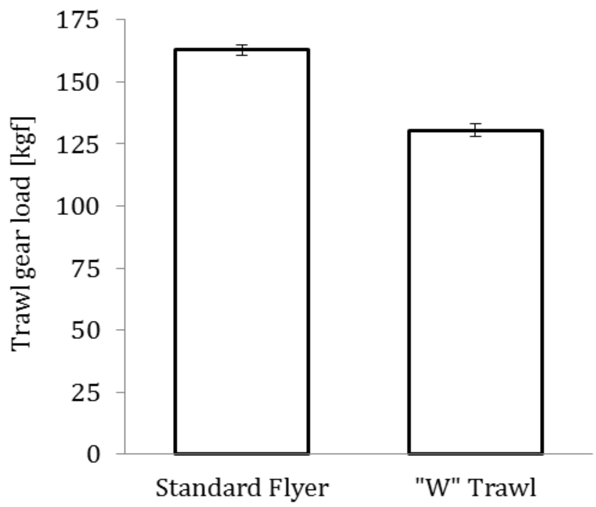


Fig. 3.14 Total trawl drag including otter boards for standard flyer and 'W' trawl with 95% confidence error bars [field results]

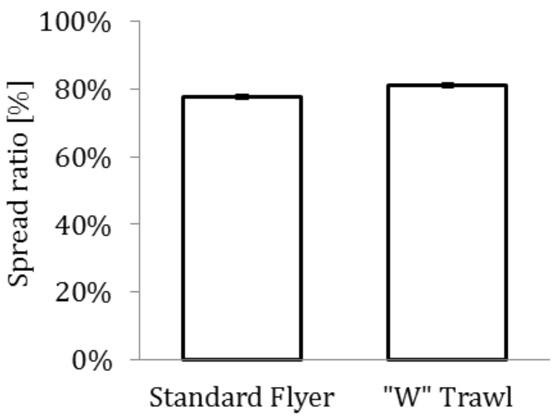


Fig. 3.15 Estimated mean spread ratio with 95% confidence error bars [field results]

Table 3.4 'W' trawl design drag benefits relative to the standard trawl in a single or twin rig configuration

Trawl	Drag	Spread ratio	Standardised Drag
Standard	1	1	1
'W'	0.844 ± 0.026	1.044 ± 0.015	0.810 ± 0.041

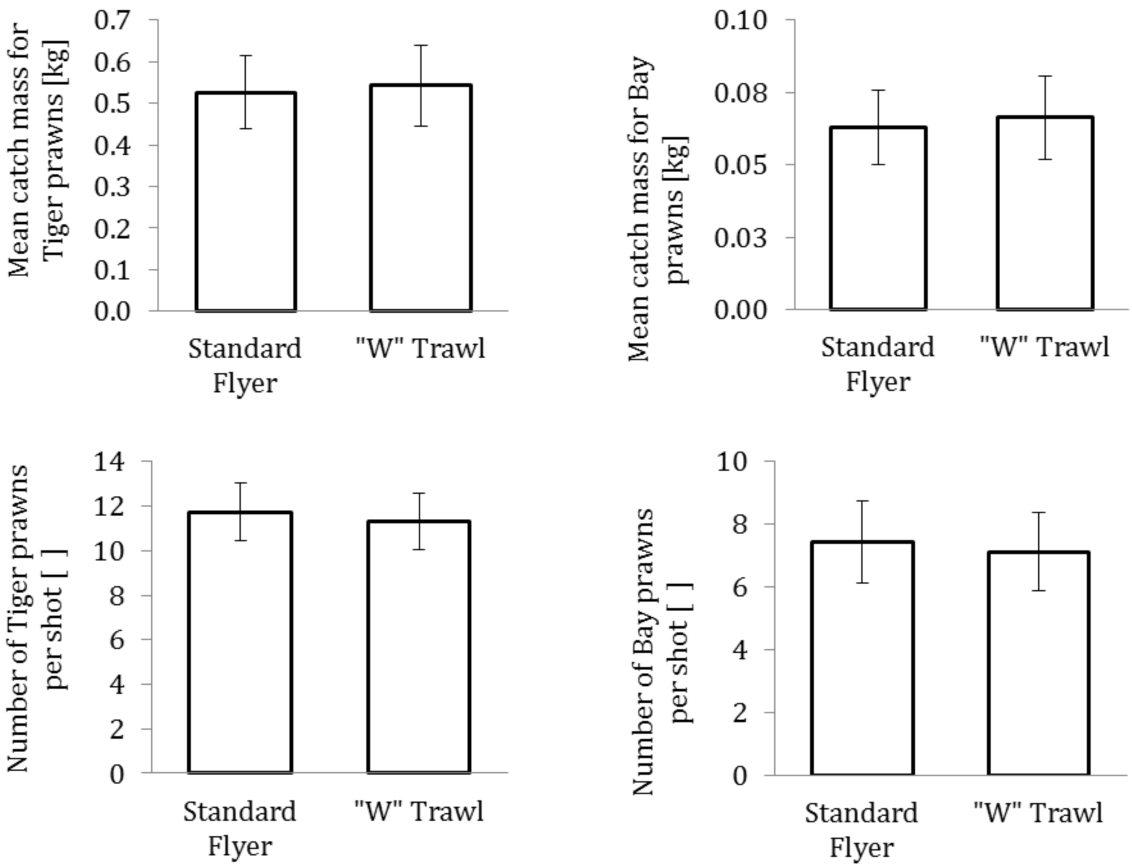


Fig. 3.16 Predicted mean catches per shot by mass (top) and numbers (bottom) for Tiger and Bay prawns

Broadhusrt et al. (2013) measured the standardised total drag for typical Florida flyer trawls in single, twin and quad rig configurations. They reported corresponding standardised fuel usage of 2.88, 2.44 and 2.2 litre of fuel per hectare (swept area) respectively. Based on these results, quad rig had a relative drag of 0.906 compared to the twin rig. Table 3.4 shows that a twin configuration of 'W' trawls has a relative drag of 0.81 compared to the standard twin rig. Therefore, twin 'W' trawls can be expected to produce a relative drag of 0.89 compared to traditional quad rig (refer to (d) and (e) in Fig. 3.1). The superior engineering performance of twin 'W' trawls over quad rig can be hypothesised to be due to the fact that the twin 'W' trawl system has half the number of side netting panels, which have a high drag contribution compared to the extra netting in the upper and lower sheets of the 'W' trawl.

Fig. 3.16 shows the predicted mean catch for Tiger and Bay prawns. The standard trawl caught on average 4% more Tiger and Bay prawns by number per shot, while the 'W' trawl caught a slightly higher amount of prawns by weight – these differences, however, are not statistically significant ($p<0.05$). Fig. 3.17 shows the predicted mean by-catch; whilst the standard trawl caught a 12% larger mass of untargeted species, the difference was not statistically significant ($p<0.05$).

As expected, there were low prawn catch rates for both trawls: firstly, the tested nets are not full size commercial gear, and they are used to locate areas of high abundance of target species; and secondly, the experiment was conducted out of season. Despite there being a small predicted reduction in the number of prawns caught for the 'W' trawl, because it was not statistically significant we do not envisage the new design to have inferior catching performance. This however warrants further investigation because the "W" trawl did have a high swept area rate (4.4%), because of its higher spread ratio, so there is an expectation that catches could be commensurately higher.

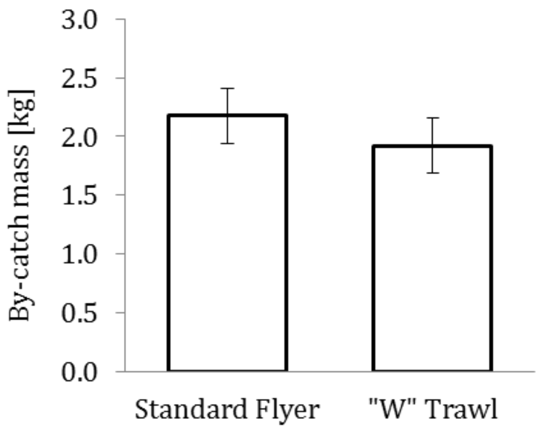


Fig. 3.17 Predicted mean by-catch mass per shot

3.5 Conclusions

Through the work presented in this Chapter, an innovative prawn trawl design has been developed and practical drag savings have been demonstrated from testing in the flume tank and in the field. The specific findings and their implications are:

(i) 64% of trawl drag can be effectively redirected from the wings to the centreline in a small commercial T0 'W' trawl with bracing ropes at the hanging ratio E=0.707 installed down the centrelines of the upper and lower panels.

(ii) Both flume tank and field data showed the use of 'W' trawls in a single rig or twin rig configuration produces significant standardised drag benefits. In the field the drag benefit was about 19% compared to the use of standard trawls. Additionally, 'W' trawls in twin rig is expected to provide approximately 11% drag savings compared to quad rig with standard trawls, and a practical advantage of having a reduced number of cod-ends, BRDs and TEDs.

(iii) Analysis of the catch data showed no statistically significant difference between the conventional and 'W' trawls. Further and more extensive sea trials are recommended with full size commercial trawls to establish comprehensively the catch-per-unit of fuel benefits of 'W' trawl systems.

References

BROADHURST, M. K., STERLING, D. J. & MILLAR, R. B. 2013. Progressing more environmentally benign penaeid-trawling systems by comparing Australian single- and multi-net configurations. *Fisheries Research,* 146**,** 7-17.

DFTI 1989. Y-design - A new concept for trawl design from DFTI. Hirtshals, Denmark Danish Fisheries Technology Institute.

ENERHAUG, B., FØRE, M., ENDRESEN, P. C., MADSEN, N. & HANSEN, K. 2012. Current Loads on Net Panels with Rhombic Meshes. *31st International Conference on Ocean, Offshore and Arctic Engineering.* Rio de Janeiro, Brazil.

GANSEL, L. C., JENSEN, Ø., E. LIEN, E. & ENDRESEN, P. C. 2012. Forces on Nets With Bending Stiffness: An Experimental Study on the Effects of Flow Speed and Angle of Attack. *31st International Conference on Ocean, Offshore and Arctic Engineering.* Rio de Janeiro, Brazil.

LOWE, T. 1996. *An Analysis of the Gains in Engineering Performance Achieved by Constructing Australian Prawn Trawls from Spectra Netting.* B.Sc., Australian Maritime College.

RIPON, M. 1991. *The pleated trawl: An analysis and comparison of the engineering performance of a new construction style of prawn trawl net.* Bach. App. Sci. (Fisheries) Australian Maritime College.

STERLING, D. & EAYRS, S. 2010. Trawl-gear Innovations to Improve the Energy Efficiency of Australian Prawn Trawling. *1st International Symposium on Fishing Vessel Energy Efficiency.* Vigo, Spain.

STEWART, P. A. M. & FERRO, R. S. T. 1987. Four Experiments Investigating Cod-end. *Fisheries Research,* 5**,** 349-358.

TSUKROV, I., DRACH, A., DECEW, J., ROBINSON SWIFT, M. & CELIKKOL, B. 2011. Characterization of geometry and normal drag coefficients of copper nets. *Ocean Engineering,* 38**,** 1979-1988.

WATSON, J. W., WORKMAN, I. K., TAYLOR, C. W. & SERRA, A. F. 1984. Configurations and Relative Efficiencies of Shrimp Trawls Employed in Southern United States Waters. National Maritime Fisheries Services, NOAA.

ZHAN, J. M., JIA, X. P., LI, Y. S., SUN, M. G., GUO, G. X. & HU, Y. Z. 2006. Analytical and experimental investigation of drag on nets of fish cages. *Aquacultural Engineering,* 35**,** 91-101.

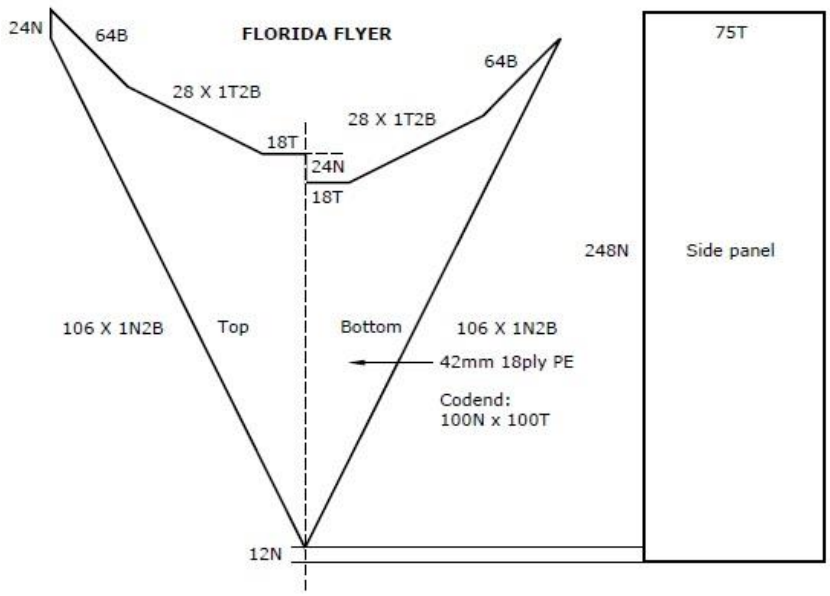
Chapter 4 - Catching performance refinement for 4-fathom ‘W’ trawl

The work presented here tested a prototype full-size ‘W’ trawl, which was specifically designed for the Moreton Bay trawl fishery against a contemporary Florida flyer trawl. The Chapter contains a summary of the relative engineering performance and a detailed examination of relative catching performance as design refinements were implemented to the novel trawl system in order to improve catching performance.

4.1 Test trawl systems and program

The net plans for both trawls are shown in Fig. 4.1. The work described in Chapter 3 identified that the characteristics of the ‘W’ trawl generates special requirements for the design of the otter boards that are to be used in the system. Due to low wing-end tension during shooting away the otter boards need to ‘self-shoot’. This was achieved in the try gear trials, described in Chapter 3, by modifying the distribution of mass within the otter boards such that the centre of gravity was pushed forward and inboard. This made the otter board more easily adopt the correct shooting away orientation as it entered the water and vastly improved the success of the shooting away process. For the trials of full size gear, available resources did not allow for the modification of conventional otter boards. However, a set of batwing boards, which have the characteristics required for the task, were available. The configuration of the batwing board is shown in Fig. 4.2. Given that batwing boards are more drag-efficient than conventional otter boards, a fair comparison of trawl systems dictated that batwing boards would need to be used on the standard flyer trawl as well. The area of the sail was 1.15 m^2 and 0.69 m^2 for the boards used for the Florida flyer and 'W' trawls respectively. The weight of each board was 120 kg and 60.7 kg. The sled and associated rigging for 'W' trawl is shown in Fig. 4.3, and the weight of the sled was 100 kg.

The testing took place on a 14 m trawler, FV Mark Twain, in Moreton Bay, QLD in February 2014. Over 4 nights of fishing, 47 x 25 minute trawl shots were undertaken. During each shot synchronised warp tension and otter board spread measurements were recorded for each side at regular intervals, along with water depth and trawl speed. For each shot warp length was recorded (this was equal for both sides for any given shot) and the catch on each side was sorted into coarse species groups and weighed using motion stabilised scales. A number of different gear settings as shown in Table 4.1 were trialled in order to assess the effect on relative catching performance. The 'W' trawl was set on the starboard side and Florida flyer on the port side (Fig. 4.4).



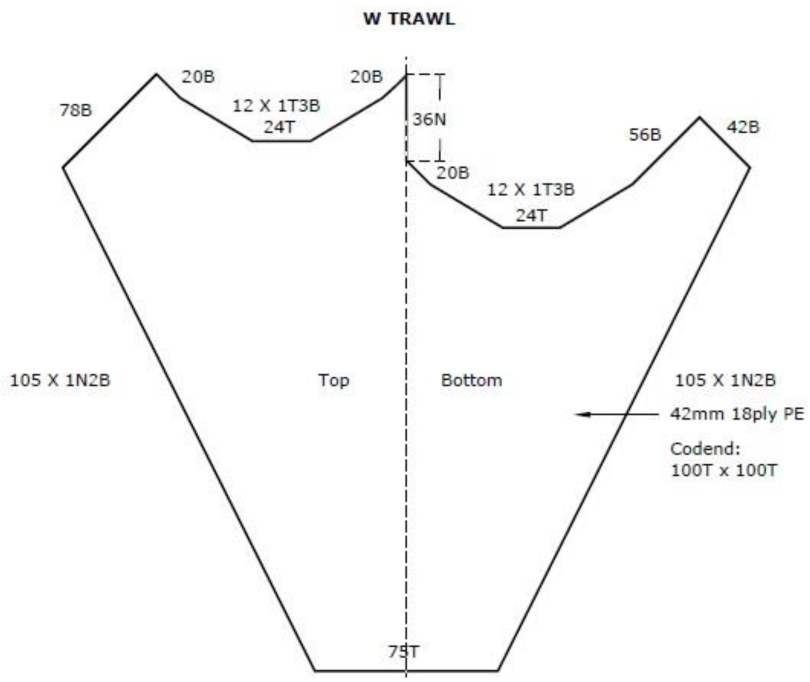


Fig. 4.1 Net plans for 4fm 'W' and Florida flyer trawls

Table 4.1 Testing program: gear modifications were implemented progressively throughout the trials to assess the effect on catch performance

Testing block	Number of shots	Gear modifications implemented to 'W' design
1	10	Standard tongue height (0.9 m)
2	2	High tongue height (1.8 m)
3	13	Standard tongue height (0.9 m); Netting at the wing-ends was secured with an even distributionalong the log ropes, rather than be allowed to slide.
4	8	Low tongue height (0.9 m); The top tongue was pulled forward 75 mm to ensure the back of the sled was in contact with the sea floor
5	2	Standard tongue height (0.9 m); One chain link was removed from each side of the 'W' trawl ground-chain (at the otter board connections) to have the ground-chain slightly shorter than the fishing line. Initially, all ground chains were set "square" - that is they were the same length as the fishing line.
6	12	Standard tongue height (0.9 m); 1.05 m long, 30 mm diameter struts (dan lenos) were installed at each wing-end of the 'W' trawl to ensure headline was being maintained at the end of the sweeps.

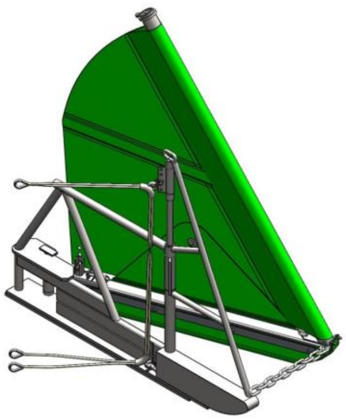


Fig. 4.2 Batwing otter board


Fig. 4.3 Sled rigging


Fig. 4.4 Gear ready for shooting away at the end of the booms: 'W' trawl on the starboard and Florida flyer on the port side

4.2 Results and Discussion

Fig. 4.5 is the average catch from each gear for each block of shots where the set-up of the gear was fixed. The 'W' trawl initially had a very low catch rate compared to the Florida flyer (testing block one – TB1). Variation of cable-to-depth ratio within this block indicated that relative catch could be improved if more warp was deployed. However, this tended to make the standard gear fish very dirty (cod-end contain a lot of shell and mud). It was not possible to deploy different wire length on each side of the vessel because of the need to have a 'marriage line' between the lazy lines for retrieval of the cod-ends at the conclusion of each shot.

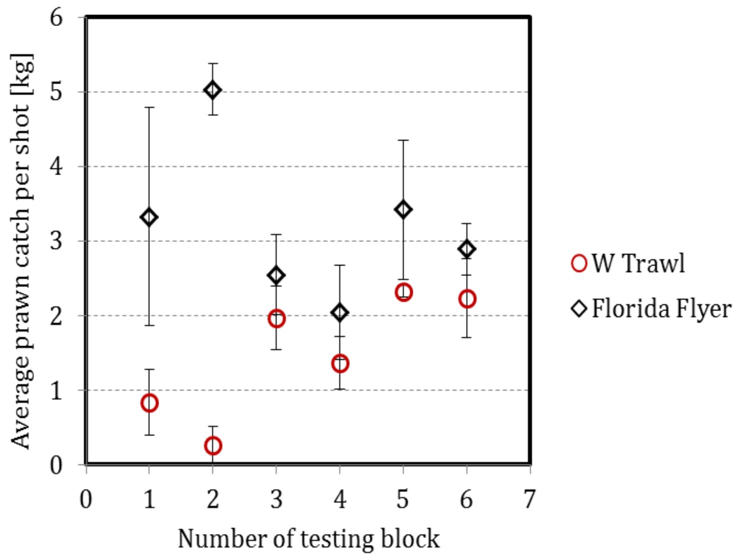


Fig. 4.5 Mean prawn catch weight for Florida flyer and 'W' trawl as gear refinements were introduced (Table 4.1)

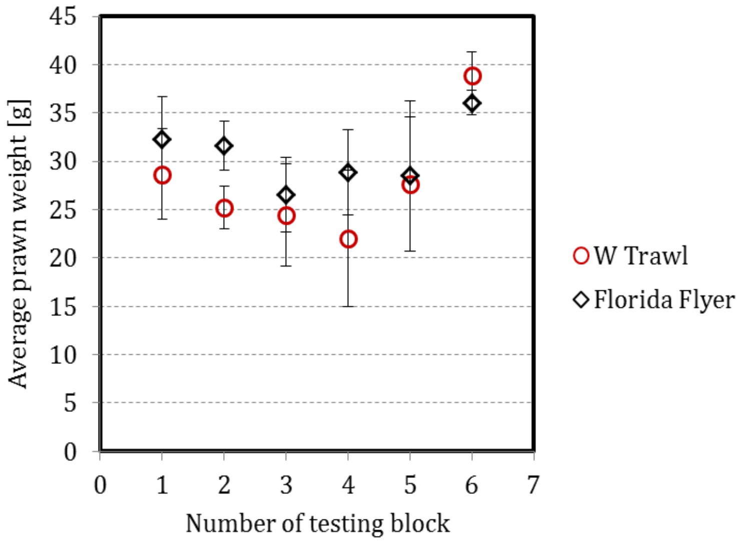


Fig. 4.6 Mean individual prawn mass for Florida flyer and 'W' trawl as gear refinements were introduced (Table 4.1)

Testing Block 2 (TB2) was related to setting the 'W' trawl to fish in high tongue-height mode. This involved disconnecting the upper tongue from the top of the sled and towing it from a 10m 'fly-wire' that was attached to the centre bridle. The connection of the centre bridle to the sled was lowered in order to account for the disconnection of the top-tongue tension from the top of the sled. The sled, however, was difficult to shoot away in this mode (the sled did not maintain a vertical orientation and snagged on wing sweeps) because its centre of gravity was too high (it needs to be very low for this gear configuration). The bridle attachment was raised until the gear was able to shoot away successfully, but it was very dubious that proper orientation of the sled would be occurring on the seabed. The change in the upper tongue height from 0.9 to 1.8 m showed no improvement in relative catch rate (TB2). High tongue height mode was disbanded after 2 shots due to the need to substantially change the design of the sled, to remove mass from the upper part of the sled and therefore lower the location of the overall centre of gravity.

To counter what was perceived to be low ground-chain pressure for the 'W' trawl, close attention was directed to the shape of the wing-ends, which are a bar-to-bar cut in the wings of the 'W' trawl as opposed to a mesh-to-mesh cut in the Florida flyer. This tailoring of the netting in the wing-end removed a lot of loose netting that is typically found in traditional trawls, however the resulting strain on the log rope and the observation that it tended to be mainly applied to the lower end of the logline produced a perception that it could be lifting the fishing line and ground chain in the wings of the 'W' trawl during the trawling process. To resolve this issue, the wing-end bars were secured evenly along the log rope to ensure that the strain in the wing-ends was being applied in a balanced way to both the upper and lower frame line. The average catch rates over the subsequent 13 hauls demonstrated a substantial improvement (TB3 in Fig. 4.5), such that there was no statistically significant difference in either the average mass of prawns caught each shot or the average size of individual prawns (Fig. 4.6) (there was however an observed reduction in catch and prawn size for the "W" trawl).

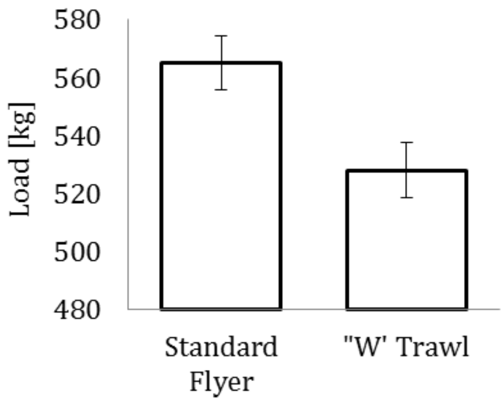


Fig. 4.7 Total system drag for 4fm standard flyer and 'W' trawl with 95% confidence error bars

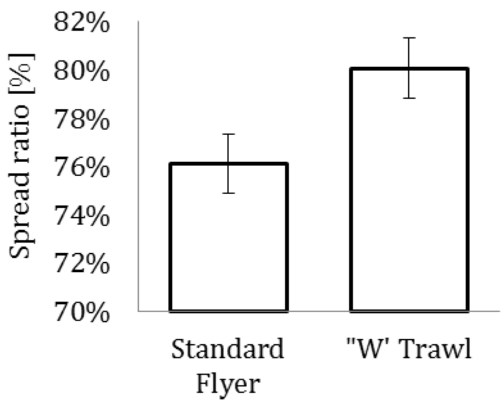


Fig. 4.8 Measured spread ratio for 4fm standard flyer and 'W' trawl with 95% confidence error bars

To further enhance the 'W' trawl catch, the top tongue was pulled forward 75 mm to ensure that the sled was not tilting forward (nose down), which may have led to the chain at the lower tongue being lifted off the sea floor. However, this refinement did not result in an improvement in catch over the subsequent 2 two shots, as shown in Fig. 4.5 (TB4).

The shortening of the ground-chain by one link on each side of the 'W' trawl (TB5) resulted in no improvement in relative catch over the subsequent 8 shots.

The modification of the log ropes in TB3 may have caused lowering of headline height, which would lead to a decreased swept volume. To test this hypothesis, a dan-leno pole was fitted to each wing end. The 1.3m length of the dan-leno poles was calculated to ensure the full vertical opening of the trawl was maintained. No statistically significant improvement in relative catching performance was observed over the subsequent 12 shots (TB6), however, there was an improvement in the size of the prawns caught. For the first time the observed average prawn size from the 'W' trawl was larger than the average size of prawn from the Florida flyer (Fig. 4.6).

Engineering data for 4-fathom trawls is presented in Fig. 4.7 and 4.8. Overall the 'W' trawl showed a 7% lower standardised drag and 5% higher spread ratio. As described above, batwing otter boards were used for these 4-fathom trials, and this is reflected in a significantly lower drag saving benefit for the 'W' trawl, compared to the 2-fathom trials where the 'W' trawl showed 19% lower drag. For the 'W' trawl system the drag benefit comes from the reduced need for otter board force to spread the trawl. In this experiment the otter boards used were more efficient than conventional boards and this benefited both trawl systems (more so the standard trawl), so the drag benefit of the 'W' trawl system in this case was less than previously because the reduced otter board force was not associated with as large a drag force.

4.3 Conclusions

The 4-fathom 'W' trawl was specifically designed for the Moreton Bay trawl fishery and was comparatively tested against a typical Florida flyer used in that fishery. batwing otter boards were used for these trials, and this is reflected in a significantly lower drag saving benefit for the 'W' trawl (7%), compared to the 2-fathom trials where the drag benefit was 19%. For the 'W' trawl system the drag benefit comes from the reduced need for otter board force to spread the trawl. The catching performance was observed to be lower than the standard gear by about 20%. Given the superior engineering performance of the new prawn trawl system and the catch rate being below expectations, the catching performance of the 'W' trawl system requires further investigation. Future field work should involve the use of underwater video cameras to ensure the gear is working at maximum efficiency. Arrangements for work extension in this regard are currently in progress.

Conclusions

The project aimed at developing and refining the knowledge of factors responsible for drag generation by prawn trawl systems that are manifested by the characteristics of the trawl itself, and proposing developments for drag reduction in the context of prawn fishing in Australia.

A series of empirical drag prediction models (equations and tables) have been developed to quantify the extent that trawl body taper, wing netting, spread ratio, and vertical opening affect drag *(Objectives 1 and 3).* The developed prediction equations and tables are to be integrated into the existing prawn trawl performance model (PTPM) described by Sterling (2005) to refine that prediction tool.

Alternation of mesh orientation (T0 and T45) in the principle parts of the trawl was demonstrated to have no practical drag implication in a conventional prawn trawl, but a substantial effect on the forward transfer of drag tension within the trawl, as demonstrated by testing of tongue-trawls *(Objectives 1).*

A novel trawl design leading to significantly reduced system drag was developed, namely the ‘W’ trawl. The concept of the ‘W’ trawl is that a large portion of the drag is redistributed within the trawl away from the wings and the otter boards to the centre line of the trawl, where top and bottom tongues have been installed. This aims to minimise the loading/size of the otter boards required to spread the trawl. In the ‘W’ trawl design, drag redirected to the centreline tongues is transferred forward through a connected sled and towing wire. The developed ‘W’ trawl effectively redistributed 64% of netting-drag off the wings and onto the centre tongues, though the implementation of bracing ropes in the trawl’s construction, and resulted in drag savings of 19% for the associated optimal ‘W’ trawl/otter-board/sled system compared to the traditional trawl/otter-board arrangement in a single trawl or twin rig configuration. Furthermore, based on previously published data, the new system is expected to provide approximately 11 % drag reduction compared to the contemporary quad rig system. The ‘W’ system also exceeds the benefits of quad rig because of the reduced number of cod-end and BRD units to be installed, maintained and emptied each haul. Field results showed that the benefits of the ‘W’ trawl was dependent on the efficiency of the otter boards used and there were mixed catch performance results showing that equivalent catching performance for the ‘W’ trawl system cannot be guaranteed at this point in the system’s development. *(Objective 2).*

Implications

The main outcome is the new trawl design, the ‘W’ trawl, provides drag reductions of approximately 19% when conventional otter boards are used. Once the potential of the new technology is fully realised (through further gear refinement to guarantee equal catch efficiency), the trawl usage will directly benefit prawn fishers by enabling them to reduce production costs by $15,000-20,000 per annum for a typical operator, which equates to about $6M per year for QLD East Coast Fishery. Similar benefits will occur for all prawn fisheries in Australia.

The drag-saving benefit was achieved in the context of an increased swept area rate of 4.4%. If catch efficiency can be improved, such that it is equivalent to conventional gear, the fuel used per unit of catch would be reduced by a total of 22%.

For the data collected to date there is no change to the total bycatch caught for the new system. A fine-scale bycatch study is required to establish if there are species specific differences in bycatch selectivity.

The research into the fundamental drag character of trawl netting and prawn trawls developed new empirical equations and tables for drag estimation of the netting part of the prawn trawl. This work will enable refinement of the existing prawn trawl drag model contained in the Prawn Trawl Performance Model (Sterling, 2005) as the current methodology for the assessment of drag from trawl models in the flume tank is more advanced than when the original work for the PTPM was conducted around 1990. These advancements relate to the use of a new Trawl Evaluation Rig and associated instrumentation, a better understanding of the flow in the flume tank and associated methodology, and improved models in terms of netting material used and rigging to more accurately mimic full-scale commercial geometry.

Recommendations

Further development

In relation to the development of the ‘W’ trawl, the project worked through a number of hypotheses regarding improved performance and established a practical design with demonstrably superior engineering performance. Each phase of testing to advance implementation of the concept in a commercial setting uncovered new important issues that needed further consideration and resolution. In the final phase of the project, where full size gear specifically designed for the Moreton Bay trawl fishery was devised/tested, the catching performance was observed to be lower than the standard gear by an average of 20%. Given the strong drag benefits, further work on the catching performance of the 'W' trawl is justified. This should involve the use of underwater video cameras to establish/ensure the gear is working at maximum efficiency. Arrangements for work extension in this regard are currently in progress as outlined below in the Extension and Adaption section.

Extension and Adoption

Opportunities exist to further refine the 'W' trawl technology in Moreton Bay and northern NSW through industry liaison that will occur in the short term. The availability of clear water locations in these areas will be important to allow video cameras make underwater observations of the gear.

Specifically, the concurrent FRDC project #2011/010 has defined an experiment which will pursue a three-way comparison undertaking on a triple-rig vessel out of Yamba, NSW in November/December 2014. The planned work will compare a standard triple rig containing three Florida flyer trawls with the same system containing three Seibenhauser trawls, and a futuristic triple rig system containing a 'W' trawl on each side and a standard flyer in between.

Discussions will recommence with Austral Fisheries to suggest testing the new technology in the context of Northern Prawn Fisheries (NPF).

Two publications have been submitted to Fisheries Research and Plos One; and two more publications are planned.

The major findings were presented at the Third International Symposium on Fishing Vessel Energy Efficiency in Vigo, Spain in May 2014. The major results of the work were also presented at the Moreton Bay Seafood Industry Association (MBSIA) annual general meeting and a group of NSW trawler operators sitting on the Mulloway Working Group.

A series of publications that reflect 4 chapters of the final report will be published in QLD Fishermen throughout 2014.

A project summary will be published in FISH Magazine in 2014.

The Australian Council of Prawn Fisheries has offered to disseminate the outcomes of the projects throughout its industry network.