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Improving the energy efficiency of shrimp trawling in Newfoundland and Labrador, Canada

George Legge, Harold DeLouche, and Paul D. Winger

Centre for Sustainable Aquatic Resources
Fisheries and Marine Institute of Memorial University of Newfoundland
P.O. Box 4920, St. John's, NL, A1C 5R3, Canada
(George.Legge@mi.mun.ca; Harold.DeLouche@mi.mun.ca; Paul.Winger@mi.mun.ca)

***Abstract* — Collaborative research began in 2009 to investigate methods of reducing fuel consumption during inshore shrimp trawling activities in Newfoundland and Labrador, Canada. Several technical measures were examined during two separate studies in an effort to reduce hydrodynamic resistance of the common trawl designs in use by the fishing industry. The two studies tested the feasibility of shortened bridles, reduced twine diameters, modified footgear, increased mesh size, and improved trawl door design, all as means for reducing hydrodynamic drag and saving fuel. The work was conducted under the controlled conditions of a flume tank in St. John's, Newfoundland, Canada, using scaled engineering models. The results were highly encouraging, but require full-scale at-sea comparative fishing experiments in order to be further validated. This work was the collaborative effort of provincial and federal governments, academia, and industry.**

Keywords-shrimp; trawl; drag; physical modelling; flume tank

I. INTRODUCTION

Northern shrimp (*Pandalus borealis*) constitute a major portion of the commercial marine landings in the province of Newfoundland and Labrador, Canada. Total annual landings in 2009 were 77,663 metric tonnes, with a landed value near $109 million CAD [1]. These shrimp are captured exclusively using mobile bottom trawls, the majority of which are towed using vessels 16.7 to 19.8 m in length (55' - 65'). A significant amount of fuel is consumed while harvesting shrimp, both in steaming to the grounds and while actively fishing. Consumption estimates of 28 million litres of diesel per year [2] currently hinder the industry which is often described as financially marginal, with high fuel costs and consumption, reducing potential profit to all involved.

Two trawl types are currently used by the fishing industry, namely low-rise 2-seam designs and high-rise 4-seam designs, each of which are highly effective at the capture of shrimp and are widely used throughout the fleet. Both types are built and sold by local trawl manufacturers, meeting the needs of approximately 350 trawler vessels around the province.

Collaborative research between government, academia, and industry began in 2009 to investigate methods of reducing fuel consumption during trawling activities. Several technical measures were examined during two studies in an effort to reduce hydrodynamic resistance of the common trawl designs in use. The two studies tested the feasibility of shortened bridles, reduced twine diameters, modified footgear, increased mesh size, and improved trawl door design, all as means for reducing hydrodynamic drag and saving fuel.

II. MATERIALS AND METHODS

Two studies were undertaken in collaboration with two different trawl manufacturers to investigate various methods of reducing fuel consumption during trawling activities. Both studies involved the construction of engineering scale models of shrimp trawls and their evaluation under flume tank conditions [3]. Several factors were investigated, including shortened bridles, reduced twine diameters, modified footgear, increased mesh size, and improved trawl door design. The individual (and sometimes cumulative) effect of these factors on trawl geometry and bridle tension was evaluated over a series of towing speeds and simulated horizontal spreads.

A. Study One

This study investigated the feasibility of various technical measures to reduce the hydrodynamic resistance (drag) of a commonly used 4-seam 1500 mesh shrimp trawl design manufactured by Hampidjan Canada Ltd. (Spaniard's Bay, Newfoundland and Labrador). Factors manipulated included shortened bridles, reduced twine diameters, and a modified footgear.

Financial assistance for this project was provided by the Province of Newfoundland and Labrador, NRC-IRAP, as well as the trawl manufacturing and harvesting sectors (see acknowledgement section for details).

Shortened Bridles:

The evaluation of shortened bridles as a means of improving energy efficiency (reducing hydrodynamic resistance) was based upon flume tank testing of a 1:8 scale engineering model of the standard Hampidjan Canada 1500 mesh trawl. A number of configurations were evaluated, at five towing speeds between 1.8 and 3.0 knots, including:

a) Traditional bridles (120') with a standard V-bridle rigging
b) Short bridles (40') with a standard V-bridle rigging
c) Short bridles (60') with a standard V-bridle rigging
d) Short bridles (40') with a parallel rigging
e) Short bridles (60') with a parallel rigging

Attachment of the bridles directly to the trawl doors with parallel rigging was evaluated in two of the treatments as a means of potentially achieving comparable headline height to the traditional configuration (a). The difference essentially involved separating the upper and lower bridles from a normally common connection and reattaching the bridles individually to the respective upper and lower door legs (Figure 1).

Each configuration was tested in a manner that achieved similar geometrical shape as the standard trawl configuration (120' V-bridle with upper wingspreads between 17.5-18.0 m), by modifying door spread accordingly.

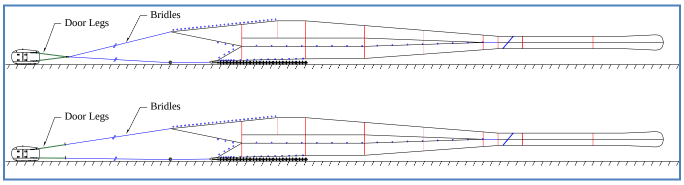

Figure 1: Comparison of the V-bridle and parallel bridle trawl riggings evaluated in Study One (drawing not to scale).

Reduced Twine Diameter:

The evaluation of reduced twine diameters (RTD) as a means of improving energy efficiency (reducing hydrodynamic resistance) was based upon a comparison between two 1:4 scale engineering models of the standard Hampidjan Canada 1500 mesh trawl. One trawl was constructed entirely of the typical polyethylene (PE) netting materials, referred to as the standard trawl. A second (energy efficient) version was constructed using PE netting in the aft end of the trawl, but with high strength reduced diameter netting material (Dynex^{TM}) in the forward section of the trawl, referred to as the RTD trawl. Both model trawls were constructed with full-scale netting materials to improve the accuracy of flume tank evaluations.

For consistency, both the standard and RTD trawls were evaluated with the same length bridles. Five door spreads were evaluated, with the first four door spreads serving mainly as an indicator of height at the aft end of the door leg. The primary evaluation was conducted at the fifth door spread, at which point the door legs were removed from the model trawl and the door leg height position was simulated at the flume tank towing mast. This allowed the relatively large model to be evaluated at a typical commercial spread, but within the confines of the flume tank width.

Modified Footgear:

The evaluation of modified footgear as a means of improving energy efficiency (reducing hydrodynamic resistance) was based upon flume tank testing of 1:4 scale engineering models of both the standard and RTD model trawls (see above).

Two footgear designs were evaluated. These included the industry standard and a modified version of the latter, substituting lower towing resistance components in certain sections. The standard footgear was constructed predominantly of rock hopper disks, with 14" disks strung on the bosom and bunt sections, and 12" disks strung on the wing section. The total wet weight of the footgear, excluding the flying wing section, was approximately 192 kg and it had 74 contact points. The redesigned (new) footgear used the same bosom and flying wing section as the standard footgear. The bunt section substituted 3 bunt bobbins (14") in place of the 13 rock hopper disks (14") used in the standard footgear. The wing section substituted 3 bunt bobbins (12") in place of the 14 rock hopper disks (12") used in the standard footgear. The total wet weight of this footgear was approximately 167 kg, excluding the flying wing section, and it had 32 contact points.

Three configurations were compared:

a) Standard trawl with standard footgear
b) RTD trawl with standard footgear
c) RTD trawl with modified footgear

B. Study Two

This study investigated the feasibility of various technical measures to reduce the hydrodynamic resistance (drag) of a commonly used 2-seam shrimp trawl design manufactured by Frank's Net and Rigging (Stephenville, Newfoundland and Labrador). Factors manipulated included twine diameter, mesh size, and trawl door design.

Traditional Trawl:

Two engineering scale models were constructed of the traditional 2-seam trawl design. These were 1:8 and 1:4 linear scale. The 1:8 model was constructed using small mesh model netting, while the 1:4 model was constructed using full-scale Polyethylene (PE) netting. The main mesh size in the body of the trawl and the top and lower wings was 50mm knot center

(KC). The twine diameter in the top panels (excluding wing tips and guard netting) was 1.3mm, while the lower panels were constructed using 1.8mm (excluding wing tips and guard netting). Larger mesh sizes with larger twine diameters were confined to the upper and lower wing tips and guard netting. Netting having larger mesh sizes and twine diameters are common in these areas and are meant to increase the longevity of the netting as it encounters a large amount of wear during fishing activity and wrapping on the net drum of a vessel.

New Trawl Design:

A new energy efficient version of the traditional trawl (see above) was designed and constructed at a 1:4 linear scale. The frame of the new design was identical to that of the traditional trawl, but newer and more innovative fibers were used in its construction. In particular, Dyneema® netting of larger mesh sizes and smaller twine diameters was strategically placed in locations designed to enhance performance. The square and first top belly, which were constructed using Dyneema® netting, were separated into three individual panels. The middle panels had a mesh size of 100 mm KC and a twine diameter of 1.5 mm. The outer panels were also constructed using Dyneema® netting, but with a mesh size of 50 mm KC and a twine diameter of 1.0 mm. The second top belly, which was also constructed using Dyneema® netting, had a mesh size of 50 mm KC and a twine diameter of 1.0 mm. The mesh size and twine diameter in the top wings were increased from 50 mm to 160 mm KC and from 1.8 mm diameter to 2.5 mm diameter, respectively. PE netting was used in the top wings (just described) as well as in all the lower panels. The mesh size and twine diameter in the lower wings and middle panel of the first lower belly was 160 mm KC and 2.5 mm diameter, respectively. The balance of the panels in the lower remained the same as the traditional trawl.

Improved Doors:

Performance of an older (larger) Type 2 trawl door manufactured by Thyboron Trawl Doors of Denmark was compared to the company's newer Type 11 trawl door. Engineering scale models were constructed and their performance evaluated under flume tank conditions. Both designs were matched for weight, however the newer Type 11 design had an estimated 16% less projected area than the older Type 2 design.

To allow for a direct comparison, both of the model trawl door designs (Type 2 and Type 11) were tested in a position forward of the same trawl model (1:8 traditional). Before performance data was collected, minor rigging adjustments were made to each trawl door to ensure both designs were operating at their maximum coefficient of lift (*Maximum CL*). The Type 2 trawl door was used as the reference design.

Evaluation of the two door types involved the matching of the upper wingspread values of the 1:8 model at a towing speed of 2.2 knots. The research team deemed it necessary to match mouth area (±1%) of the 1:8 model, while comparing the two door types in order provide a more precise evaluation of fishing system drag. Testing was then carried out over a range of three towing speeds (1.8, 2.2, and 2.6 knots).

III. RESULTS

A. *Study One*

Shortened Bridles:

Results demonstrated that the traditional V-bridle rigging had progressively limited application as bridle length was shortened. Headline height in particular dropped notably when moving from a standard long 120' V-bridle connection to a shorter V-bridle connection (Figure 2). In the case of the 60' V-bridle configuration, the headline height was reduced by greater than 0.7 m throughout the speed range tested. In the 40' V-bridle arrangement the headline height was reduced by greater than 1.1 m throughout the speed range tested.

The parallel bridle configuration produced favourable results, by comparison. In the case of the 60' parallel bridle configuration, the headline height was reduced by no more than 0.1 m throughout the speed range tested. At some speeds it exceeded the target headline height by as much as 0.1 m. In the 40' parallel bridle arrangement the headline height was reduced by no more than 0.3 m throughout the speed range tested.

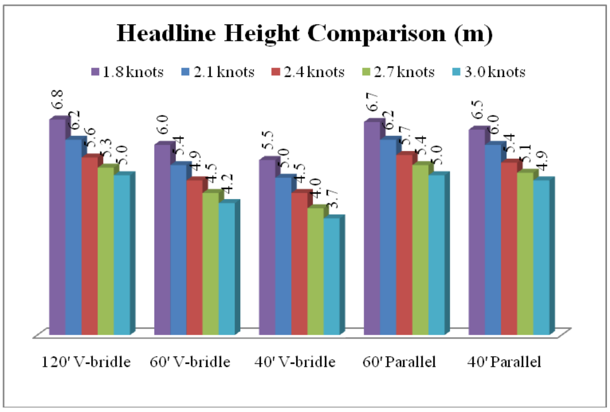

Figure 2: Headline height (m) observed at different towing speeds for the different bridle rigging configurations evaluated in Study One.

Mouth area recorded for the five configurations is shown in Figure 3. The loss of headline height, with decreased bridle length, produced significantly lower mouth areas for the V-bridle configurations. The 60' V-bridle experienced a loss in mouth area of between 16 and 19% throughout the speed range evaluated. The loss of mouth area for the 40' V-bridle was even more severe, ranging from 18 to 29% throughout the speed range evaluated.

The parallel bridle configurations experienced very little loss in mouth area, by comparison. The 60’ parallel bridle experienced a gain in mouth area of between 1 and 4% throughout the speed range evaluated. The loss of mouth area for the 40’ parallel bridle was minimal, ranging from 1 to 3% throughout the speed range evaluated.

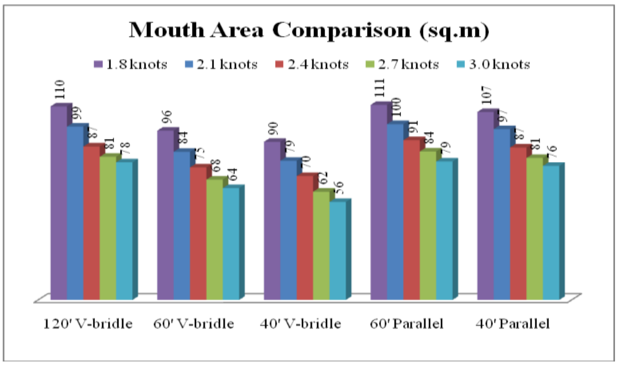

Figure 3: Mouth area (square meters) observed at different towing speeds for the different bridle rigging configurations evaluated in Study One.

Mouth drag recorded for the five configurations is shown in Figure 4. It was hypothesized that the V-bridle configurations, which produce lower bridle tensions, may produce a lower mouth drag. Figure 3 illustrates that this was not the case, as the V-bridle configurations, in all but one instance, experienced the highest mouth drag of all configurations tested. This was due to the loss of mouth area for this type of configuration.

The 60’ V-bridle configuration experienced an increase in mouth drag of between 2 and 10% throughout the speed range evaluated. The 40’ V-bridle configuration experienced an increase in mouth drag of between 7 and 21%, except for at 1.8 knots where it experienced a loss in mouth drag of 13%.

The 60’ parallel bridle configuration produced mouth drags that were from 2% lower to 4% higher than experienced with the standard 120’ V-bridle throughout the speed range evaluated. The 40’ parallel bridle configuration produced mouth drag values that were 2 to 6% greater throughout the speed range tested.

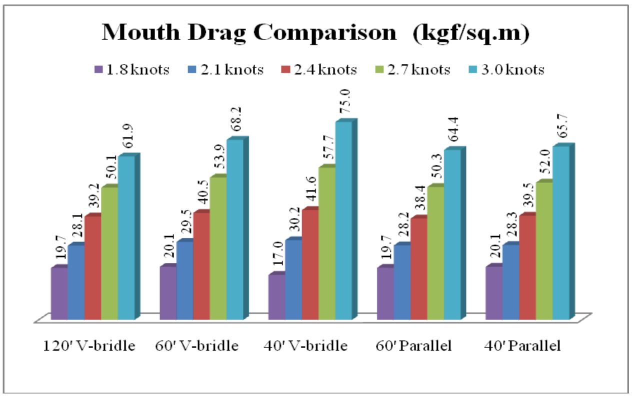

Figure 4: Mouth drag (kgf/sq.m) observed at different towing speeds for the different bridle rigging configurations evaluated in Study One.

Finally, shortening the bridles demonstrated a reduced requirement for door spread (Figure 5). For both of the 60’ bridle configurations, a reduction in trawl door spread of approximately 24% will produce comparable upper wing spreads as the standard 120’ V-bridle trawl. For the 40’ bridle arrangement, a 31% reduction in door spread will produce similar upper wing spread results.

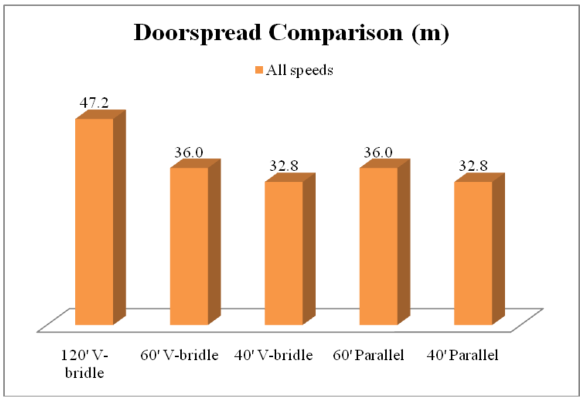

Figure 5: Door spread (m) observed at different towing speeds for the different bridle rigging configurations evaluated in Study One.

Reduced Twine Diameter:

A reduction in total bridle tension of approximately 8% was experienced with the adoption of reduced twine diameters. This reduction translated into a statistically significant reduction (ANOVA, $p < 0.01$) in mouth drag in the order of 18-20%, as illustrated in Figure 6.

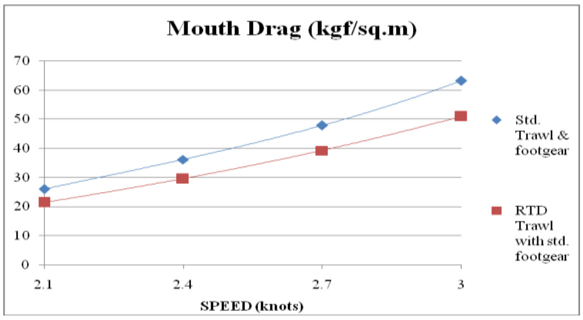

Figure 6: Mouth drag (kgf/m^2) observed at different towing speeds for the standard and RTD trawls, both fitted with the standard footgear.

Headline height (m) recorded for the standard and RTD trawl models is shown in Figure 7. Both trawls were evaluated with the same number of floats on the headline, additionally; bridle length, bridle configuration and door spread were effectively matched. The result was an increase in headline height for the RTD trawl, as evidenced in Figure 7, amounting to 0.4 to 0.6 m more headline height than the standard trawl. This additional headline height was the result of reduced netting drag and would allow for the removal of floats, if desired, to produce a comparable headline height as the standard trawl.

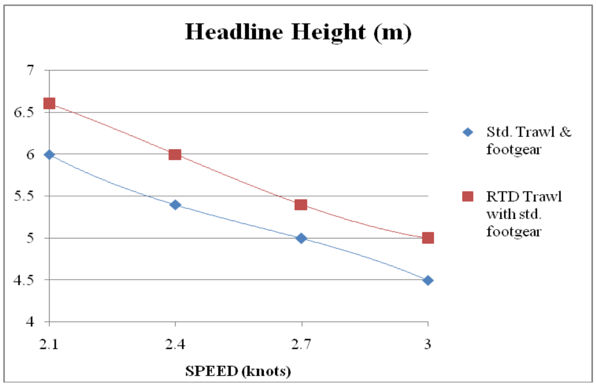

Figure 7: Headline height (m) observed at different towing speeds for the standard and RTD trawls, both fitted with the standard footgear.

Modified Footgear:

Statistical comparison of the 3 trawl configurations tested (see methods) revealed a significant difference in mean bridle tension (ANOVA, $p < 0.01$). Post hoc analysis revealed that, at any given speed, the bridle tension of the RTD trawl with modified footgear was significantly less than the RTD trawl with the standard footgear, which in turn was significantly less than the standard trawl with standard footgear.

This reduction in total bridle tension translates into a reduction in mouth drag in the order of 8 to 11% when compared to the reduced diameter (RTD) trawl fitted with the standard footgear trawl.

Figure 8 shows the combined effect of reduced twine diameter and modified footgear (green line), as compared to the standard trawl and standard footgear (blue line). Together, these two innovations produced a mouth drag which is 26-27% lower over the range of speeds tested.

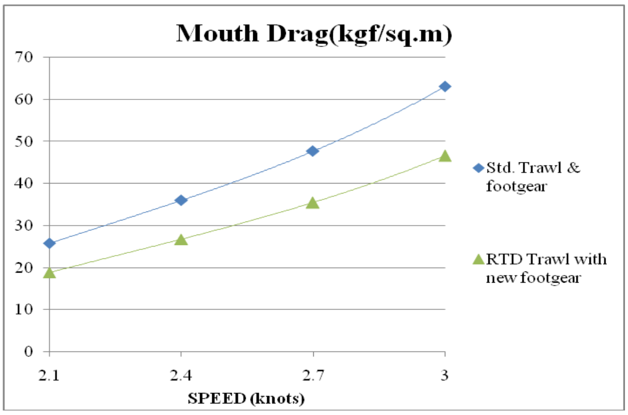

Figure 8: Mouth drag (kgf/m^2) observed at different towing speeds for the standard trawl with standard footgear, compared to the RTD trawl with modified footgear.

B. Study Two

Mouth area (m^2) decreased with increasing towing speed and was comparable between both the traditional trawl and new trawl designs at most speeds (Figure 9). Only at the lowest speed tested (1.8 knots) did the new trawl design exhibit a slightly larger (3.3%) mouth area than the traditional design. This was attributed to the larger headline height and mean wing-spread experienced at this speed.

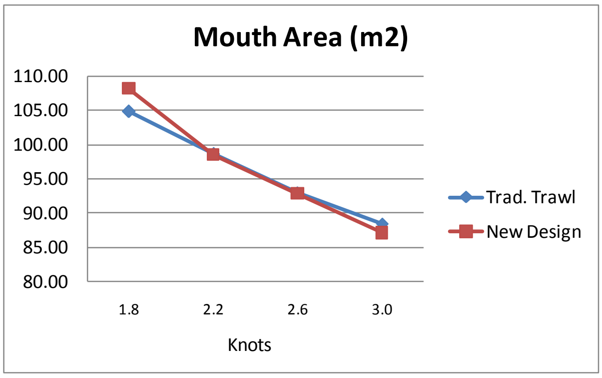

Figure 9: Mouth area (m^2) observed at different towing speeds for the traditional trawl and new trawl designs in Study Two.

Mouth drag (kgf/m^2) increased with increasing towing speed but was consistently lower for the new trawl design (Figure 10). The largest reduction in mouth drag (18%) was recorded at the lowest towing speed of 1.8 knots. At 2.2 knots the reduction in mouth drag was 16%, while at the higher towing speeds of 2.6 and 3.0 knots, a reduction of 17% was measured.

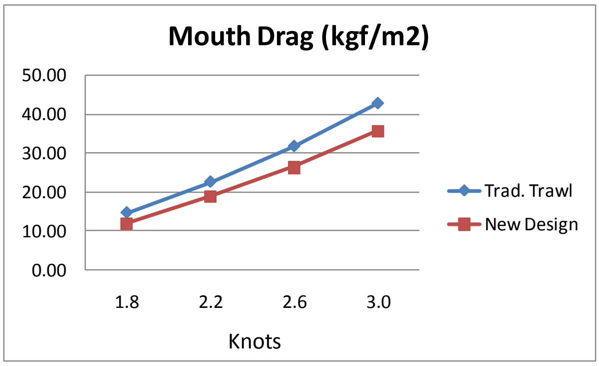

Figure 10: Mouth drag (kgf/m^2) observed at different towing speeds for the traditional trawl and new trawl design in Study Two.

Bridle tension (tonnes) increased with increasing towing speed and was repeatedly lower for the new trawl design (Figure 11). At 2.2 knots (typical towing speed) the bridle tension was 16% lower than the traditional trawl. At 2.6 and 3.0 knots the bridle tensions were 17% and 18% lower respectively than the traditional trawl. It was worth noting that trawl door spreads increased by approximately 4% for all towing speeds, while the bridle angle increased by approximately 5% for all towing speeds.

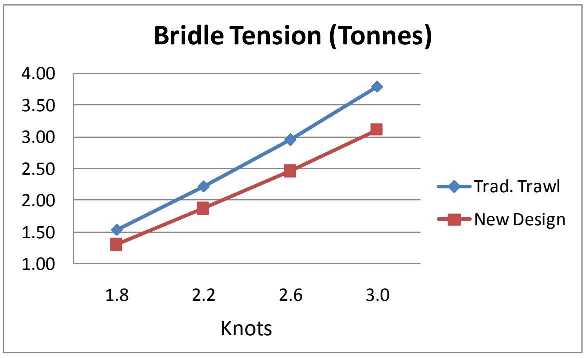

Figure 11: Bridle tension (tonnes) observed at different towing speeds for the traditional trawl and new trawl designs in Study Two.

Warp tension (resolved as total trawl drag in tonnes) increased with increasing towing speed and was consistently lower when using the high performance Type 11 trawl doors (Figure 12). This reduction in drag was approximately 3.2% at 1.8 knots, 2.4% at 2.2 knots, and 1.3% at 2.6 knots.

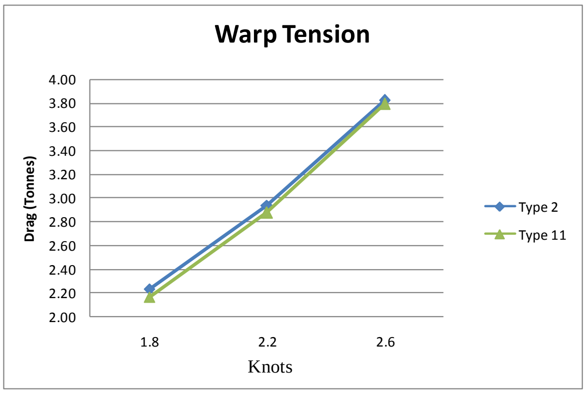

Figure 12: Warp tension (tonnes) observed at different towing speeds when using the traditional Type 2 trawl doors versus the high performance Type 11 trawl doors in Study Two.

IV. DISCUSSION

A. Study One

The use of short bridles in this study did not provide any direct evidence of reduced mouth drag. Interestingly however, the study showed that a switch to shorter bridles, in all configurations, required less door spread necessary to match the target (or traditional) wing spread. This reduction in door spread could provide an opportunity for significant fuel savings. To reduce the door spread, the spreading force of the door would need to be lowered. This may be accomplished by either adjusting the angle of attack of the door or by using a trawl door with reduced area. Either of these changes will reduce the drag of the trawl door, thereby reducing fuel consumption, and will complement other benefits associated with utilizing short bridles.

The use of reduced twine diameters resulted in a significant reduction in total bridle tension (8%) in this study. This reduction in bridle tension has 2 potential advantages:

a) A direct benefit related to overall lower trawl drag.
b) An indirect benefit related to lower inward pulling force, which allows for the use of either smaller doors, or a “reduced drag” trawl door rigging.

When coupled with the 60’ (parallel) short bridle option; where trawl door spread can be reduced by up to 24% without any appreciable change in trawl geometry, the combined reduction of inward pull exhibited by both the bridles and the warps becomes even more significant.

The modified footgear resulted in significantly lower bridle tensions and mouth drags, regardless of towing speed. Coupling this footgear with reduced twine diameters and short bridles, should result in significant reductions in overall trawl drag, reducing the inward pull applied to the trawl doors.

B. Study Two

Results from the flume tank evaluation of the two 1:4 models indicated a significant reduction in bridle tension for the new design. At the typical towing speed of 2.2 knots a reduction in total bridle tension of 16% was realized and 18% at 3.0 knots. These results are from a combination of using larger mesh sizes and smaller twine diameters. The placement of the new netting materials and mesh sizes in key areas of the trawl design also played an important role in reducing bridle tension. This reduction in bridle tension will have a direct impact on fuel consumption as the total drag of the trawling system will be reduced.

The evaluation of the trawl doors indicated an overall maximum direct reduction in the drag component of the warp tension of approximately 3% at 1.8 knots when using the Type 11 trawl door. Considering the trawl mouth area and bridle angles were similar throughout the tests, it is believed that the 3% reduction in warp tension is attributed directly to the Type 11 trawl doors.

Measurements collected on both trawl doors were used to calculate “*Projected Door Area*”. Results indicated that the Type 2 trawl door area was approximately 16% greater than the Type 11. Trawl doors generate lift (spread) through a combination of hydrodynamic forces and sheer/frictional forces created by contacting the seabed. The lift generated by the Type 11 trawl door was to a large extent greater than that of the Type 2. Calculations based on the results collected during testing revealed warp angles (horizontal) were larger when using the Type 11 trawl door, suggesting greater spreading capacity. The majority of this increase in spread is due to the enhanced design of the Type 11 door and its ability to improve performance, based on the hydrodynamic forces acting on it. Because much of the door spread is generated artificially by the towing mast in the flume tank it would be difficult to determine the actual lift generated by the individual trawl door with the approach used here. Further flume tank testing and numerical modelling should be conducted to provide a proper analysis.

V. CONCLUSION

The findings from these two studies demonstrate the feasibility of several potential technical measures for reducing hydrodynamic resistance of bottom trawls targeting Northern shrimp in Newfoundland and Labrador, Canada. The potential for fuel saving is encouraging, particularly when several modifications are made at the same time. Modifications showing promise included shortened bridles, reduced twine diameters, modified footgear, larger mesh, and the use of high performance trawl doors.

The results of these two studies must be accompanied by full-scale at-sea comparative fishing experiments in order to validate the findings. At-sea comparative fishing experiments of these initiatives are planned for the spring/summer of 2010.

ACKNOWLEDGMENT

The two studies outlined in this paper were the collaborative effort of industry, government, and the Fisheries and Marine Institute of Memorial University. Significant contribution by industry was critical to the success, including the trawl manufacturing sector (Hampidjan Canada Ltd. and Frank's Net and Rigging) and harvesting sector (R&C Enterprises Ltd. and B&D Fishing Ltd.).

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