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Effect of mesh size, twine material and trawl gear accessories on the bottom trawls hydrodynamic performance

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Abstract

Nowadays, fishing industry is facing several constraints such as increased fuel prices and declining fish stocks. To improve profitability and ensure the sustainability of the resource, many countries have worked and continue to find ways to make bottom trawls more efficient and more selective. We reviewed how researchers approached the question using different models to make bottom trawls more efficient and selective. The dynamic behavior of a bottom trawl is largely affected by its shape, design, construction, rigging as well as the hydrodynamic and frictional forces experienced while towing along the seabed. In order to make the bottom trawl more economical in terms of fuel consumption and selective, many researchers have worked on the flume tank experiment and on the numerical modeling taking into account several factors, namely: the trawl drag, its swept surface, the materials and the characterization of the flow around its structure. They have developed numerical methods that have combined with flume tank test and sea tests to understand and predict geometry, strength and downward forces on the seabed under different conditions. This set of works has made it possible to develop effective numerical simulation software such as Dynami T (France), Simu Trawl (Korea) and Trawl Vision PRO (Uruguay), the most used by fishing gear manufacturers and researchers. An overview of the evolution of trawl performance, the methods used, as well as an assessment of the results of each numerical modeling, experimental and numerical simulation method by different fishing gear design software, as well as their reliability of these results are conducted in order to provides valuable insights to fishing companies, trawl designers, net manufacturers, researchers and educators using numerical modeling methods and flume tank studies to improve bottom trawl performance.

Keywords: bottom trawl, numerical simulation, trawl performance, flume tank

1. Introduction

The development of fishing gears for the commercial fishing industry has changed dramatically over the last few decades as a result of increasing regulations, the need for species-and size-selectivity stringent bycatch restrictions, as well as the necessity to reduce fuel consumption and minimize ecosystem impacts. Bottom trawls used for commercial and scientific purposes have become increasingly complex in their design, material choice, and construction. Understanding the dynamic behavior and performance of these flexible structures prior to expensive sea trials is a key step in the fishing gear development cycle (Winger *et al*., 2006). Numerical modelling and simulation in particular are becoming one of the popular methods of evaluating trawl designs and assessing their performance during the early stages of gear development (Fiorentini *et al*., 2004; Lee *et al*., 2008; Queirolo *et al*., 2009; Nguyen *et al*., 2015&2016 and Ming-Fu Tang *et al*., 2017). Historically, some researchers have developed drag-prediction equations for particular trawl designs and components based on regression analysis of experimental test results. For example, Priour (2005) [25] developed a finite element method for simulating flexible structures made of nettings, cables and bars, such as fishing gear and fish farming cage, which focus on a specific triangular element devoted to net modelling, G. pichot (2007) [29] developed simulation of the flow around and inside a rigid axisymmetric net, Kristiansen and Faltinsen (2012) proposed and discussed a screen type of force model for the viscous hydrodynamic load on nets, assuming that the net is divided into a number of flat net panels and Tang M F *et al.* (2017) [34] developed fluid-net interaction model of a trawl system to understand the hydrodynamic behaviour of trawl by k-ω shear stress turbulent (SST) model. An improvement in energy efficiency could be achieved using a different fishing technique: Macdonald *et al.* (2007) compared longline fishing with trawling, Thomsen (2005) showed that vessels converted from single trawling to pair trawling saved 40-45% of fuel, Rihan (2005) suggests returning to the traditional single rig trawling of twin gear in order to decrease fuel consumption, Kim *et al*.(2007), and D Priour (2012) approached this problem from the angle of hydrodynamic resistance by developing a new approach to analysis fishing gear performance using computer simulations. Parente *et al*. 2008), Sterling and Eayrs (2010) and Elvar Hermannsson (2014) have also developed optimization techniques to reduce fuel consumption rather by working on the hydrodynamic resistance of the trawl doors and characterizing the flows around it. In the present study, we describe the different methods used to increase performance of bottom trawl net. The methods described in this review are based on numerical modelling (Lee *et al*., 2005; Takagi *et al*., 2003; Tsukrov *et al*., 2003; Priour, 2013;Tang M F *et al*.(2017)) [15, 28,3 4] or analytical modelling (Park, 2007; Amelia de la Prada and Manuel González, 2011), flume tank tests (Ward *et al*.,1993, Ferro *et al*., 1996; Balash and Sterling, 2015) and full scale tests at sea (Fiorentini *et al*., 2004; Sala *et al*., 2011).

2. Background

Fishing vessels have a high energy demand and as nearly all modern vessels are powered with fossil fuels, rising fuel prices have resulted in inflating the operating costs of the fishing industry. When fuel expenses increase, the incentives for improving fuel efficiency also increase. The towed fishing gear generates significant resistance (drag), which leads to a significant fuel consumption. Trawling is one of the most important commercial fishing methods constituting about 60% of the marine fish landings of world (Morgan, 2004). Studies shown that 70-80% of the fuel for trawling is being used for towing fishing gear (trawl-net 53%, trawl-doors 25%, warp wires 4%, sweeps 7% and Weights 8%)(Adrian and R Bonnet, 1996). Energy efficiency of bottom trawl is greatly affected by the drag, as well as by the area it sweeps during fishing operations. Generally, the drag results in an overall increase of the energy consumption. Many types of optimization techniques have been developed to tackle bottom trawl design in order to reduce the volume of fuel per kg of fish caught (Khaled and D Priour, 2010; D Priour and De La Prada Amelia, 2015**)**. Recently, the profitability of the industry has become marginal due to declining stocks of some species and fluctuating fuel costs. The different research conducted within the bottom trawl industry has primarily focused on by-catch reduction, fuel consumption reduction and effects of bottom trawl trawling on the seabed with little attention given to gear design (Sterling, 2007; D. priour 2012; Y Yao, 2016). However, gear modifications may not only improve fishery profitability, but maximize effects on ecological sustainability.

3. Investigation on the trawl design

Trawl performance is investigated using flume tank tests (Ward and Ferro, 1993; Ferro *et al*., 1996), full scale tests at sea (Sala *et al*., 2011), analytical modelling (Park, 2007), or numerical model (Lee *et al*., 2005; Tsukrov *et al*., 2003; Priour, 2003; Priour, 2013). These investigations take into account the design of the gear, the water speed, and the bottom contact, but there are few studies on catch effect in the bibliography; only two seem relevant. In the first study on this subject, which was based on exhaustive flume tank experiments, O'Neill *et al*. (2005) concluded that the towing speed and the maximum frontal area of the codend were the predominant components of the codend drag. The second study dealt with the development of a numerical-statistical model of the catch shape and volume inside the codend, also based on flume tank tests (Priour and Herrmann, 2005).

An experimental study can be conducted at model (figure 1) or full-scale. In model experiments, a studied process commonly has to be simplified with certain assumptions which may produce an error. However, the model experiments eliminate the noise effect of the environment and they are also more economical (Cheslav Balash. 2014).

Initially a relation between experiments at model and full-scale was suggested by Tauti (1934) [35]. According to his theory, the drag force is assumed to be proportional to the square of the water velocity U (1): drag ~ U^2.

Chow (1969) and Hu *et al*. (2001) applied the law to model mid-water trawls at a number of scales. The comparisons with full-scale showed a 50-70% drag force over prediction. Fiorenti *et al*. 2004; G. pichot 2007; Sala *et al*., 2011 also applied Tauti's law for bottom trawls and found a large difference in drag between full-scale and model values. When Tauti's law is applied to model tests, a high drag prediction occurs because the drag coefficient is assumed to be constant between the model and the prototype, whereas this is often not the case. Dikson (1961) proposed to use the Froude number for scaling: Fr = $\frac{U}{\sqrt{gL}}$ (where U is the flow velocity, g is the acceleration due to gravity, and L is a characteristic trawl length). A recent application of Dickson's approach (Hu *et al*. 2001) showed a significant divergence in the drag force between full-scale and model values as for Tauti's method. Applying the Froude number as a condition of dynamic similarity assumes that the net is a solid three-dimensional body, but it is a porous two-dimensional surface (O'Neill, F.G. 2003). Instead O'Neill proposed to use twine thickness d, not trawl length L, as a geometric parameter for the Froude number; and the Reynolds number incorporated the trawl length. It was modified as follows to satisfy the similarity between inertial and viscous forces: Re=$\frac{Ud^2}{\theta L}$. G. pichot *et al* (2007) demonstrated that Froude and Reynolds number cannot be satisfied at the same time, since Froude's number expresses the relationship between inertial and gravitational forces and Reynolds number the ratio of inertial forces to viscosity forces. She says that in practice, the Reynolds number is larger, but for reasons of technical feasibility, she used the Froude number because Reynold number would cause speeds too high velocities, higher than the applicable limit speed in the flume tank test.

Fridman (1973) conducted a dimensional analysis and recommended similarity criteria for fishing gear. The Froude number was modified as a ratio of the hydrodynamic forces to buoyancy forces: Fr = $\frac{\rho U^2}{\gamma L}$. It was shown that for a Froude number above 130, which is a common case, the effect of buoyancy forces on the shape is not significant (Fridman, AL 1973). The Reynolds number was assumed to have a negligible effect on the drag coefficient for model experiments conducted in the subcritical flow regime. Dynamic similarity was proposed by keeping the ratio of static (generated by rigging) and hydrodynamic forces constant, namely Newton's number: Ne=$\frac{q}{\rho L^2 U^2}$ where q are the static forces generated by rigging.

In trawl modelling, an important condition is to ensure that the netting solidity, the ratio of twine area to projected area, is similar between the models and full-scale. It is often impossible to scale down twine diameter and mesh size proportionally, which results in net blockage area being different between the model and prototype, and hence may lead to scaling miscalculation. Tauti (1934) [35], Dickson (1961) and Fridman (1973) suggested using full-scale material in model experiments. These experiments are commonly conducted in flume tanks and wind tunnels. In a flume tank setup, the flow velocity and consequently hydrodynamic force have to be scaled down to minimize turbulence and wall proximity effects. Sterling (2005) [33] described a comprehensive performance prediction tool for low-opening prawn-trawling systems (Prawn Trawl Performance Model; PTPM ver3), which includes trawl and otter board drag, and seabed-contact forces from the ground gear and otter boards. Sterling's (2005) [33] model is based on core empirical equations characterising the drag of the component trawls as a function of the values of key defining variables readily recorded in trawl plans by net makers and trawl operators. Since its inception, the PTPM continues to be extensively used for fisheries research and management, and especially as a tool for trawl-system design and assessing the fishing power of operators in key Australian prawn fisheries in the first case, errors in predicting swept area rate, considered an important performance parameter, were less than 5%. In the second case, the results suggest that between 50% and 60% of the variation in the seasonal catching performance of trawlers in the Northern Prawn Fishery (NPF) is explained by predictions of swept area rate derived by the PTPM from the available data for that fishery.

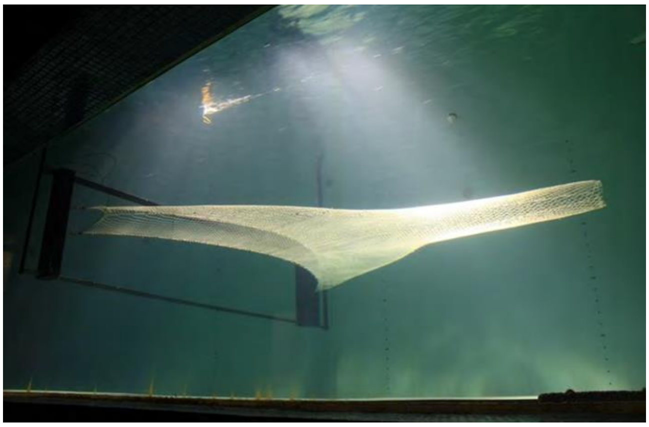

Fig 1: Trawl model attached to the Trawl Evaluation Rig and tested in the mid-stream of the flume tank of at the Australian Maritime College (*Cheslav Balash et al***,** 2014).

4. Research on the bottom trawl performance

The studies dedicated to trawl optimization are not recent. A revolutionary drag saving technology was introduced in the Gulf of Mexico in the early 1950's with a concept of multiple rigs. During the 1970s large meshes were introduced in the mouth of the trawl, which led to a decrease of the drag and therefore a decrease of the fuel consumption, without affecting the catch. Studies on the dynamic behaviour and performance of bottom trawls have been investigated for several decades using various theoretical and experimental methods for reducing the trawl drag and thereby reducing fuel consumption. (Tauti, 1934; Dickson, 1961; Fridman, 1973; 1986; Wileman., 1984) [35].

4.1 *Bottom Trawl performance through efficient designing*

Large mesh sizes of net and thin twine diameter can generally reduce the drag of the net with respect to specific horse power (krishamury 1975, Prado 1977, Fujishi 1985). The drag resistance exerted by fishing vessel is about 15 to 20% of the drag resistance of trawl (Fiorentini *et al*., 1981). Sterling (1998) demonstrated that triple rig can give about 50% reduction in drag compared to single rig. The nature of drag saving with multiple rigs cannot be solely attributed to reduction in twine surface area but due to redistribution of the otter board drag which is required for the horizontal spread of the trawl mouth. The results of the study carried out by Sala *et al*. during 2008 showed that it is possible to design trawls with 30% reduction in fuel consumption during the tow and with 40% more headline height, using larger mesh sizes, stronger gear materials and effective designing of wings. Drag reduction technologies have been evolved with the view to make the trawls more energy efficient. Trawl design modifications also aimed at possibility for drag force reduction. From the experimental sea trials of Prat *et al* (2008), he found that both the total gear drag and the net drag were strongly affected by the towing speed and warp length. He also found that there was an increase in drag with the increasing warp length or bottom depth. During the 1960s, bottom trawling was developed as a capture technique for shoaling species. In trawling net and wires together may account for 2/3 of the total drag whilst trawling (Balash, 2012). Balash *et al*., (2015 and 2016), developed a new technology called the "W" trawl for further drag reduction of trawl system and studied drag characterisation of prawn-trawl. The principle of this trawl is that a large proportion of drag due to netting can be transferred to a central towing wire through a trawl sled, which is connected to upper and lower tongues, as opposed to putting load on the otter boards through the wings of the trawl. The study was carried out in Australian prawn fishery in which they developed shorter trawl by increasing the body tapper and by altering the netting angle to the direction of towing. This altered design showed decrease in drag and reduction in by catch (Broadhurst *et al*., 2012).

4.1.1. Effect of mesh size on the bottom trawl hydrodynamic performance

Increase in the mesh size brings about decrease in total trawl resistance and reduction in weight of rigging and hence pave way for increasing trawling speed (Fridman, 1969). During late 1980s investigations regarding the application of T90 (90mm square mesh) meshes in netting used in cod ends and extension sections as a means of improving size selectivity. Wileman and Hansen (1988) carried out flume tank experiment with model nets. The study included the estimation of drag effect of demersal models with reduced netting area using larger meshes, thinner yarns and knotless netting in different parts of the trawl. Results from this investigation showed that a drag reduction of 25% could be achieved with the new model demersal trawl. Based on this result material for all sections of the trawl were changed for potential fuel saving. Arkley (2008) reported that approximately T90 meshes are required as much as one third of the net compared with standard diamond mesh to make the net energy efficient. The study revealed that the use of T90 mesh can reduce the twine surface area of the trawl net and hence would pay way for the reducing of drag of the net automatically. Balash *et al* 2016 studied Prawn

Trawl Shape due to Flexural Rigidity and Hydrodynamic Forces, during this study they developed a novel experimental technique to quantify flexural rigidity for nets. The geometric parameters of nets were measured applying a digital photogrammetric method. The drag was found to be strongly and non-linearly affected by flexural rigidity: an increase of the flexural rigidity by 16% caused the drag increase of 7% and an increase of the flexural rigidity by 19% lead to the drag being increased by 20%.

4.1.2. Effect of twine material and twine diameter on the bottom trawl hydrodynamic performance

Reducing the towing drag or resistance of trawl nets can be reached by changing twine material and twine size. Verhulst and Jochems (1993) conducted a series of experimental fishing replacing polyamide ropes with ropes of strong material namely Dyneema SK 60 in the front part of a large Dutch pelagic trawl. The experiments revealed the possibility for obtaining about 10% higher towing speed for the same engine power with the new type of rope. Apart from the increased towing speed the mouth area of the net could be increased by 25%. Lowe (1996) investigated the drag saving potential for Spectra netting compared with polyethylene netting prawn trawls. Spectra permits higher breaking strength, so for similar breaking strength, 49% thinner twine was used to build spectra trawls. However, in a non-dimensional form, as can be seen in Figure 1, the drag coefficient for spectra netting is on average 10% higher compared to polyethylene; it varies 3-14% depending on the spread ratio. The drag variability could occur due to different material stiffness. Another method for achieving reduced drag is by using smaller diameter twines in the trawl netting. Diameter reduction of twine visibly resulted in decreased drag force. ‘Tricolor Elite High Tenacity Braided Polyethylene’ is a new netting material which is thinner and stronger per unit weight than the traditional or ‘Regular Braided Polyethylene material’ (Wray, 2001). From the compared study between the normal braided twine and ‘Tricolor Elite High Tenacity Braided Polyethylene’, it shows that the gear tension was reduced by 8.3% and 42% reduction in surface area. According to Balash and Sterling, (2015) the most recent innovation to significantly reduce drag is the use of stronger Dyneema and spectra netting materials that allow the use of thinner twine compared to traditional gear materials. The breaking strength of small diameter Dyneema and spectra netting has been found to be comparable with traditional gear material, however the thinner twine resulted in decreased drag.

Ward *et al*, 2005, Kim *et al*., 2007 conducted an experiment study related to the impact of reduction of twine diameter and increase of mesh sizes on the fuel consumption in trawling. They observed significant decrease in fuel consumption due to the reduction of twine diameter and increase of mesh size. In order to reduce the drag per swept area, a numerical tool was developed by R. Khaled and D. Priour (2012 and 2015) for the automatic optimization of the trawl design. They improved energy efficiency by sequential research method (SOT) and SRT method (sequential refinement). There obtained reduction of 16% with SOT method and 30% with SRT method.

4.2. Effect trawl gear accessories modification on the hydrodynamic performance

The trawl doors, sweep lines, foot-rope and floats account for about 40% of the drag of the trawl (Adrian, R. Bonnet., 1996, Wray, 2001). Khaled *et al*. (2013) found that it would be possible to reduce the ratio between trawl drag and catch efficiency by up to 46% by optimizing the length of the cables. Further they found that increase in the mouth area of trawl lead to better catching efficiency without any increase in otter door drag.

Sterling and Eayrs (2010) developed a more recent prototype termed the ‘batwing’ otter board to overcome the various issues related to otter boards. This otter board was designed to remain at a constant angle of attack of 20 degree with robust stability which was achieved through a unique rigging strategy and the drag was reduced to 7%. Sterling (2008) compared a standard ground chain of Australian prawn trawls which was designed to heavily skim across the surface of the seabed to a Soft-brush ground gear consisting of a floated dyneema rope with short light-weight vertical chains. During this study, he found that the overall drag of a single-net trawl rig could be reduced as much as by 3.4% besides increasing the spread of the net increased by 3.6%when the Soft-brush ground gear was used. Many research has been done on the optimization approach for trawl-doors accurate, high-fidelity computational fluid dynamics(CFD) models (Mulvany, Tu, Chen, and Anderson 2003; Leifsson *et al*., 2014; leifson,2015; Takahashi, Fujimori, Hu, Shen, and Kimuraba ,2015), which exploits an iterative scheme with local response surface approximation(RSA) models of the expensive CFD trawl-door model constructed in each iteration. The research of Elvar Hermannsson, Leifsson *et al*.(2012,2013 2014 2015,) [9, focused on optimization algorithm of trawl door using two and three-dimensional (2D and 3D) computational fluid dynamics (CFD) models. They pointed out that accurate CFD models, especially 3D, are computationally expensive. Their proposed method is iterative and uses low-order local response surface approximation models as surrogates for the expensive CFD model to reduce the number of iterations. The results showed that the hydrodynamic efficiency could increase by 32% for the typical modern trawl door, and by 13% for the novel airfoil-shaped trawl door from the 2D design optimization and that the hydrodynamic efficiency could increase by 6% for both the above mentioned trawl doors from the 3D design optimization. In order to maximize the lift-to-drag ratio Cl=Cd with no additional constraints Ingi Mar Jónsson(2016) had used a mixed modelling approach based on surrogates for trawl shape optimization, i.e., construct a function approximation substitute using variable physics-based fidelity models. the result showed that, compared to the initial design, Cl = 2.46 and Cd = 0.0275 giving a lift-to drag ratio of 89.6, the lift coefficient has decreased about 10.3% and the drag coefficient decreased even more, or about 10.6% resulting in an increase of approximately 7.82 % of the lift-to-drag ratio.

J Liu, H L Huang *et al*. (2017) conducted the research on the effect of angle of attack on hydrodynamic characteristics of the oval cambered double slotted otter board in bottom trawl fisheries. The result showed that the D3 otter board (with a front flow deflector angle of 29 °) had a better hydrodynamic performance and efficiency than the other tested board, and suggests that the best working scope for the angle of attack is between 15°~30°, in which case, CL>0.633 and K>2.643, and that the mean value of the lift coefficient was 1.071 and the mean lift to drag ratio was

3.482.

4.3. Modelling of flow around model net

The experiments carried out in the flume tank allowed to solve the problem of the coupling net / fluid. The first test (Bearman, P., 1984) used a Laser Doppler velocimetry (LDV) technique to obtain components, while the second experiment used a particle image velocimetry (PIV) technique (figure 3). This last campaign focuses on the location of turbulent structures in the vicinity of the net through instantaneous images of the stream. Vincent (1999) described mechanical equations (structural and hydrodynamic) to characterize the shape and performance of a bottom trawl and the research was done in the flume tank of 'Boulogne-sur-Mer' in France in order to improve the knowledge of the velocity field that is established inside and outside the rear part of a towed trawl at constant speed. This allowed him to simulate the viscous and turbulent flows around the cod-end of trawl, assuming the shape of the trawl and the axisymmetric flow, after studying several models he drew up abacuses for the determination of the three coefficients used by the numerical model. G. pichot, D. priour and R. Lewandowski (2006, 2007, 2008, 2009), measured velocity profile inside and around a rigid resin model in the flume tank " Boulogne sur mer"(figure 4). Hydrodynamical measurements are obtained using a laser Dopper velocimeter (LDV). They studied the approach of flow simulations around net axisymmetric rigid and the flow modelling was carried out with fluid / structure interaction in order to model the fish in the codend and make it more selective. They show the existence of a weak solution to the problem coupled in dimension 2. And then, present the axisymmetric computation code that they developed, named SeaNet. They modelled codend taking into account the interaction between the fluid and the structure by solving the Navier-Stokes / Brinkman equations with a turbulent viscosity νt = νt (k), where k is the turbulent kinetic energy. They had used a truncation of the function νt = ν where is taken equal in each point to the local size of the mesh; k is the solution of the standard equation. The resolution is based on finite element technique. An implicit scheme is chosen for the problem governing the unknowns (u, p) (initialized by solving an auxiliary Stokes problem) and a semi-implicit scheme for k (initialized to a constant). In 2012 E. Bouhoubeiny *et al.* (2012 and 2013) studied the characteristics of flow governing the hydrodynamic behavior of bottom trawls. Measurement and post-processing tools have been implemented to obtain and characterize experimental databases governing hydrodynamic behavior of different parts of a trawl. Specifically, particle image velocimetry (PIV) and orthogonal eigenvalue decomposition (POD) post-treatments were performed in different planes around a bottom trawl, net panel and codends. Ming-Fu Tang *et al* (2017) has developed a numerical model to analyze the flow field through the trawl by proposing the deformation of the trawl. The Shear Stress Turbulent (SST) k-ω model is used to describe the trawl flow field and the element method. Non-linear finishes with large deformation. The main concept of the numerical approach was to combine the SST k-ω model with the high-strain nonlinear finite element method to simulate the interaction between the flow and the trawl with unidirectional coupling techniques. They propose numerical model simulation to calculate a drag force on the net panel. To ensure the reliability of the calculated results, a 50 mm mesh size reference trawl model was built with the twine of 1.45 mm diameter, the number of ply is 27 applied in Sterling (2005). The reference model was tested over a wide range of SRs from 0.60 to 0.78, with the increment of 0.03 and the flow velocity of 1.0 m·s-1. The calculated drags on the reference trawl model obtained from the numerical simulation agree well with the data estimated using the PTPM ver3 (Sterling, 2005) and the relative errors were less than 6.36%. It means that the numerical model can be applied to calculate FD on trawl nets. (Figure 5).

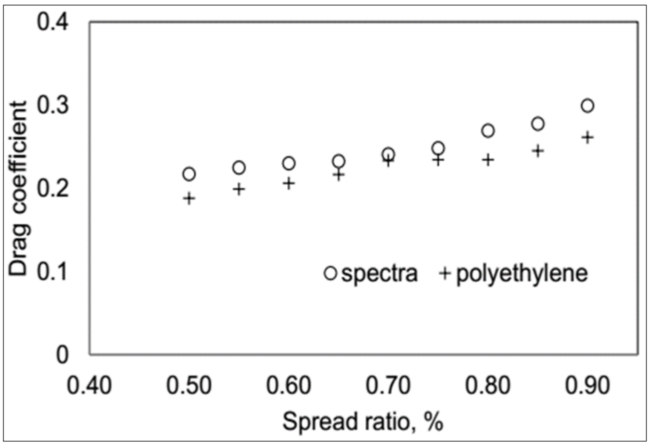

Fig 2: Drag coefficient for prawn trawls of equal design and different netting material (spectra and polyethylene). Sea-trials data for a constant towing speed of 1.6m/s (Lowe 1996).

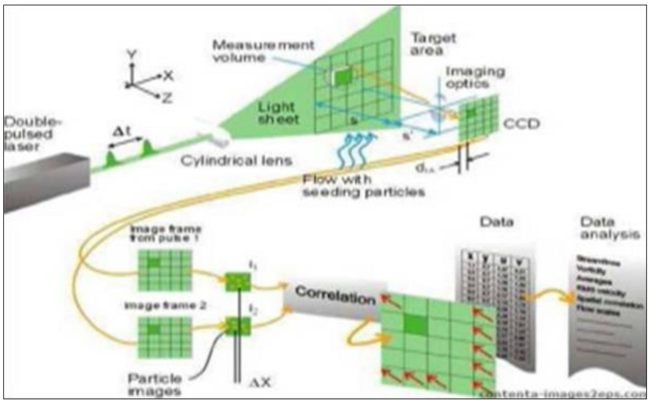

Fig 3: principle measurement of PIV method: velocity profile measurement (Bouhoubeiny, E., Germain, G., Druault, P., 2011).

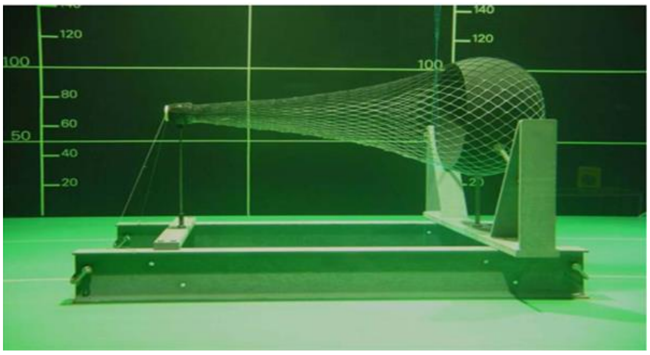

Fig 4: Net model with a closed entrance and its frame set at the bottom of the IFREMER flume tank (R. Lewandowski, G. Pichot 2007).

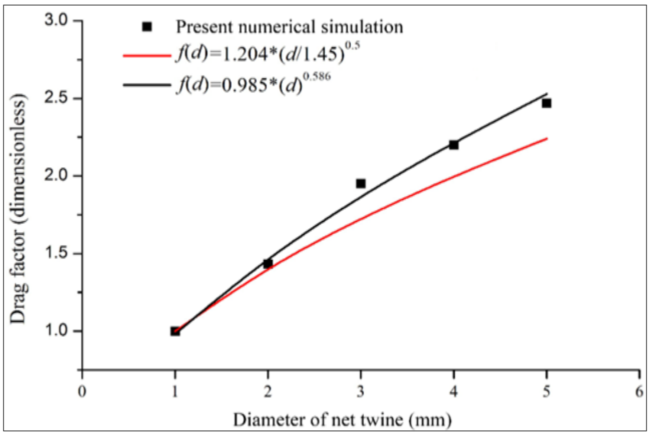

Fig 5: Estimation of drag force on trawl using present model and Sterling Model (Ming-Fu Tang and al., 2017).

4.4. Reduction of fuel consumption through speed optimization

The fuel costs can contribute 50% of the total operational expenses of a trawler fishing trip (Wileman, 1984).Aegisson and Endal (1992) found that the amount of fuel used to generate each horsepower of output increases rapidly as the load is reduced. He also developed a formula to calculate fuel consumption per nautical mile based on the changes in the speed. From the study, he concluded that 10% reduction in trawl speed could save 28% of fuel and 20% reduction could save 51% of fuel consumption. He also noticed that pair trawling could result in fuel cost reduction in fleet by 25 to 35% per tonne of fish when compared with otter trawling. Thomsen (2005) observed that ships converted from single to pair trawling could save 40 to 45% of fuel.

5. Typical bottom trawl simulation software

Numerical modeling of fishing gear systems has improved considerably as a result of major advances in mathematical theory, numerical simulation methods and the computational power of modern desktop computers (Bessonneau & Marichal, 1998; Lee & Cha, 2002; Lee *et al*., 2005; 2008; Zhang *et al*., 2011 and 2016; Priour, 2013; Li *et al*., 2015). An increasing demand for the use of computer based numerical modeling is reflected by the recent rise in trawl simulation software commercially available in the market. With regard to bottom trawls, the market currently offers several trawl simulation software packages (DynamiT, Trawl Vision PRO and SimuTrawl), allowing users to conceptualize trawl designs and evaluate their performance from the comfort of a desktop computer. Today, many gear designers, researchers and manufacturers prefer to begin with numerical modeling of early conceptual ideas, followed by physical testing of scale engineering models in a flume tank (Winger *et al*., 2006). Eventually, full-scale prototypes are constructed and evaluated under real fishing conditions for their mechanical performance and catchability. While numerical and physical modeling have their respective advantages and limitations (Priour, 2013), both have been shown to be complimentary tools in predicting full-scale trawl performance (Nguyen *et al*., 2015, 2016). Most of these packages have the ability to simulate the mechanical behavior and effects of different materials and design features on trawl configuration and performance in different rigging and towing scenarios (Vincent, 1999; Queirolo *et al*., 2009; Nguyen *et al*., 2015, 2016). The software can also be used to study the impact of trawl gear on the seabed or how a trawl can be modified to reduce fuel consumption (van Marlen *et al*., 2010). DynamiT and SimuTrawl allow the user to create and simulate any trawl design, including complex trawling systems involving complicated riggings and multiple wingtips, without the requirement of pre-defined trawl template which is an essential requirement for Trawl Vision PRO. We found that both DynamiT and SimuTrawl can provide users the opportunity to build their own database (information about fishing gear materials) or store elements used to define a trawl in a library in order to call them back in later use. This greatly simplifies the design process as well as saves input time compared to the Trawl Vision PRO. Unlike DynamiT and SimuTrawl, the Trawl Vision PRO software has a highly simplified user interface that can significantly reduce time and effort required by the user to design and simulate a trawl gear. A series of helpful coefficients (horizontal/vertical coefficients and angular coefficient) or rigging adjustment options (backstrops offset, warp offset and bridle offset) are developed for the Trawl Vision Simulator which enable the user to control the simulation performance. However, unlike DynamiT and SimuTrawl, there does not appear to be a numerical mesh (virtual trawl) model within Trawl Vision PRO for the calculation of trawl shape and performance. The user is not really aware of how calculations are being performed or which assumptions are being made regarding the theory of trawl hydrodynamics. Trawl Vision PRO is not able to simulate the effect of side current acting on the trawl, whereas this capability is developed in both DynamiT and SimuTrawl.

6. Discussion and future studies

Nowadays the major problem in the fishing sector is decline of fisheries resources in all waters. If the current trend continues, the most commonly fished species today will have entirely disappeared in 2048(B. Worm, E. B. Barbier, N. Beaumont, J. E. Duffy, 2006).

The optimization of fishing gear is based on two main elements, namely the selectivity of fishing gear defined as the property of one fishing gear to capture one species rather than another (inter-specific selectivity) or to retain, for a given species, individuals of a certain size (intra-specific selectivity) (Fridman, 1992; G. Deschamps., 2003) and reducing the drag of fishing gear to reduce fuel consumption, which consumes about 70% of the fuel during trawling (Adrian, R. Bonnet., 1996). The geometric optimization for energy saving is most often done by modifying the shape of trawl structure (Bessonneau and Marichal., 1998, Niedzwiedz., 2001, Lee *et al*., 2004; Tsukrov *et al*., 2003; Daniel Priour 2012) [14], by decreasing of twine diameter or by increasing of mesh size (Ward *et al*., 2005; Kim *et al*, 2007; D. Priour, F. O'Neill, A. Sala, P. Chevallier, and B. Herrmann. 2007,2008,2009,2010) [11] , either by studying the flows around fishing gear (Brabant, J-C. Nédélec, C., 1988; Braza, M. Faghani, D. and Persillon, H., 2001; Carpenter, PW. Davies, C. Lucey, AD., 2000; Geraldine Pichot, 2007; Elkhadim, BOUHOUBEINY, 2012) [30] or on the hydrodynamic shape of trawl door (Leifsson *et al*, 2015; J Liu, *et al*, 2017) [9].

With regard to numerical modelling of bottom trawls, many researcher have since Taut in 1934 continued to find numerical solutions to improve the performance of fishing gear. Thus the scientific literature on advancing numerical modelling work is developing and available. One of the finer points of numerical modelling is that it takes into account the design of the fishing gear and its environment, which makes it possible to accurately solve the equations of fluid dynamics and structures while taking into account the hydrodynamic forces applied on each part of the gear at the same time (Vincent & Roullot, 2006; Nguyen *et al*. 2016). The numerical modelling work has been developed according to several methods, namely the discrete approach which consists of writing the balance of the efforts on each node, and calculating the position associated with the network, finite element method which, at first, gets closer to the features. Of a global structure by dividing it into small substructures called finite elements (now called elements any short)(Ferro RST, 1988), this approach was adapted by Daniel priour in 2005 and by the CFD method which is a very efficient method and also used in recent years, particularly by Asian researchers, to characterize the flow around the trawl. As indicated by the different research that we have gone through this numerical modelling doesn't incorporate the distribution of fish during trawling (Ramez Khaled, Daniel Priour and Jean-Yves Billard, 2012). Therefore, before any optimization work, it is essential to take into account the biology and behaviour of the resource to optimize the use of fishing gear. The efficiency of fishing vessel propeller, which is a variable parameter, is not taken into account during the optimization work (Ramez Khaled, Daniel Priour and Jean-Yves Billard, 2012), Therefore, if the parameters (trawl doors area and propeller efficiency, trawl shape) are considered at the same time in the optimization process, and if the relationship between the drag and these parameters is known then they could give more efficient results. It should be noted that the articles that have dealt with the numerical modelling of hydrodynamic flows around the trawl in order not only to make the fishing gear more optimal but also more selective. But they didn't take into account the coupling between net/ fluid / fish, during simulation of flow around fishing gear and deduction of the Navier-Stokes / Brinkmann equations. With regard to numerical simulation, we have found that some software is well established among machine manufacturers and researchers, as well as the available scientific literature to document their development and application. Other software such as Trawl Vision PRO the scientific literature is not available. We attribute these findings to the fact that some software like DynamiT has been commercially available for many years and was developed by a state-funded non-profit organization. One of the main strengths of these software is that they allow users to capture many real parameters of a trawl, and then use this information to solve momentum equations, taking into account the hydrodynamic forces applied to the trawl each part of gear at the same time. However, like many other numerical modelling methods, the method of using these software to estimate the net performance still relies on a number of modelling assumptions. In addition, the water flow (due to towing movement or natural conditions, eg tidal, wind and wave currents) is assumed to be independent of the trawl (the trawl does not interfere with the speed of the water). In addition, the height of the sole is not simulated with a high degree of fidelity (diameter and spacing of the rubber discs). In fact, the resistance of trawl nets, and trawl door contributes significantly to the overall resistance of the trawling system (Folch *et al*., 2008). However, under real fishing conditions, the drag measurements will contain uncertainties due to natural variations in oceanographic conditions (current, wind and swell) (Fiorentini *et al*., 2004, Sala *et al*., 2009) [31]. As a result, simulated results produced by software have low scientific confidence and must be carefully considered when used for scientific purposes. That said, the software is a very effective tool for understanding the principles of trawl hydrodynamics, particularly because of their high quality graphical interface and high-speed (near real-time) simulations. Based on my analysis, I recommend that the software could be used for the most trawl optimization because of the results as effective as flume tank tests. The software also can be a useful tool for gear manufacturers and trawl makers to improve the existing gear and demonstrate trawl performance to fishermen (Nguyen and Paul D, 2016).

All the work has been done in numerical modelling with several methods such as the finite element method or the CFD method and by the tests in the flume tank. The flume tank tests are the most accurate because the tests are done through the trawl models making it possible to have real data. The combination of numerical modelling and experimental work has made it possible to develop numerical simulation software for fishing gear that is less expensive than flume tank tests. Many works have proved it as work on technological innovation in the energy optimization of the shrimp trawl gear (Jérôme L, Plourde Y, Roudeau M H, 2009). They worked on reducing of hydrodynamic resistance of the shrimp trawl for northern shrimp fishing without reducing the efficiency of capture, they used both the experimental method by doing the different tests on the model in the flume tank and also by doing a numerical simulation of the fishing gear through the DYNAMIT software. The results obtained with the two methods showed a similarity with very similar differences, but the costs of the numerical simulation are lower than the costs to be used for the experiments in the flume tank.

Thus, with regard of different work that has been done on bottom trawl optimization, several perspectives have been identified and require continuity in research to make the bottom trawl even more efficient. Sterling (2005, 2008) [33] proposed to improve the PTPM vers 3 taking into account during the calculation of trawl drag all trawl system and ground effect force. G pichot (2007) [29] proposed to do numerical simulation of codend with extension and the coupling between fluid/trawl net/ fish during resolution of navier-stokes/brinkman equation. R. Khaled and D. Priour (2012) proposed that during optimization of trawl shape and length cable to take in account variation in the efficiency of the fishing vessel's propeller and the flow disturbed by trawl structure. Balash *et al*., (2014) propose Further testing of assorted fish and prawn nets with respect to flexural rigidity will create an increasingly powerful set of data to robustly define the relationship between netting flexural rigidity and linear twine density. The softness of Dyneema® material, which is due to its multi-filament structure and small overall diameter, is said to produce unwanted complications during trawling operations. Further development of the gape-drag relationship would best involve the analysis of additional drag data from low-stiffness model trawls with fixed body tapers and a systematic variation in gape. A numerical drag model of these variant netting structures could also be developed and might become a validated tool for interpolation and extrapolation of drag predictions (Balash *et al*., 2016). M. samusev (2018) recommended to do 3D FEM with triangular element on T90 mesh to improve more selectivity.

7. Conclusion

In conclusion, each of the bottom trawl optimization methods reviewed in this study has its advantages, inconvenient and limitations, but the best solution is a flume tank test or a combination of numerical modeling and flume tank test. Therefore, it is preferable to combine the numerical methods with the experimental test, allowing to have just the right solution. We also recommend the use of simulation software just after studies for data comparison in addition to sea trials.

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9. Reference

1. Forrester AIJ, Sobester A, Keane AJ. Engineering design via surrogate modelling: a practical guide. John Wiley & Sons Ltd, Chichester, U.K, 2008, pp. 4.
2. Bouhoubeiny E, Germain G, Druault P. Time-Resolved PIV investigations of the flow field around cod-end net structures. Fisheries Research. 2011; 108:344-355.
3. Deschamps G Ifremer. Histoire du chalut : évolution des techniques et de matériaux, 2004.
4. Jonsson E. Aerodynamics Optimization by Variable-Resolution Modelling and Space Mapping. Reykjavik University, Reykjavik, Iceland, 2012.
5. Jonsson E, Hermannsson E, Juliusson M, Leifsson L, Koziel S. Computational Fluid Dynamic Analysis and Shape Optimization of Trawl-Doors. AIAA, 2013.
6. Hermannsson E, Leifsson L, Koziel S, Ogurtsov S, Glubokov O, Fakhraie R. *et al* Hydrodynamic Design Optimization of Trawl-Door Shapes with Local Surrogate Models. 3rd International Conference on Simulation and Modelling Methodologies, Technologies and Applications, Simultech, Reykjavik, Icelandm, 2013.
7. Ferro RST. Computer simulation of trawl gear shape and loading, Proceedings of word symposium on fishing gear and fishing vessel design, 1988, 259-262.
8. Ferro R, Hou E. Selected review of hydrodynamic force coefficient data on stranded wires used in fishing gear. Technical Report 31, Department of Agriculture and Fisheries for Scotland, 1984, 19 p
9. Jonsson IM, Leifsson L, Koziel S, Tesfahunegn YA Bekasiewicz A. Shape optimization of trawl-doors using variable-fidelity models and space mapping. Procedia Comput Sci. 2015; 51:905-1
10. Juza T, Cech M, Kubecka J, Vasek M, Peterka J, Matena J. The influence of the trawl mouth opening size and net colour on catch efficiency during sampling of early fish stages. Fish Res. 2010; 105:125-133.
11. Kim HY, Lee CW, Shin JK, Kim HS, Cha BJ, Lee GH. *et al*. Dynamic simulation of the behavior of purse seine gear and sea-trial verification. Fish Research. 2007; 88:109.
12. Kinoshita H, Kumazawa T. Taisei development of trawl gear with canvas kite. Jpn Soc Fish Eng. 2011; 48:89-98
13. Kirkpatrick S, Gelatt CD, Vecchi MP. Optimization by Simulated Annealing, Science. 1983; 220:671-680.
14. Le Dret H, Lewandowski R, Priour D, Chagneau F. Numerical simulation of a cod end net part 1 Equilibrium in a uniform flow. Journal of Elasticity. 2004; 76:139-162.
15. LJ Lee, Chun-Woo Lee, Moo-Youl Choe, Gun-Ho Lee. Applying Fishing-gear Simulation Software to Better Estimate Fished Space as Fishing Effort. Fish Aquat Sci. 2011; 14(2):138-147,
16. Lee CW, Lee JW, Cha BJ, Kim HY, Lee JH. Physical modeling for underwater flexible systems dynamic simulation. Ocean Eng. 2005; 32:331-347
17. Lee CW, Zhang CI, Shin HO. Simplified trawl system modeling and design of a depth control system using fuzzy logic. Fish. Res. 2001; 53:83-94
18. Lee GH, Lee CW, Kim YB, He Pingguo, Choe MY. Simulation of the virtual mackerel behavior to the trawl gear. J Korean Soc. Fish. Technol. 2008; 44(1):10-19 (in Korean with English abstract)
19. Li Y, Zou X, Zhang X, Zhang M, Chen X, Song L, Zhou Y. Modeling of the Midwater Trawl Dynamical Behavior Based on R Language. In 2015 International Conference on Mechatronics, Electronic, Industrial and Control Engineering (MEIC-15). Atlantis Press, 2015.
20. Liu J, Huang HL, Wu Y, Rao X, Li LZ, Chen S. *et al*. Model test of hydrodynamic characteristics of two types of vertical cambered slotted otter boards. S China Fish Sci. 2015; 11:68-74.
21. Leifsson L, Koziel S. Airfoil shape optimization using variable-fidelity modelling and Shape-preserving response prediction. Computational Optimization, Methods and Algorithms, Springer, 2011, 356.
22. Lowe T. An Analysis of the Gains in Engineering Performance Achieved by Constructing Australian Prawn Trawls from Spectra Netting, B.Sc. thesis, Australian Maritime College, 1996.
23. Massé J, Koutsikopoulos C, Patty W. The structure and spatial distribution of pelagic fish schools in multispecies clusters an acoustic study, I ICES J. Mar. Sci. 1996 ; 53:155-160.
24. Makarenko AI, Poddubnyi VI, Shamarin YE. Research on three-dimensional nonstationary motion of trawling systems. International Applied Mechanics. 1998; 33(11):920-925.
25. Priour D. Calculation of net shapes by the finite element method with triangular elements. Communications in Numerical Methods in Engineering. 1999; 15(10):755-763.
26. Priour D. Study of a grid in a cod-end: numerical simulations, Proceedings of the fourth International Workshop on Methods for the development and Evaluation of Marine Technologies, Rostock, November, 1999, 163-167.
27. Priour D. Numerical optimization of trawls design to improve their energy efficiency, Fish Res. 2009; 98:40-50.
28. Priour D. A finite element method for netting: Application to fish cages and fishing gear. Springer Briefs in Environmental Science, 2013.

29. Pichot G. Modélisation et analyse numérique du couplage filet-écoulement hydrodynamique dans une poche de chalut. Thèse de l'université Rennes 1, 2007.
30. Pichot G, Germain G, Priour D. On the experimental study of the flow around a fishing net. Eur. J. Mech. B/Fluids, 2009, 103-116.
31. Sala A, Farran JDAP, Antonijuan J, Lucchetti A. Performance and impact on the seabed of an existing- and an experimental-otter board: Comparison between model testing and full-scale sea trials. Fish Res. 2009; 100(2):156-166.
32. Sala A, De Carlo F, Buglioni G, Lucchetti A. Energy performance evaluation of fishing vessels by fuel mass flow measuring system. Ocean Eng, 2011.
33. Sterling D. Modelling the physics of prawn trawling for fisheries management (PhD thesis), Curtin University of Technology, Perth, 2005, 236.
34. Tang MF, Dong GH, Xu TJ, Zhao YP, Bi CW. Numerical simulation of the drag force on the trawl net. Turkish Journal of Fisheries & Aquatic Sciences. 2017; 17(6):1219-1230.
35. Tauti M. A Relation between Experiments on Model and on Full-scale of Fishing Net', Nippon Suisan Gakkaishi. 1934; 3:171-177.
36. Taeg-Yun OH. Study on the basic efficient of trawl net. J Korean Soc. Fish. Technol, 2006. DOI: 10.3796/ KSFT.2006.42.3.148
37. Theret F. Etude de l'équilibre de surfaces réticulées placées dans un courant uniforme application aux chaluts, Thèse No. ED 82-31, Nantes Ecole Centrale de Nantes et l'Université de Nantes, 1993.
38. Walsh SJ, McCallum BR. Performance of the Campelen 1800 shrimp trawl during the 1995 Northeast Atlantic Fisheries Centre autumn ground fish survey. NAFO Sci. Coun. Studies. 1997; 29:105-116.
39. Walsh SJ, Hickey WH, Porter J, De Louche H, McCallum BR. NAFC Survey Trawl Operations Manual: Version 1.0. Fisheries and Oceans, Northwest Atlantic Fisheries Centre, Newfoundland Region, St. John's, 2009, 190.
40. Zhang X, Wang JH, Wang MY, Yu YF. Xu BS. Hydrodynamic characteristics of rectangular cambered V type otter board I: Relationship between cambered ratio of fairwater fin and hydrodynamic characteristics of otter board J. Fish. Sci. China. 2004; 11(suppl.):5-8.
41. Zhang X, Wang M, Xu L. Modeling and visualization of part behavior of purse seine using R language. In Image and Signal Processing (CISP), 4th International Congress. 2011; 4:2080-2083). IEEE.