Comparison between two methods of trawl optimisation

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ABSTRACT: Trawls energy efficiency is greatly affected by the drag, as well as by the swept area. The drag results in an increase of the energy consumption and the sweeping influences the catch. In order to reduce the drag per swept area two methods of optimisation of the trawl design has been compared. Based on a finite element method model for flexible netting structures, the tool modifies step by step a reference design. For each step the best-modified design, in terms of drag per swept area is kept. The method based on *successive search per parameter* gives better result (reduction of 54% of the drag per swept area) that the method based on *random search* (reduction of 33%), even the first method requires a longer time calculation.

1 INTRODUCTION

The fuel price blow-up chronically and severely impacts fishing industry budget account: The fuel part in a firm's turnover varies from 10 to over 60% (Le Floc'h et al. 2007). This impact is not recent but is getting more and more unbearable to fishing firms on account of the fuel cost. This effect is even increased on account of the bad state of many fish stocks. Without adaptation, the economic viability of numerous firms will not be guaranteed.

Trawls, being one of the most common fishing gears, are subject to numerous studies devoted to energy efficiency improvement, such as decrease of twine diameter, increase of mesh sides, alternative techniques (Ward et al. 2005, Macdonald et al. 2007, Thomsen 2005, Rihan 2005, Parente et al. 2008) optimisation (Priour D., 2009).

Trawls can be fuel-greedy fishing gears on account of their high drag. In other words their energy efficiency is often very low. In fact, a pelagic trawl must filter a volume of water to catch fish. Considering its swept area or mouth opening, the gear must be towed over a certain distance. The drag energy, or energy required to tow the trawl, is exactly the distance multiplied by the drag. Given the efficiency of the engine and propeller, the fuel energy required is the drag energy divided by this efficiency. In order to increase the energy efficiency, one may increase the efficiency of the engine and propeller, increase the swept area or decrease the drag. The last suggests that the catch is proportional to the swept area. In fact it is not so clear: numerous works have studied the relation between catch and mouth opening such as Main and Sangster (1981).

This paper deals with trawl optimisation by decreasing the drag and increasing the swept area for a pelagic trawl. The two proposed methods improve the trawl energy efficiency by altering the panel cuttings, by means of an automatic tool which is based on a numerical method devoted to shape calculation of fishing gears.

The two methods are used with a Finite Element Method (FEM) 3D model of the net based on a triangular element (Priour 1999, 2001, 2002). The triangle was chosen to describe the surface elements, because it is the simplest surface shape, thus all the netting details can be represented by adjusting the triangle size. The FEM model takes into account the inner twines tension, the drag force on the net due to the current, the pressure created by the fish in the cod-end, the floatability and weight of the net, the mesh opening stiffness and the bending stiffness. The FEM model is able to describe the whole net and cables, which means that for a trawl, the cod-end, the wings, the headline and also the rigging up to the boat are taken into account. Triangular elements model the net while linear elements model the cables, warps and bridles. The drag and shape of structures such as trawls can be calculated with this numerical tool.

Trawls mostly consist of several panels of netting. The panels are polygons delimited by segments of straight lines joining their vertices. Now, the question is to make out whether the design of the panels or the panels cutting is optimal in terms of drag per swept area, and therefore in terms of fuel consumption. For example, very often trawls are made of pieces of netting that are trapeze. The question is: what is the effect of the height and the width of the trapeze on the fuel consumption? And more precisely what is the impact of the two coordinates in number of meshes of the 4 corners of the trapeze on the 3D shape of the whole trawl and therefore on its energy efficiency?

The following part of the paper proposes to compare two methods of optimisation.

Due to the fact that this work is in an exploratory process it has been decided to not use standard optimiser (such as mode frontier) that needs to develop specific interfaces.

2 MATERIAL AND METHODS

The finite element method

The FEM model described above calculates the drag and the swept area of trawls taking into account the following forces exerted on the structure:

The inner tension in twines

$$Tn = EA \frac{n - n0}{n0}$$

Tn: Tension in twines (N),
E: modulus of twine elasticity (Pa),
A: twine section (m²),
n0: unstretched length of mesh side (m),
n: stretched length of mesh side (m),

The drag force exerted on the net by the current

$$F = \frac{1}{2} \rho Cd\, D\, L (V \sin\theta)^2$$

$$T = f \frac{1}{2} \rho Cd\, D\, L (V \cos\theta)^2$$

F: normal force (N) to the twine. This expression comes from the Landweber hypothesis.

T: tangential force which comes from the Richtmeyer hypothesis.

ρ: mass density of water (kg/m^3),
Cd: normal drag coefficient (here 1.2),
f: tangential coefficient (here 0.08),
D: diameter of the twine (m),
L: length of the twine (m),
V: amplitude of the current (m/s),
θ: angle between the twine and the current (radian).

Optimisation method

Since the net being the main part of the drag the optimisation concerns the netting parts. The cables, floats and dead weights are not concerned by the optimisation and thus remain constant along the process.

The automatic optimisation with the two methods is carried out step by step. A step consists in an automatic modification of panels netting coordinates. These coordinates are called the parameters. The FEM model described above calculates the drag and the swept area for each modification. The best modification in terms of drag per swept area is kept.

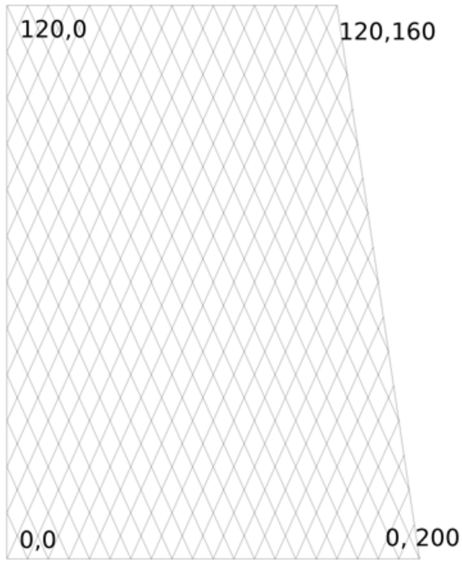


Figure 1. Panel of netting of 120 meshes high, 160 meshes on the top horizontal border and 200 on the bottom one. Only one twine out of tens is drawn. The mesh coordinates of nodes are noted. The origin of meshing is node 1 (bottom left).

For example, the panel given on Figure 1 has 4 vertexes. The vertexes netting coordinates are $\begin{pmatrix}0\\0\end{pmatrix}$, $\begin{pmatrix}0\\200\end{pmatrix}$, $\begin{pmatrix}120\\160\end{pmatrix}$ and $\begin{pmatrix}120\\0\end{pmatrix}$. These coordinates are the parameters and could be written as:

$$U_{ref} = \begin{pmatrix}0\\0\\0\\200\\120\\160\\120\\0\end{pmatrix}$$

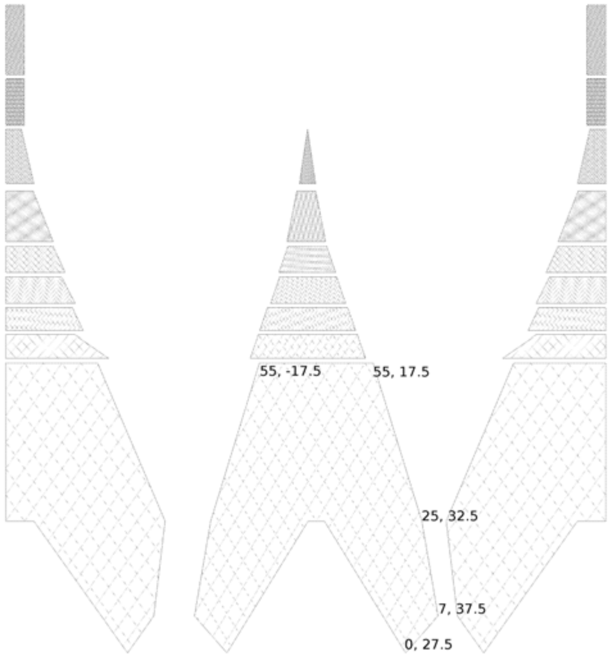


Figure 2. Netting panels of the pelagic trawl. Due to the symmetry of the trawl only half part of the back and the belly are presented. Due to the large number of twines only 1 twine out of 5 is drawn. The mesh coordinates of the first vertices are noted.

The second example is from Figure 2. In this example there are 93 vertexes, which means 186 coordinates (2 per vertex). The first vertex coordinates of this trawl are on Figure 2 and are $\begin{pmatrix}0\\27.5\end{pmatrix}$, $\begin{pmatrix}7\\37.5\end{pmatrix}$, $\begin{pmatrix}25\\32.5\end{pmatrix}$, $\begin{pmatrix}55\\17.5\end{pmatrix}$, $\begin{pmatrix}55\\-17.5\end{pmatrix}$. These coordinates are the parameters and could be written as a vector beginning by:

$$U_{ref}=\begin{pmatrix}0\\27.5\\7\\37.5\\25\\32.5\\55\\17.5\\55\\-17.5\\.\\.\end{pmatrix}$$

This vector has in fact 186 components, which are the two netting coordinates of the vertexes of all the 25 panels of the trawl.

The objective of the optimisation process is to find the best parameters vector in term of drag per swept area.

In the two methods described in the next paragraphs the parameters vector is modified step per step. The modification represents a percentage of the maximum size per panel. For example, the panel given on Figure 1 has a maximum size of 120 meshes vertically and 200 horizontally. A modification of 5% of this panel will lead to a displacement frame of each vertex of 6 meshes vertically and 10 meshes horizontally. The frame of the modification is the vector (U_{fra}):

$$U_{fra}=\begin{pmatrix}6\\10\\6\\10\\6\\10\\6\\10\end{pmatrix}$$

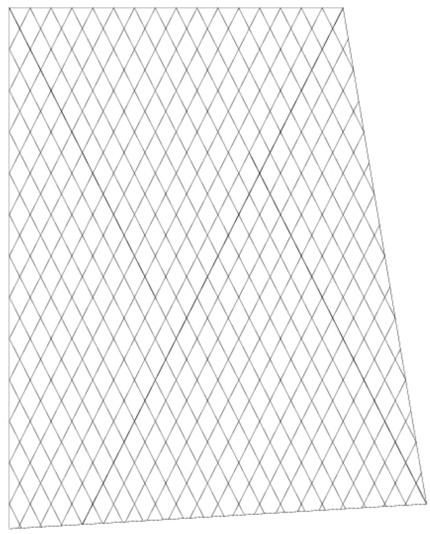


Figure 3. One vertical modification about node 1 (bottom left).

The first method: successive search per parameter

In the first method, the modifications involved are brought to parameter one by one. The first step is the positive modification of the first parameter. This modification is:

$$U_{mod1}=\begin{pmatrix}6\\0\\0\\0\\0\\0\\0\\0\end{pmatrix}$$

This modification is added to the reference parameters. That gives the first parameter vector, which varies from the reference vector (U_{ref}) only by the first component (Figure 3):

$$U_1=\begin{pmatrix}6\\0\\0\\200\\120\\160\\120\\0\end{pmatrix}$$

The second step involved a negative modification of the first parameter. That gives a second parameter vector:

$$U_2 = \begin{pmatrix} -6 \\ 0 \\ 0 \\ 200 \\ 120 \\ 160 \\ 120 \\ 0 \end{pmatrix}$$

The third step involved a positive modification of the second parameter. That gives a third parameter vector:

$$U_3 = \begin{pmatrix} 0 \\ 10 \\ 0 \\ 200 \\ 120 \\ 160 \\ 120 \\ 0 \end{pmatrix}$$

This process continues up to the end of the parameters vector. In case of Figure 1 that means 16 modifications (4 per vertex, 2 vertically and 2 horizontally). From these 16 modifications the best case in term of drag per swept area is kept and the process starts again.

In case of Figure 2 that means 372 modifications. From these 372 modifications the best case in term of drag per swept area is kept and the process starts again.

The second method: random search

In the second method, the modifications involved are brought to all the parameters in the same times. The modification represents a random part of the maximum modification per coordinates. For example, for the panel given on Figure 1, as said previously, a maximal modification of 5% of this panel will lead to a random displacement of each vertex from -6 meshes to +6 meshes vertically and from -10 meshes to +10 meshes horizontally. There will be 8 random modifications: 2 for each vertex (1 vertically and 1 horizontally). This modification added to the reference parameter could be written as:

$$U_1 = \begin{pmatrix} 0+random(6) \\ 0+random(10) \\ 0+random(6) \\ 200+random(10) \\ 120+random(6) \\ 160+random(10) \\ 120+random(6) \\ 0+random(10) \end{pmatrix}$$

random(n) means a random value between –n and n.

In case of Figure 2 the vector has 186 components.

Pelagic trawl

These two methods of optimisation have been applied to a pelagic trawl. The pelagic trawl, named 57 52, has a footrope and headline length of 57m and lateral ropes length of 52m. It is used for scientific surveys (Massé J. et al., 1996). The design is presented on Figure 2. The warps are 200m long and the bridles 100m long. The towing speed is 2.058m/s. The calculation will be carried out from the boat with constant doors: the forces exerted on the doors are assumed to be the same for the reference trawl and the optimised one. A maximal modification of 1%, 2%, 4% & 8% for the first method (successive search per parameter), and a maximal modification of 1%, 2%, 4%, 8%, 16% and 32% for the second method (random search) have been decided on for the optimisation process.

To avoid too large calculation time, the discretization elements of the trawls are 4m large. To avoid too large errors in the calculations, the results are given with a smaller size (1m), as specified in Priour 2009.

3 RESULTS

The calculated drag of the reference trawl is 67 174 N and the swept area is 200 m^2, which gives a drag per swept area equal to 336 N/m^2. The shape of the reference trawl is on Figure 4.

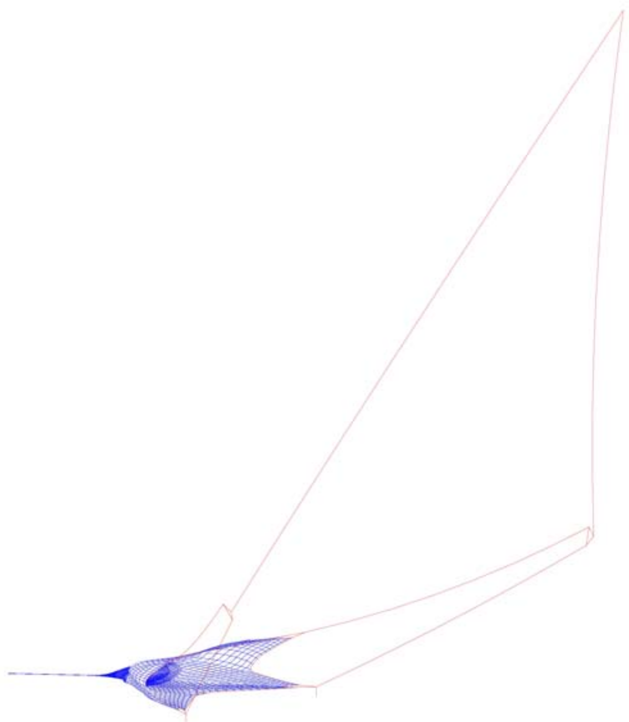
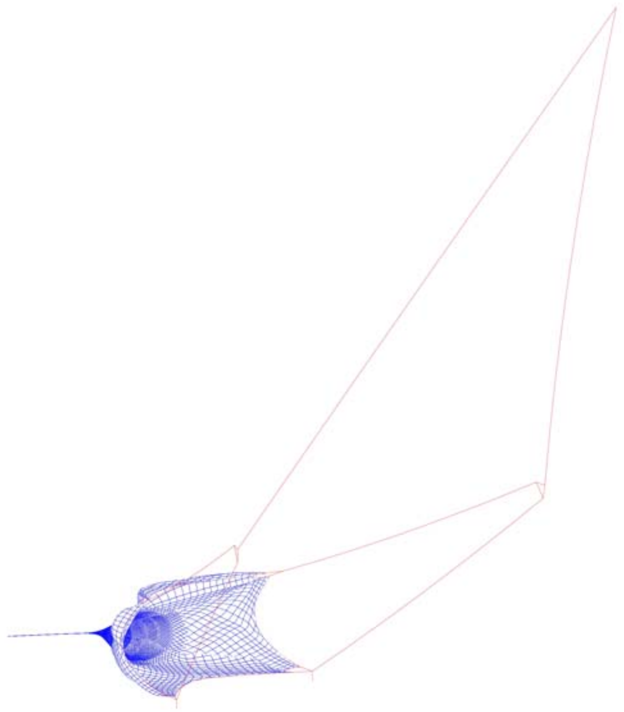


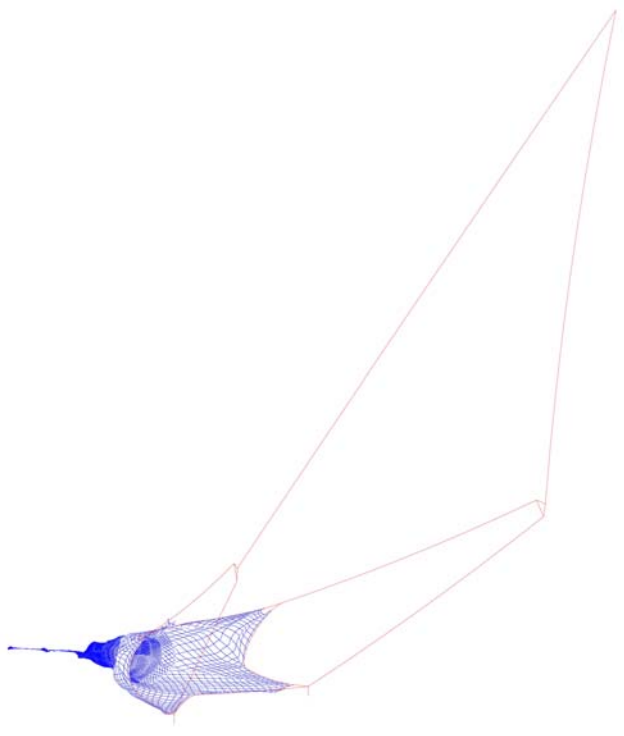
Figure 4. Shape of the reference trawl. Only 1 twine on 5 are drawn.

The main results of the optimisation process with the first and the second methods are displayed on Table 1.

This table shows that the best results obtained with the first method (successive search per parameter) is for a maximal modification of 8%. The shape of the trawl is given on Figure 5a and the design is on Figure 6a.

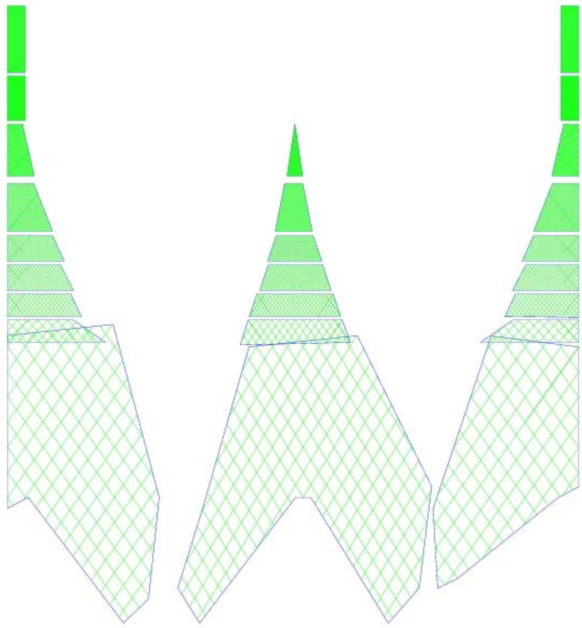


a

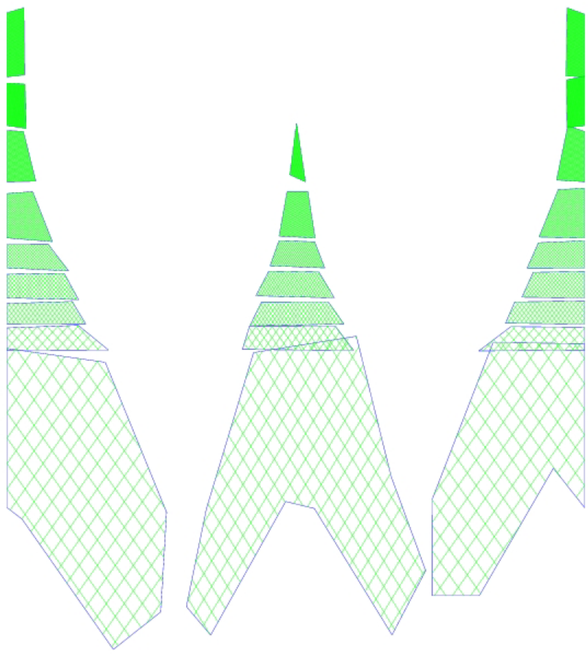


b

Figure 5. Shapes of trawls optimised by the first method (a) and the second method (b). Only 1 twine on 5 are drawn.



a



b

Figure 6. Design of trawls optimised by the first method (a) and the second method (b). Only 1 twine on 5 are drawn.

This table also shows that the best result obtained with the second method (random search) is for a maximal modification of 16%. The shape of the trawl is given on Figure 5b and the design is on Figure 6b.

Table 1. Main results for the two methods of optimisation (per parameter and random modification) and for different modification sizes (from 1% to 32%). These results are: Reduction of drag per swept area relatively to the reference trawl, number of calculations of modified trawl, time of calculation.

	Reduct. %	Trawl nb.	Durat. h
Per parameter			
1%	48	25752	27
2%	44	10656	12
4%	51	15540	30
8%	54	9324	16
Random modification			
1%	8	5850	17
2%	14	5357	17
4%	26	4079	17
8%	19	2797	17
16%	33	2673	17
32%	0	3078	17

4 DISCUSSION & CONCLUSION

In term of objective (drag per swept area) it is clear from the Table 1 that the best result (reduction of 54%) is obtained by the first method (*successive search per parameter*), which is larger that the best reduction (33%) obtained by the second method (*random search*).

The shape of the trawl obtained by the first method (Figure 5a) seems pretty better than one obtained by the second method (Figure 5b). Especially in the rear part of the trawl, which is more rough with the second method (Figure 5b). This point could be explained by the fact that in the second method all the parameters are modified in the same time, this point is visible on Figure 6: The design generated by the second method (Figure 6b) shows that the panels in the rear part is modified contrary to the first method (Figure 6a) where the panels in the rear part are identical as the reference design (Figure 2).

This good result for the first method is partly mitigated by the number of calculated trawls required by the first method (15540 modifications of the reference trawl) and the calculation duration (30 h) which are larger than required by the second method (2673 modifications in 17h).

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