Optimisation of trawl energy efficiency under fishing effort constraint

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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. Methods of optimisation of the trawl design have been developed in order to reduce the volume of carburant per kg of caught fish and consequently the drag per swept area of the trawl. 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. Such optimisation can lead to a decrease of the drag or an increase of the swept area. In the second case, that could lead to an increase of fishing effort. To avoid such increase, which could be not welcome in some fisheries; a tool of homothetic transformation of fishing gears has been developed. Such global tool (optimisation and homothetic) has shown potential saving of 39% in fuel cost without increasing the fishing effort.

KEY WORDS:

Fishing, fuel, fishing gear, trawl, optimisation, fishing effort.

INTRODUCTION:

Fishing industry is largely dependent to fossil energy: the part of energy in the budget account can reach few ten percent. Such dependence weakens fishing enterprises especially when the energy price is volatile. This weakness is intensified by the bad condition of numerous fish stocks.

Quite often the dependency of this industry to the energy is quantified by the ratio between the fossil energy (fuel) consumed per landed fish. This value varies a lot, but the mean value is around 0.6 l/Kg (Tyedmers, et al. 2005). In order to decrease the dependency of the fishing industry to fossil energy the condition of stocks have to be improved when they are bad: it is clear that a fuel litre will be less efficient when used on bad condition stock than on good condition. The improvement could be also to use fishing gears that are potentially fuel sober. For trawl, which is one of the main fishing gears used in Europe, the improvement concerns the material: reduction of twine diameter of netting (Ward et al. 2005) or the cutting panel (Parente et al. 2008).

The present paper described an automatic optimisation of panel cutting of trawls added to a homothetic transformation of the trawl in order to decrease the fuel consumption without increase the fishing capacity of trawls.

METHOD:

The objective of the optimisation:

The method is applied in this paper to a pelagic trawl. In such trawl, the energy required during the hauls is due to the drag (D) and the distance of the hauls (L). If we accept that the efficiency of the propulsion system is known (η) as well as the heating capacity of fuel (h_f), the fuel volume (V_f) used a year can be assessed by the following relation:

$$V_f = \frac{D\ L}{\eta\ h_f}$$

D: Drag of the gear (N),
L: Towed distance per year (m),
η: Propulsion efficiency, often close to 0.1,
h_f: Heating capacity of fuel, around 36Mj/liter.

An improvement of fishing gear must be carried out without damaging the quantity of fish caught a year (F). This quantity is assessed with the volume filtered a year by the trawl, which is the product of the distance (L) by the swept area of the trawl (S) and by the trawl catchability (T_c). Here, the catchability is expected not affected by the method of trawl improvement. In these conditions the fish caught a year is:

$$F = S\ L\ T_c$$

F: Fish caught a year (Kg),
S: Swept surface of the trawl mouth (m^2),
L: Towed distance per year (m),
T_c: Trawl catchability (Kg/m^3).

The improvement of gear leads to the decrease the ratio between the fuel consumed and the fish caught:

$$\frac{V_f}{F} = \frac{D}{S} \frac{1}{\rho_p\ h_f\ T_c}$$

Because it is expected that the parameters η, h_f and T_c are constant, the optimisation leads to a decrease of the ratio D/S. In other words D/S is the objective of the optimisation. As it will be seen latter in the paper, the risk of such optimisation is to increase too much the swept area of the trawl (S). In such case that means that the fishing effort of this optimised trawl increases which could be not expected due to stocks management.

The drag of the netting:

In Table 1 the drag repartition between the components of trawl are shown for few examples of pelagic trawl. It can be seen that most of the drag is due to the netting.

Table 1: Drag repartition between components for trawls: without (a) and with (b) catch on a 57/52 pelagic trawl. These figures are from modelling.

	a	b
Cables	28%	24%
Otter boards	17%	15%
Netting	55%	44%
Catch	0%	17%
Total	100%	100%

Optimisation process:

Because the drag is mostly due to the netting the optimisation tool automatically affects the panel cutting in order to reduce the ratio D/S. Such optimisation uses a FEM model (Priour 1999) that has been adapted (Priour 2009) for such purpose. The principle is the following: The optimisation tool affects parameters in order to decrease the objective. The parameters are the coordinates in number of meshes of the polygons making the panels of netting and the objective is the ratio D/S as seen previously.

For example the following vector represents the parameters of the simple structure of Figure 1:

[-40, -40, -40, 15, 40, 15, 40, -40, 0, 0, –40, -5, -40, 5, 40, 5, 40, -5]

The Figure 1 don’t represent a real structure, but just a very simple one used here to explain the method.

This parameter vector begins by the number of meshes along the horizontal of the first node of the first panel, followed by the number of meshes along the vertical of the same node, followed by the second node of the first panel up to the last node of the first panel followed by the second panel and so on up to the last panel. The size of this parameter vector is the number of nodes by 2 (the number of meshes coordinates of each node).

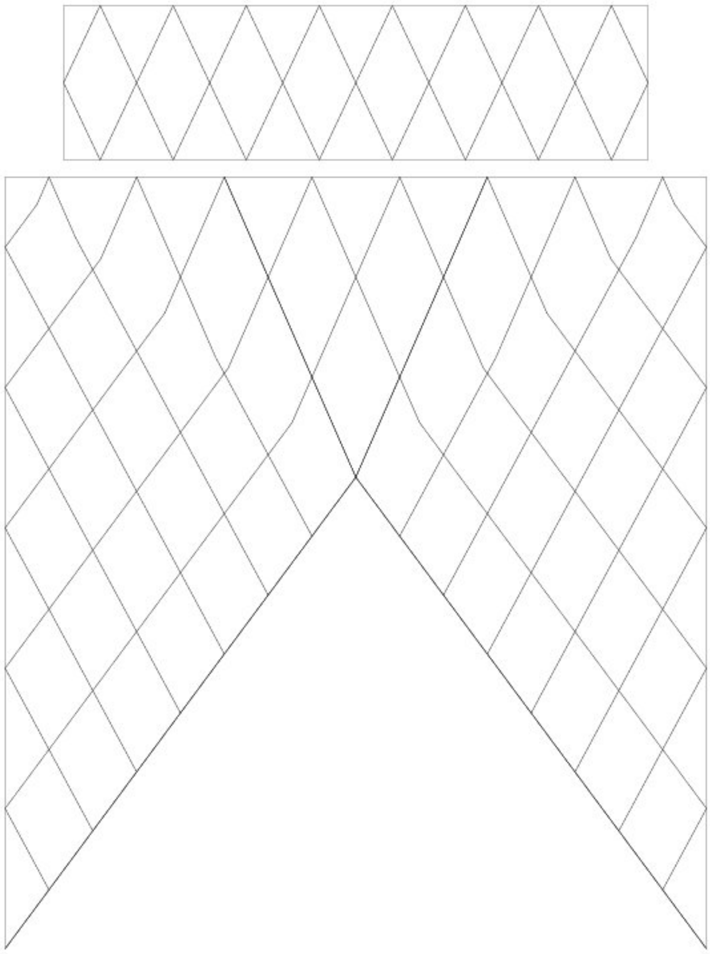

Figure 1: Simple structure with 2 panels of netting with 9 nodes. The first panel (bottom one) has coordinates in number of meshes: -40, -40, -40, 15, 40, 15, 40 –40 and 0, 0. The second panel has –40 -5, -40 5, 40 5, and 40 -5. The first nodes of the two panels are the bottom left and the numbering is clockwise. Only one twine on ten is drawn.

This tool modifies step by step this parameter vector up to find the best objective. Two methods of modification (successive search per parameter and random search) have been compared in Priour and Khaled 2009 only one (assessed as the best) is used in this paper: successive search per parameter.

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

U_1 = [-39, -40, -40, 15, 40, 15, 40, -40, 0, 0, –40, -5, -40, 5, 40, 5, 40, -5]

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

U_2 = [-41, -40, -40, 15, 40, 15, 40, -40, 0, 0, –40, -5, -40, 5, 40, 5, 40, -5]

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

U_3 = [-40, -39, -40, 15, 40, 15, 40, -40, 0, 0, –40, -5, -40, 5, 40, 5, 40, -5]

This process continues up to the end of the parameters vector. In case of Figure 1 that means 36 modifications (4 per vertex: 2 vertically and 2 horizontally for the 9 nodes). The last step involved a negative modification of the last parameter. That gives the following parameter vector:

U_{36} = [-40, -40, -40, 15, 40, 15, 40, -40, 0, 0, –40, -5, -40, 5, 40, 5, 40, -6]

From these 36 modifications the best case in term of drag per swept area (D/S) is kept and the process starts again.

In case of Figure 2, which is the design of a pelagic trawl, 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.

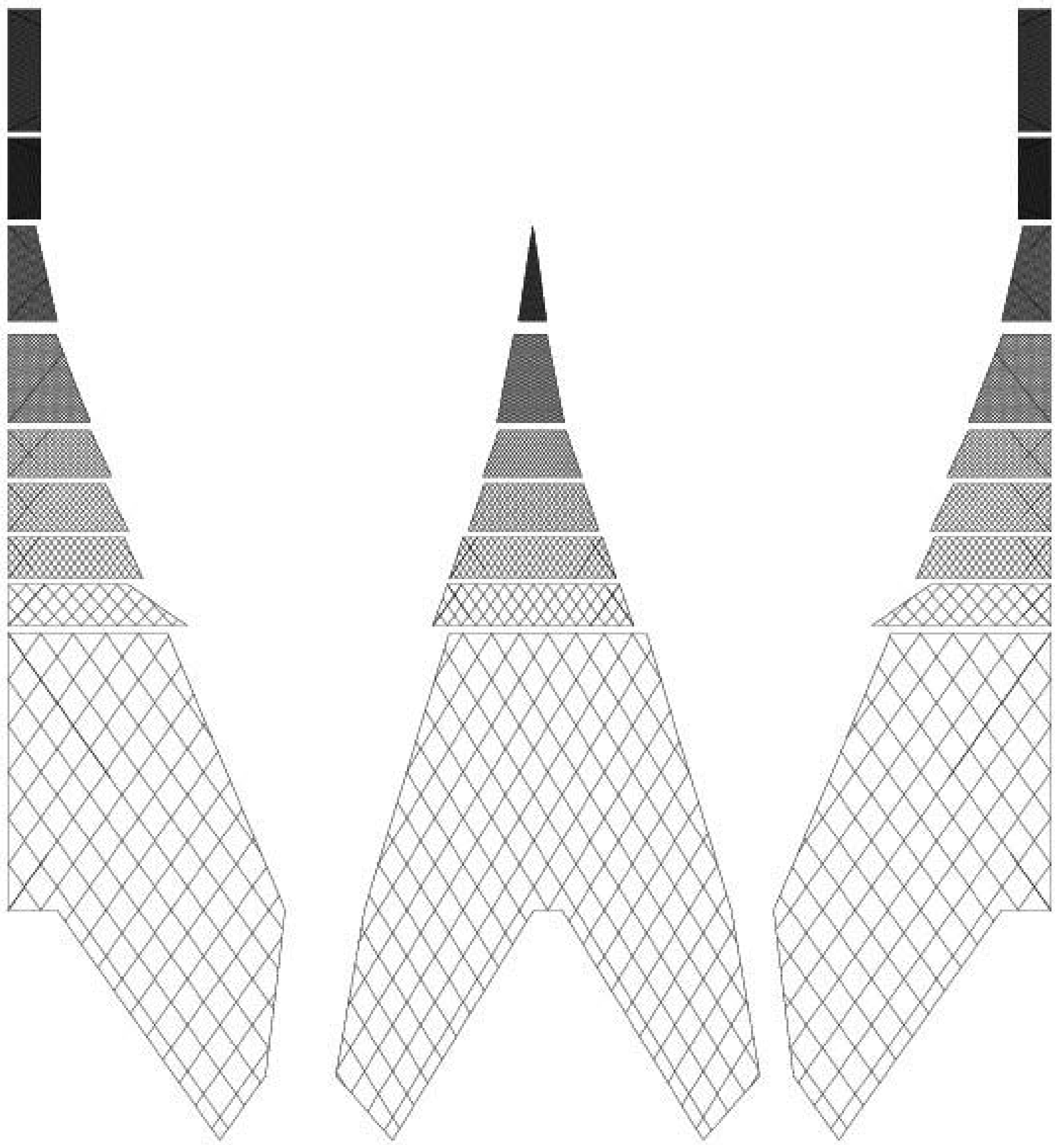

Figure 2. Netting panels of the pelagic trawl. Due to the symmetry of the trawl only half part of the back and the belly are presented. Due to the large number of twines only 1 twine out of 5 is drawn.

The modification size:

In the case of Figure 1 the modification size has been arbitrary chosen at one mesh: one mesh along the horizontal and one mesh along the vertical. In fact this modification size depends on each panel: this modification step is calculated as a proportion to the maximal size of the panel along the horizontal and along the vertical, as explained in Priour 2009. In case of Figure 2, the maximal size of panel one along the horizontal is 75 meshes and 55 along the vertical. If the modification is 10% that means that the modification along the horizontal of the first panel is 7.5 meshes and 5.5 along the vertical. Obviously this modification size changes from panel to panel.

The homothetic transformation:

As said previously, the risk of such optimisation is to increase too much the swept area of the trawl (S). To avoid such increase while keeping the improvement of the optimisation process a homothetic transformation of the trawl has been developed. This transformation uses a homothetic ratio (h). This transformation creates a new design plan of the gear where all the netting coordinates are reduced by the homothetic ratio (h) as well the cables length and diameter. With this transformation the surface involved in the drag is more or less reduced by h^2, and it can be expected that the drag would be also reduced by h^2.

The trawl

This method of optimisation and the homothetic transformation 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.

Modification sizes of 1%, 2%, 4%, 8% 16% and 32% have been decided on for the optimisation process. To avoid too large calculation time, the discretization elements of the trawls are 3m large. To avoid too large errors in the calculations, the results are given with a smaller size (1m), as specified in Priour 2009.

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 3.

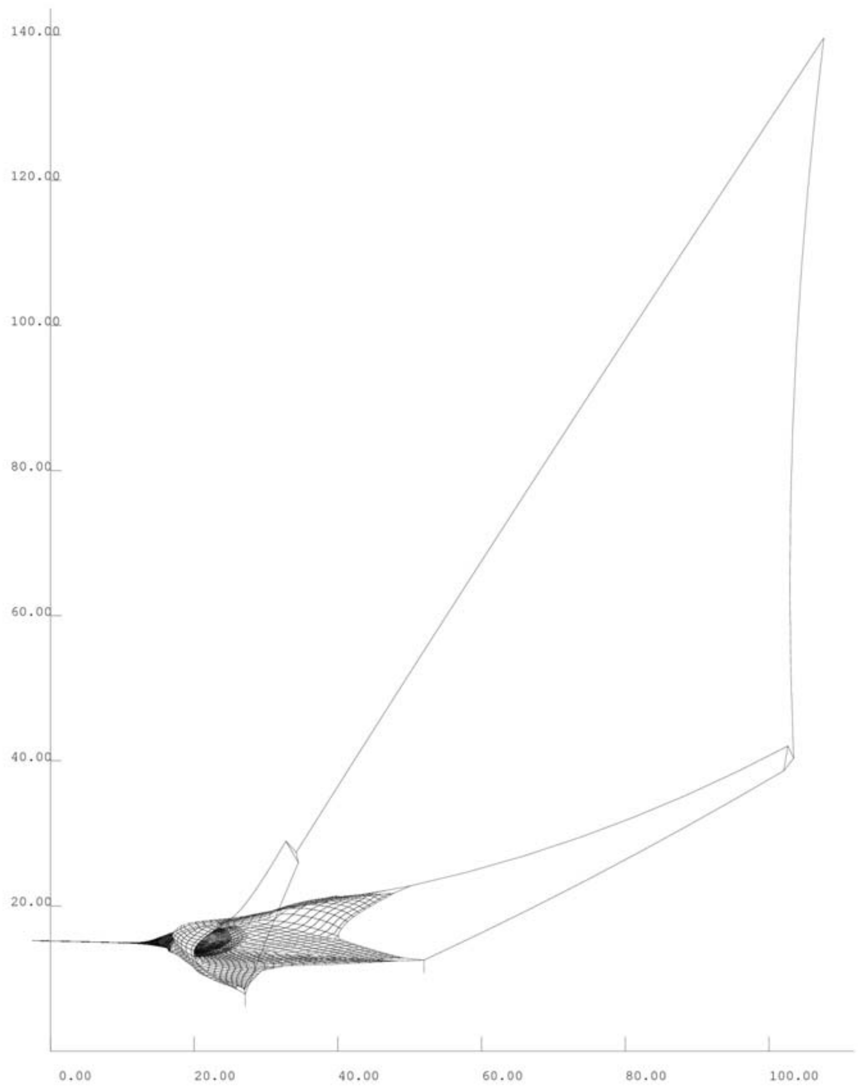

Figure 3. Shape of the reference trawl. Only 1 twine on 5 are drawn.

Optimisation process:

The main results of the optimisation process are displayed on Table 2.

This table shows that the best results obtained is for a modification of 8% (and 16%). The shape of the trawl is given on Figure 5 and the design is on Figure 4.

It can be seen on the design (Figure 4) that few panels have been modified relatively to the reference one (Figure 2). It is clear also that the shape of the optimised trawl (Figure 4) is quite different the reference one (Figure 3).

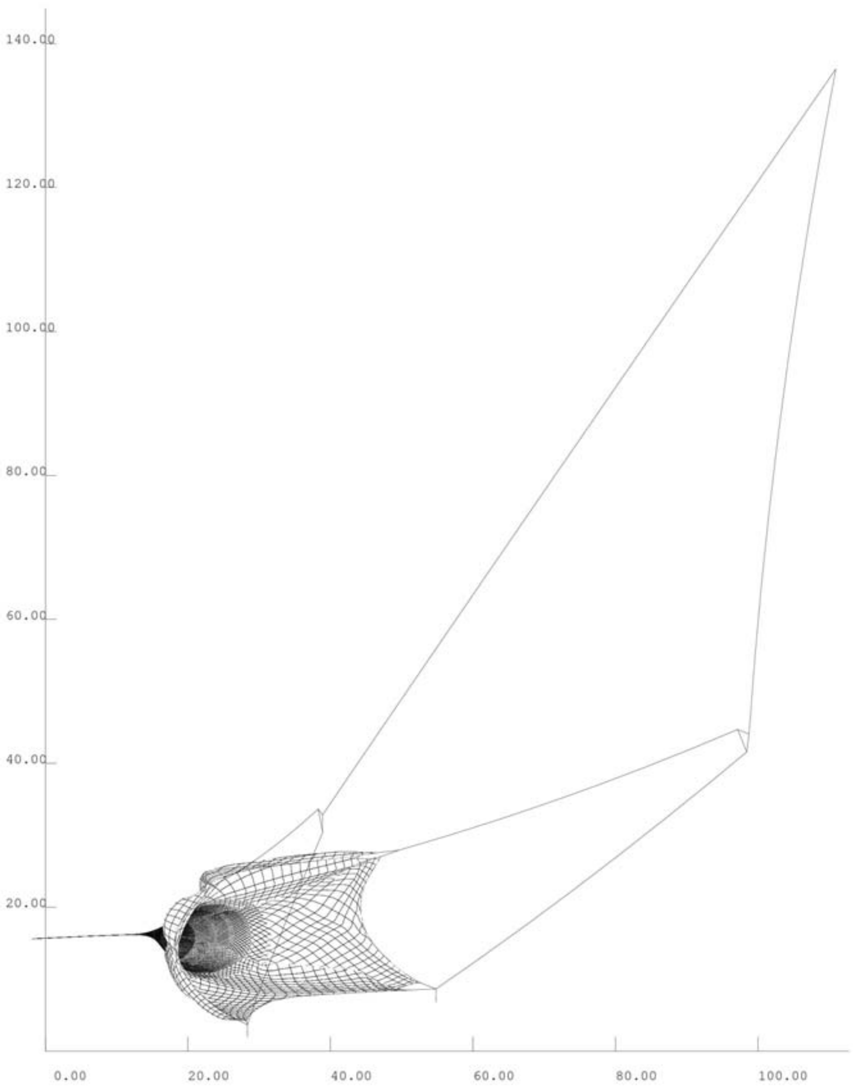

Figure 4. Shape of trawl optimised. Only 1 twine on 5 are drawn.

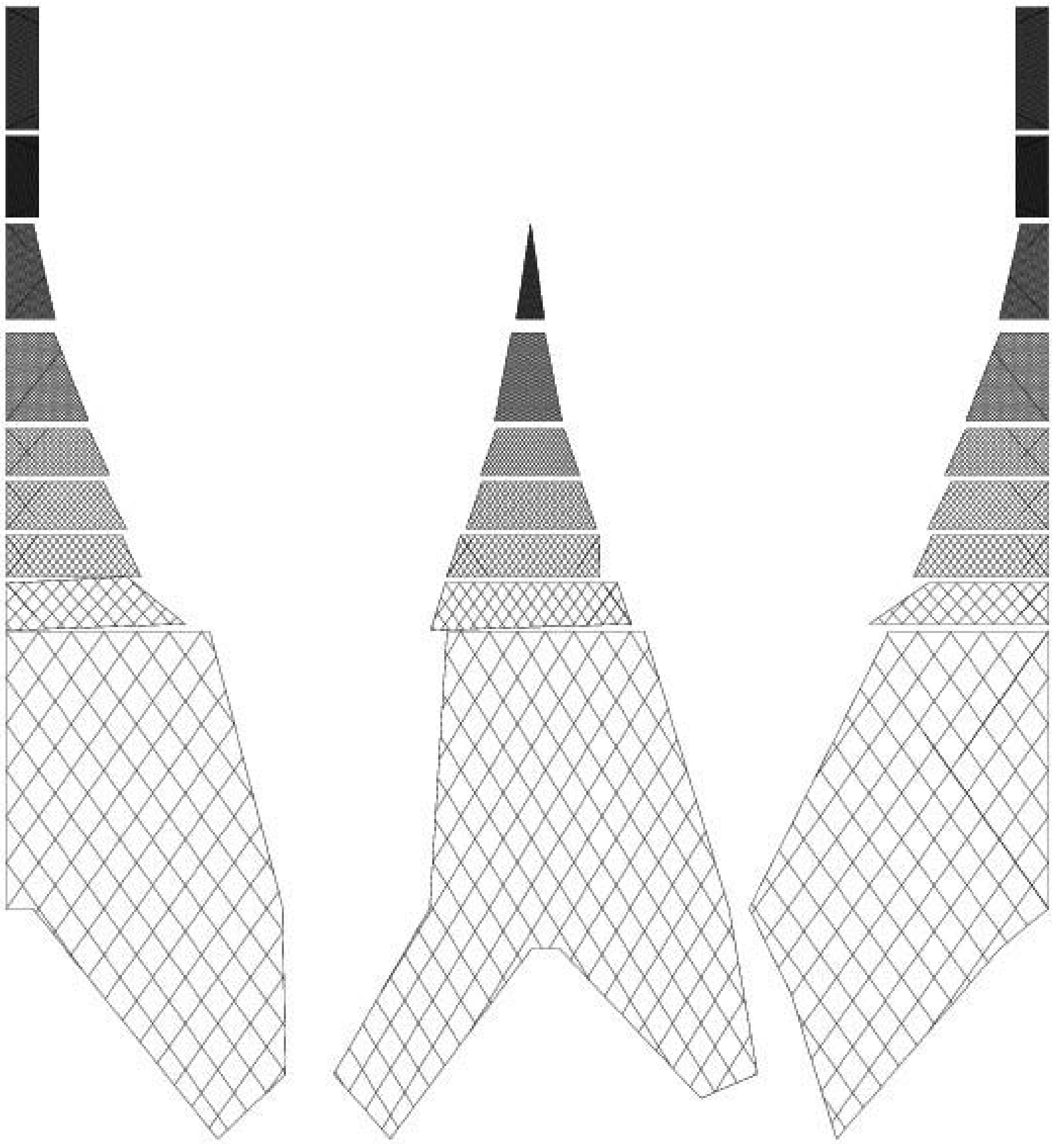

Figure 5. Design of trawl optimised. Only 1 twine on 5 are drawn.

Table 2. Main results of the optimisation and for modification sizes from 1% to 32%. These results are: Drag of the trawl, swept area and reduction of drag per swept area relatively to the reference trawl.

	Drag (kN)	Swept surface (m^2)	Reduction (%)
Reference trawl	**67**	**200**	**0**
1%	78	442	48
2%	74	393	44
4%	82	497	51
8%	**80**	**516**	**54**
16%	76	491	54
32%	71	273	23

It is clear that the optimised trawl has a much more larger swept area (516m^2) than the reference one (200m^2). That means a potential increase of fishing effort.

Homothetic transformation

To avoid the increase of fishing effort, which is required in many fisheries due to management regulations, the optimised trawl is transform trough homothetic transformations in order to obtain a swept area close to the reference swept area. The homothetic transformation of n% consists: i) in the reduction in number of meshes of all the panel of n% (horizontally and vertically), ii) in the reduction of the length and the diameter of cables used in the trawl, iii) in the reduction of the doors size of n% horizontally and vertically in order to expect that the drag forces and the surfaces involved in the homothetic trawl is n^2% of the optimised trawl.

Table 3: Main results of the homothetic transformations and for several ratio (from 65% to 72%). These results are: Drag of the trawl, swept area and reduction of drag per swept area relatively to the reference trawl. The ratio, which gives the closest swept area to the reference, is 71%.

	Drag (kN)	Swept surface (m^2)	Reduction (%)
Reference trawl	**67**	**200**	**0**
65%	34	161	38
70%	40	194	38
71%	**41**	**202**	**39**
72%	42	211	41

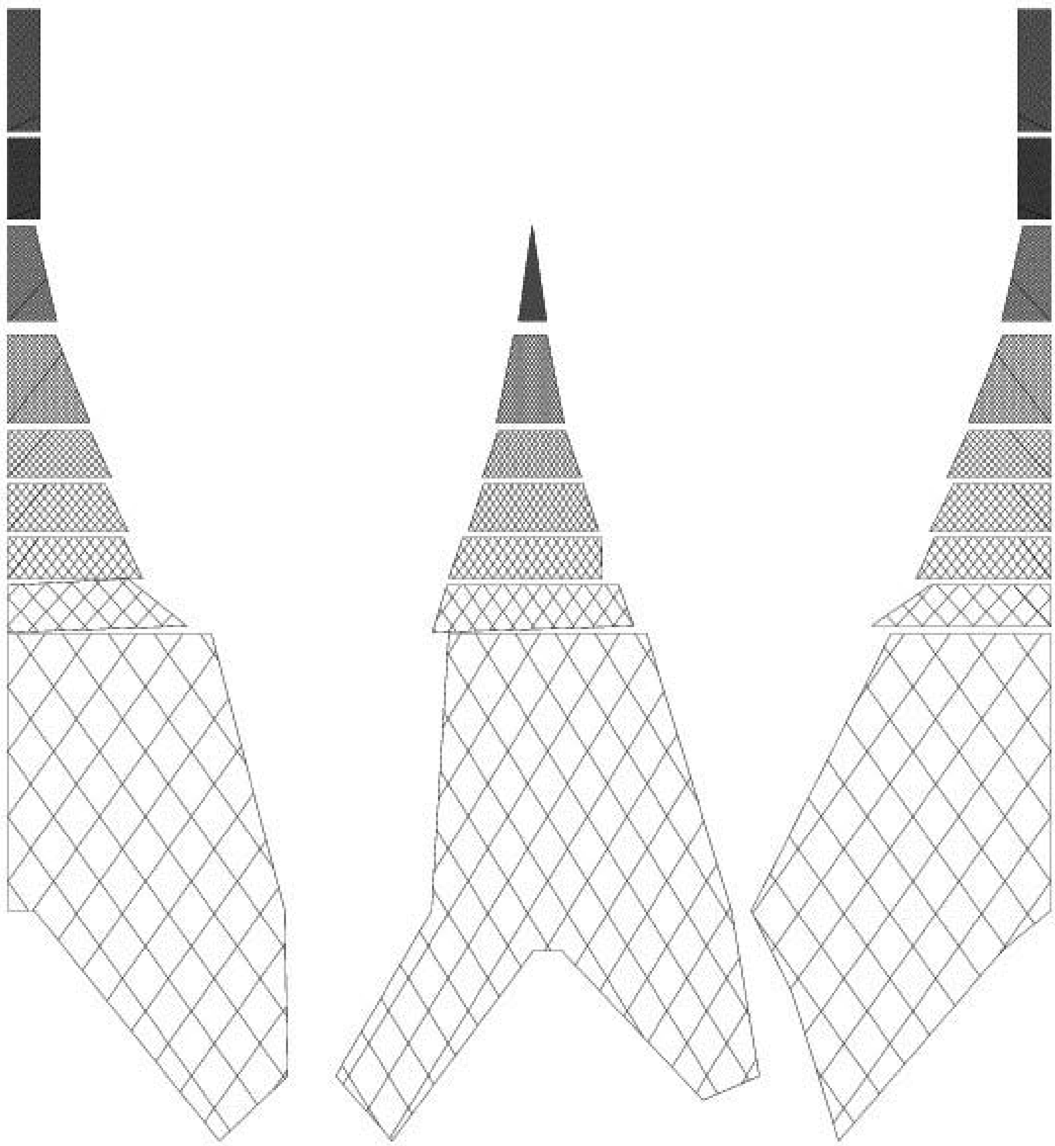

Figure 6 : Design of trawl optimised and homothetically transformed (ratio of 71%). Only 1 twine on 5 are drawn. The number of meshes is 71% of the number of meshes of the design of Figure 5.

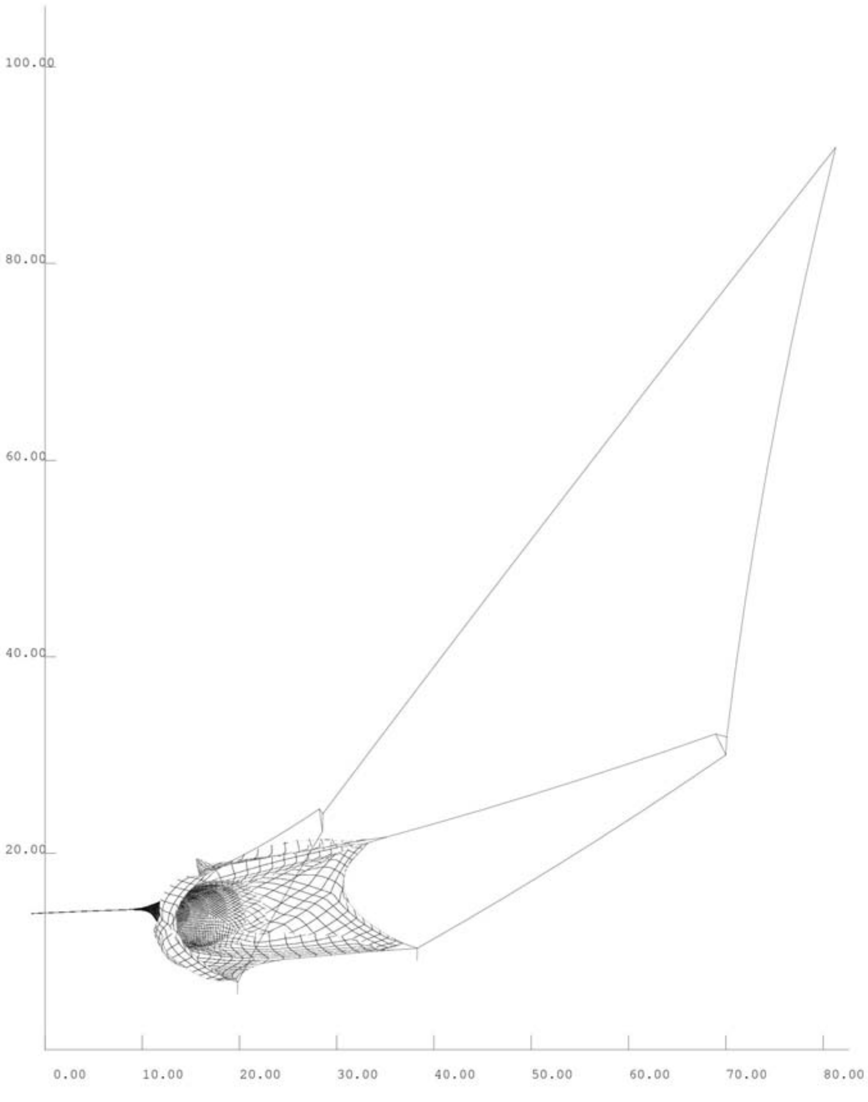

Figure 7: Shape of optimised trawl homothetically transformed. Only 1 twine on 5 are drawn. The shape is similar to the Figure 4, but smaller.

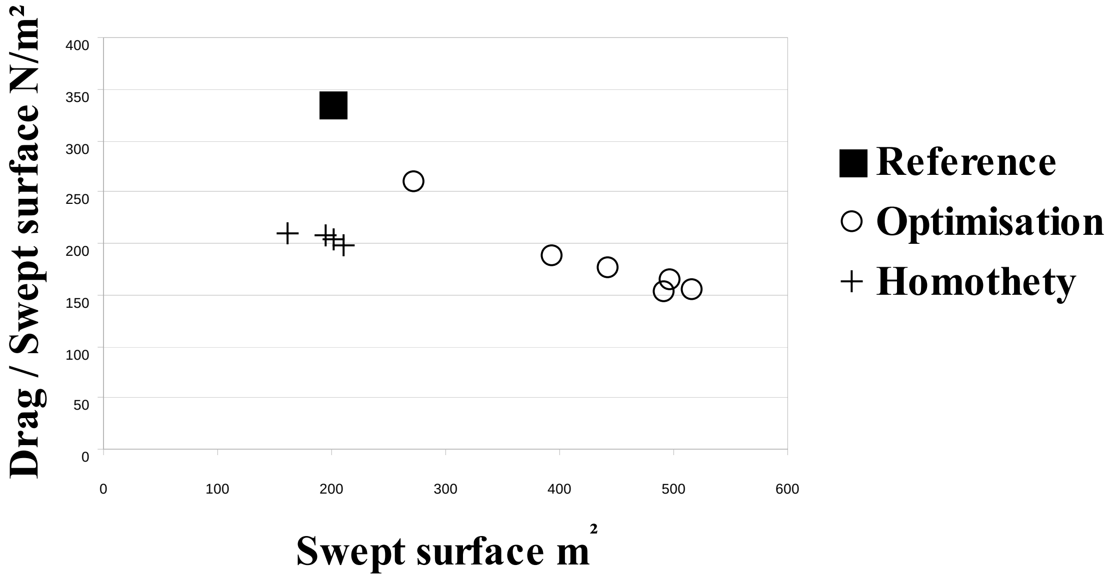

Figure 8: Drag per swept surface versus swept area for the reference trawl (■), the optimised trawls (○) and the trawls homothetically transformed (+). Data are from Table 2 and Table 3.

It can be seen on the Figure 8 that the optimisation process increases a lot the swept surface and the homothetic transformation is required to reduce it.

The shape of the trawl transformed by the homothety is on Figure 7, it can be seen that the shape is similar to the optimised one (Figure 4) but that the size is smaller in order to get the same swept area to the reference trawl (Figure 3). The design of the trawl transformed by the homothety is on the Figure 6. It can be seen that the number of meshes is smaller than the design of Figure 5.

DISCUSSION AND CONCLUSION:

The optimisation process alone gives an improvement of 54% in the fuel consumption (Table 2) and the homothetic transformation damages it to get 39% (Table 3). That means that the regulation of the fishing effort can leads to less efficient fishing gear calculated with the tool described in this paper that the gear only optimised. Another alternative to reduce the fishing effort is to reduce the time at sea in order to have the same filtered volume a year between the reference trawl and the optimised one (Priour 2009). This alternative is mostly applicable in fisheries using Individual Quotas (IQ). In other words this tool gives, in the example presented here, better result in fisheries with IQ.

Due to the large number of calculations (few thousands) for the optimisation process the tool requires a long time: around 20h. It could be profitable to use the full capacity of calculation of Personal Computer and especially the multi cores for calculating few optimisations in the same time.

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