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Numerical optimisation of trawls design to improve their energy efficiency

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ABSTRACT

Trawls energy efficiency is greatly affected by the drag, as well as by the swept area regarding pelagic trawls and by the swept width for bottom ones. 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 (or width) a numerical tool dedicated to the automatic optimisation of the trawl design has been developed. 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 (or width), is kept. Such a methodology was used in two cases: which show a 43% increase in energy efficiency regarding the pelagic trawl case and 27% for the bottom trawl one.

1. Introduction

In 2008, the European fishing firms budget account was severely impacted by the fuel price blow-up, which is the quasi-exclusive energy of this industry: the fuel part in a firm's turnover varies from 10 to over 60%. This impact is not recent but is getting more and more unbearable to fishing firms on account of the fuel cost which has been increasing by around 8% per year in constant Euro over the last 10 years (Le Floc'h et al., 2007) and has doubled over the past year. 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 subjected to numerous studies devoted to energy efficiency improvement. These studies also bear on alternative techniques: Macdonald et al. (2007) have tested an alternative to trawling: the jig fishing. But this technique has been tested on areas unsuitable for trawling. Anyway the results indicate that jig fishing could be profitable. Thomsen (2005) has analysed the statistics of 8 ships in the Faeroe Islands fisheries. As the main modification, these ships have been converted from single trawling to pair trawling. It was shown that they kept landings but saved 40–45% of fuel. Rihan (2005) suggests to turn back to traditional single rig trawling from twin rigs. This has been experimented on Nephrops fisheries in Ireland. The fuel consumption decrease is partly mitigated by the reduction of the catch.

The studies dedicated to trawl optimisation are not recent: during the seventies, 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. Recently, new twine materials have been tested in some parts of the trawl with the aim of reducing twine diameter and therefore the drag. Ward et al. (2005) studied trawls involving novel materials, which generated a drag cut down by 6% compared with the usual trawls, and a mouth opening increased by 10%. Parente et al. (2008) have improved bottom trawls by using larger meshes and by changing the panel cuttings, which led to a potential increase of the net cash flow up to 27%. Considering that the drag is also a function of the towing speed many fishermen reduce this parameter in order to lower fuel consumption.

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 the propeller, increase the swept area or decrease the drag. This also applies to bottom trawls: they must sweep a bottom surface to catch fish. Their sweeping width, which, for some fish species, may be the distance between wing ends or between doors for others, implies a towing distance. In order to increase the bottom trawl energy efficiency, one may increase the efficiency of both the engine and

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Table 1
Drag repartition between components for trawls: without (a) and with (b) catch on Italian bottom trawl, without (c) and with (d) catch on a 57/52 pelagic trawl. These figures are from the FEM model.

	a	b	c	d
Cables	8%	7%	28%	24%
Otter boards	21%	19%	17%	15%
Netting	66%	60%	55%	44%
Catch	0%	10%	0%	17%
Ground rope	5%	4%	–	–
Total	100%	100%	100%	100%

propeller, increase the sweeping width or decrease the drag. The last suggests that the catch is proportional to the swept area for pelagic trawl and sweeping width for bottom trawl. In fact it is not so clear: numerous works have studied the relation between catch and mouth opening such as Main and Sangster (1981) in case of bottom trawls.

This paper deals with trawl optimisation by decreasing the drag and increasing the swept area for a pelagic trawl (or the sweeping width for a bottom trawl). The method proposed improves the trawl energy efficiency by altering the panel cuttings according to Parente et al. (2008), though by means of an automatic tool which is based on a numerical method devoted to shape calculation of fishing gears.

Yet, such automatic (or numerical) tools for optimisation are not available but only those dedicated to shape calculation: Ferro (1988), Theret (1993), Bessonneau and Marichal (1998), Niedzwiedz and Hopp (1998), Tsukrov et al. (2003), Le Dret et al. (2004), Lee et al. (2005) have developed 3D numerical methods which describe the twines of the net as numerical bars. These techniques take into account a large number of twines for each numerical bar. The forces considered are not only the drag due to the water flow, but also the weight and the buoyancy of the net. Some of the methods also take into account the twine elasticity. The drawback of these models is that they cannot represent netting details smaller than numerical bars. O'Neill (1997) has developed a 2D model for axi-symmetrical structures, such as the trawl cod-end. The twine tension, the mesh opening stiffness and the pressure of the fish catch on the net are taken into account. Another drawback of this modelling is that it is devoted to the only axi-symmetrical structures. To avoid the problem of constrained numerical elements and axi-symmetry hypothesis, and yet take into account further mechanical behaviours, a Finite Element Method (FEM) 3D model of the net based on a triangular element has been developed (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 these numerical tools.

The whole drag of the trawl can be split between the different parts of the structure. Table 1 gives the drag of the various parts of a pelagic trawl and a bottom trawl, calculated by the FEM model. It clearly appears that most of the drag is attributable to the netting part.

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 for the pelagic trawl or per sweeping width for the bottom trawl, and therefore in terms of fuel consumption. The following part of the paper proposes an answer in the form of an optimisation numerical tool.

2. Methodology

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

2.1. 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 (m^2), $n0$: unstretched length of mesh side (m), n: stretched length of mesh side (m).

2.2. The drag force exerted on the net by the current

$$F = \frac{1}{2}\rho CdDL(V\sin\theta)^2$$

$$T = f\frac{1}{2}\rho CdDL(V\cos\theta)^2$$

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).

2.3. The drag on the bottom

$$Fc = Coef\ Fv$$

Fc: drag on the bottom (N), Fv: vertical force on the bottom (N), $Coef$: friction coefficient (here 0.5).

The automatic optimisation of the trawl is carried out step by step. A step consists in an automatic modification of the panels, one

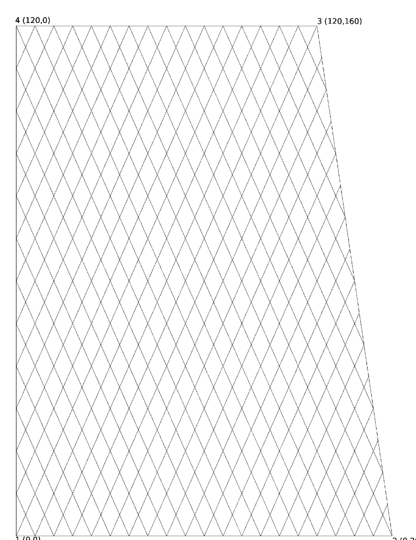

Fig. 1. Panel of netting of 120 meshes high, 160 meshes on the top horizontal border and 200 on the bottom one. Only 1 twine out of 10 is drawn. The number of meshes of nodes is noted. The origin of meshing is node 1.