A new generation of tools for trawls Dynamic numerical simulation

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Abstract :

IFREMER and ECN have been working together for almost ten years on problems related to the numerical simulation of trawls and more generally the numerical simulation of any kind of fishing gear. To develop such a simulation tool, we need to build (i) a software in which all the parameters of the fishing gear are taken into account; (ii) a software that computes the physical behaviour of the fishing gear (static or dynamic); (iii) a software to visualise the results of calculations. The most complex part of this work most of the time rests in the point (i), because of the huge amount of parameters and elements of an actual fishing net.

We have already developed a tool (point (i), named Cachalot) to describe a trawl. However, this software was designed to build numerical meshes that are intended for the calculation software CATS. Thus, Cachalot software cannot take into account the most important actual building specifications of a trawl.

The new method for calculating numerical meshes for trawls which we are presenting in this workshop, is in keeping with recent research results about dynamic simulation of nets: the previous limiting factors due to the hypothesis of CATS do not longer exist. It is now possible to compute a net with its actual parameters, like elasticity, symmetrical shape or not, strengthening rope, different kinds of meshes, hanging ratio, etc … We will present the operating mode and the possibilities of this new software. We will also show the different prospects of the simulation software : turning circle, obstruction, simulation of fish catch, etc …

Finally, we will show some examples of application of these software : animation of pelagic and bottom trawls, twin trawls etc …

NOMENCLATURE

m_i : momentum of the knot number i

$\vec{\gamma}_i$: acceleration of knot number i

$\vec{T}$: strain in a bar (Newton)

$\vec{H}$: hydrodynamic effort on a bar.

k : stiffness coefficient of a bar

ℓ_{kl0} : length of a bar when T=0

$\vec{X}_k$: co-ordinates of the knot number i

$\vec{V}_n$: normal velocity

$\vec{V}_t$: tangential velocity

ρ : water mass per unit of volume

C_f : hydrodynamic friction coefficient

C_d : hydrodynamic drag coefficient

D : diameter of the bar
L : length of the bar

1. THEORETICAL BASIS

1.1 INTRODUCTION

The main improvement resting in the new dynamic method (versus CATS, the previous method developed in our lab) consists in solving all of the equilibrium equations at the same time: this method can be qualified of "fully coupled method". Consequently, there is no more restrictive hypothesis in the description of the structure.

1.2 MECHANICS

Each twine of the net is modelled by a rigid bar. These bars are linked together with perfect knee joints. The flexibility of the twines is considered with another intermediary perfect knee joint. The equations that model a net with N knots and M bars are written below:

- N equations of the dynamic mechanic balance, written for the knot number i :

$$m_i \vec{\gamma}_i = \sum_{fils\,voi\sin s} \left(\vec{T} + \vec{H} \right) \tag{1}$$

- M length equations taking into account the elasticity of the bar which extremities are the knots number k and l :

$$\ell_{kl}^{\,2} = \ell_{kl0}^{\,2}(1 + kT)^2 = \left(\vec{X}_k - \vec{X}_l \right)^2 \tag{2}$$

1.3 FLUID MECHANICS

In order to simplify the writing of the equations, we use scalar products to determine the different velocity components relatively to each bar : $\vec{V}_n$ and $\vec{V}_t$.

One can write : $\vec{V}_t = \dfrac{\vec{V}.\vec{\ell}}{\|\vec{\ell}\|^2} \vec{\ell}$ or $\vec{V}_t = \dfrac{1}{\ell^2} \begin{pmatrix} V_x \ell_x{}^2 + V_y \ell_x \ell_y + V_z \ell_x \ell_z \\ V_x \ell_x \ell_y + V_y \ell_y{}^2 + V_z \ell_y \ell_z \\ V_x \ell_x \ell_z + V_y \ell_y \ell_z + V_z \ell_z{}^2 \end{pmatrix}$ (3)

and $\vec{V}_n = \vec{V} - \vec{V}_t$ that is to say $\vec{V}_n = -\dfrac{1}{\ell^2} \begin{pmatrix} V_x\left(\ell_x{}^2 - \ell^2\right) + V_y \ell_x \ell_y + V_z \ell_x \ell_z \\ V_x \ell_x \ell_y + V_y\left(\ell_y{}^2 - \ell^2\right) + V_z \ell_y \ell_z \\ V_x \ell_x \ell_z + V_y \ell_y \ell_z + V_z\left(\ell_z{}^2 - \ell^2\right) \end{pmatrix}$ (4)

The interest of this writing rests in the possibility to have a partly implicit expression of the velocity components (and consequently, a partly implicit expression of the hydrodynamic efforts) :

$$\vec{V}_{n/t}{}^{n+1} = \vec{f}_{n/t}(V_x{}^{n+1}, V_y{}^{n+1}, V_z{}^{n+1}, V^n)$$ (5)(6)

Finally, the two velocity components of hydrodynamic efforts are modelled as follows :

$$\vec{F}_t = \frac{1}{2}\rho DL C_f \vec{V}_t \left\| \vec{V}_t \right\|$$ (7)

$$\vec{F}_n = \frac{1}{2}\rho DL C_d \vec{V}_n \left\| \vec{V}_n \right\|$$ (8)

The use of (5) and (6) in (7) and (8) allows us to have a greater time step in the iterative resolution, and consequently a faster calculation.
Water current (due to the towing movement or due to the natural conditions (tide currents, wind currents, swell current …) are supposed to be independent of the net : this means that the net device does not perturb the water velocity.

1.4 RESOLUTION OF THE EQUATIONS

Equations (1) (2) are mixed together and solved at the same time. External efforts (hydrodynamic efforts and other external efforts due to water current for instance) are "almost" solved at the same time as (1) and (2), due to the partly implicit writing. At each time step, we get a dynamic equilibrium of the structure where every position and every strain is known.

2. INPUTING THE TRAWL PARAMETERS AND CHARACTERISTICS

2.1 DESIGNING THE TRAWL

The main improvement of the latest version of the software to input the trawl design rests in :
- its capability to consider the actual parameter of a trawl
- an easier and intuitive interface to input data.

Moreover, the software is able to compute automatically most part of the "non intuitive" data that can pose a problem to a non specialist user :
- The software proposes a "default" numerical mesh, which is the basis for the simulation. The mesh can be modified dynamically by the user. This definition is entirely "mouse-controlled".
- Shortest bars are automatically removed or replaced.
- The initial structure shape is generated so as to minimise the duration of the simulation (CPU time consuming reduction).

At each level of the design definition, a useful system of library allows the user to call back elements that have been already defined (user time consuming reduction).

2.2 CHANGING PARAMETERS

One of the aims of this simulation software is to optimise the working mode of a trawl. Thus, in such an optimisation process, it is quite useful to have the possibility to change parameters during the simulation. The obvious advantage of such a solution is that one does not need to start all over again the entire simulation with its new parameters.

The commercial version of the trawl simulator DynamiT allows the user to modify any design parameter from the input software and to force the calculation module to take it into account. A lot of time can be saved this way.

3. EXAMPLES

We now present two examples of what can be done with the software. These examples are mainly quantitative but, of course, we also pay a lot of attention to the precision of the numerical results. In connection with that, several times a year, we lead experimental campaigns at sea to measure the parameters (geometry and forces) of actual trawls (bottom and pelagic).

For the time being, we can conclude that the most important uncertainty lies in the behaviour of otter boards. Despite this fact, we have maximum differences of about 15% between numerical and measured parameters for a pelagic trawl.
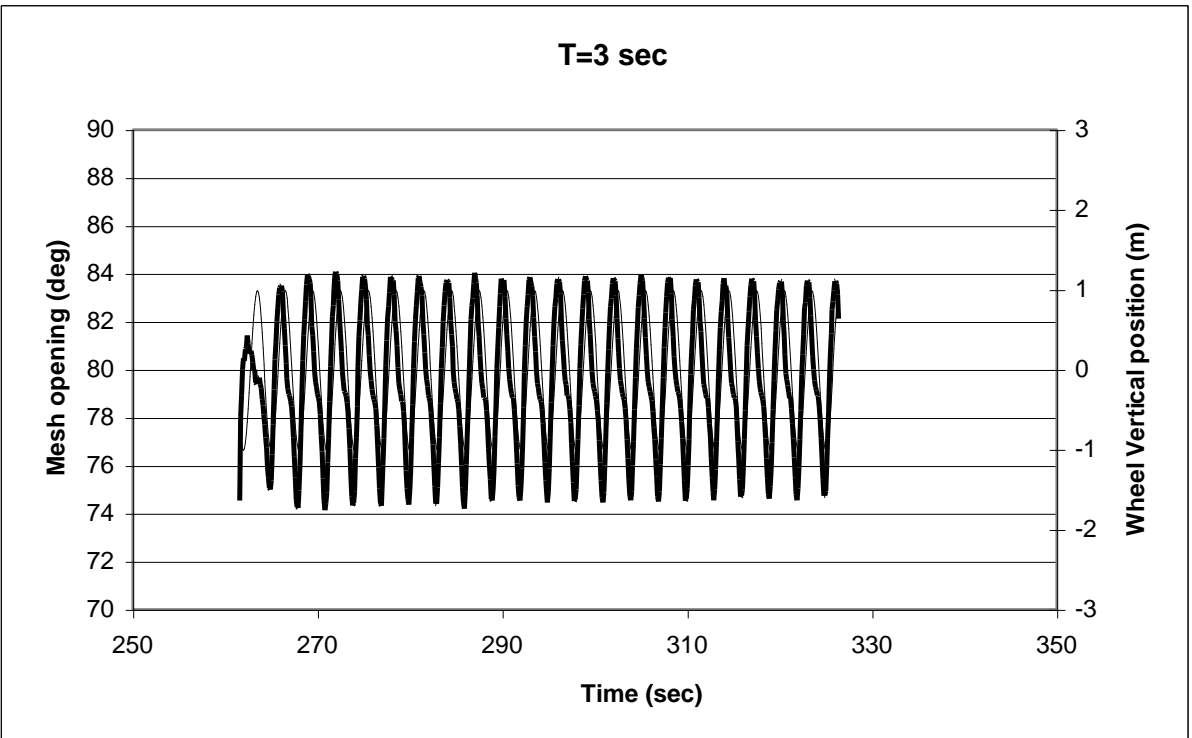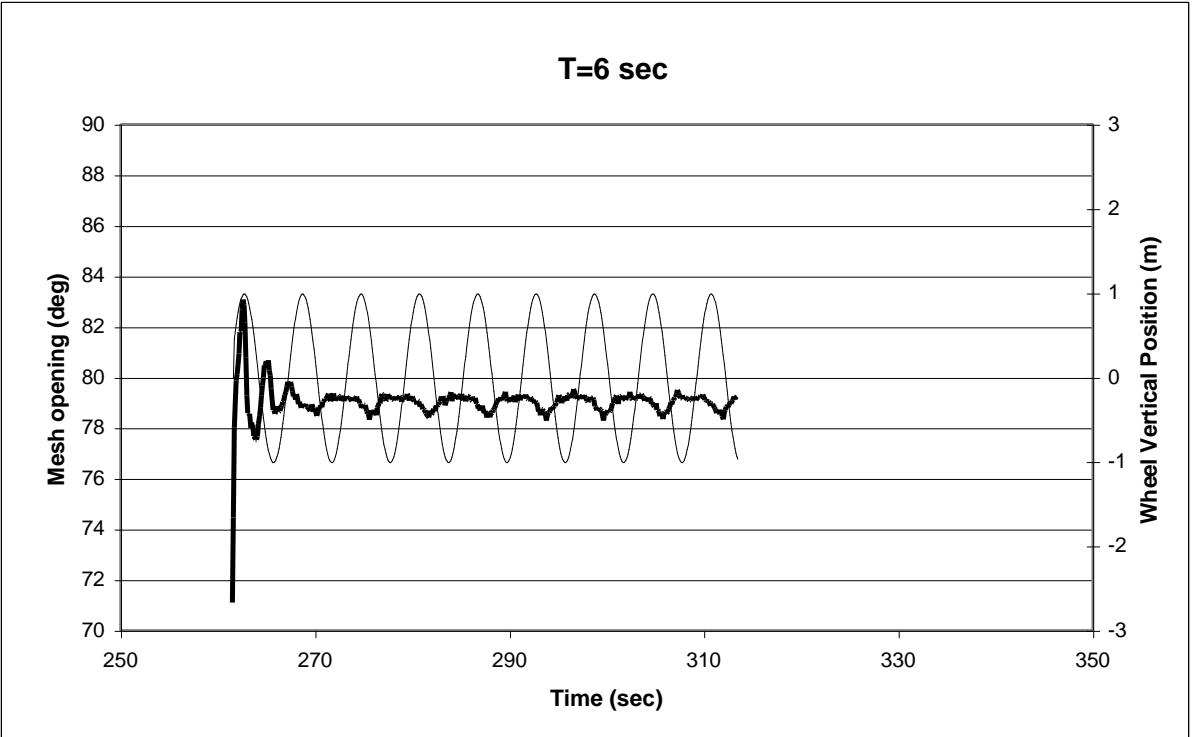

3.1 DYNAMIC SIMULATION

The first example we present shows the capability of the software to take into account "non time-constant towing condition". From this example, one can imagine the possibilities to simulate the turning circle of the trawler for instance.
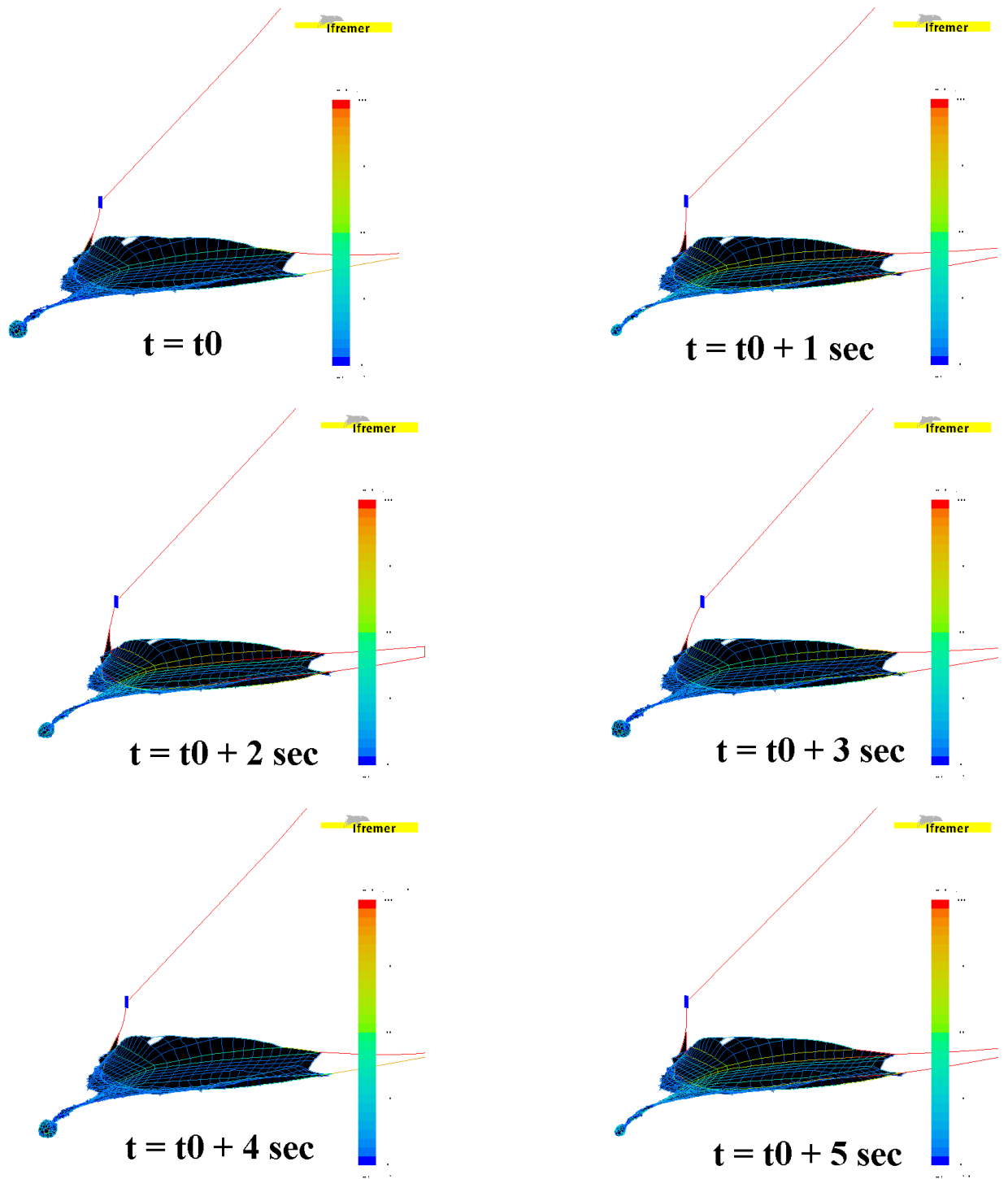
The pictures bellow are the results, at different time, of a trawl simulation under following conditions:
- the trawler is going forward swell,
- the trawl has a capture in its codend,
- the depth (and consequently the warp length) is rather short.

Towing speed	3.5 knots
Warp length	300 m
Sea bottom	100 m
Otter boards	Polyfoil oval 7.4 m²
Vertical amplitude of pulley wheel	1 m
Horizontal amplitude of pulley wheel	1 m
Capture	1m3 – 1000 kg

We have tried different swell frequencies so as to determine an hypothetical "natural mode" of the trawl and its capture. Graphs are given bellow. The thick line is the mesh opening. The fine line is the vertical position of the towing point.
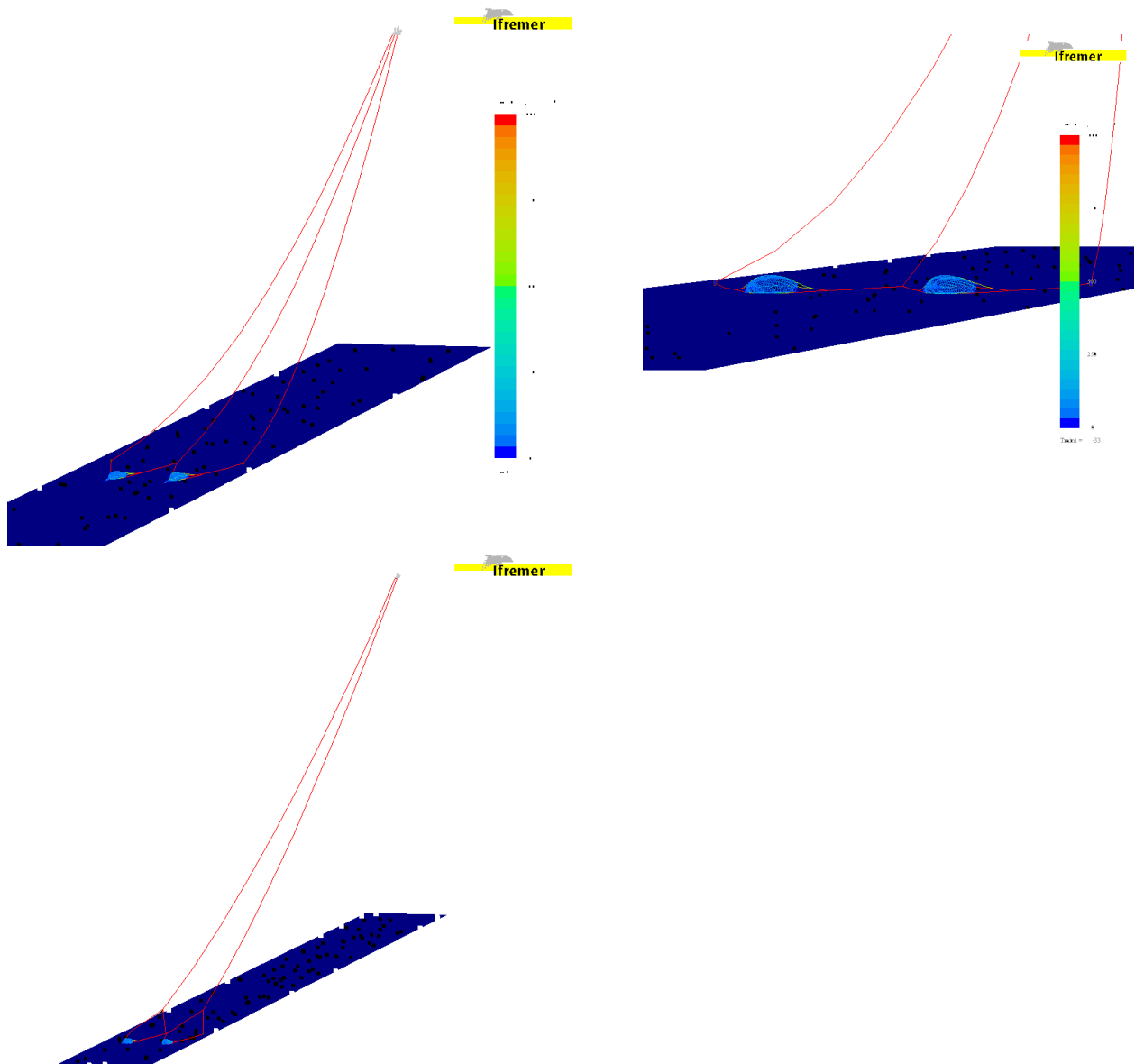
T=6 sec

T=3 sec

These pictures (swell period of 6 seconds), which are direct results of the simulation show the deformation of the codend at different time steps. One can also see the otter boards and the head rope are changing positions.

3.2 TWIN TRAWLING

This fishing technique is more and more used. Its rig is a bit more complicated than that of a single usual trawl. In this case DynamiT is useful to determine the good sweep adjustments.

4. PROSPECT

The simulation examples above point out the capacity of the software:
- To consider the actual parameters of the trawls.
- To compute a lot of interesting simulations, depending on the external and towing conditions.

This software is dedicated to the trawl simulation but any kind of device built with net can also be calculated with this method (fish farming, gillnets, or even cable systems …).

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