Study of the manoeuvrability and security of a trawl gear

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ABSTRACT

A complete method is presented for determining the static and dynamic behaviour of a fishing gear. The net, which is very flexible, is modelised by a set of rigid bars. The hydrodynamic forces, applied to each bar, are determined by combining and generalizing the Landweber and Morison hypothesis. A CFD method is used to calculate the forces on trawl doors. The fundamental principle of dynamics is completed with length equations expressing the elasticity of the bars. It leads to a set of second order non-linear differential equations, which is solved using a Runge-Kutta method. We will now present a few examples of the various applications of our works : the study of the trawl gear equilibrium in a uniform flow, an example of manoeuvrability (gyration of the trawl gear) and an application to security with the simulation of an obstruction.

KEYWORDS

Trawl gears, manoeuvrability, security, doors, obstruction

INTRODUCTION

We have studied the static equilibrium and the dynamic behaviour of submerged supple nets for several years [Théret, 1993 and Bessonneau, 1997]. With time we have made some modifications to improve our method: for instance, we have replaced an iterative method by a Runge-Kutta method to solve the equations. We have also introduced an elasticity condition for the bars. Moreover, the CFD methods allow us to study in detail the forces on the trawl doors. These three major improvements enable us to tackle more efficiently the issues of manoeuvrability and security.
A trawl is a flexible net having – under towing and fishing conditions – a roughly conical shape. Its vertical opening is obtained by weights at the bottom and floats on top; its horizontal opening is made possible by the hydrodynamic spreading effects of trawl doors, the shape of which being simple (plane and rectangular) or sophisticated (V-shaped, cambered, including slots…).
The trawl is towed by the vessel via cables called wraps.
Wraps, trawl doors, the trawl itself and its rigging are referred to as "the fishing gear".
For a long time, fishermen could not exactly know the shape of the trawl as they were fishing, and improving this shape was done through a very slow and empirical process.
Then flume tanks were built, which offered a good example of realistic trawl models and some quantitative observations. More recently, underwater equipment such as high-sensitive video cameras, tension transducers, and opening transducers… enable the professionals to figure the immersed trawls with even better accuracy.

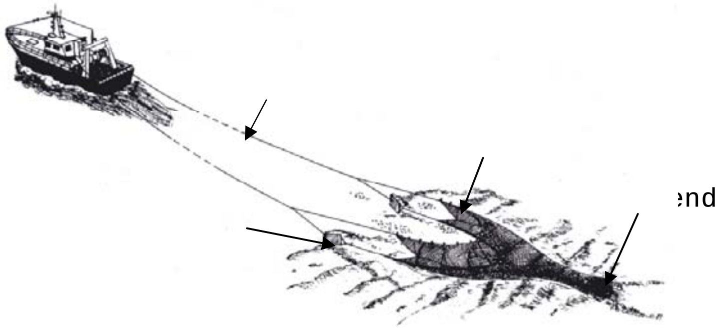


Figure 1. General overview of a trawl (George, 1991)

Each element of a trawl gear represents in itself a research theme which we have dealt separately. In this work, we put together the different methods we have proposed to study the dynamics of a complete trawl gear where all the constituent parts interact. This study is a fundamental action that aims at improving fishing conditions and also safety conditions at sea.
In the examples here presented, the trawler is forced to follow a given trajectory (for example, study of the trawl gear gyration). However, its motion could be completely determined using M. A. Abkowitz studies [Abkowitz, 1969]. The trawler could also have a time dependent angle of rudder or be submitted to the action of currents and waves. For these studies it is necessary to know all the hydrostatic and hydrodynamic coefficients of the trawler. Software allows now to work them out. Now, this represents a great deal of work and the results given hereafter only apply to a single boat.
Wraps are underwater circular cylindrical cables. We have developed a study of the dynamics of these flexible elongated structures by generalising the L. Landweber hypothesis [Landweber, 1947].
Nets are reticulated supple surfaces. Their study is conducted assuming that they are made of cylindrical rigid bars, constituting the mesh sides (each mesh side is represented by two rigid bars to ensure its suppleness). In order to decrease the number of unknowns, it may be necessary to use a "globalisation" method by introducing a virtual mesh representing a set of real meshes.
The hydrodynamic forces that have an effect on trawl doors are characterised by a preliminary study. For this purpose, a commercial CFD software is used. We determine the full torque (three forces, three moments) of the hydrodynamic forces that act on the trawl door as a function of the three angles that define its orientation relatively to the towing speed.
All the equations obtained are put together and lead to a set of second order differential non linear equations which are solved by a time step method.
Thus we are able to study the dynamics of the system in various situations : gyration, forced trajectory, effects of the sea state on the trawl, obstruction, etc.

THE FLUID-STRUCTURE INTERACTION PROBLEM

General sketch of the mechanical problem

We intend to investigate the dynamic behaviour of a trawl gear. This is a complex problem of mechanics:

- a netting panel is a most flexible structure, which can be greatly deformed. It presents a non linear behaviour for each mesh side may be either taut or more or less slack…
- the water flow through the meshes is a complex phenomenon. It depends on the mesh size, its opening, its orientation…
- the stresses resulting from these flows thus depend (regarding both intensity and direction) on the shape of the flexible structure. Now its shape is itself function of the stresses.

- usually, the initial configuration of a trawl is a supple twine heap without any shape of its own. This non-definite initial shape is one of the main difficulties to solve in the mechanical study of reticulated flexible surfaces.

This described, the present study turns out to be an original and most complex problem, with strong interactions between shapes, flows and forces, and very large shape variations...
In order to take into account the mesh sides distortion, each side is divided in two equal segments. A more precise cutting up would improve the representation, but would significantly increase the number of unknowns to be determined.

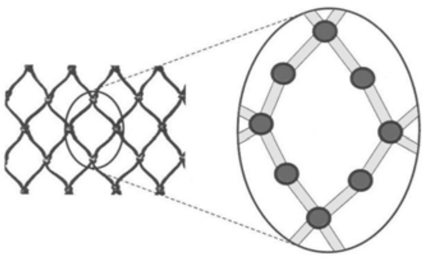


Figure 2. Representation of the net meshes

We are now going to write the "dynamic equilibrium" of each of the bars constituting the sides of the studied mesh. Each bar undergoes hydrodynamic actions (pressure drag and tangential friction), and the action of the bars linked to it. To describe the fundamental principle of dynamics it will therefore be necessary to introduce the tension of the adjacent bars. This does not lead to more unknowns thanks to the elasticity condition. Finally, some bars are submitted to particular forces (trawl doors, floats...).
All actual knots (links between mesh sides) and intermediary junctions points are supposed to be rotoïdal links. Thus, it is assumed that no knot can transmit any moment to rigid bars. This hypothesis proceeds from a bad knowledge of the netting panel rather than a difficulty to write the corresponding equations.

Hydrodynamic forces acting on the net (and on the wraps)
The whole hydrodynamic force amounts to the superposition of the forces applied to each cylindrical rigid element. Mesh bars may be considered as hydrodynamically independent in relative water flow (there is no hydrodynamic interaction between a rigid element and the other bars).
These formulations are written generalising the Landweber hypothesis (case of circular cylindrical cables in equilibrium in a uniform flow). The hydrodynamic forces can be split into:
- a drag pressure force T_p orthogonal to the element
- a tangential friction force F_t
- an added mass force, A_p which is only due to the acceleration perpendicular to the element

In a classical way, we can write:

$$\mathbf{T_p} = -\frac{1}{2}\rho\, d l C_d\, \mathbf{V_p} \left\| \mathbf{V_p} \right\| \quad (1)$$

$$\mathbf{F_t} = -f\,\frac{1}{2}\rho\, d l C_d\, \mathbf{V_t} \left\| \mathbf{V_t} \right\| \quad (2)$$

$$\mathbf{A_p} = -\rho \frac{\pi d^2}{4} l C_m \boldsymbol{\gamma}_\mathbf{p} \quad (3)$$

where:

C_d is the pressure drag coefficient of a rigid element, f its tangential friction coefficient, and C_m its added mass coefficient,

V_p the rigid element velocity V projected on a plane P orthogonal to the element

V_t the tangential component of V

With reference to Théret's study [Théret, 1993], we have chosen to use C_d = 1.2 for most of the mesh bars. This drag coefficient is equal to the value generally assumed for a fixed rigid cylinder. In the same way, we use a value for f equal to 0.1 and a value for C_m equal to 1. These values slightly change for bars on wraps or very long meshes, owing to the important vibrations that occur along them. According to experiments we considere the following ones: C_d = 1.8 and f = 0.01.
These different forces are calculated using relative velocity of the middle of each rigid bar. At this time, we suppose a priori that the trawl does not modify the relative flow. It is obvious that this hypothesis is conditioned by the size, the orientation and the opening of each mesh. It is therefore quite acceptable for the front part of the trawl. In the cod end, the aft part of the trawl, the mesh bars are closer one to each others Studies are currently lead to determine more precisely how the cod end acts on the flow.

Internal links

Internal linking forces provoke a distribution of tension throughout the whole fishing gear. At any given "time", we assume that the tension stays constant along each rigid bar. Rigid elements are only able to approach the behaviour of supple twine meshes under tension, because, unlike rigid elements, twines are flexible and cannot transmit compressive forces. Thus, we will have to check the values of the tensions to deal specifically with negative ones (we cannot obtain any negative tension).
One of the greatest advantages of this method is that it is very easy to introduce many other internal and external forces which describe as far as possible the complexity of the problem, such as the action of the trawl doors or the contact with the ground for the concerned meshes. These specific forces are taken into account in the equations, but will be developed later in the following sections.

Mechanical equations

We apply the fundamental principle of dynamics to each knot "i" of the meshes (mesh sides junctions and intermediary knots).

$$\sum \mathbf{F}_{\mathbf{external}} = m\,\gamma \qquad (4)$$

Hydrodynamic forces applied to each rigid bar are evenly distributed between the two ends of the cylindrical element. Internal linking forces (principally tension of bar) are considered as external forces acting on the concerned knot. Each knot mass m_i is equal to half of the mass of all rigid elements around it.
If N is the number of the knots to be considered as real, we obtain N equations:

$$\sum_{j=n_1(i)}^{n_k(i)} \left\{ \mathbf{t_{ij}} + \frac{1}{2}\left(\mathbf{T_{p_{ij}}} + \mathbf{F_{t_{ij}}} + \mathbf{A_{p_{ij}}}\right) + \mathbf{L_i} \right\} = m_i\,\boldsymbol{\gamma}_\mathbf{i} \qquad (5)$$

where:

- k is the number of knots adjacent to knot i
- $n_1(i),\ldots,n_k(i)$ are the numbers of the knots adjacent to knot i
- t_{ij} is the tension of bar ij
- L_i represents the particular linking forces applied on the knot i
- $\mathbf{T_{p_{ij}}}$ and $\mathbf{F_{t_{ij}}}$ are the hydrodynamic forces acting on the bar ij

We need to add the equations giving each bar length to these equations dealing with forces. We introduce an elasticity coefficient χ:

$$l_{ij} = l_{0_{ij}}\left(1 + \chi\, t_{ij}\right) \qquad (6)$$

where l_{0ij} is the length of the bar ij when no tension is applied to it.
Equation (6) may be written in the following way:

$$t_{ij} = \frac{1}{\chi}\,\frac{l_{ij} - l_{0_{ij}}}{l_{0_{ij}}} \qquad (7)$$

knowing that:

$$l_{ij} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2 + \left(z_i - z_j\right)^2} \qquad (8)$$

where x_i, y_i and z_i are the coordinates of each knot i at time t.
Finally, equation (5) is then written as:

$$\gamma_{\mathbf{i}} = \frac{1}{m_i} \sum_{j=n_1(i)}^{n_k(i)} \left\{ \mathbf{t_{ij}} + \frac{1}{2} \left(\mathbf{T_{p_{ij}}} + \mathbf{F_{t_{ij}}} + \mathbf{A_{p_{ij}}} \right) + \mathbf{L_i} \right\} \tag{9}$$

where the functions $\mathbf{t_{ij}}, \mathbf{T_{p_{ij}}}, \mathbf{F_{t_{ij}}}, \mathbf{A_{p_{ij}}}$ and $\mathbf{L_i}$ only depend on the knots coordinates x_i, y_i and z_i and on time t.

The Runge-Kutta method

These last equations make a second order, non-linear, differential system which we shall solve using a Runge-Kutta integration method. This is a time step method which main difficulty rests in the initialisation of the shape. If we introduce the column vector Y associated to the coordinates of all the knots studied, the equations written above are obviously already written in a general form:

$$Y'' = \Phi\,(t, Y, Y') \tag{10}$$

Where Y' and Y'' are the first and second order derivatives of the Y vector (the speeds and accelerations of all the knots), t is time and Φ the non-linear matrix function linking all these parameters together. The Runge-Kutta method offers different algorithms for solving this kind of differential equations [Abramowitz, 1970].

At the end of each time step, this method enables to calculate the values of the tensions and to impose a zero value on the non taut bars (no negative tension). We can also check that no element passes through the ground (in that case it is also easy to impose a zero value on its vertical coordinate).

STUDY OF THE HYDRODYNAMIC FORCES ON TRAWL DOORS

Trawl doors are surfaces that create a lift force (very particular foils). The use of two symmetrical doors enables the horizontal opening of the trawl. Unlike the usual foils, for stability and equilibrium reasons, trawl doors work with large incidences (usually between 30° and 40°). The door incidence is adjusted by modifying the position of its fastening points.
There are various types of doors, which are different by their size, shape and type of trawling. Bottom trawl doors are equipped with a thick shoe plate which is supposed to remain in contact with the ground, unlike pelagic trawl doors which are entirely surrounded by water. Some manufacturers also add slots to improve the lift on the door.
The hydrodynamic forces caused by doors are not well known. Developments of CFD now enable to determine them more precisely. We will apply this method to the study of a door used as a research equipment on one of Ifremer’s vessels. It is a bottom trawl door which shoe plate is specially shaped to host measurement devices. It is equipped with a slot and is V-shaped, to set it upright more easily if it bent over during the trawling.

Stationary forces

We intend to determine hydrodynamic efforts (the three components of the forces and the three components of the moments acting on the door) for a great number of orientations of the door relatively to the direction of the towing speed. The different cases are obtained by changing the values of the three angles (yaw, pitch and roll in this order) which define the door position.

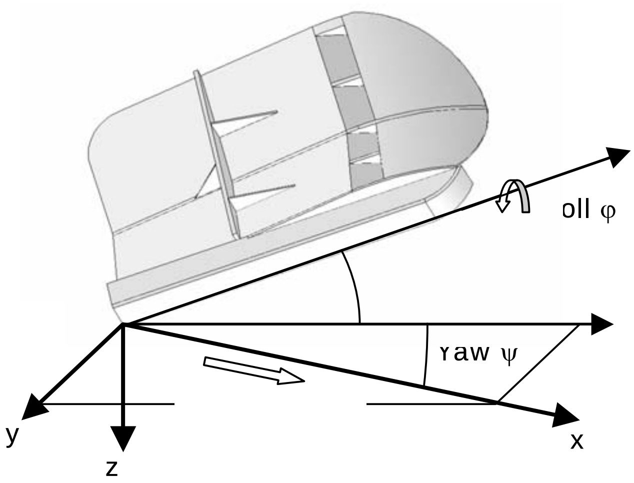


Figure 3. Yaw, pitch and roll angles of the door

The figure below shows an example of path lines around the door.

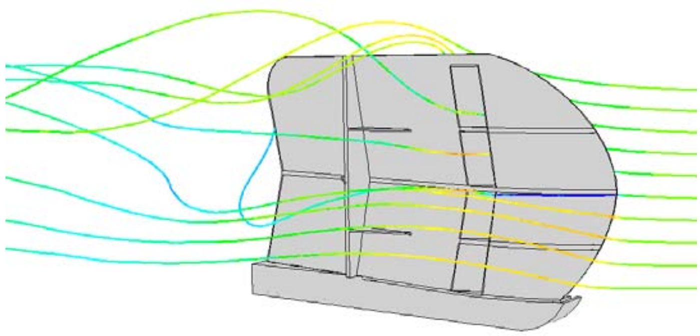
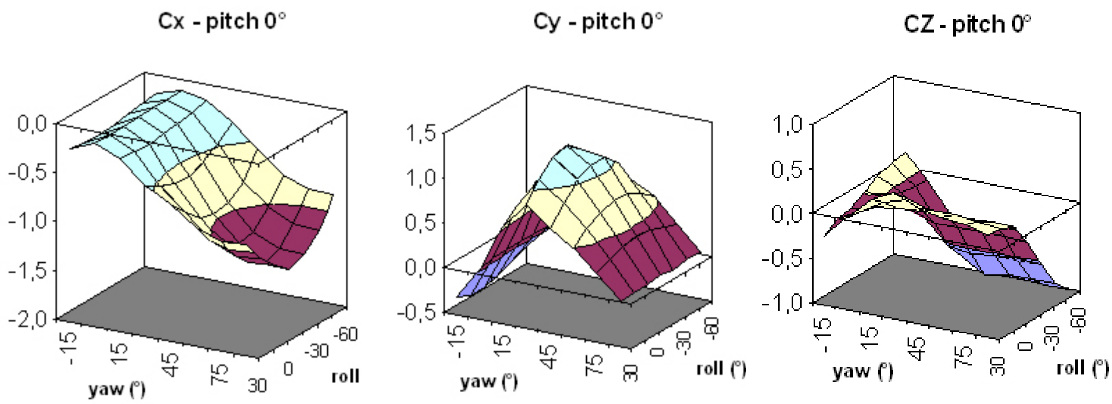


Figure 4. Path lines around the trawl door (yaw 15°, pitch 0°, roll 15°)

The efforts are presented as adimensional coefficients (the reference surface is measured while laying down the door flat on the ground, thus it remains constant for all the cases). The moments are calculated about the point located on the front at mid-height of the door. The variations of these six coefficients for a zero pitch angle are shown on the next figures.



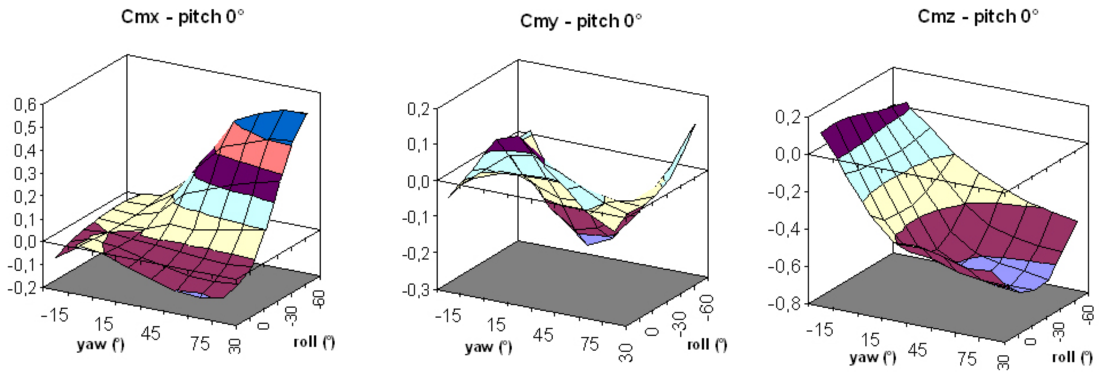


Figure 5. Variations of the door coefficients with yaw and roll (pitch = 0°)

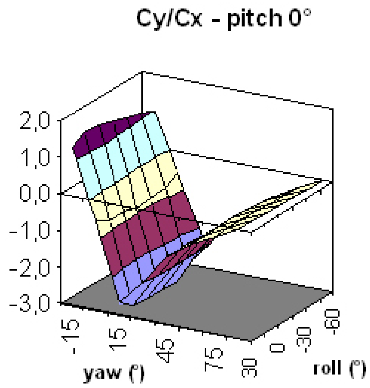


Figure 6: Efficiency of a door (lift/drag)

We obtain similar curves for other values of the pitch angle. In order to calculate easily each force and momentum coefficient of the doors when simulating the trawl gear, a set of polynomial functions that interpolate these different curves is used.

Added masse forces
The dynamic forces and momentum (added mass and inertia) are determined using the same CFD software applied to the simulation of an acceleration (absolute) of the door in each direction. The unstationary study is made by imposing an initial flow corresponding to the relative flow in the characteristic conditions of the trawling.

APPLICATIONS

Many applications of our work can be considered, which directly concern manoeuvrability and security fields. We are now presenting, without comments, three examples which clearly show the efficiency of our method.

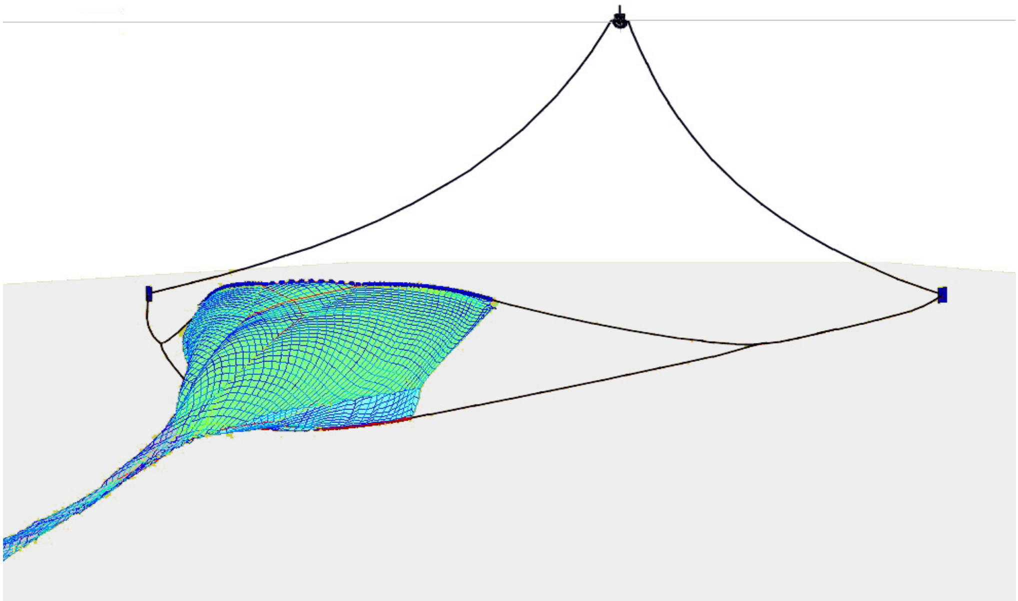


Figure 7. Numerical simulation of the equilibrium of the complete trawl gear

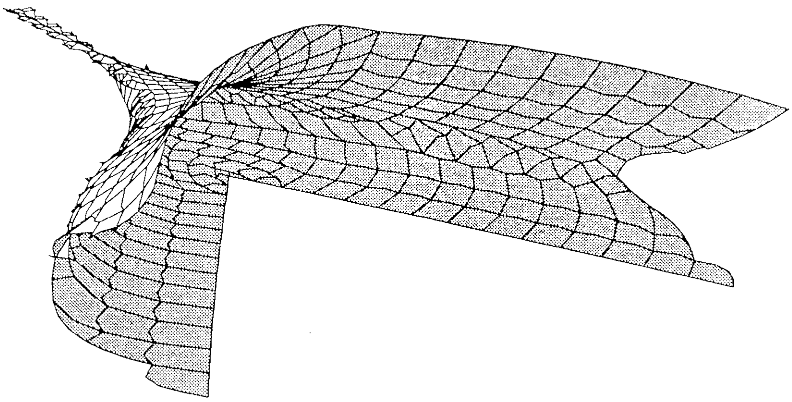


Figure 6. Modification of the net shape in case of an obstruction

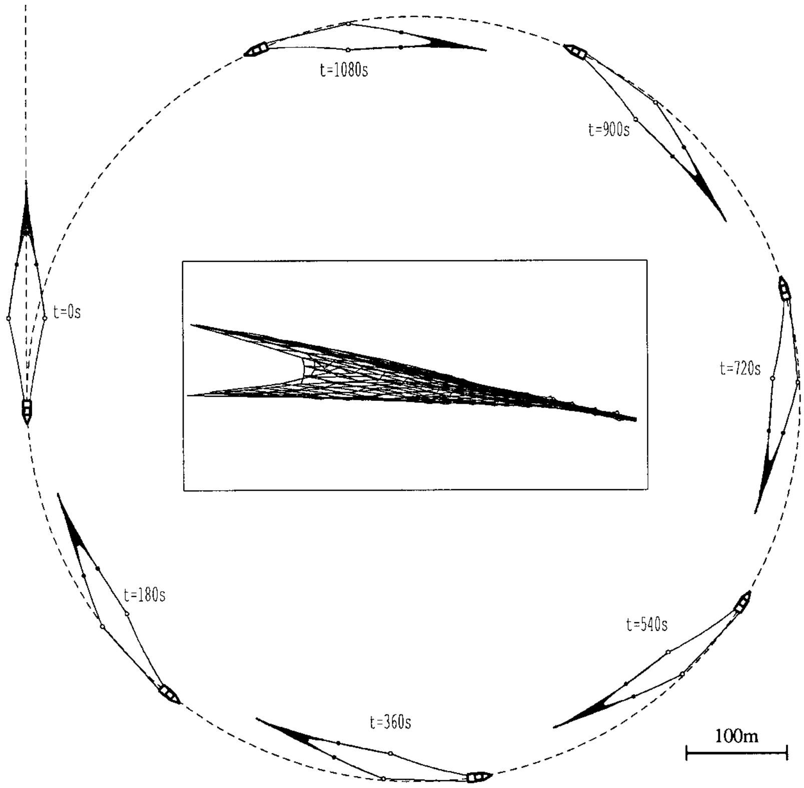


Figure 7. Trawl gear gyration

REFERENCES

Abkowitz, M. A. (1969): Stability and Motion Control of Ocean Vehicles, *Course of Instruction in Ocean Engineering*, Massachusetts Institute of Technology

Abramowitz M., Stegun I. A. (1970): *Handbook of Mathematical Functions*, Dover Publications, Inc., New York

Bessonneau, J.-S. (1997): *Etude dynamique de surfaces réticulées souples et immergées,* Thèse de Doctorat, Université de Nantes, Ecole Centrale de Nantes

Georges, J.-P., Nédélec, C. (1991): Dictionnaire des engins de pêche, Ifremer, Editions Ouest-France

Landweber, L. (1947): The shape of a light flexible cable in a uniform current, Journal of Applied Mechanics, June 1947, pp. 121-126

Théret, F. (1993): *Etude de l'équilibre de surfaces réticulées placées dans un courant uniforme*, Thèse de Doctorat, Université de Nantes, Ecole Centrale de Nantes