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A MATHEMATICAL MODEL FOR THE DETERMINATION OF THE SHAPE AND THE TENSIONS OF A TRAWL PLACED IN A UNIFORM CURRENT

by

François THERET
IFREMER, 8 rue François TOULLEC, 56100 LORIENT, FRANCE

ABSTRACT

The determination of trawls shapes and tensions is a very complex problem. At this time only the static aspect has been considered, the trawl being placed into a uniform current.

Three types of difficulties have been met :

- Firstly, the hydrodynamic behaviour of the meshes is not well known ;
- Secondly, a net is a complete flexible structure with no own shape unless submitted to the action of external forces, but so we are facing an actual " fluid-structure interaction" problem ;
- Thirdly, a flexible reticulate structure is made of an anisotropic and discontinus material.

In this paper, the net studied is a trawl for which, the only parameters known are the drawing and the characteristics of the cables which link it to the trawler.

The method that we propose to determine the shape and the tensions in the net consists in writing the equilibrium equations at each knot of the net and resolve this system by an iterative method.

INTRODUCTION

This work has been instigated by the wish to have a numerical model of the trawls for two goals. Firstly, in order to create an actual computer assisted trawl simulation and secondly to easily and fastly study the influence of different external parameters of adjustment of a trawl on its shape and tensions. The final objectif is to give the best adjustment of the trawl to the skipper in its working conditions. This software will be the result of the EC CATS project which is conduct by IFREMER and two Danish institutes, the DIFTA from Hirtshals and the DMI from Copenhagen. Here is just presented the theoritical work on the hydrodynamic part of this project.

Up to now, only the static problem have been considered, the trawl being towed with a uniform speed in calm water.

We have studied a pelagic and a bottom trawl. In the case of the bottom trawl, the bottom is a limit condition but for the time being, we have not studied the effect of the bottom frction not for a theorical or numerical problem but because the friction is not well known.

The study of the equilibrium of trawls in towing conditions is difficult for three main reasons :

- The hydrodynamic behaviour of twine and mesh assembled to make a net is not clearly known.

When passing through a mesh, is the water accelerated or slowed down, or just deviated (this is the "mesh filtrating effect" problem) ? What influence have both mesh opening and angle of attack of the surface containing the mesh on hydrodynamic forces applied to the mesh ? What kind of interaction exists between a mesh and its neighbours ? The few existing papers often show different results which may even be contradictory. These results have generally be obtained when testing plane rectangular netting panels, or parts of net cones stiffened by coatings, but similarity laws do not appear through these experiments, preventing any generalization of the results.

- A net is an infinitely flexible structure, without any definite shape, and only external forces allow it to find its shape.

When dealing with nets towed in water, these external forces depend on the shape of the net itself ; we have so to solve an actual-fluid structure coupling problem.

Before shooting, the trawl is either wound round a net drum or piled up on deck ; during shooting, its shape progressively reaches the equilibrium shape which we try to determine. This change in shape cannot be considered as the result of small deformations around a mean position.

- A net is a reticulate surface made in a discontinuous and anisotropic material.

Assembling the meshes together creates preferential directions for stress and deformation propagation. In some equilibrium conditions, it may happen that some meshes are completely closed, so behaving as completely unstretchable wire ; some others meshes may be completely loose, with no definite geometrical shape.

Some solutions, both partial and approximate, have been proposed to solve this problem, using systematic test series and extrapolations. This method does not allow great innovation as it must be applied to nets the type of which has already been studied. What we propose here is a method including writing the equilibrium conditions of each knot of each mesh and solving the equations system by an iterative process.

This way seems to be original and more general, and could also be easily applied to many other problems.

1 - TRAWL DESCRIPTION

A net is described by the drawing of each of its part. One must find in such a drawing all the informations needed by a computer to predict the shape and the tensions of the trawl when the net is assembled and in equilibrium in a water flow. So we have to change this drawing into three numerical tables giving

1) The description of all knots

Remark 1 :"knot" may have a mathematical meaning, as a geometrical point having a mass and the equilibrium equations of which are written.

"knot" may also have a physical meaning; the knot, being the junction between two twines, has its own thickness which generates local efforts.

Remark 2 : To be able to take into account the curvature of some mesh bars and avoid the existence (artificial and numerical) of negative tensions, we have divided each mesh bar in two rectilinear parts, so multiplying the number of knots by at least three.

2) The description of all the twines (length, diameter, mass, drag coefficient...).

3) The description of the singularities (external forces acting on special knots creates, for example, by : floats, ballasts, knots diameter, otterboards).

These tables have to be completed by the description of limit conditions (towing points...)

1.1 - Knots Description

We are studying here nets using diamond meshes. The same method could be applied to hexagonal meshes, the only condition to comply with being that no more than four twines arrive on the same knot.

Most of the knots of a diamond mesh piece of netting are :

- on one hand, those where the junction between four mesh bars is realized ;

- on the other hand, those which we have introduced in the middle of the mesh bars (two twines knots).

But cuts and seams may create some other types of knots. For the time being we have identified eighteen different types (and some more may exist...).

Each knot is completely described by a line in a file called "links table".

1.2 - Twines Description

Mechanical characteristics of each twine appear in a table called "twine file". This file also includes the elements which allows the calculation of the components of the efforts created by singularities existing at some knots (floats, ballasts, otterboards...).

For each knot appearing in the table, the length, diameter, and mass per length unit of the two twines stemming from the knot are given, together with the singularities existing (if that is the case) at the knot.

1.3 -Initial Shape

The initiative calculation process which we use requires that a plausible arbitrary shape, compatible with the different mechanical links existing in the trawl, is given to begin the calculation. At the present time, this shape is a straight line, the trawl being completely closed, all the meshes being gathered on this line.

2 - HYPOTHESIS

2.1 - Uniform Speed Field

When a trawl is towed in calm water, the relative speed field is uniform far from the trawl, but water passing through the meshes disturbs this uniformity. We have not found in the literature any accurate information about the speed field created inside the trawl. Some authors say that water is accelerated, the trawl beeing a kind of porous funnel ; some other ones think that meshes create an obstruction, slowing down the flow, making some water pass around the trawl and in some cases creating some backwards currents. The first measurements which we have alreay done have not shown noticeable changes in the water speed for all the trawls already studied. We have for that reason admitted that the trawl does not change the relative water flow and that the trawl is placed in a flow which is uniform in every place.

2.2 -External Forces

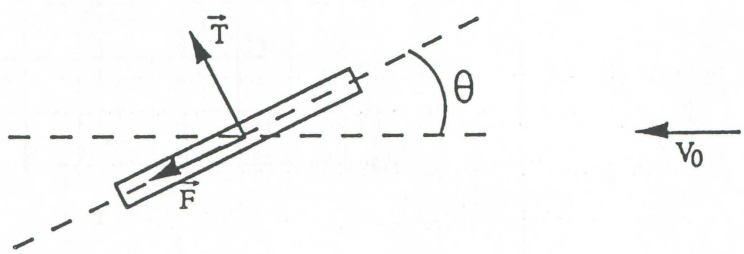
The external forces applied to a trawl belong to four different categories :

<u>2.2.1. External Forces Applied By Water To The Mesh Bars</u>. Using previous results, as those of BLENDERMAN for example, and also measurements obtained in the Lorient flume tank, we have established that a net - as far as hydrodynamic calculations are concerned - can be considered as the juxtaposition of N hydrodynamically independant twines. So we calculate the hydrodynamic forces applied to each mesh bar as if this one was also alone in an uniform flow - LANDWEBER's hypothesis are then applied : each hydrodynamic force can be resolved in two components.

- one force T due to pressure drag, perpendicular to the mesh bar and proportional to the square of the normal component of the speed ;
- one tangential friction force F, proportional to the square of the flow speed, measured infinitely ahead.

(1) $$T = \frac{1}{2} \rho \, C_d \, l \, d \, (V_o \sin\theta)^2$$

(2) $$F = \frac{1}{2} f \rho \, C_d \, l \, d \, V_o^2$$



where C_d and f respectively are the drag coefficient and the friction coefficient of the element of twine studied, V_o is the towing speed and $V_o \sin\theta$ its component perpendicular to the twine element.

C_d and f values have been established by identification, applying our calculation method to a simple experimental case i.e. a rectangular (when plane) piece of netting attached to a rigid hoop as the entry outline. We have looked for the C_d and f coefficients giving the best correlation between calculated and experimental values of tensions and dimensions (fig 1 and fig 2).

We have obtained C_d = 1,2 and f = 0,08. This Cd value is the usual one found for a cylindrical solid of revolution, within the same range of Reynolds number. The f coefficient is 10 times the expected value, but this may be due to the existence of crossings and junctions between the twines.

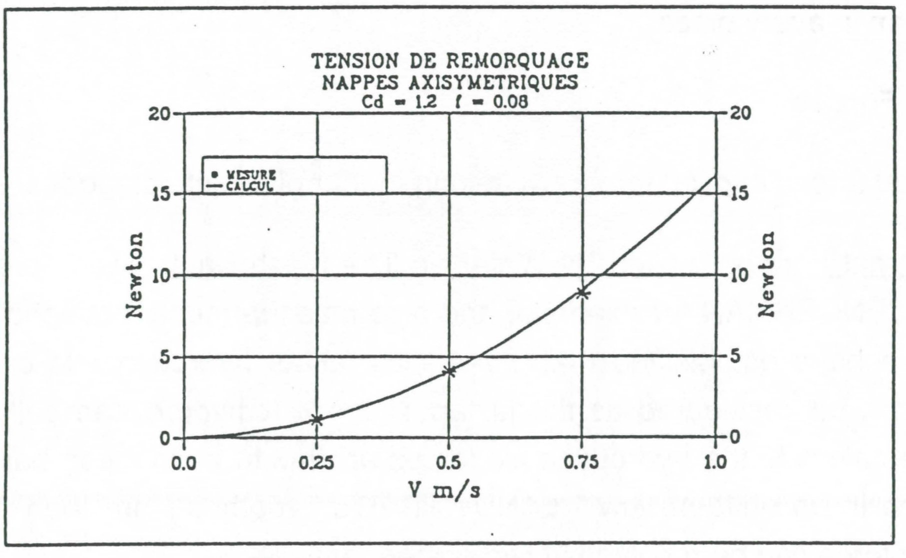


Figure 1 . Towing tension.

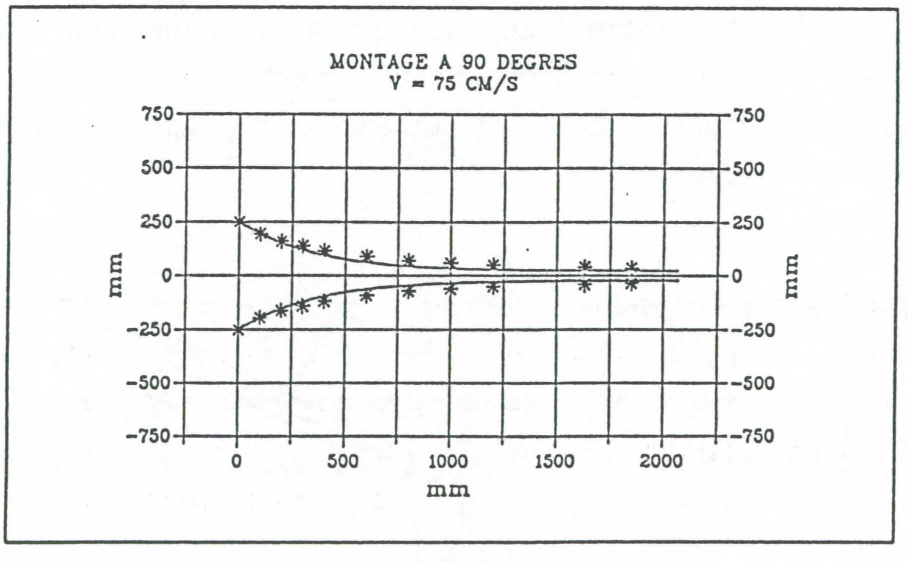


Figure 2 .Net attached on a rigid hoop.

2.2.2. - Gravity Forces. They include the weight in water of all the trawl gear (cables, otter boards, ballasts, floats, twine weight...).

2.2.3. - Singularities (elements introducing ponctual forces). A singularity introduces forces applied to the knot to which it is attached. These forces are resolved in three components : for example, a spherical float applies to its knot a vertical component equal to its apparent weight, a component parellel to the water flow which is its hydrodynamical drag ; in this case the third component is equal to zero for symetry reasons.

2.2.4. - Linking Forces. Generally speaking, these forces are those applied to the net by its moving or towing system, which are often unknown. For a trawl, the linking forces are the warps tensions the knowledge of which is very important to predict the required towing power and the fishing gear strength and dimensions.

3 - THE EQUATIONS

3.1 - General Equations

According to the knot type (2,3 or 4 twines), the equations are different. We just show here the most common case, i.e the equilibrium of 4 twines knot.

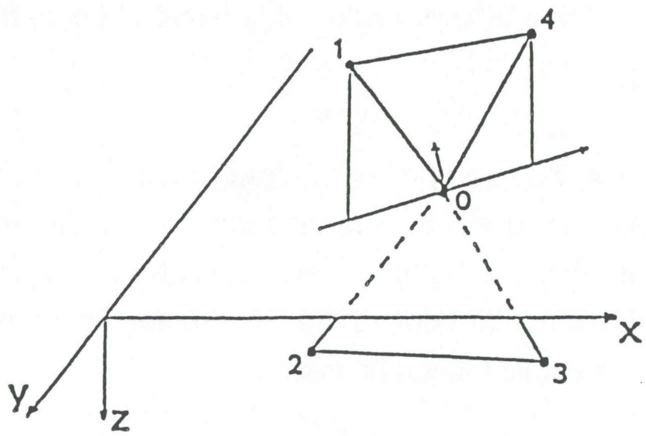


Figure 3 . Equilibrium of a knot.

External forces applied to each mesh bar are equally divided and applied to the two ends of this bar. The equilibrium of each knot is so reached thanks to the balance between four half resultant of hydrodynamic and gravity forces applied to the twines joining in this knot, of tensions of these twines and forces created by singularities. The equilibrium equations are then written, after projection on to three axes Ox, Oy and Oz :

(3) $$\sum_{i=1}^{4} T_i \frac{(x_i - x_0)}{l_i} + \sum_{i=1}^{4} \frac{Hx_i}{2} + Sx_0 = 0$$

(4) $$\sum_{i=1}^{4} T_i \frac{(y_i - y_0)}{l_i} + \sum_{i=1}^{4} \frac{(Hy_i + P_i)}{2} + Sy_0 = 0$$

(5) $$\sum_{i=1}^{4} T_i \frac{(z_i - z_0)}{l_i} + \sum_{i=1}^{4} \frac{Hz_i}{2} + Sz_0 = 0$$

Where T_i is the tension in the bar number i, Hx_i the hydrodynamic effort applied on bar number i projected on the axe Ox, Sx_0 the force created by a singularity projected on the axe Ox, P_i the weight of the bar number i and x_i the coordinates of the knot number i.

This equations system is completed by the length conditions written for two "upper" bars of the studied knot.

(6) $$(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2 = l_1^2$$

(7) $$(x_4 - x_0)^2 + (y_4 - y_0)^2 + (z_4 - z_0)^2 = l_4^2$$

The solution of these equations brings to a pair of values for z_i which may be positive or negative. We have admitted that the net could only be stretched as much as possible.

3.2 - Bottom Action

During the iterative process, when a point of the trawl goes down to the bottom or goes through it (numerically), we introduce a vertical force, which is adjusted during the iterations, to ensure the link with the bottom. This vertical force is the bottom reaction without friction ; indeed we have not introduced the friction, not for a theorical or numerical reason but because, at this time, this friction is unknown.

4 - SOLUTION

As already said before, a diamond mesh net with N physical knots includes about 2 N bars ; as each bar has been split in two parts, we have introduced 2 N intermediate knots and doubled the number of twines. The equiliibrium conditions of the net - as a reticulate surface - are known when are determined :

- 3 times 3 N coordinates of knots (both physical and intermediate)
- 4 N twines tensions.

This means about 13 N unknown. As N may be very high even in a trawl model, the number of unknown may become far too high for usual computers capacity. To decrease the time and achieve the convergence of computation, we have studied a method for creating mesh clusters and so decrease the number of knots used in the calculation ; the results of this work are being adapted in our model.

The results already obtained must first allow us to chek if the hydrodynamic hypothesis used are valid, then be used as a reference to check the results of a more global method.

All the equations written (3 N times 3 equilibrium equations for knots and 4 N times 2 length conditions for the twines) are non linear because

- the hydrodynamic forces are obtained from knots coordinates through complex trigonometric relations ;

- the twine tensions appearing in equilibrium conditions are multiplied by the knots coordinates ;

- the length conditions are obviously non linear.

To solve this equations system, we propose an iterative method. The starting point is either an arbitrary shape given to the trawl and compatible with the length conditions, or the shape calculated during the previous step, and the hydrodynamic forces applied to the mesh bars are calculated. The equilibrium conditions equations are then used to calculate the tensions of these bars and some knots coordinates. The missing coordinates are calculated using the length conditions. The convergence is said to be reached when the calculated shape being kept constant from one iteration to the following one.

5 - EXAMPLES AND CONCLUSION

The following figures present some results of the model. It was not possible here, but generally we present those results with color where the different colors represent the different tensions in the bars which are computed in our model.

The figure 4 shows a pelagic trawl where the cables placed in front of the trawl are considered as particular meshes. This configuration represents pair trawling where two trawlers are towing one trawl.

The figure 5 presents a bottom trawl towed by one vessel. We can observe the contact with the bottom and the otterboards effect. The vertical opening of the trawl is obtained thanks to floats placed in the front part of the upper pannel of the net.

Those two figures present results which are in agreement with the observations of the trawls tested in Lorient (F) and Hirtshals (DK) flume tanks (the differences between the results obtained from calculations and from flume tank tests are lower than 10%).

The difference between figure 6 and figure 7 shows the influence of the speed. When we increase the speed, the pelagic trawl goes up and the upper part of the net becomes more straight than the lower one.

On the figure 8, we observe that the curvature of the bars is well taken into account by the division of each of them in two parts.

All the phenomenon we observe and the results we obtain are in good agreement with reality.

This work is not completely finished. But the results we obtain show the validity of our method for solving this original fluid-structure coupling problem.

REFERENCES

[1] V.A BELOV et autres "Engins de pêche remorqués", Editions Agropromizdat Moscou 1987.

[2] W. BLENDERMANN "On analysis of the hydrodynamics forces on cables and nets", Applied Ocean Research 1987, vol 9 n° 4.

[3] D. MARICHAL "Etude numérique des chaluts de pêche" ATMA session 1990 Paris.

[4] D. MARICHAL, F. THERET "Etude sur l'équilibre de surfaces réticulées dans un courant uniforme", 3ème Journée de l'hydrodynamique, Grenoble Février 1991.

[5] F. THERET, "Etude de l'équilibre de surfaces réticulées placées dans un courant uniforme - Application aux chaluts", thèse de Doctorat, Université de Nantes, Ecole Centrale de Nantes, 1993.

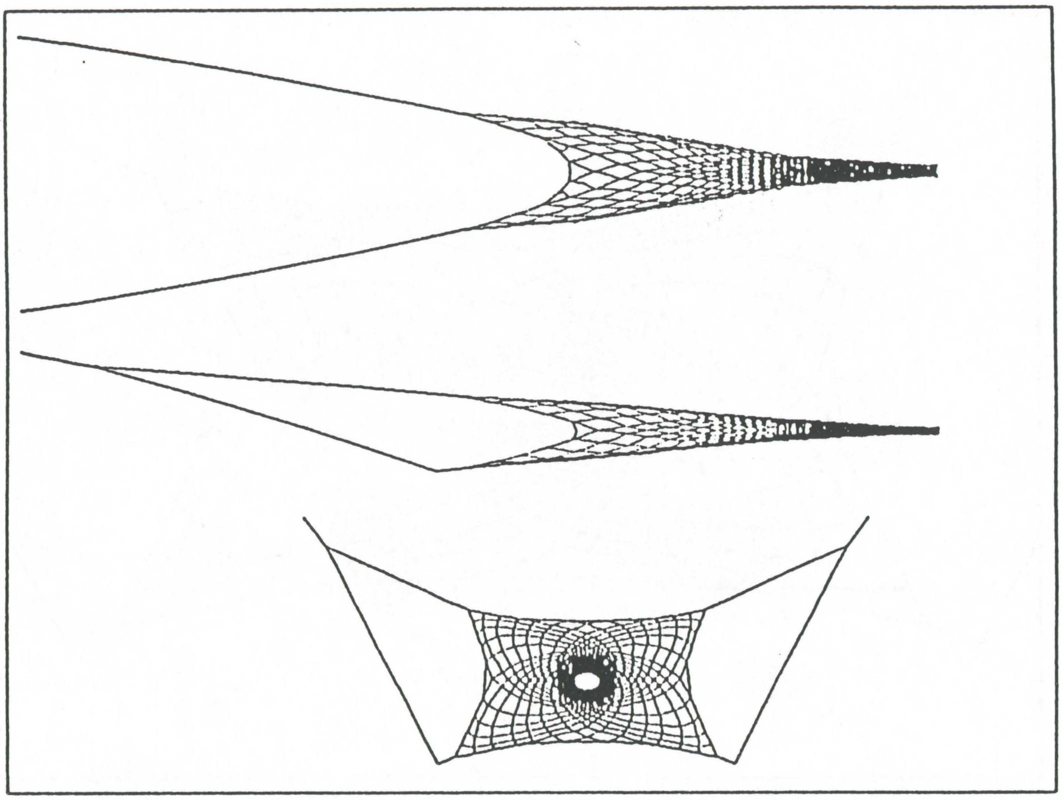


Figure 4 . General view of the pelagic trawl (V_0 = 0.87 m/s).

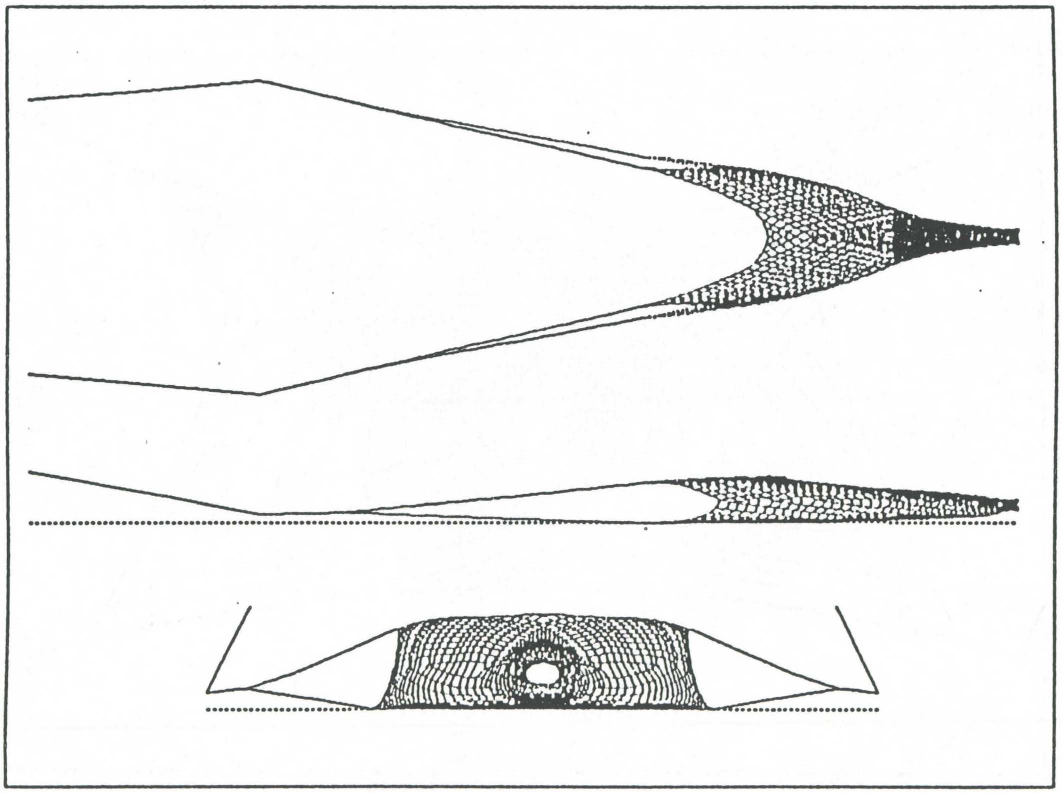


Figure 5 . General view of the bottom trawl (V_0 = 0.58 m/s).

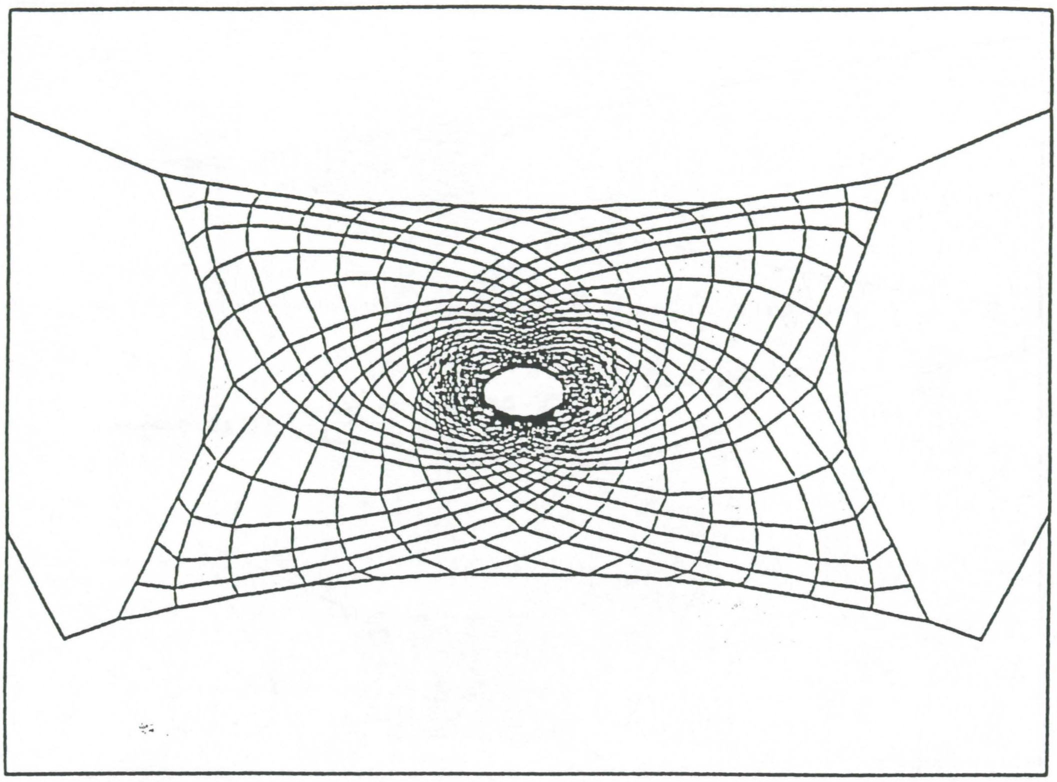


Figure 6 . Front view of the pelagic trawl ($V_0 = 0.87$ m/s).

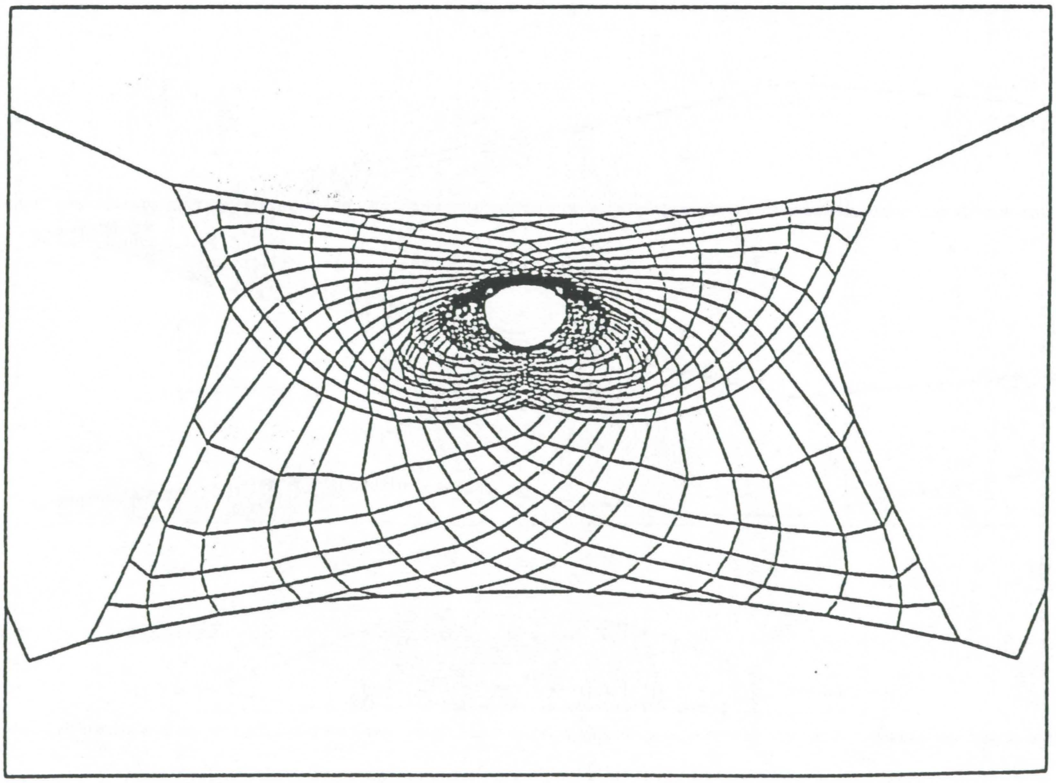


Figure 7 . Front view of the pelagic trawl ($V_0 = 1$ m/s).

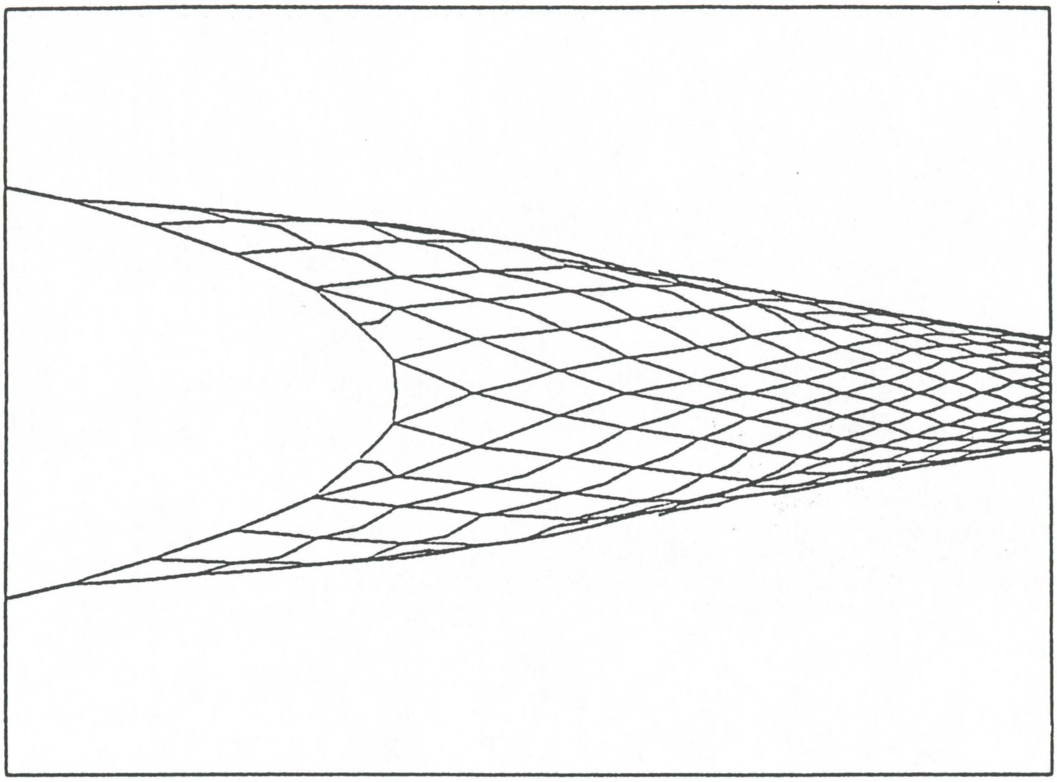


Figure 8 . Upper view of the pelagic trawl ($V_0 = 0.87$ m/s)