ESTIMATION OF FLOW SPEED AND PRESSURE DISTRIBUTION IN A FISHING TRAWL COD-END

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Abstract

Studying of flow speeds and pressures distribution in/around fishing net structures is caused by a strong influence of hydrodynamic fields on the shape of trawl elements, acting forces, fish behavior and, finally, on catchability of fishing gears. The paper presents an estimation of opportunity to describe such speed and pressure distribution using FEMLAB software.

Hydrodynamics of various types of fishing net structures, in particular, of a trawl, as the problem attracts attention of scientists for a long time. The Fig. 1 shows the trawl system scheme.

Why it is necessary to know parameters of trawl hydrodynamic fields?

Importance of flow parameters estimation consists in an exclusive dependence of the forces acting both on a trawl as a whole and on each of its parts from flow speeds and pressures distribution in the trawl. The knowledge of these forces allows defining the shape, drag and behavior of the structure during a trawling process, tension and loads in its threads and ropes. As well flow speeds and pressures in its end section, named as the cod-end, have a very significant influence on the fish moving process.

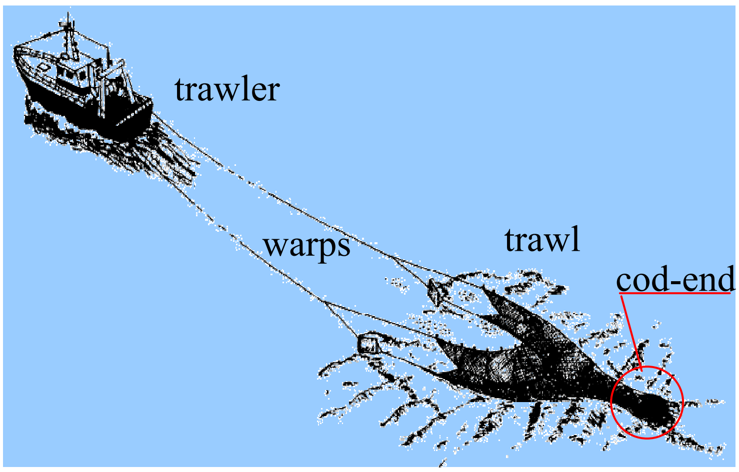
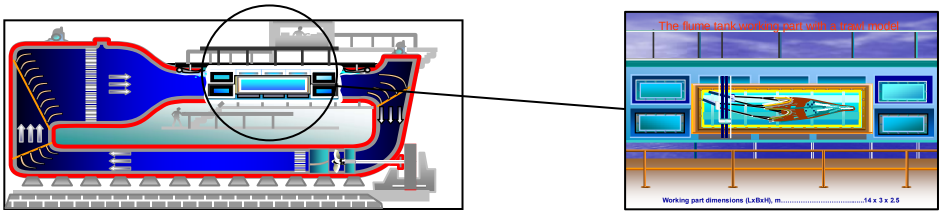


Figure 1: Scheme of a fishing trawl system

The quantity and quality of the catch collected in the cod-end depends on fish behavior. Besides influencing of the cod-end design on flow speeds/pressures it causes a net “meshing” with fish that in its turn influences on hydrodynamics of the cod-end and consequently on its catchability.

In spite of the significant experimental material was collected, and also theoretical methods of hydrodynamic fields definition were suggested, the problem remains as actual one at present time.

Experimental researches on trawl, cod-end models with imitation of catch various values, for examples [1, 2,] have been conducted in flume tanks. Views of the flume tank, which is located in Kaliningrad, Russia, are shown in the Fig. 2.



a) b)

Figure 2: View of the flume tank (a) and the working part (b)

Flow speeds were measured in experiments [3] both inside and outside of net construction. An example of experimental data is shown in the Fig. 3.

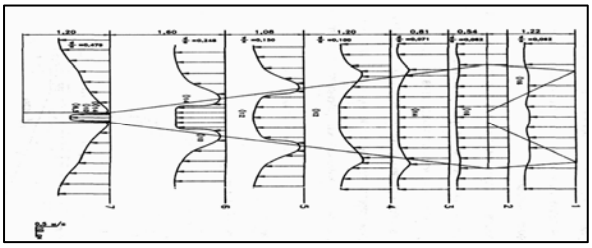


Figure 3: Flow speed distribution around a trawl model

The flow through a net surface of the fishing structure can be described [4] as a mathematical model of flow through the so named “permeable surface”, which is shown in the Fig. 4.

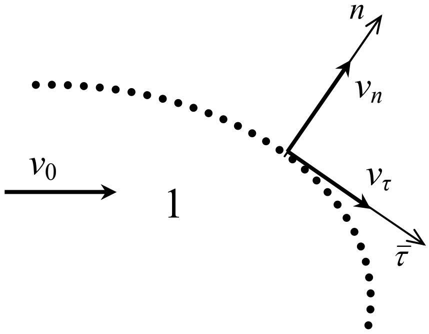


Figure 4: Scheme of a flow through the permeable surface

Water flow through a permeable surface is defined with laws:

Mass conservation $\rho_1 \cdot v_{1n} = \rho_2 \cdot v_{2n}$, (1)

Impulse conservation
$$\begin{aligned} &\rho_1 \cdot v_{1n} \cdot (v_{2n} - v_{1n}) = p_1 - p_2 - R_n, \\ &\rho_1 \cdot v_{1n} \cdot (v_{2\tau} - v_{1\tau}) = -R_\tau, \end{aligned} \quad (2)$$

Energy conservation $\rho_1 \cdot v_{1n} \cdot \left(\frac{v_2^2}{2} - \frac{v_1^2}{2} \right) = p_1 \cdot v_{1n} - p_2 \cdot v_{2n} - \overline{R} \cdot \frac{\overline{v}_1 + \overline{v}_2}{2}$, (3)

where: ρ_1, ρ_2 – water densities; v_{1n}, v_{2n} – speed projections on the normal; v_1, v_2 - speed modules; p_1, p_2 - pressures; R_n, R_τ - normal and tangential components of a flow force acting on a permeable surface unit; $\overline{R}$ - the resulting vector of R_n, R_τ.

Areas "1" and "2" in the Fig. 4 and indexes in equations 1 – 3 define flow parameters in front of the permeable surface and behind it.

Water filtration through a net surface and its permeability is characterized with:

a filtration speed $v_f = \frac{Q}{F_f} = \frac{Q}{(F - F_t)}$ (4)

a filtration coefficient $k_f = \frac{v}{v_f}$ (5)

a permeability coefficient $k_p = \frac{Q}{Q_1} = \frac{(F\text{-}F_t)}{F}$ (6)

Using of this model is needed in evaluation of impact of the permeable surface different details (threads and knots of the net) on the water flow. It presents difficulties because of the multiple diffraction and interference of a flow disturbance around net threads. Interaction between an incident flow and the permeable surface depends on meshes distribution, their number and inclination to the speed vector. These conditions can be described with coefficient k_p distribution on the surface or the surface has the definite value of the coefficient k_p.

It is possible to take assumptions that the flow around net surface has some features:

a) *shape conservation* – the net construction has factually unchangeable shape under the flow impact;

b) *net construction shape creation* – the construction «chooses» itself such shape under the flow, that pressure difference on its surface has a constant value;

c) *net construction has a definite permeability* – which is a main factor of a flow stability around the net construction.

Boundary conditions can be defined generally taking into consideration real features of the water flow through net surface:

- for *a fixed* permeable surface (for example, a set long line or seine):

on the surface $\frac{\partial \varphi}{\partial n} = v_i$; in infinity $\frac{\partial \varphi}{\partial x} = v_0$, $\frac{\partial \varphi}{\partial y} = \frac{\partial \varphi}{\partial z} = 0$. (7)

- for *a moving* permeable surface (for example, a trawl or cod-end):

on the surface $\frac{\partial \varphi}{\partial x} = -v_0 \cdot \cos(v \wedge n) + v_i$; in infinity $\frac{\partial \varphi}{\partial x} = \frac{\partial \varphi}{\partial y} = \frac{\partial \varphi}{\partial z} = 0.$ (8)

where: φ - speeds potential.

Then it is necessary to give a correct law of the force $\overline{R}$ dependence both from water and permeable surface parameters, and pressure changing Δp in order to use the Navier-Stokes equations for flow consideration.

$$\overline{R} = \mathrm{f}\left(\rho, \vec{v}, v_n, v_n', \upsilon, h, \chi_i\right) \tag{9}$$

where: $v_n' = \frac{\partial v_n}{\partial t}$ - a flow acceleration through a permeable surface; ρ – density; υ - kinematic viscosity; t – time; h – a character linear size of a permeable surface (for example: a mesh size); χ_i - combination of nondimensional characteristics of a permeable surface.

As it was mentioned above, a lot of experimental tests were carried out, in that number flow investigations on trawl models and schematized net constructions (SNC) – net cylinders and cones [5]. A scheme of the test is shown in the Fig. 5, 6.

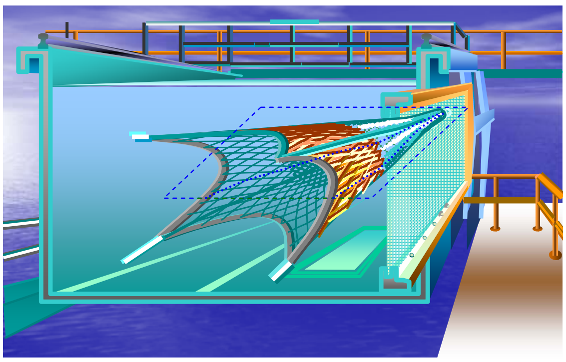


Figure 5: Scheme of the flume tank trawl model test

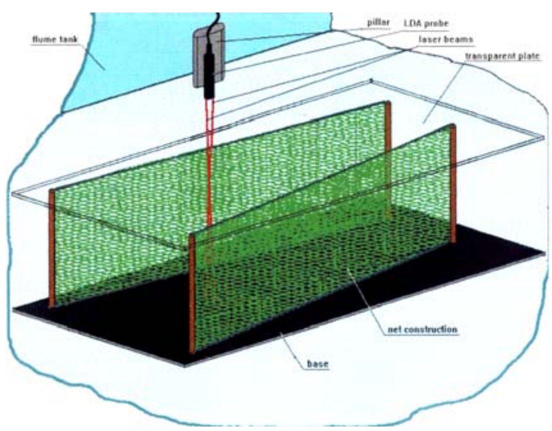
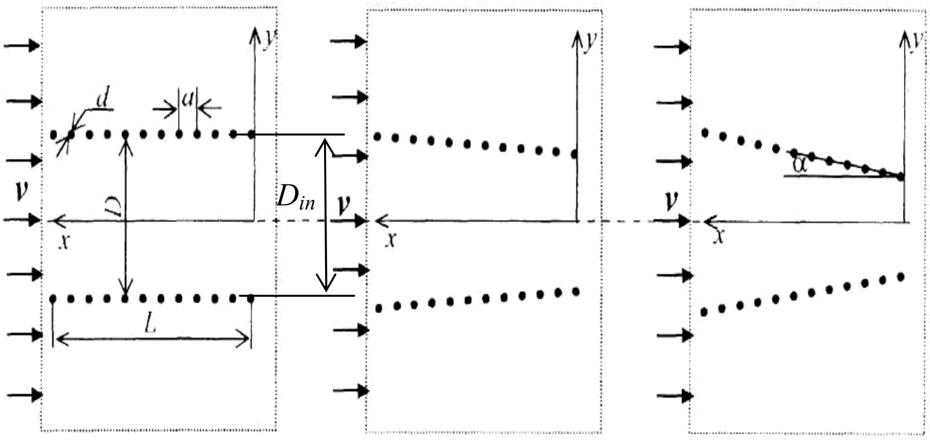


Figure 6: Scheme of the flume tank SNC test

Flow speeds around SNC were studied with the Laser Doppler Anemometry method. It was proved that, taking into account an axisymmetric shape of such constructions as the trawl cod-end, the flow around it can be simulated with good reliability in thin cross or longitudinal sections, as it is shown in the Fig. 5. Thus, cross sections of net threads can be replaced with composition of cylinders or ellipses cross sections. Flow around these structures is equivalent to flow around threads. It is possible to simulate diameters of threads and mesh sizes of the net, as well the permeability coefficient with diameters and interposition of cylinders (ellipses) changing.

Taking into account this assumption a preliminary estimation of opportunity to use the FEMLAB software for hydrodynamic field of net constructions definition was made. A "net" cylinder and "net" cones which are the basic elements of the real trawl cod-end were accepted as "net" constructions for speeds and pressures calculations. Thus, the two-dimensional parallel flow around systems of different cylinder's cross sections, located perpendicularly to a flow direction and simulating longitudinal section of net cones or cylinders was considered. It is known that such flow is described with Navier-Stokes equations. The schemes of "net" constructions are shown in the Fig. 7. Parameters of models are: the inflow speed v = 1.0m/s; the length of models L = 1.55 m; the thread diameter d = 3mm; the mesh size a = 50mm; the inflow model diameter D_{in} = 1.3m.

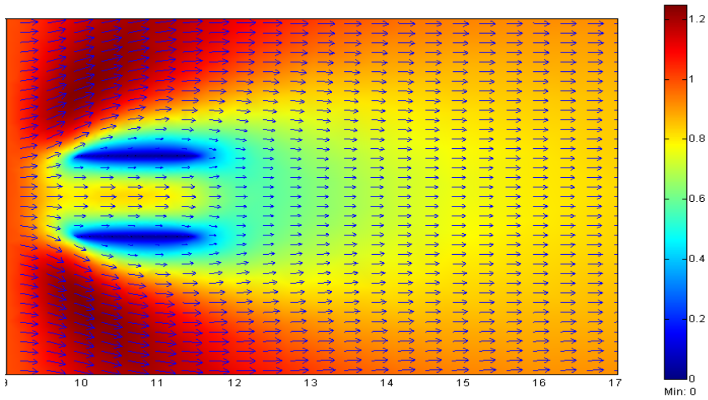


a) cylinder b) cone α≈5°. c) cone α≈10°.

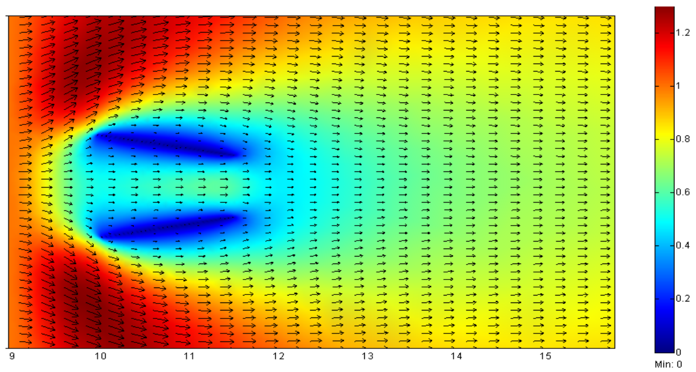
Figure 7: Scheme of the net models

The flow speed area is shown as a dotted rectangular. On the left side – an "inflow" condition with v=1.0m/s; on the right side – an "outflow/pressure" condition; on the top and lower sides a "neutral" condition. As an analysis has shown, the top and lower sides have to be placed on the significant distance from the model, in order to avoid an influence on the flow around it. In this case the distance was equal of 20 m. On "threads" boundaries the condition "no slip" was given.

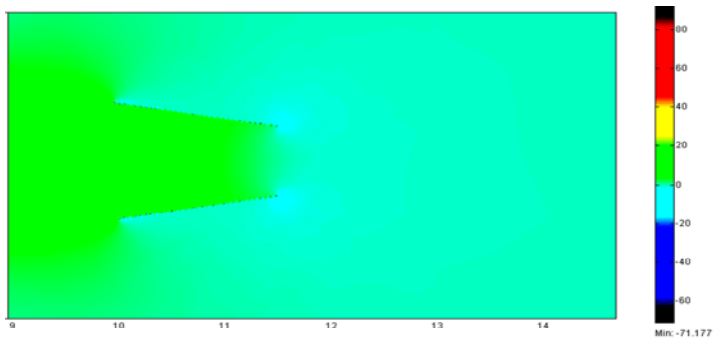
Figures below illustrate flow speed a), b) and pressure c) distribution around "net" models.



a) cylinder



b) cone α≈10°.



c) cone α≈10°.

Figure 8: Speeds and pressures distribution for flow around "net" models

The Fig. 9 shows dependences of relative speeds $\bar{v} = v/v_0$ and pressures $\bar{p} = p/p_0$ along the model's longitudinal axes from the relative abscissa x/L.

The "net" models as an obstacle in flow causes some speed decrease in front of the "net" inlet (x/L>1.0), then at the middle part the speed increases, but falls to the model outlet. The pressure is smoothly decreases along the length of the model. For a comparison the dependence for the SNC "cylinder" [5] is given with a green dotted line. The dependences for the SNC and calculated "net" models have a similar character. This fact says about a principal possibility to use the FEMLAB software for calculation and studying of hydrodynamic field of net construction.

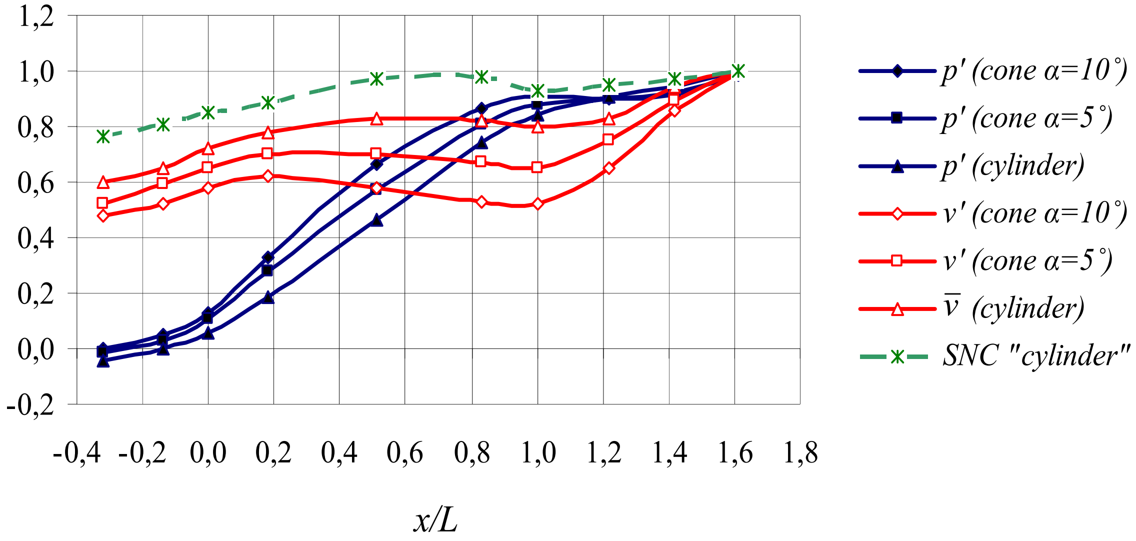


Figure 9: Nondimensional flow speeds and pressures along axes of “net” constructions

The Fig. 10 illustrates the flow into rear net cylindrical part of the cod-end with “a catch” simulation. The fish simulation was creates with solid balls given as cylindrical cross sections. It is seen that “the catch” gives a backwater flow and, so named, “locking” effect. It permits to have a possibility for a fish escape from the trawl or make “meshing” of the cod-end that is to block meshes of the net.

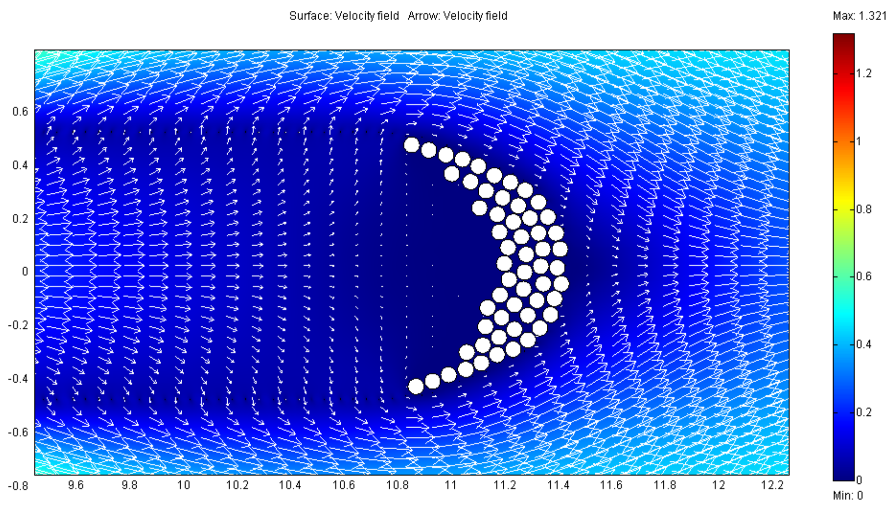


Figure 10: Speed distribution with a “catch” imitation in a cod-end

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