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QUANTITATIVE ESTIMATE OF THE VOLUME OF WATER SWEPT BY THE FISHING GEAR

by

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Introduction

This paper is prepared according to a Resolution of the 61st Statutory Meeting of ICES (C.Res.1973/4:10) and should be considered as further more detailed explanation ~~to~~ of the ~~Appendix~~ application of SVM to the problem on active (trawls) and passive (drift nets) gears. Examples are given of quantitative estimate of the volume of water swept with use of different methods that allow to estimate the fishing effort both in an industrial and an artisan fishery.

1. Estimate of water volume (SV) swept by trawls

Presently, three methods are used for the estimate of water volume swept by trawls. They are:

1.1. combined actual measurement/calculative method,

1.2. combined graph/analytical method,

1.3. analytical methods.

1.1. Measurement-assessment method determining SV

First, vertical and horizontal trawl opening are measured with the help of special instruments, then the water volume swept throughout the period of trawling is estimated

$$V = abV_t t \qquad (1)$$

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where V - volume of water swept, m^3;

a - vertical opening, m;

b - horizontal opening, m;

V_t - speed of trawling, m/sec;

t - duration of trawling, sec.

Fishing capacity of the trawl (W) is determined by the Formula (2)

$$W = \frac{V}{t} \qquad (2)$$

Taking 24 hours or 86.400 sec as time unit and representing volume of water swept as $10^9 m^3$, one can obtain a final Formula (3) of fishing capacity as

$$W = 8.64\ 10^{-5}\ a \cdot b \cdot v \quad \text{proms}^{x/} \qquad (3)$$

Vertical and horizontal trawl openings are measured with the help of instruments based both on the mechanical principle (see Figures 1-3) and on the hydroacoustical one (type net - sound).

In case the instruments for measuring the horizontal and vertical openings are absent on vessels of small tonnage, the openings may be determined with use of buoys and goniometers (see Figure 4).

1.2. Graph-analytical method of SV determination

This method allows to determine SV using the trawl drafts, cable equipment and the size of angles of attack of otterboards. This method was elaborated and examined many times with the help of the space imitation.

First, the angles of attack of trawl cables are determined using the values characterising the areas of trawl plates, then vertical and horizontal openings are found by the method of the successive approximation using the graphical construction of projection, the latters allow to define the fishing capacity.

The technics of calculations and constructions are given in a more detailed form in the Appendix 1.

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x/ prom [pm] is a unit of fishing capacity measurement equal to $10^9\ m^3 \cdot 24h$ (ICNAF Redbook, 1973, part III, p.240).

1.3. Analytical methods of SV determination

One of the simplest methods of calculative determination of the horizontal trawl opening is based on the fact that the shape of the trawl headline is similar to that of the chain line, and the angle of attack of the upper cable α is equal to the difference between the angle of attack of the board and its constructive angle.

Using this angle as one of the elements of the whole chain line, one can find a relation $\lambda = \frac{L}{S}$, where "L" is a chord tightened the ends of the chain line; "S" is the value characterizing the length of the chain line equal to that of the headline at the section of a net attachment.

Thus, the resulting value "b" characterizing the horizontal trawl opening will be determined such as

$$b = \lambda S + 2 l \cos \alpha ,$$

where "l" is the length of the bare end of the headline.

The result obtained by this formula gives an average value for the horizontal opening along the ends of the top and the lower wings, as the conclusion of the formula is made on the assumption that the attack angles are equal for the top, average and lower trawl cables.

It was found that the correlation between the horizontal and the vertical openings in the bottom trawls used by the USSR may be approximately determined from the correlation

$$a = 0.35 b$$

Such a correlation may be made in the conditions of every country using as base the observations obtained. Thus, according to data by P.I.G. Carrothers (ICNAF Res. Doc. 74/28), Canadian bottom trawls possess the following characteristics:

Trawl type	Horizontal opening "b", m	Vertical opening "a", m	a : b
Yankee - 36	10.3	2.9	0.282
Yankee - 41	13.4	2.9	0.216
Yankee - 41 - 5	13.4	2.9	0.216
Granton	13.7	2.9	0.212
Engel	15.3	5.8	0.379
A - W II A	10.7	4.4	0.410
A - W III	15.2	3.8	0.250

Therefore, the average value of the conversion factor between the vertical and the horizontal openings for the Canadian trawls is equal to 0.281, and the formula may be given as

$$a = 0.281\ b$$

Substituting the values "a" and "b", there is no difficulty to define the fishing capacity for those trawls using the formulae (1) and (2).

The second analytical method of SV calculation is based on interdependence between the trawl cut, its equipment and working regime. This method is the result of investigations of trawl shape in laboratory conditions and in high sea (2). First, one can find the angle of attack of square by the drafts, then vertical and horizontal openings are determined by the equations, at last, those are used for calculation of the mouth area and the fishing capacity of trawl.

A detailed SV calculation is considered in Appendix 2.

2. The assessment of the relationship between the volume of water swept by trawl and the catch

Previously, we had possibility to determine the relationship between the volume of water swept and the size of summary catches taken in different areas throughout a long period.

The analogous comparison of swept volumes of water and of catches taken by vessels working simultaneously in the same area at the same density of fish concentrations are of a great significance.

The results of comparative tests for catchability of two trawls possessing different fishing capacity (i.e. the volume of water swept per time unit) are given in Table 1. The tests were conducted in the area of George's Bank throughout the period 25 April to 14 May 1967 on board the vessels "Dushanbe" and "Gerfenbergeris" (fishing capacity - 2000 HP, length - 84.7 m, displacement - 3 800 tons). Trawlings were made along parallel routes and all other measures were undertaken in order to make the conditions of fishery quite identical.

Table 1. Results of the first series of tests.

Test	Fishing capacity of trawl 10^6 m^3 / hour	Time of trawling, hour	Total swept volume of water, $10^6 m^3$	Total catch tons
1	0.49	39.3	19.2	122.4
2	0.44	42.2	18.6	95.2

The first series of experiments being over, the vessels exchanged trawls, and conducted the second series of experiments; the results of the latter are given in Table 2.

Table 2. Results of the second series of experiments.

Experiment	Fishing capacity of trawl $10^6 m^3$/ hour	Time of trawling, hour	Total volume of water swept, $10^6 m^3$	Total catch tons
1	0.44	18.1	8.0	62.9
2	0.49	18.2	8.9	80.9

The experiments were repeated in the eastern part of the Central Atlantic throughout the period 14 April to 31 May, 1968 on board the vessels "Kozerog" and "Seliger" (fishing capacity - 1340 HP, length - 79.8m, displacement of the vessel - 3 275 tons). Trawls of other designs and sizes were used as well. Those experiments gave the following results:

Table 3. Results of the third series of experiments

Experiment	Fishing capacity of the trawl $10^6 m^3$ / hour	Time of trawling hour	Total volume of water swept, $10^6 m^3$	Total catch tons
1	0.97	40.8	39.6	177.2
2	0.88	35.9	31.6	148.8

Two different trawls were investigated during the process of alternative trawling on board the vessel "Suvalkya" (fishing capacity - 3880 HP, length - 102m, displacement of the vessel - 4 640) in the area of Wallfishbay in the southeastern Atlantic throughout the period 13 December 1973 to 25 January 1974. The results of the experiments are given in Table 4.

Table 4. Results of the 4th series of experiments

Experiment	Fishing capacity of the trawl, $10^6 m^3$/hour	Time of trawling, hour	Total volume of water swept, $10^6 m^3$	Total catch, tons
1	0.81	11.5	9.3	25
2	0.71	11.5	8.2	20

The data represented above testify on the fact that the correlation between the measuring units for vessels, i.e. their fishing capacity, length, displacement was the constant item within the limits of each experiment, as in the first three series of experiments the vessels were similar and during the fourth trawling on board the same vessel different trawls were used. At the same time, the catch volume resulting from each experiment changed, quite obviously depending on the volume of water swept by the trawl.

Comparing the results of different series of experiments and considering the factors of some experiment as a unit (for example, those of Experiment 1, Series 4), it seems one can obtain very characteristic data (Table 5):

Table 5. Correlation of the factors obtained as a result of experiments completed at different vessels

Series	Experiment	Correlation of catches	Correlation of volumes of water swept	Correlation of vessels displacements	Correlation of vessels lengths
4	1	1	1	1	1
	2	0.80	0.88	1	1
1	1	4.90	2.06		
	2	3.81	2.00	0.82	0.83
2	1	2.52	0.86	0.82	0.83
	2	3.24	0.96		
3	1	7.09	4.26	0.70	0.78
	2	5.95	3.40		

Data given in the Table show that between the catch and the volume of water swept exists a much more evident dependence than between the catch and the characteristics of vessel that is observed not only under identical conditions (fishing process at the parallel or alternative trawlings at one time and within the same area), but also under different conditions. It was registered that usually the gross tonnage vessels catches are larger than those taken by small ones during the same time, which may be explained by the fact that those vessels use fishing gears of greater size, tow them with higher speed and, as a rule, possess fishing gears and scouting instruments of better quality.

3. Calculation of water volume (SV) fished by drift nets

While discussing the methods of commercial effort estimation, the necessity to precise the ~~appendix~~ application SVM to passive fishing gears and particularly to drift nets was stressed. Below, we tried to give such a precision.

In time of the fishing process, two opposite actions may occur, namely, when drift nets move in parallel or across. In the first case the area of nets action (fished volume of water) V_{dr} may be expressed by a formula as follows:

$$V_{dr} = a \cdot l \cdot n \cdot S, \qquad (8)$$

where "a" is the net height (m);

"l" is the net length (m);

"n" is the number of nets in a set;

"S" is the way passed by a set throughout the period of drifting (m).

In the second case, no obvious filtration of water volume was observed due to lengthwise moving nets. Catches are taken by nets in this case mainly due to fish displacements. Let us consider the phenomena using an example.

Let us assume that the shooting of net sets begins at a point "A" and this process is over at a point "B" at the moment "t_o" of an area (see Figure 5). Some time later Δt_1, a net's set has drifted a way ΔL. Throughout that period fish, keeping at a distance "S" from a set beginning from the moment nets were shot, approached the set and came into contact with nets, i.e. they began to be fished.

Evidently, the way passed by fish during the period Δt_1, is equal to $S = U_f \Delta t_1$, where "U_f" is the speed of fish movement. Thus, the area of sets action for the time period mentioned above may be as follows:

$$V_1 = aU_f\Delta t_1(ln - \Delta L + \Delta L) = alnU_f\Delta t_1$$

Throughout the following time interval Δt_2, the set shifted for a new value ΔL will be able to keep those fish, which passed the way $U_f \Delta t_2$. A new area of net's set action may be represented as follows:

$$V_2 = alnU_f\Delta t_2$$

For the final time space Δt_1, the area of set action will make

$$V_i = alnU_f\Delta t_i$$

Thus, a summary area of net's set action may be given for the whole time of drifting t_{dr} as

$$V = V_1 + V_2 + \ldots + V_i = aln\ (\Delta t_1 + \Delta t_2 + \ldots + \Delta t_i) = alnU_f t_{dr}$$

The same deduction may be obtained, if we consider the case of sighting set of net which is closer to that one used in practice. Let line "AB" be a set of drift nets installed at the moment "t_o" (Figure 6). In order the fishing of a school

N, keeping at a distance "S" from a line of set drifting be successful, it is necessary that the school approach the set at the moment "t_1" and come into contact with it.

Therefore, the area of set action may be determined by volume of water space limited both by the set length, the height of nets and by the way passed by fish that is equal to the case of work of set drifting downstream.

Hence, in any case the fishing capacity of a drift net may be given like that one for movable fishing gears by the formula:

$$W_{dr} = 8.64 \cdot 10^{-5} \, alnU_f \qquad (10)$$

where W_{dr} is the fishing capacity of a set in proms ($10^9 \frac{m^3}{\text{per day}}$)

U_f is the speed of fish moving m/sec;

a,l,n are the values having the same meaning as those in the formula (8).

This formula is supposed to be a true one, the more so as it is important to know the method characterising the maximum fishing capacity of these gears in order to regulate commercial efforts and not particular versions explaining the phenomena, when the volume fished is decreasing due to any reasons.

The relationship between the catch and the volume of water swept determined by the method given above is shown in Document C.M.1971/B:9.

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APPENDIX I

Graph-analytical determination of trawl SV.

Main propositions.

I. The projection shape on the horizontal surface of the headline and the footrope of the midwater trawl and of the headline of the bottom trawl as well as parabolas type $y=ax^2$.

The projection of the bottom trawl footrope is the hyperbola

$$y = \frac{a}{b}\sqrt{b^2 + x^2}.$$

2. The effect of the outfit strength both of the headline and the footrope results in the fact that the projections of those ones for bottom and midwater trawls on diametrical surface make straight lines.

3. The resultant of the cables tension is directed towards the trawl movement under the angle equal to the difference between the angle of attack and the constructive angle of the board.

4. The variation of the hanging ratio along the trawl is subjected to the rectilinear law.

The cross hanging ratio along the fore edge of the cylinder part of the trawl bag is equal to 0.5.

5. The trawl has the form of the ellipsis or of two half-ellipses in any cross-section from its mouth up to the cylinder part of the bag. In the last case, the great axis (horizontal opening in the section) is a general item, and small half-axes are equal correspondingly to the greatest distances from the topenant surface up to the upper and the lower trawl plates.

Cross-sections of the cylindrical part of the trawl bag have the shape of a circle.

6. The tensions of the ends both of the headline and the footrope are proportional to the areas of the netting of the upper and the lower plates.

Hence, data were obtained for determination of the angle of attack for the ends of the footrope and the headline (i.e. for the corresponding cable):

$$tg\,\gamma_r = \frac{F_u}{F_o}\,tg\,\gamma_u + \frac{F_\ell}{F_o}\,tg\,\gamma_\ell\,,$$

where " γ_r " is the angle between the resultant of the cable tension and the direction of movement;

" γ_u " is the angle of attack of the cable projection for the headline given horizontally;

γ_ℓ - is the angle of attack of the cable projection for the footrope given horizontally.

" F_o " is a general fictitious area of trawl netting;

F_u, F_ℓ are fictitious areas of the upper and lower trawl plates.

Sequence in determination of trawl parameters.

I. The angle for resultant of the cable tension is found with use of determined angles of attack " $\gamma_{a.b.}$" and the constructive angle " $\gamma_{c.b.}$" of board.

$$\gamma_r = \gamma_{a.b.} - \gamma_{c.b.}$$

2. False areas of the upper plate F_u and the lower one F_ℓ , as well as general summary false area of netting F_o are found with help of cutting designs of the trawl.

3. A series of angles of attack for projections of the upper γ_u and the lower " γ_ℓ " cables on the horizontal surface is found there, these angles ensure the equality (I).

The projections are made from an arbitrary chosen point A (Fig.7) under the angles obtained γ_u and γ_ℓ on the horizontal surface of cables simultaneously with bare ends of the headline and the footrope using the definite scale.

4. Using the determined incidence angle of the ends of the headline and the length of the last one, one can determine λ, i.e. the ratio of the chord (horizontal opening) "B" to the headline length (parabola arc) S_h. 1 and the relation $\frac{B}{f}$, where "f" is the arrow of the sag.

The hyperbola peak E (footrope) may be determined, if a mark will be done by somebody with help of the spread of a pair of compasses equal to $(0.96 + 0.98)\frac{S_{fr}}{2}$ from the point C on the trawl axis O'O.

5. A segment ED being the projection of the square length on the horizontal surface should be measured. Evidently, its value should be within the limits. $S^{o}_{sq} > ED \geqslant S^{o}_{sq}\sqrt{1-U_1^2}$, where "$S^{o}_{sq}$" is the length of a stretched square, "U_1" is the constructive hanging ratio of the netting.

Using the method of the successive approximation one can choose such angles γ_u and γ_e, at which the value of the section $ED = S_{sq}$ will be within the limits given.

6. The vertical hanging ratio $U_{2m} = \frac{S_{sq}}{S^{o}_{sq}}$ mean for square and the mean horizontal hanging ratio $U_{1m\,sq}$ corresponding to it are determined.

7. The ratio $\frac{\ell_1}{L_{tr}}$ is found, where $\ell_1 = \frac{S^{o}_{sq}}{2}$ and "L_{tr}" is the trawl length stretched from the upper bosom up to the cylinder part of the codend.

It was determined that the chord passing through the hyperbola peak within the existing limits of trawls footropes makes 0.96 - 0.98 of the length of its arc $\frac{S_{fr}}{2}$

8. The horizontal hanging ratio is determined graphically in the edge of the upper bosom $\perp$ $U_{1u.b.}$

The ratio $\frac{\ell}{L_{tr}}$ is put aside on the absciss axis (where " ℓ " is the variable trawl length beginning from the section of the upper bosom), and the hanging ratio from 0 up to 0.5 - on the axis of ordinates. Evidently, $U_1 = 0.5$, if $\frac{\ell}{L_{tr}} = I$; and $U_1 = U_{1m.sq.} = \sqrt{I - U_{2m}^2}$, if there is a ratio $\frac{\ell_1}{L_{tr.}}$.
" $U_{1u.b.}$ " is found, if one connects two points on a graph with help of a straight line and continues it up to the crossing with the ordinate axis (Fig. 8).

9. The relation $\frac{S^{o}_{sq}}{L_{tr}}$ being determined by graph of hanging, it is possible to find a horizontal hanging ratio " $U_{1l.b.}$ " corresponded to the section of the lower bosom (Fig. 8).

IO. A segment DF is put aside on the axis O'O (Fig.7) beginning from the point D, it is equal to the projection on the horizontal surface of the trawl length in hanging $L_{tr.h.} = L_{tr}\sqrt{1 - \frac{(0.5 + U_{1u.b.}^2)}{4}}$.

Segments FG and FG_1 are put aside from the point F perpendicular to the axis O'O, these segments are equal to a half diameter of the cylindrical codend part in hanging. Lines connecting the points G and A, G', and A' determine the maximum possible attitudes of topenent lines of a trawl. If the lines AG and $A'G'$ cross a line of the footrope (i.e. pass between the projections of the upper and the lower cables), all the constructions made earlier must be repeated in such a way that the angle of attack of the upper cable " γ_u " be diminished, thus, the value characterizing the square in hanging S_{sq} will be ensured within the limits given in point 5.

II. From the points D and E lines are drawn perpendicular to the axis O'O up to the crossing by the topenant lines, that allows to determine the horizontal trawl opening by each section, i.e. larger axis of the ellipsis.

I2.Half-perimeter is estimated in hanging of the upper half-ellipsis for the section of the lower bosom.

I3.Half-perimeter is estimated in hanging of the lower half ellipsis for the section of the lower bosom.

I4.Small half-axes of the upper and the lower half-ellipses of the lower bosom section are determined by the formula given below.

$$b_e = \frac{a_e}{9}\left(1+\sqrt{\frac{6P_e}{\pi a_e}-8}\right)^2,$$

where " a_e" is a greater half-axis of the ellipsis;

" P_e " is a doubled half-perimeter of the upper or the lower half-ellipses of the upper bosom section.

I5.The trawl projection of the diametrical trawl plane is drawn (Fig.9). Then, the ground line QQ' is given. From the point E of the footrope a perpendicular is put, where the sections EJ and JK are put aside. Those sections are equal to small half-axes of the upper and the lower half ellipses for the lower bosom section. From the point " J ", a topenant line " JO' " is drawn parallel to the ground line, where a segment " JF " equal to " EF " is put aside (Fig.7). From the point " F ", segments " FM " and " FM' " are put aside perpendicular to the topenant line and in different directions from it, those segments are equal to a half diameter of the cylindrical part of the co-dend in hanging.

Points M' and E, M and K are connected. The line MK is continued up to its crossing with the section of the upper bosom in the point D determining the vertical trawl opening maximum possible.

I6.The projection A' of the point A is given on the vertical

surface at the distance equal to a half board height $0.5h_b$.
The point A' is connected to those D and D' determining the insidence angles in this plane of the upper and the lower trawl cables.

The calculation of the main parameters for commercial trawls used more often is represented on the Table 1 according to the method discussed above.

Table 1

N N	Trawl construction	bn $\lambda_{h.l.}$	Length of the headline Shl, m	Length of the foot-rope Sfr, m	Horizontal opening along the nets of the upper wings B, m	Square length in hanging Ssq, m	Length of a stretched square S^{o} sqr, m
I	2	3	4	5	6	7	8
I	Bottom trawl Yankee -type 36	0.5I	I8.3	25.4	9.32	4.0	4.3I

$U_{2m} = \frac{S_{sq}}{S^{o}_{sq}}$	U_{1} m sq.	$\ell_1 = \frac{S^{o}_{sq}}{2}$, m	L_{tr} Stretched up to a cylindrical part of the cod-end, m	$\frac{\ell_1}{L_{tr}}$	U_1 u.b. of the upper bosom (the result of graph construction)	S^{o} sqr, L_{tr}	U_1 l.b. of the lower bosom
9	I0	II	I2	I3	I4	I5	I6
0.928	0.37	2.I5	I3.45	0.I6	0.345	0.32	0.395

Cross-section perimeter of the lower bosom stretched, m	Cross-section perimeter of the lower bosom in hanging (I7) x (I6) m	Great axis of the elipsis cross-section of the lower - bosom (from a draft)m	Small half-axis of the upper half-ellipsis for the cross-section of the lower bosom, m	Small half-axis of the lower half-ellipsis for the cross-section of the lower bosom, m
I7	I8	I9	20	2I
32	I2.64	5.4	I.2	I.2

/Cont'd. ....

Table 1 (ctd)

Vertical opening in the cross-section of the lower bosom (20) + (2I), m	Topenant height, m	Width of the plate of the upper bosom stretched, m	Width of the plate of the upper bosom in hanging (24) x (I4), m	Conditional perimeter of the cross-section of the upper bosom in hanging (25) x 2, m	Great axis of the cross-section of the upper bosom (draft), m
22	23	24	25	26	27
2.4	I.2	22.9	7.92	I5.85	7.I

Small half-axis of the upper half-ellipsis for the cross-section of the upper bosom, m	Vertical trawl opening in the cross-section of the upper bosom, m	Area of the upper bosom cross-section m^2, ω	Trawling speed - V, knots	Fishing power W, in proms
28	29	30	31	32
I.4	2.6	I5.6	3.5	0.0024

APPENDIX 2

Analytical determination of the trawl IV

Main propositions

I. Estuary part of trawls possesses the initial form of the circular cone.

2. Outlines of the headline and of the footrope, as traces of conical sections, are parabolas or hyperbolas.

3. Trawl outfit ensures the possibility for converse transformation of the trawl estuary from the circular shape into the ellipsis (working one).

4. The angle of attack for net wings " φ_w " is practically equal to that one " γ_r " located between a resultant of the cables tension and the current direction.

The method allows to determine main parameters and the fishing power of trawls, as well as the conformity of designed and the actual shapes with use of drafts.

The succession in determination of parameters and fishing power trawls

I. Initial parameters at the speed V m/sec.

I. u_l or a constructive hanging ratio is determined both by number of meshes n_b^i of a given size (from one knot to the other one) and by a designed length S_b^u of the upper and the lower bosoms S_b^ℓ , thus

$$u_l = \frac{S_b^u}{2a_b^u n_b^u} = \frac{S_b^\ell}{2a_b^\ell n_b^\ell}.$$

2. Initial ordinates (radii) both of the upper bosom y_b^u and the lower

one y_b^{ℓ} , as well as the square length S_{sq} are determined with use of cutting design,namely

$$y_b^u = \frac{2a_b^u n_{sq}^u u_1}{\pi}; \quad y_b^{\ell} = \frac{2a_b^{\ell} n_{sq}^{\ell} u_1}{\pi}; \quad S_{sq} = 2a_b^u m_{sq}\sqrt{1-u_1^2},$$

where n_{sq}^u , n_{sq}^{ℓ} is the mesh number along the upper and the lower edges of square correspondingly ; m_{sq} is the mesh number along the square length.

3. Then, one can find the initial angle of attack for the square and its trigonometrical functions $\sin\varphi, \cos\varphi, tg\varphi, ctg\varphi$

$$\varphi = \arcsin \frac{y_b^u - y_b^{\ell}}{S_{sq}} .$$

4. The initial incidence angle for the plane of the headline θ and its trigonometrical functions $\sin\theta$ and $tg\,\theta$ are calculated by the formula:

$$\theta \simeq \arcsin \frac{y_b^u + y_b^{\ell} - h}{S_c + S_{wt}} ,$$

where S_c-is the length of mean cable, m;

S_{wt}-is the length of the wing topenant, m ;

h - danleno height, m.

5. Carrying power(buyancy)$P_\phi[\frac{kg}{m}]$of floats in the number n_ϕ is determined by the formula: $P_\phi = \frac{n_\phi}{\pi y_b^u} \cdot p_\phi$, where p_ϕ is the carrying power (buoyancy) of one float.

6. The initial tension of one linear meter of netting $\sigma[\frac{kg}{m}]$ is calculated by a half-perimeter of square

$$\sigma \cos\varphi \simeq \frac{P_\phi}{tg\varphi + tg\theta} \leq max.$$

7. The initial mouth area "ω" is found in the upper bosom, m^2 for

a) bottom (asymmetrical) trawls

$$\omega = \frac{\pi}{2}(y_b^u + y_b^{\ell}) \cdot y_b^u .$$

b) mid-water (symmetrical trawls)

$$\omega = \pi\, {y_b^u}^2$$

8. The initial specific resistance is calculated for the netting part of the trawl-R, i.e.

$$R = 2\pi y_b^u \sigma \cos\varphi = r\omega; \quad r = C_R \frac{\rho v^2}{2},$$

where $r\ [\frac{kg}{m^2}]$ is the specific resistance per I m^2 of the mouth area at the speed V;

C_R is the ratio of trawl resistance related to the mouth area;

$\rho\ \frac{kg \cdot sec^2}{m^4}$ is the density of marine water (≈ I04)

9. The initial angle of attack φ' and its trigonometrical functions $\sin\varphi'$, $ctg\,\varphi'$ are precised $C_R v^2 = \frac{r}{\rho/2}$

where $v^2 \approx \frac{2}{\rho} \cdot \frac{P_\phi\, ctg\,\varphi'}{C_R\, y_b^u}$,

i.e. $ctg\,\varphi' \approx \frac{r\, y_b^u}{P_\phi} \geqslant ctg\,\varphi$.

Further calculation is made by the presised angle $\varphi' < \varphi$. The initial resistance R remains previous, as the hanging ratio $u_1 \approx \sqrt{2}\sin\varphi$ is changed proportionally to the decreasing of the mouth area ω.

IO. Initial vertical opening a is determined in meters as

a) projected opening $a = y_b^u + y_b^\ell$;

b) actual opening $a' = a\, \frac{\sin\varphi'}{\sin\varphi}$.

II. Initial horizontal opening b is determined in meters

a) in the section along the top bossom, the projected one

$$b_{u.sect} = 2\, y_b^u;$$

the actual one

$$b'_{u.sect} = b_{u.sect}\, \frac{\sin\varphi'}{\sin\varphi};$$

b) between the ends of wings,

the actual one $b'_W = b'_{u.sect} + 2 S_{wt} \cdot \sin\varphi'$.

12. The actual mouth area is calculated by bosoms W^I and by the ends of wings ω^I_w

$$\omega^I = \omega \frac{a' b'_{u.sect}}{2 y_b^u \cdot a}; \quad \omega'_w = a' \cdot b'_w \left(1 - \frac{1}{2} \frac{b'_w}{b'_w + 2S_c \sin\varphi'}\right).$$

II. Working parameters at speed $V_{tr} > V$

13. Taking into account a well-known correlation $\lambda_t = \frac{b^{tr}}{S_{h.l.}} = 0{,}5 \div 0{,}6$ one can find sinus of the angle of attack for net wings φ_w^{tr}

$$\sin\varphi_w^{tr} = \frac{\lambda_t S_{h.l} - b'_w}{2 S_{wt}}.$$

This angle ≈ is equal to the angle of attack for the cables--topenants or to the resultant of the cables tension $\gamma_r = (\gamma_a - \gamma_c) \pm \Delta$, where γ_a is a critical angle of attack for the otter-boards;

γ_c - is a constructive angle of attack for the otto-boards,

Δ - is a systematic correction - in degrees.

14. The working horizontal opening is calculated

a) in the section along the upper bosom

$$b^{tr}_{u.sect} = b'_{u.sect} \frac{\sin\varphi_w^{tr}}{\sin\varphi};$$

b) between the ends of wings

$$b_w^{tr} = b^{tr}_{u.sect} + 2 S_{wt} \sin\varphi_w^{tr}$$

15. Cosinus of the angle modulus is found with help of tables - included complete elliptic integrals of the second degree $\cos\alpha^{tr} = f(b^{tr}_{u.sect})$

$$\frac{b^{tr}_{u.sect}}{b'_{u.sect}} = \frac{\pi/2}{E^{tr}}; \quad E^{tr} = \frac{\pi/2 \, b'_{u.sect}}{b^{tr}_{u.sect}} = f(\alpha^{tr})$$

according to data given in tables.

16. The working vertical opening a^{tr} is determined in metres by the formula given below

$$a^{tr} = a' \frac{b^{tr}_{u.sect}}{b'_{u.sect}} \cdot \cos\alpha^{tr}$$

17. The working area ω_i^{tr} and the volume of the water swept

" $V_i^{tr} \cdot \omega^{tr}$ " through the trawl mouth are found by the formula

$$\omega^{tr} = \omega \frac{a^{tr} \cdot b^{tr}_{u\,sect}}{2 y_b^u a} ; \quad \omega_w^{tr} = a^{tr} b_w^{tr} \left(1 - \frac{1}{2} \frac{b_w^{tr}}{b_w^{tr} + 2 S_t \sin \varphi_w^{tr}}\right).$$

I8. The fishing capacity W_i^{tr} of the trawl is determined in proms with help of the formula:

$$W_i^{tr} = 8{,}64 \cdot 10^{-5} \cdot \omega_i^{tr} \cdot V^{tr}.$$

Let us consider the bottom trawl Jankee 36 as an example, this trawl is more often used by USA and Canada.

All methods of parameters determination given above (pp.I-I8) may be represented in metric system of measures,they are:

I. $u_l = \frac{3.I}{0{,}I27.60} = \frac{3{,}I}{7{,}62} = 0{,}4$

2. $y_b^u = \frac{0{,}I27.I80.0{,}4}{\pi} = 2{,}9$

$y_b^l = \frac{0{,}II4.I40.0{,}4}{\pi} = 2{,}0$

$S_{sq} = 0{,}I27.4. \quad \sqrt{I-0{,}I6} \quad = 3{,}94$ m

3. $\sin\varphi = \frac{2{,}9-2{,}0}{3{,}94} = 0{,}2285 \qquad \varphi = I3^{\circ}I5'$

$tg\,\varphi = 0{,}235$

4. $tg\,\theta = \frac{2{,}9+2}{7{,}6 + 9{,}15} = 0{,}233 \qquad \theta = I2^{\circ}20'$

5. $P_\phi = \frac{I0+2{,}I0}{\pi \; 2{,}9} \cdot 2{,}9 = \frac{870}{9I} \cong 9{,}5 \frac{kg}{m}$

6. $\sigma \cos\varphi = \frac{9.5}{0{,}235+0{,}233} = 20{,}4 \frac{kg}{m}$

7. $\omega = \frac{\pi}{2} / 2{,}9+2{,}0 / \cdot 2{,}9 = 22{,}3 \text{ m}^2$

8. $R = 2\pi .2{,}9.20{,}4 = r \cdot 22{,}3$

$r = \frac{372}{22{,}3} \simeq I7{,}5 \frac{kg}{m^2}$

9. $ctg\,\varphi' = \frac{17.0 - 2.9}{9.5} = 5{,}20 \qquad \varphi' = 10^\circ 40'$

$\sin\varphi' = 0{,}185$

10. a) $a = 2{,}9 + 2{,}0 = 4{,}9\ m$

b) $a' = 4{,}9\ \frac{0{,}1850}{0{,}2285} = 3{,}96\ m = 2{,}34 + 1{,}62\ m.$

11. a) $b_{u.sect} = 2 \cdot 2{,}9 = 5{,}8\ m\ ; \quad b'_{u.sect} = 5{,}8\ \frac{0{,}1850}{0{,}2285} = 4{,}66\ m.$

b) $b'_w = 4{,}66 + 2(7{,}6 \cdot 0{,}92) \cdot 0{,}185 = 4{,}66 + 2{,}56 = 7{,}22\ m$

12. $\omega' = 22{,}3\ \frac{3{,}96 \cdot 4{,}66}{2 \cdot 2{,}9 \cdot 4{,}9} = 14{,}5\ m^2$

$\omega'_w = 3{,}96 \cdot 7{,}22\left(1 - \frac{0{,}5 \cdot 7{,}22}{7{,}22 + 2 \cdot 9{,}15 \cdot 0{,}185}\right) = 19{,}0\ m^2$

13. $\sin\varphi_w^{tr} = \frac{0{,}6\,(2 \cdot 7{,}6 + 3{,}1) - 7{,}22}{2 \cdot 7{,}6} = 0{,}246$

$\varphi_w^{tr} = 15^\circ 16'$

14. a) $b^{tr}_{u.sect} = 4{,}66\ \frac{0{,}2460}{0{,}1850} = 6{,}20\ m$

b) $b_w^{tr} = 6{,}20 + 2 \cdot 7{,}6 \cdot 0{,}246 = 9{,}9\ m \simeq 32{,}4\ ft$

15. $\frac{b^{tr}_{u.sect}}{b'_{u.sect}} = \frac{6{,}20}{4{,}66} = 1{,}33\ ; \qquad E^{tr} = \frac{1{,}57}{1{,}33} = 1{,}180$

$\alpha^{tr} = 63^\circ 00 \qquad \cos\alpha^{tr} = 0{,}4540.$

16.

$a^{tr} = 3{,}96 \cdot 1{,}33 \cdot 0{,}4540 = 2{,}38\ m = 1{,}41 + 0{,}97 \simeq 8\ ft$

17

$\omega^{tr} = 22{,}3\ \frac{2{,}38 \cdot 6{,}20}{5{,}8 \cdot 4{,}9} = 11{,}6\ m^2$

$\omega_w^{tr} = 2{,}38 \cdot 9{,}9\left(1 - \frac{0{,}5 \cdot 9{,}9}{9{,}9 + 2 \cdot 9{,}15 \cdot 0{,}246}\right) = 18{,}5\ m^2$

18. The trawl fishing power will be at v^{tr} equal to 3.5 knots = 1.8 m/sec. as follows

$$W_w^{tr} = 8.64 \cdot 10^{-5} \cdot 11.5 \cdot 1.8 = 0.0026 \text{ proms}$$

$$W^{tr} = 8.64 \cdot 10^{-5} \cdot 11.6 \cdot 1.8 = 0.0016 \text{ -"-}$$

IV. The accuracy of the analytical determination of the main parameters of trawls fishing capacity according to their drafts.

1. Comparison of parameters for trawl type Yankee 36 according to the analysis data and to those included into the documentation.

Data given	Vertical opening m	Horizontal opening m	Mouth area m^2	Speed knots	Fishing capacity
according to calculation	2.38	9.9	18.50	3.5	0.0029
according to documentation	2.40	10.3	19.40	3.5	0.0030
relative divergence	$\frac{2.4-2.38}{2.4} \cdot 10^2 = 1.20\%$	$\frac{10.3-9.9}{10.3} \cdot 10^2 = 3.9\%$	$\frac{19.4-18.5}{19.4} \cdot 10^2 = 4.65\%$	idem	$\frac{3.10^{-3}-2.9.10^{-3}}{3.10^{-3}} \cdot 10^2 = 6.4\%$

2. Comparing of trawl Yankee 36 perimeters according to drafts, analysis data and graphic conjugation.

a) actual hanging ratio

$$u_1' = \frac{\pi \quad b/2}{2 a_b^u n_b^u} \equiv \frac{3.14 \cdot 4.662}{0.127 \cdot 180} = \frac{7.31}{22.8} = 0.32$$

b) half-perimeter of the upper bosom - according to trawl drafts

$$0.127 \cdot 180 \cdot 0.32 = 7.31$$

c) according to the analysis data and graphic conjunction

$$2.3125 \cdot 1.17 = 7,30 \text{ m}$$

g) - working angle of attack of wings (topenants)

$$\sin \varphi_w^{tr} = \frac{b^{tr}_{u.sect} - b^{tr}_{e.sect}}{2 S_{sq}} = \frac{6.25-4.3}{2.3.94} = 0.248;$$

= I4° 00' in precise conformity to the figure attached.

Some difference between values characterizing trawl parameters being the result of the analytical method and those ones obtained by graph-analytical method may be explained by two reasons,namely

I. absence of concrete information on the angle of attack and the constructive angle for the otter-boards;

2. effect of the headline outfit while calculating with help of the analytical method.

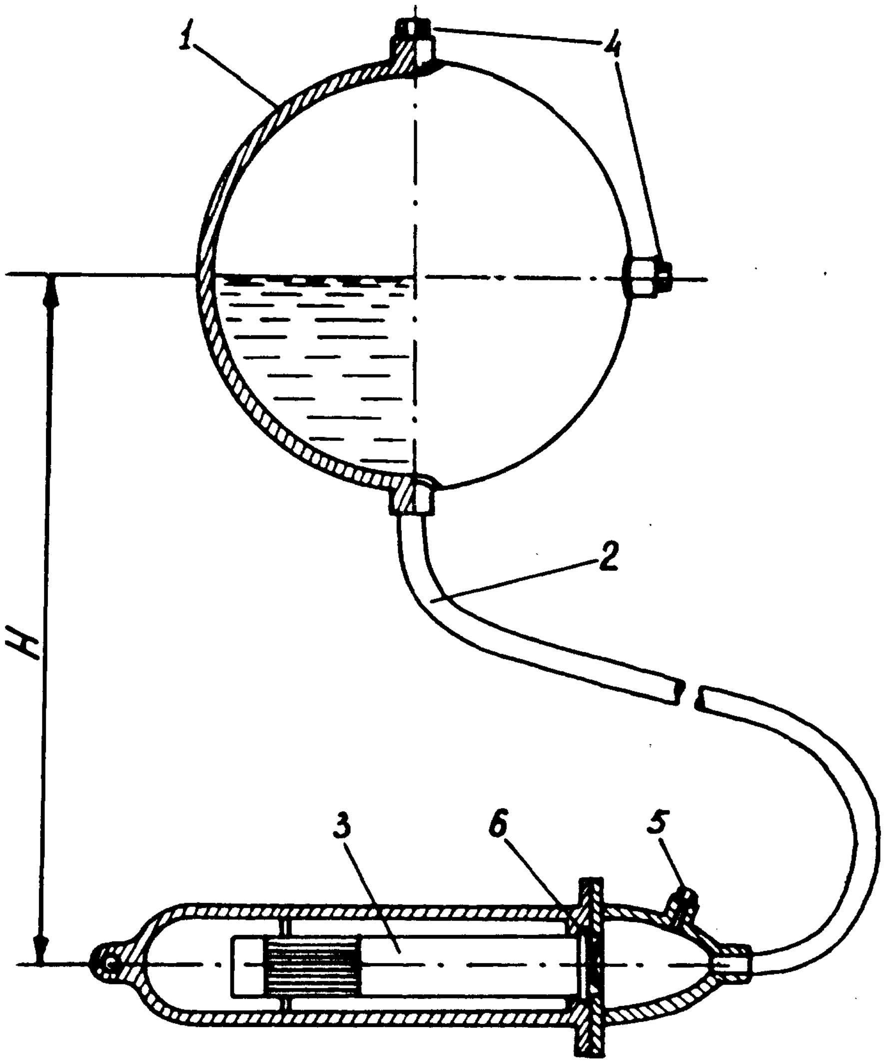

Figure 1. Trawl vertical opening recorder (TVOR):

1. Expansion tank
2. Flexible hose
3. Recorder
4. Plug of the expansion tank
5. Plug controlling the availability of air into the hose
6. Membrane.

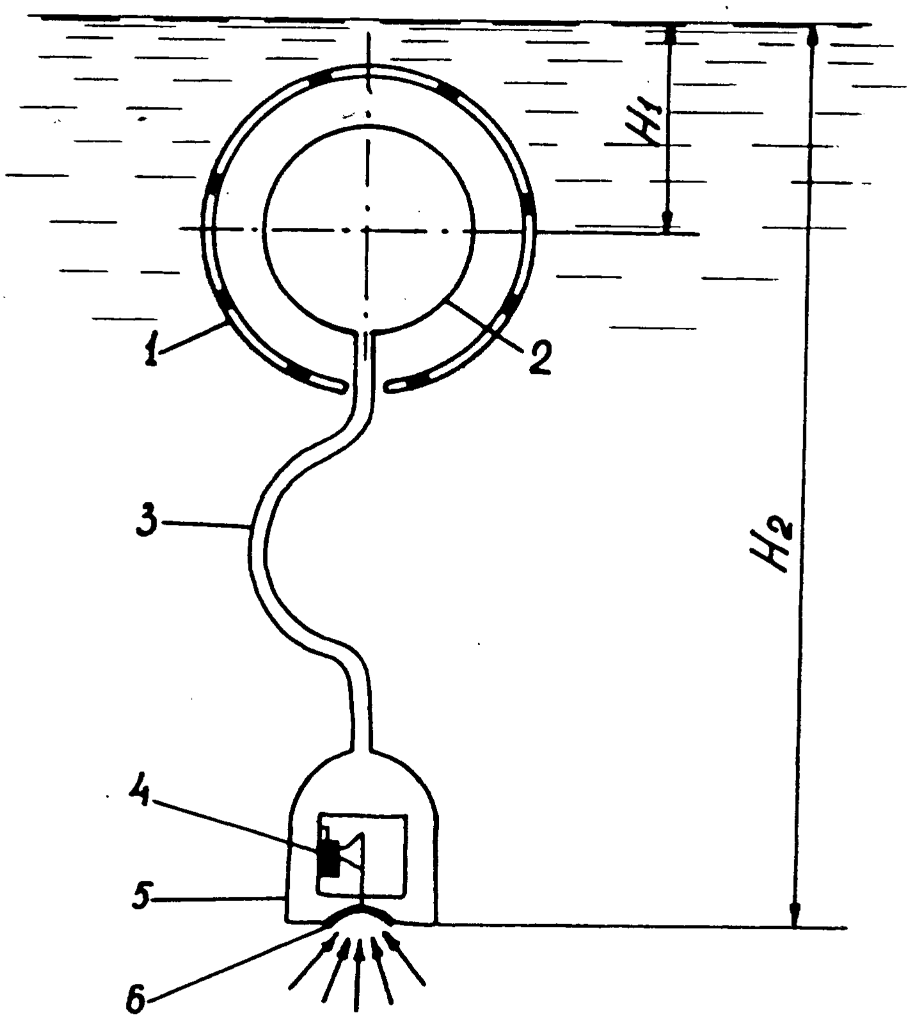

Figure 2. Principle scheme of the recorder:

1. Metal balloon
2. Compression chamber
3. Flexible hose
4. Recorder
5. Body
6. Membrane

H_1 - Depth of chamber

H_2 - Depth of membrane

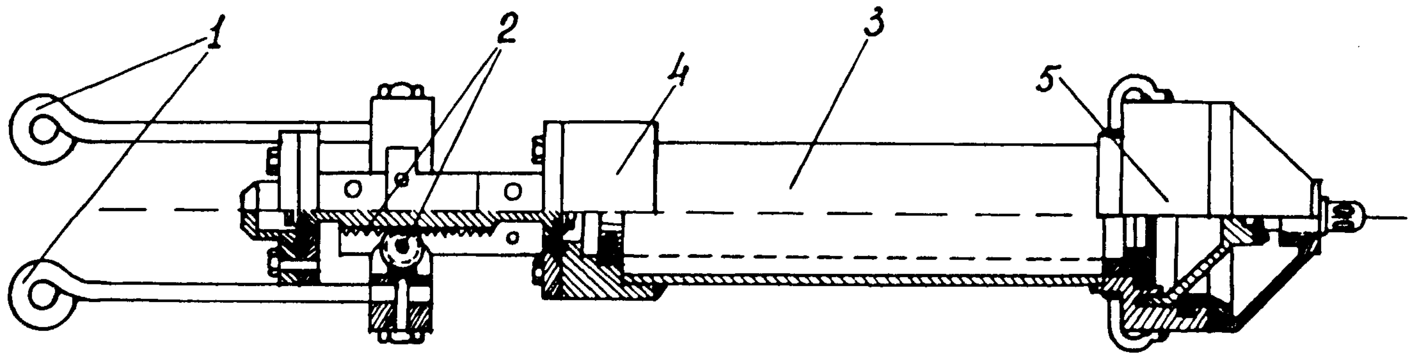

Figure 3. Trawl horizontal oepning recorder (THOR):

1. Levels
2. Rack and gear
3. Recorder
4. Body
5. Tail with the forcing screw and condenser.

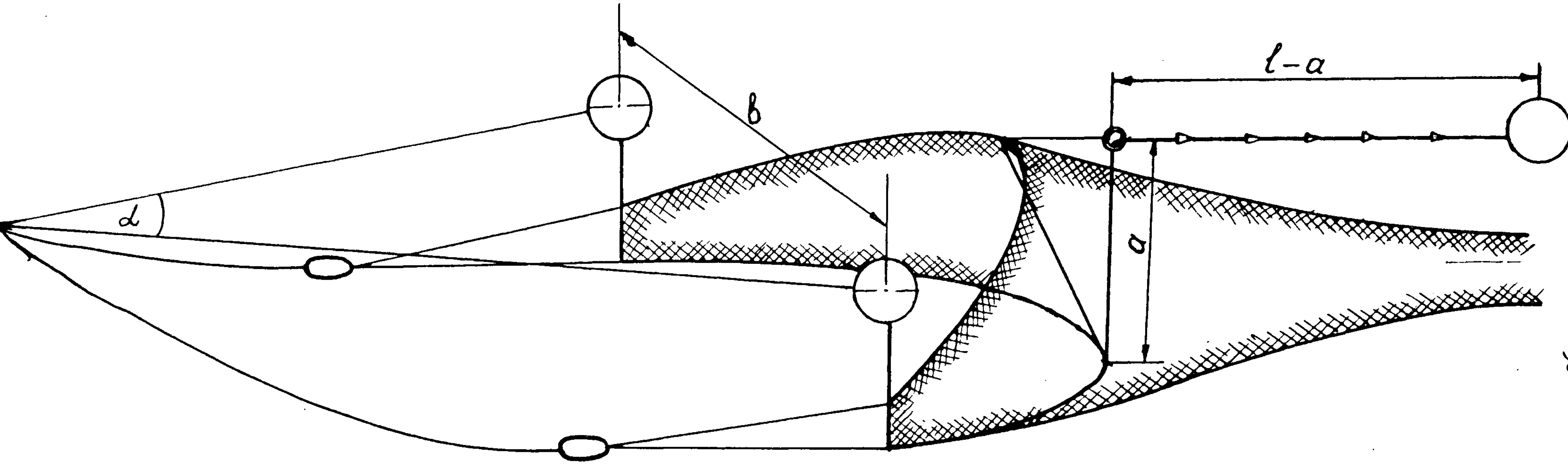

Figure 4. Measuring of the trawl opening on small-sized vessels:

a - vertical opening determined by means of a measuring line going from the center of the footrope through the pressing ring attached to the headline;

b - horizontal opening determined by the angle between bobbins and by the distance between them.

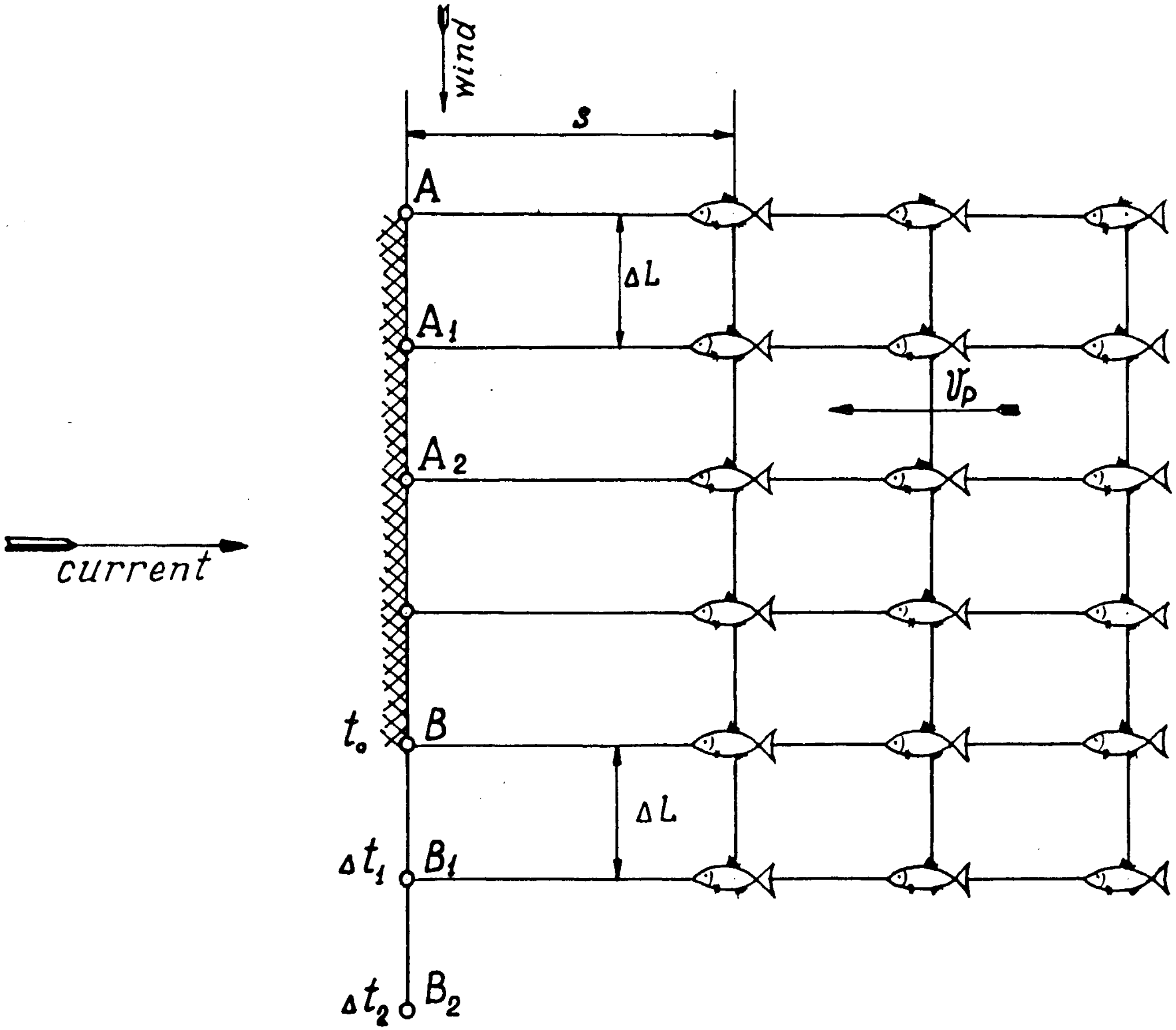

Figure 5.

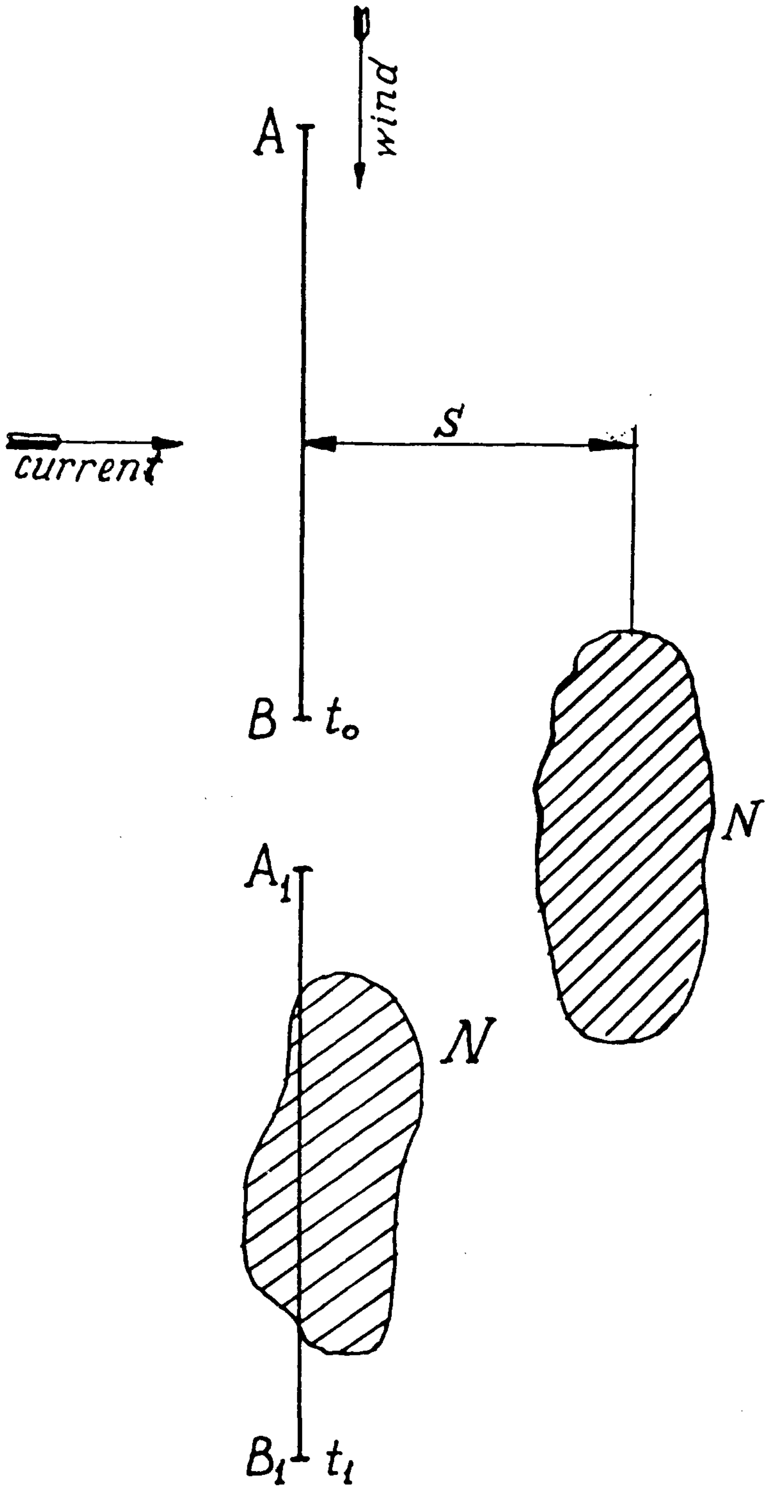

Figure 6

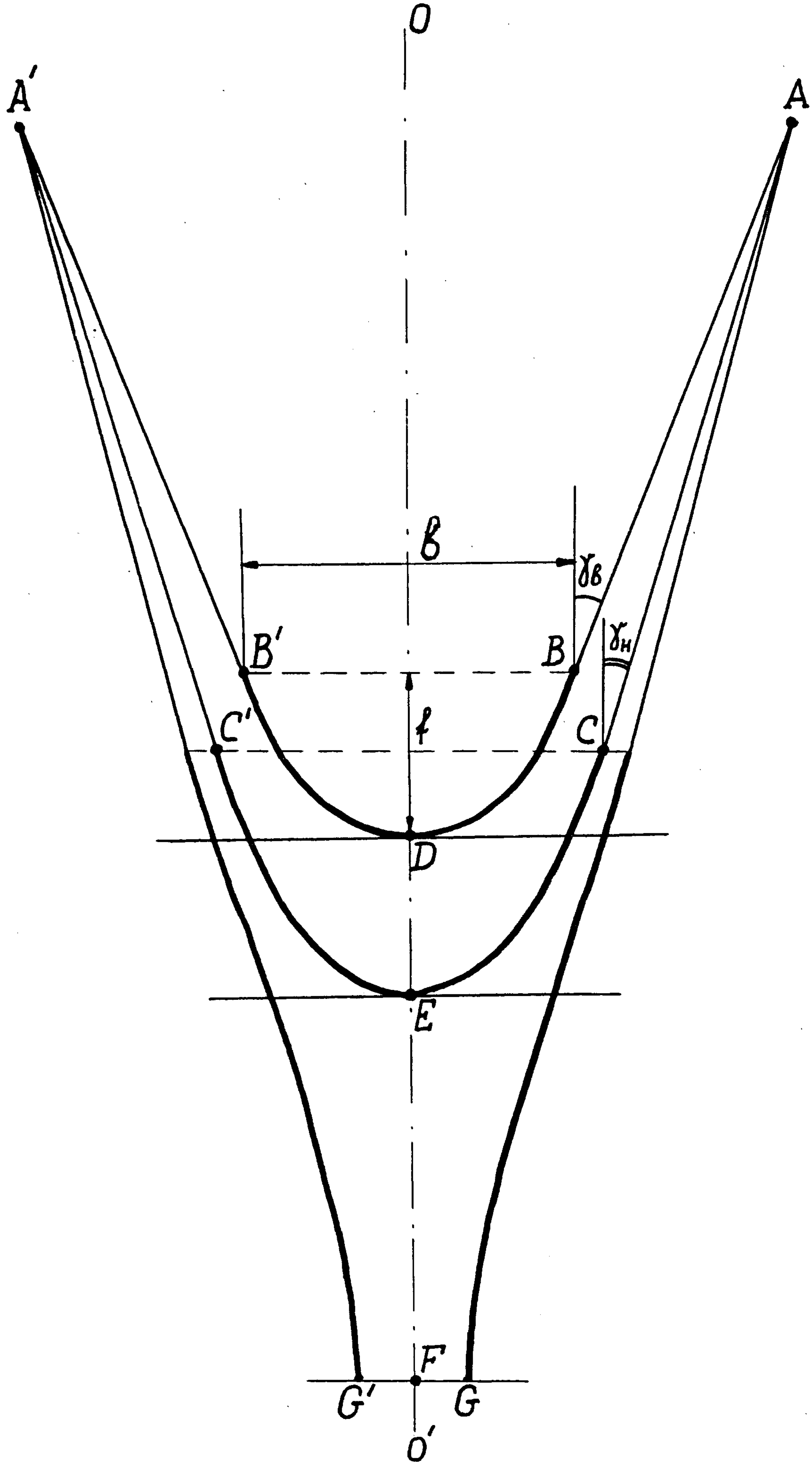

Figure 7.

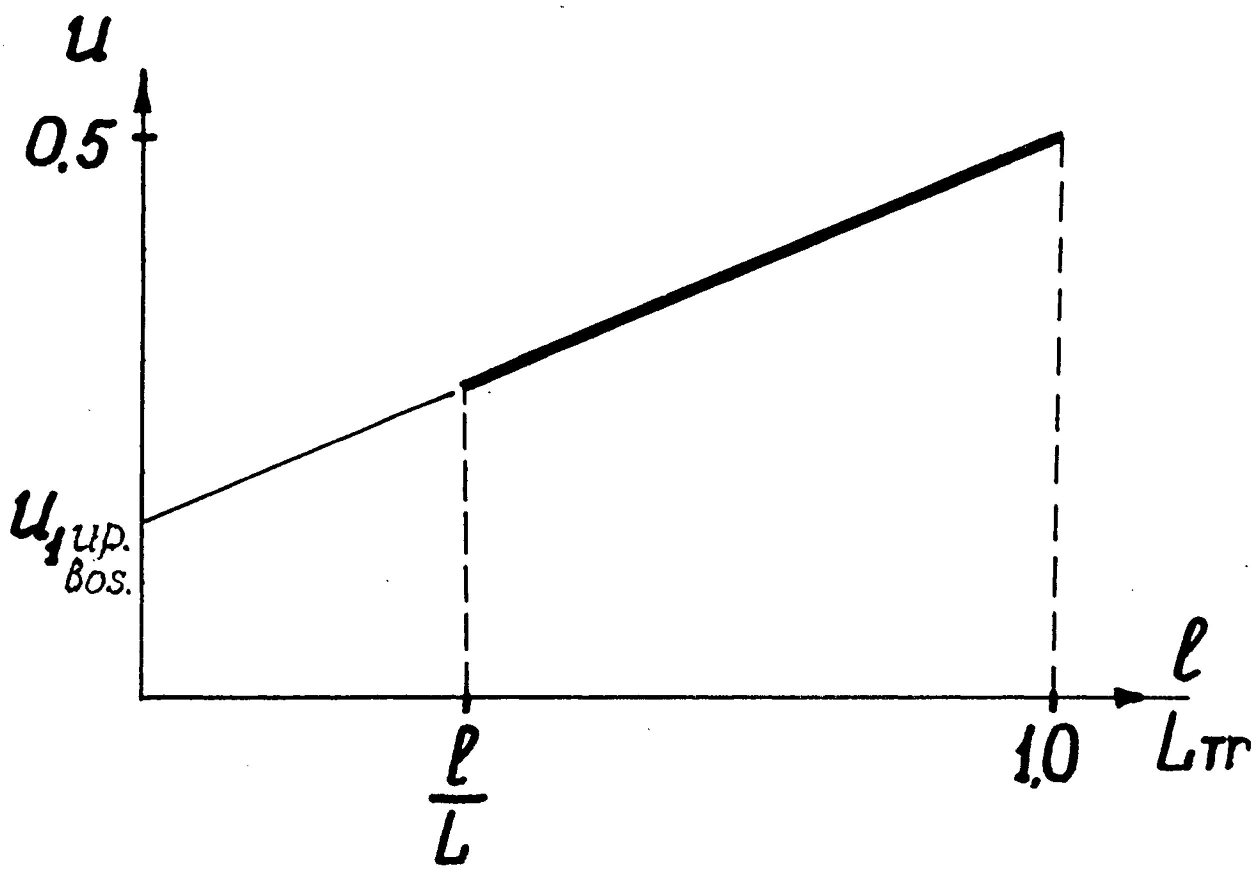

Figure 8.

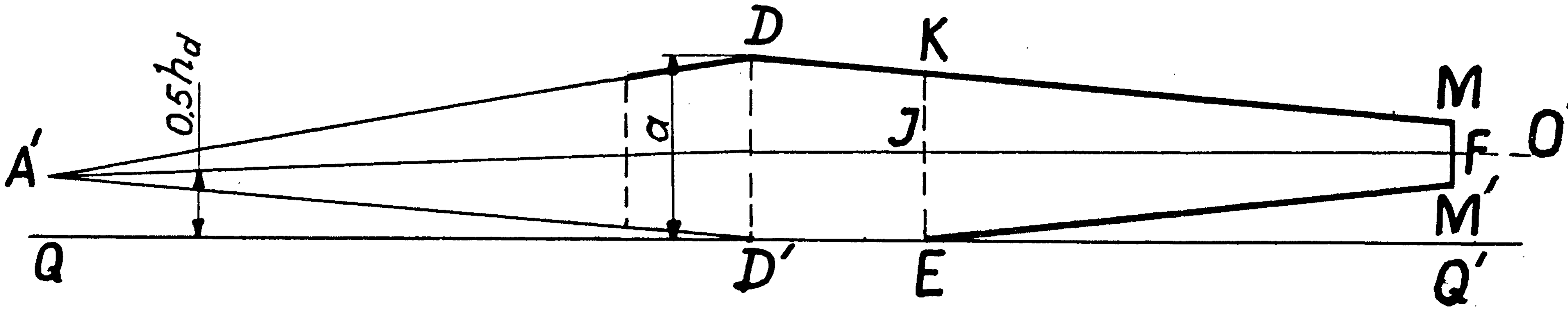

Figure 9.

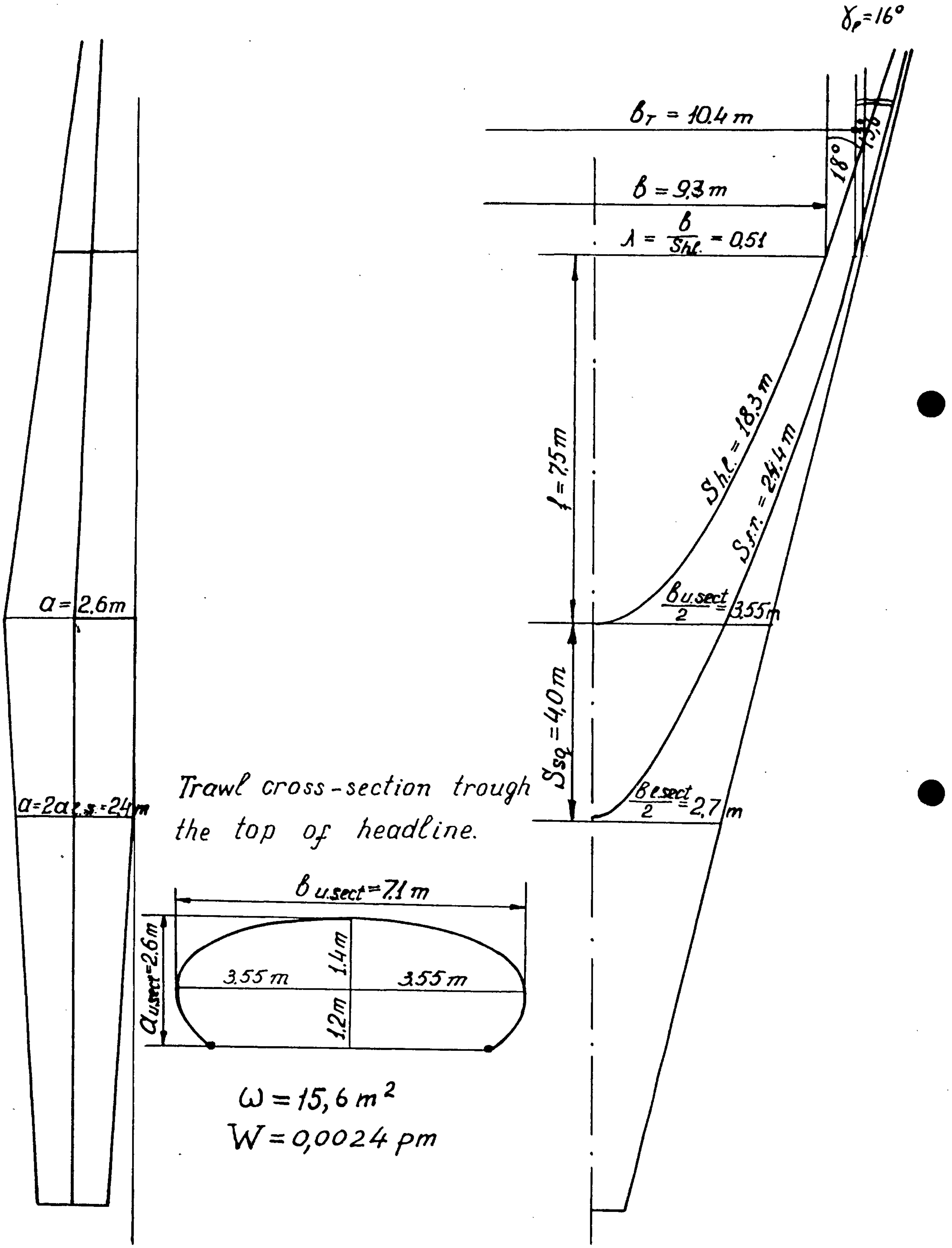
$\gamma_r = 16°$
$b_T = 10.4\,m$
$18°$
$b = 9.3\,m$
$\lambda = \frac{b}{S_{hl}} = 0.51$
$f = 7.5\,m$
$S_{hl} = 18.3\,m$
$S_{fr} = 24.4\,m$
$\frac{b_{u.sect}}{2} = 3.55\,m$
$S_{sq} = 4.0\,m$
$\frac{b_{e.sect}}{2} = 2.7\,m$
$a = 2.6\,m$
$a = 2a_{e.s.} = 2.4\,m$
Trawl cross-section trough the top of headline.
$b_{u.sect} = 7.1\,m$
$a_{u.sect} = 2.6\,m$
3.55 m
3.55 m
1.4 m
1.2 m
$\omega = 15,6\,m^2$
$W = 0,0024\,pm$

Figure 10.

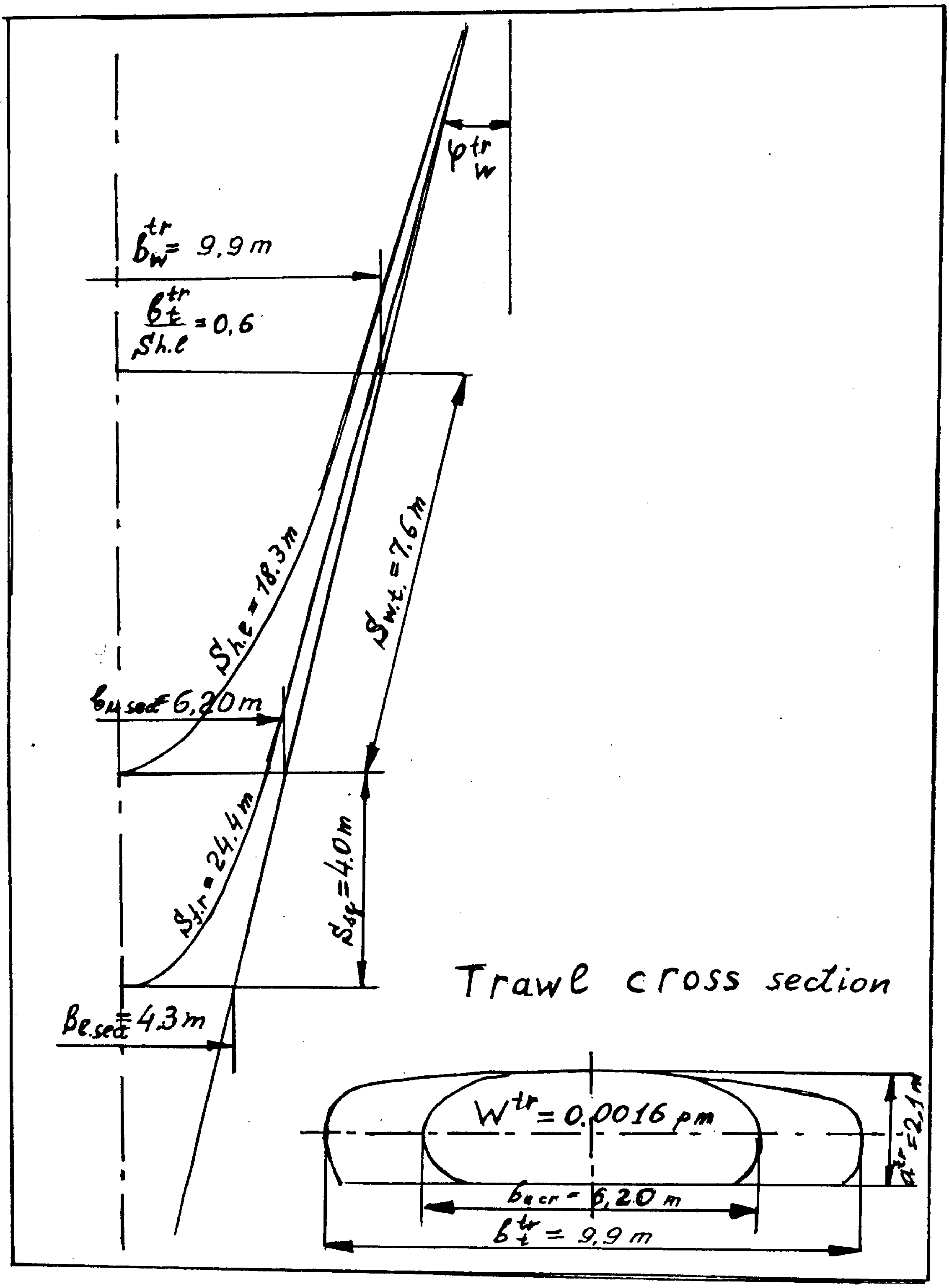
φ^{tr}_{w}
b^{tr}_{w} = 9.9 m
$\frac{b^{tr}_{t}}{S_{h.l}}$ = 0.6
$S_{h.l}$ = 18.3 m
$S_{w.t.}$ = 7.6 m
$b_{u\,sed}$ = 6.20 m
$S_{t.r}$ = 24.4 m
S_{sq} = 4.0 m
$B_{e.sed}$ = 4.3 m
Trawl cross section
W^{tr} = 0.0016 pm
a^{tr} = 2.1 m
$b_{u\,cr}$ = 6.20 m
b^{tr}_{t} = 9.9 m

Figure 11.