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Methods for the Theoretical Calculation of Wing and Door Spread of Bottom Trawls

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Abstract

Baranov's (1969) and Carrothers' (1980) methods of theoretical calculation of trawl door spread and methods to calculate the wing spread are discussed. Baranov's formula was simplified and a correlation between the net drag of the trawls (as a measure of the system's size), and the differences between the measured values of door spread and its calculation by Baranov's equation was found, thus making it more accurate. For four-fifths of trawl nets under study the value of those differences were below 7%. It was evident that Baranov's formula fitted better than that of Carrothers' for the experimental door spread values of the sample. An empirical formula is proposed for estimating wing spread of bottom trawls. The differences between calculated and measured wing spread values are under 17% in 90% of cases. Since the order of accuracy obtained with described formulae is within the range of variation of experimental results, the level of agreement is felt to be acceptable.

Key words: Bottom trawl, gear, trawl geometry, wing-door spread

Introduction

Trawl doors are of crucial importance to the engineering performance of trawl gear systems. Their main functions are to guarantee the horizontal spread of the trawl, a stable horizon for trawling (midwater trawls) and, in conjunction with other accessories, to form the gear's working area.

Unlike midwater trawls, fishing carried out with bottom trawls demands the artificial increase of the fish shoal concentration in the area influenced by the gear, because fish shoals are usually bigger than the mouth area of bottom trawls (Rozenshtein, 1976). This function is accomplished primarily by the trawl doors, because of the turbulence produced by their distance of bottom sediments (herding effect).

Knowing and influencing bottom trawl geometry is important for different reasons: for the correct interpretation of survey catches (Engås and Godø, 1986; Godø and Engås, 1989; Koeller, 1991), especially for surveys which attempt to obtain a measure of absolute abundance of a stock; during commercial fisheries, for adapting the working parameters of trawls to a specific fishing ground and species; in the planning phase, when different trawl designs are compared and an appraisal of possible parameters is required. Consequently, there is a need to determine a theoretical procedure to calculate with reasonable accuracy the spread between the doors and the wings of bottom trawls given the lack, in many fisheries, of reliable methods for measurements.

Baranov's (1969) and Carrothers' (1980) methods of theoretical calculation of trawl door and wing spread are discussed in this paper. In addition, an empirical formula is proposed for estimating wing spread from headline length that is different because of its simplicity and accuracy. Evaluation of the procedures developed, by calculating the bridle angle of the net during trawling, is proposed.

Materials and Methods

Baranov (1969) proposed a general method for the calculation of trawl door spread (DS). This method is based on the simplification of the forces that determine the equilibrium of the vessel-trawl system. Here, only the horizontal force components are taken into account (Fig. 1), assuming independence between the horizontal and the vertical spread of the net.

The DS is calculated by:

$$\frac{0.5\,DS_1}{\sqrt{(Sc^2 - 0.25\,DS_1{}^2)}} = N - (1+M)\,\frac{DS_1}{2L} \qquad (1)$$

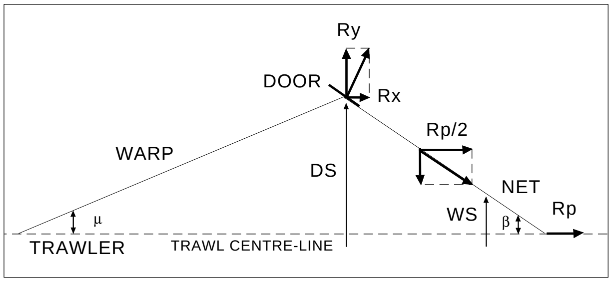

Fig. 1. Diagram for calculating door spread (DS) by Baranov's method (not to scale). (See text for definitions of coded parameters).

where

L = projection in the horizontal plane of the length of the trawl warp, Lw. L = (0.9–0.95) Lw, m.

M = relation between the hydrodynamic resistance of the door, Rx, and the component in the horizontal axis of the bridle tension (half of the net drag, Rp), M = 2 Rx/Rp.

N = relation between the spreading force of the door, Ry, and the component in the horizontal axis of the bridle tension, N = 2 Ry/Rp.

Sc = sum of the backstrops length, Lbs, bridle length, Lbr, and selvedge length, Ls, m (codend not included).

According to this method, the main influence on the magnitude of DS comes from the spreading force of the trawl door. It is possible to calculate the variable DS by an iterative method using formula (1).

To obtain his formula, Baranov considers the shape of the warp and bridles as straight lines, thus creating the angles μ and β with the trawl centre line (Fig. 1). Baranov states that μ is small (smaller than 10 degrees) and so $\tan \mu = \sin \mu$. If we assume that β is small also (it ranges from 10 to 20 degrees), then $\tan \beta = \sin \beta$ and formula (1) becomes simpler, thus not requiring the iterative calculation. Therefore:

$$DS_2 = \frac{2\ L\ Sc\ N}{[L + Sc(1+M)]} \qquad (2)$$

Then the wing spread (WS) is:

$$WS_1 = DS_2 \frac{Ls}{Sc} \qquad (3)$$

In this paper we analyze and discuss both these formulae, since the additional error resulting from use of formula (2) may be small with respect to overall uncertainty.

Carrothers (1980) proposed a method for the calculation of trawl door spread that also takes into account a simplification of the forces that determine the equilibrium of the vessel-trawl system. This author fitted one line catenary to the ground warp, upper wing leg and forward one-eighth of the headline, and another catenary was fitted to the bight of the headline.

Carrothers' method assumes previous knowledge of WS, and from that magnitude the value of DS is estimated. This is, in principle, a limiting factor of the method in case of not being able to count on measuring instruments, especially knowing that DS calculation by this method is quite sensitive to errors in WS; a 5% error in WS causing a 7% error in DS (Carrothers, 1980).

In order to compare the theoretical methods, the fit of each of them to experimental values of DS and WS of bottom trawls was verified. The source of comparison was research done by Galbraith (1983). This author measured the spreads of different bottom trawls during the tows. In addition to this source of information we used measurements on a research trawl done by Engås and Godø (1986). This sample includes trawl nets whose resistance (net drag) varies between 0.64 and 8.25 tons, for trawlers from 50 to 2 000 HP, a range that includes most of the trawl nets used in bottom fishing.

The technical characteristics and some engineering performance parameters (measured values) of these trawls, necessary to carry out the calculations of DS and WS, are shown in Table 1. Table 2 shows the parameters required to calculate DS by Baranov's general method and its simplified version (formula (2)). Carrothers' method of calculation was used to determine the warp-rope catenary parameters, Aw, and DS, as shown in Table 3. A computer program proposed by the author was used.

The differences in meters and percentage between estimated and experimental values of DS and WS for all trawl nets in the study give measures of the accuracy of each method (Tables 4, 5 and 6).

Also, we decided to find an empirical formula to estimate WS based on the parameters that most influence this magnitude thus simplifying the calculations. Input data for this calculation were taken from Carrothers (MS 1974, 1980) as well as

TABLE 1. Technical characteristics and some engineering performance parameters (measures values) from trawls, Galbraith (1983) and Engås and Godø (1986).

Net reference number	Warp length (Lw, m)	Backstrops length (Lbs, m)	Bridle length (Lbr, m)	Headline length (Lh, m)	Selvedge length (Ls, m)	Towing speed (knots)	Net drag (Rp, t)	Door spread (DSo, m)	Wing spread (WSo, m)
BT 124R	137	1.5	27.5	16.47	16.78	2.75	0.64	20.7	9.1
BT 124Q	137	2.0	55.0	22.00	21.61	2.75	0.93	28.0	10.1
BT 124J	137	2.0	27.5	26.15	26.81	2.75	1.27	22.9	12.2
BT 130C	137	3.0	55.0	28.00	24.94	3.00	2.29	43.9	15.2
BT 130B	137	3.0	55.0	34.00	31.04	3.00	2.84	45.7	15.5
BT 130E	137	13.0	73.0	38.30	36.09	4.00	6.08	68.6	24.7
BT 134	137	13.0	73.0	42.13	39.22	4.00	5.81	75.6	25.3
BT 135	137	13.0	73.0	47.40	44.85	4.00	8.25	72.0	27.6
Campel 1800/96	450	10.0	40.0	29.70	38.86	2.92	5.55	55.0	18.0
Campel 1800/96	800	10.0	40.0	29.70	38.86	2.92	5.55	58.3	18.5

TABLE 2. Calculated parameters for estimation of DS by Baranov's method. See Formulae (1), (2).

Net reference number	L (m)	Sc (m)	Rx (t)	Ry (t)	N	M	DS_1 (m)	DS_2 (m)
BT 124R	130.15	45.78	0.08	0.10	0.313	0.250	19.64	19.91
BT 124Q	130.15	78.61	0.12	0.15	0.323	0.258	28.53	28.86
BT 124J	130.15	56.31	0.20	0.24	0.378	0.315	26.65	27.13
BT 130C	130.15	82.94	0.47	0.53	0.463	0.410	40.01	40.45
BT 130B	130.15	89.04	0.47	0.53	0.373	0.331	34.55	34.77
BT 130E	130.15	122.09	1.29	1.63	0.536	0.424	55.40	56.03
BT 134	130.15	125.22	1.29	1.63	0.561	0.444	58.12	58.80
BT 135	130.15	130.85	1.66	2.09	0.507	0.402	54.49	55.07
Campel 1800/96	405.00	88.86	0.68	0.89	0.321	0.245	43.91	44.81
Campel 1800/96	720.00	88.86	0.68	0.89	0.321	0.245	47.90	49.45

TABLE 3. Measured and calculated parameters for estimation of wire-rope catenary parameter, Aw, and DS by Carrothers' method.

Net reference number	Rp/2 (Newton)	Diameter of ground warp (m)	Hydrodynamic pressure	Aw (m)	DS_3 (m)
BT 124R	3 139	0.012	1 024	182	28.18
BT 124Q	4 562	0.012	1 024	265	37.56
BT 124J	6 229	0.014	1 024	362	26.78
BT 130C	11 232	0.020	1 219	329	51.75
BT 130B	13 930	0.020	1 219	408	43.22
BT 130E	29 822	0.020	2 166	492	97.79
BT 134	28 498	0.020	2 166	470	88.73
BT 135	40 466	0.020	2 166	667	89.14
Campel 1800/96	27 223	0.020	1 154	842	56.66
Campel 1800/96	27 223	0.020	1 154	842	58.94

TABLE 4. Comparison of estimated values of DS by Baranov's and Carrothers' methods with experimental data.

Net reference number	DS_o observed (m)	DS_1 formula (1) (m)	$DS_o - DS_1$ (m)	$DS_o - DS_1$ (%)	DS_2 formula (2) (m)	$DS_o - DS_2$ (m)	$DS_o - DS_2$ (%)	DS_3 Carrothers' (m)	$DS_o - DS_3$ (m)	$DS_o - DS_3$ (%)
BT 124R	20.7	19.64	+1.06	5.1	19.91	+0.79	3.8	28.18	-7.48	36.1
BT 124Q	28.0	28.53	-0.53	1.9	28.86	-0.86	3.1	37.56	-9.56	34.1
BT 124J	22.9	26.65	-3.75	16.4	27.13	-4.23	18.5	26.78	-3.88	16.9
BT 130C	43.9	40.01	+3.89	8.9	40.45	+3.45	7.9	51.75	-7.85	17.9
BT 130B	45.7	34.55	+11.15	24.4	34.77	+10.93	23.9	43.22	+2.48	5.4
BT 130E	68.6	55.40	+13.20	19.2	56.03	+12.57	18.3	97.79	-29.19	42.6
BT 134	75.6	58.12	+17.48	23.1	58.80	+16.80	22.2	88.73	-13.13	17.4
BT 135	72.0	54.49	+17.51	24.3	55.07	+16.93	23.5	89.14	-17.14	23.8
Campel 1800/96	55.0	43.91	+11.09	20.2	44.81	+10.19	18.5	56.66	-1.66	3.0
Campel 1800/96	58.3	47.90	+10.40	17.8	49.45	+8.85	15.2	58.94	-0.64	1.1

TABLE 5. Procedure to improve DS calculation by Baranov's method, considering the size of trawl-door system.

Net reference number	DS_o observed (m)	DS_2 formula (2) (m)	Rp (t)	θ formula, Fig. 2 (m)	$DS_2^1 = DS_2 + \theta$ (m)	$DS_o - DS_2^1$ (m)	$DS_o - DS_2^1$ (%)
BT 124R	20.7	19.91	0.64	-0.65	19.26	+1.41	7.00
BT 124Q	28.0	28.86	0.93	+0.07	28.93	-0.93	3.30
BT 124J	22.9	27.13	1.27	+0.92	28.05	-5.15	22.50
BT 130C	43.9	40.45	2.29	+3.47	43.92	-0.02	0.10
BT 130B	45.7	34.77	2.84	+4.84	39.61	+6.09	13.30
BT 130E	68.6	56.03	6.08	+12.93	68.96	-0.36	0.52
BT 134	75.6	58.80	5.81	+12.26	71.06	+4.54	6.00
BT 135	72.0	55.07	8.25	+18.35	73.42	-1.42	2.00
Campel 1800/96	55.0	44.81	5.55	+11.61	56.42	-1.42	2.60
Campel 1800/96	58.3	49.45	5.55	+11.61	61.06	-2.75	5.00

TABLE 6. Input data to obtain an empirical formula of WS, WS = f (N, Lh).

Net reference number	N = 2 Ry/Rp	Lh (m)	WS_o (m)
BT 124R	0.313	16.47	9.10
BT 124Q	0.323	22.00	10.10
BT 124J	0.378	26.15	12.20
BT 130C	0.463	28.00	15.20
BT 130B	0.373	34.00	15.50
BT 130E	0.536	38.30	24.70
BT 130E	0.441[a]	38.30	24.00
BT 134	0.561	42.13	25.30
BT 134	0.470[a]	42.13	26.10
BT 135	0.507	47.40	27.60
BT 135	0.419[a]	47.40	26.70
Campel 1800/96	0.321	29.70	18.00
Engel 145-ft, oval doors	0.584	29.26	14.08
Engel 145-ft, rect. doors	0.385	29.26	15.24
Yankee 41, rect. doors	0.414	24.38	13.47
Yankee 36, polythene	0.636	18.29	10.15
Yankee 41, polythene	0.563	24.38	13.41
Yankee 41, 4 m^2 rect. doors	0.588	24.38	14.20
Yankee 41, 2.8 m^2 oval doors	0.565	24.38	13.59
Granton, polythene	0.588	24.38	13.20
Atl. Western III	0.453	24.08	10.85

[a] Calculated for 3 knots.

TABLE 7. Comparison of estimated values of WS by Baranov's method (formula (3)) and by empirical formula (4) with experimental data.

Net reference number	WS_o observed (m)	WS_1^1 formula (3) (m)	$WS_o - WS_1^1$ (m)	$WS_o - WS_1^1$ (%)	WS^2 formula (4) (m)	$WS_o - WS^2$ (m)	$WS_o - WS^2$ (%)
BT 124R	9.1	7.06	+2.04	22.4	7.88	+1.22	13.4
BT 124Q	10.1	7.95	+2.15	21.3	11.50	-1.40	13.9
BT 124J	12.2	13.36	-1.16	9.5	14.22	-2.02	16.6
BT 130C	15.2	13.21	+1.99	13.1	15.43	-0.23	1.5
BT 130B	15.5	13.81	+1.69	10.9	19.36	-3.86	24.9
BT 130E	24.7	20.38	+4.32	17.5	22.18	+2.52	10.2
BT 134	25.3	22.26	+3.04	12.0	24.69	+0.61	2.4
BT 135	27.6	25.17	-2.43	9.7	28.14	-0.54	2.0
Campel 1800/96	18.0	24.67	+6.67	27.0	16.54	+1.46	8.1
Campel 1800/96	18.5	26.70	+8.20	30.7	16.54	+1.96	10.6

Galbraith (1983) and Engås and Godø (1986) (Table 7).

Results and Discussion

Door spread

Door spreads estimated by Baranov's general method, DS_1, and its simplified version, DS_2, differ from experimental door spreads, DS_o by 2 to 24% (Table 4). In both cases, and in 70% of trawl nets sampled, the values of differences were over 15%. In 80% of cases calculated values were lower than experimental DS values. For the sample studied, the Baranov simplified version proved to be as accurate as the more rigorous (general) version of the method.

Door spread estimated by Carrothers' method, DS_3, differed from experimental door spreads by 1 to 43% and in one-third of the cases the values were over 34%. Carrothers' method overestimated the real DS values for almost all trawl nets studied. Therefore, the Baranov method gave the better fit to the experimental data.

The main reason for the underestimation of DS by Baranov's method could be an underestimation when calculating the forces acting on the board during towing (Rx, Ry). These forces were calculated without considering the influence of the bottom, and since the board moves along the seabed, the outward spreading force is increased and even more, the drag (FAO, 1974; Kondratiev, 1973). The difference between calculated and experimental door spread (Table 4) varies according to the size of the trawl-door system, as measured by net drag, Rp (Fig. 2). The explanation for the behaviour of these errors is that the greater the trawl-door system, the greater the difference in the shape of bridles from the straight line assumption underlying the Baranov method. Estimation of DS by Baranov's method can be improved by adjusting for the size of the trawl-door system through adding $\theta = 2.4971$ Rp -2.2493 (Fig. 2) to calculated values of DS_2 for each trawl, thus obtaining a new value for DS_2. This new value is identified as DS_2^1. For four-fifths of trawls under study, the difference between DS_2^1 and DS_o was under 7% (Table 5).

Fridman and Rozenshtein (1987) exposed the inefficiency of Baranov's formula for knowing the real trawl door spread by obtaining theoretical values with an appreciable margin of error. We consider this assertion could be totally valid for trawls where the forces that act vertically have magnitudes close to the forces that act horizontally, i.e. for midwater trawls. In the systems where horizontal forces are predominant in determining the configuration of bottom trawls, Baranov's method may of-

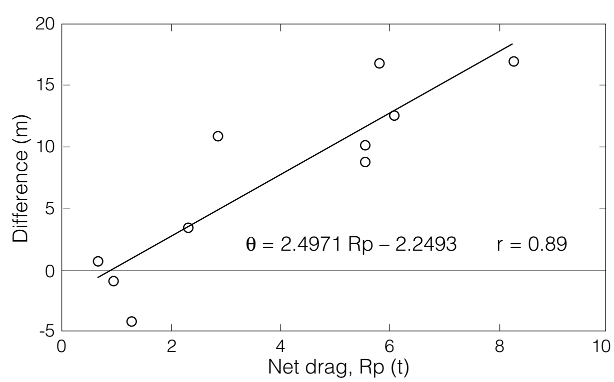

Fig. 2. Relationship between net drag and difference between experimental door spread (DS_o) and door spread calculated using the simplified version of the Baranov method (DS_2).

fer values significantly closer to the real ones, as demonstrated in this paper.

Wing spread

Wing spreads were estimated by Baranov's method from equation 3 but DS_2^1 rather than DS_2, was used to give a value of wing spread, labelled WS_1^1. Differences between observed values, WS_o, and calculated WS_1^1, varied from 9 to 31% (Table 7), and 40% of the differences exceeded 20%.

Theoretically, we consider that WS is a function of the forces which act on the horizontal spread of the bottom trawl, i.e. the spreading force of the trawl door and the hydrodynamic resistance of the net, and of the technical characteristics of the gear, in particular length of the trawl warp, bridle length and headline length. These factors were examined in the development of our empirical formula for calculation of WS.

At any particular fishing depth, door spread, and hence wing spread, is strongly influenced by warp length (e.g. Koeller, 1991). This has long been known and it is common practice when trawling to vary warp length systematically with depth, using higher warp:depth ratios in shallower water than are used in deep water. In Cuban commercial fisheries, for example, a warp:depth ratio of 3:1 is usually used, varying between 4.5:1 and 2.5:1. However, the warp:depth ratios used in practice may not result in net geometry staying constant over depth. For example, Godø and Engås (1989) found WS increased by 50% as depth increased from 50 m to 450 m, although warp:depth ratio was decreased from 3:1 to 2:1. Nonetheless, the practice of reducing warp:depth ratio with depth tends to compensate for the effect of warp length on door and wing spreads. Also, the effect of warp length is greater on door than on wing spread (Kondratiev, 1973; Fridman, 1981), e.g. Koeller (1991) found wing spread increased only 50% when door spread doubled, while Engås and Godø (1986) recorded in one test only an 8% increase in wing spread when door spread increased by 41%. We decided, therefore, that the effect of warp length on wing spread could be discounted in devising our empirical formula.

Kondratiev (1973) and Fridman (1981) state that bridle length exerts very little influence on wing spread. This is corroborated by Engås and Godø (1986), who found that doubling bridle length did not affect wing spread. Thus, bridle length is also discounted.

Headline length is, however, a key factor in determining wing spread. Fridman (1981) pointed out that for trawls it is common that wing spread represents between 45 and 55% of the headline length, with a form approximating a catenary curve during the tow.

With regard to the forces acting on trawl spread, the spreading force of the trawl door and the hydrodynamic resistance of the net act contrary to one another. Thus, we included in our formula the coefficient N (as in equation (1)) to reflect the relation of these forces.

Based on these considerations, the statistical association between WS, the coefficient N and headline length, Lh, was examined using a stepwise regression based on the experimental data given in Table 6. The variable N did not transpire to be a significant factor but the variable Lh proved decisive in determining WS. The equation derived was:

$$WS_2 = 0.655Lh - 2.9097 \qquad (4)$$

where: r = 0.9628

standard error = 1.6693.

Differences between observed values, WS_o, and calculated values using formula (4) varied from 1 to 25%, and were under 17% in 90% of cases (Table 7). This is a substantial improvement over the results using the Baranov method.

Application of results

For the practical application of the methods described, it is recommended that WS be calculated by formula (4) and DS be calculated by Baranov's simplified version (formula (2)). If the parameters of the trawl nets under study are within the range of the sample, then it is recommended that the result of DS be corrected with those values obtained by the formula in Fig. 2 (as in Table 5), thus making it more accurate. The method in FAO (1974) may be used to calculate the forces acting over the doors, Rx and Ry, and MacLennan (1981) for calculating Rp (see Appendix).

In order to evaluate in a simple manner the validity of the theoretical procedure, considering that DS and WS are calculated by different methods, we recommend estimating the value adopted by the bridle angle, α, during towing by using this formula:

$$\sin \alpha = \frac{DS - WS}{2\,(Lbs + Lbr)} \qquad (5)$$

The value obtained must range from 10 to 20 degrees, as reported by different authors (Rozenshtein, 1976; Galbraith, 1983; Engås and Godø, 1986). This calculation gives an idea of the shape adopted by the trawl net while at work. For our sample α values vary between 9 and 24 degrees.

The order of accuracy obtained with the above derived formulae (Tables 5 and 7) is within the range of variation in trawl geometry observed by Godø and Engås (1989) and Koeller (1991) during standard resource surveys. We conclude, therefore, that the methods developed here to theoretically estimate DS and WS are of acceptable accuracy to be used for both stock assessment and engineering work linked to bottom trawls.

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Appendix

Spreading Force (Ry) and Hydrodynamic Resistance (Rx) Calculation for Trawl Doors

It is well-established that forces generated by water flow around a body are proportional to the density of water (ρ, kg s^2/m^4), the surface area (S, m^2) of the body and the square of its towing speed (V, m/s) through the water. This may be expressed mathematically for otter board forces by two equations (FAO, 1974):

$$Rx = 1/2\ \rho\ V^2\ S\ Cx,$$

$$Ry = 1/2\ \rho\ V^2\ S\ Cy.$$

For the density of water, the value 102 kg s^2/m^4 is commonly used. Cx and Cy are called the hydrodynamic and spreading coefficients, which have no dimensions and depend on the angle of attack of the board and board type. As the angle of attack of boards is very stable under normal fishing conditions, we give here a summary of the coefficients for commonly used boards in fisheries.

Board type	Common angle of attack	Coefficients Cx	Coefficients Cy
Rectangular Flat	40°	0.82	0.72
Rectangular Cambered	35°	1.26	0.81
Oval Flat, Slotted	35°	0.86	0.63
Oval Cambered, Slotted (polyvalent type)	35°	0.93	0.74
Rectangular Vee Type	40°	0.80	0.65

Net Drag (Rp) Calculation

By its simplicity and accuracy we propose to use the MacLennan formula (1981) for calculation of net drag, Rp.

$$Rp = Ta\ [61.2 + 46.6\ V^2/(1 + 0.0641\ V)]/9807\ \text{(ton)}$$

where

V = trawling speed (knots)
Ta = twine area for the complete trawl (m^2)

The twine area of the trawl net section can be obtained from the following formula:

$$T_s = 2\ [(N + n) * H]\ [a * b] * 10^{-6}$$

where

N = number of meshes across front edge
n = number of meshes across aft edge
H = number of meshes in depth
a = bar length of mesh in mm
b = diameters of netting twine in mm.

The formula is applied to each section of the net and summed to give the overall netting twine surface area for the complete trawl.

Modern fishing vessels are usually equipped with instruments for measuring the overall resistance of the overall net-doors-warp system. Given that the net drag of bottom trawls is about 55-60% of the overall resistance of the whole system (Bucki, 1981; Fridman, 1981), we can easily calculate the net drag.

In many cases the designers or manufacturers have the experimental data on Rx, Ry and Rp for each door and trawl, which provides more accurate figures for the calculation of door spread.