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Trawl drag area and netting geometry

by

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ABSTRACT

The bag of a trawlnet is considered as an elliptical cone, its wings as merely forward extensions of this cone. The dimensions of the cone are derived from the measured wingend spread and the headline height (gape) of the net and from its specification drawings. From these operational and constructional dimensions the mean angle of attack of the netting panels and the mean setting angle of the meshes are derived. All operational dimensions change with towing speed. Formulae are then given which with further inputs of twine diameter bar length and developed area of each netting panel allow an estimate of the drag area of the netting cone. The codend in the form of a tube, the net appendages and the ground friction are each considered separately. Thus a total drag area is derived; multiplication by the hydrodynamic pressure and addition of the friction give the total geometrically derived drag of the trawlnet. This is compared with the measured drag over a range of speeds for 3 very different bottom drawls and two substantially different midwater trawls. Examples of the comparisons are presented. The method provides a means of predicting change of trawlnet drag with change of shape.

INTRODUCTION

The **drag** of the trawlnet D results from a drag area term A, the hydr**o**dynamic pressure q or $\left(\rho v^2/2g\right)$ and in the case of bottom trawls a friction term F, so that $D = A_q + F$. The drag area term includes the drag area of the netting cone, the codend, the appendages (floats bobbins etc.). The different components of the drag area and the friction are here considered separately and then reconstituted to be compared with the measured drag. The measured trawl net drag is the sum of the components of wing bridle tensions lying parallel to the direction of motion.

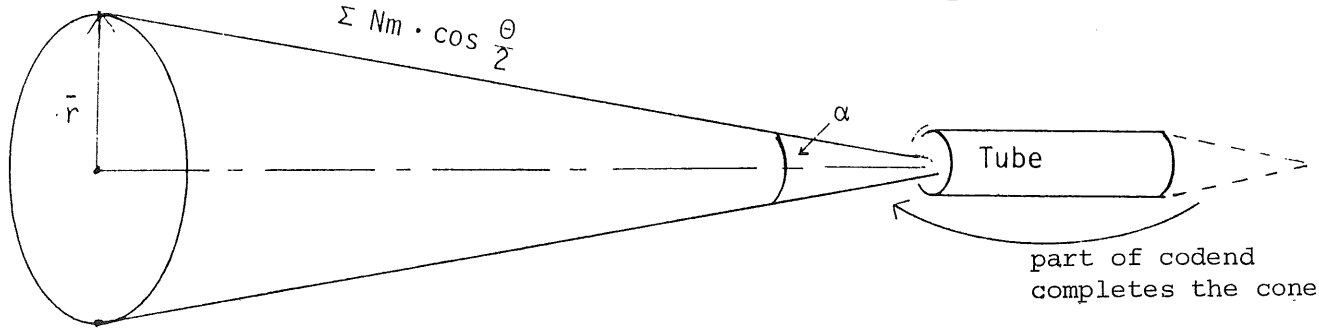
In order to deal with the matter generally 5 trawls of very different design and size were chosen for analysis, from Carrothers (1969) data the Granton trawl as the most typical of groundfish trawls, the Atlantic Western III four panel trawl, a lightweight trawl about the size of the Granton but designed for a 200 HP vessel, a large midwater trawl with a size of 264# by 2000 mm mesh and a smaller 572# by 560 mm mesh; those last operated by the same vessel with the same otterboards are spread to a very different extent.

GENERAL APPROACH

The case of the midwater trawls is the easiest to consider because they are nearly circular round the bag of the net from the centre of the headline aft. The wings may be considered as forward extensions of this cone. A large part of the twine in both bottom and midwater trawls goes into the codend, but this does not at all contribute in the same proportion to the drag. Part of the codend is therefore considered as completing the cone and the remainder as a tube presenting zero angle of attack to the waterflow.

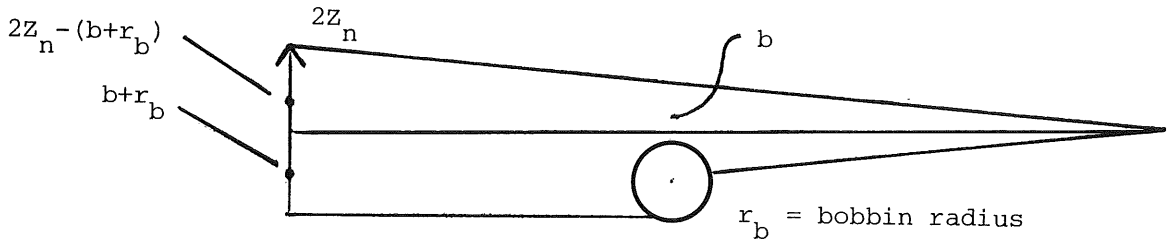
The vertical opening of the net at the headline centre is given by the netsonde and the corresponding horizontal opening is given by proportion along the sides of the cone from the spread between wingtips ($2y_n$). The setting angle of the meshes ($\theta/2$) is determined by the perimeter of the net mouth and the number and size of the meshes round the net. It would be good enough for midwater trawls to determine the mean radius ($\bar{r}$) of the mouth of the cone from the mean of the vertical and horizontal diameters.

N = number of meshes lengthwise in a panel
m = meshsize of each panel



The angle of attack (α) of the walls of the cone is determined from $\bar{r}$ and the sum of the lengths of the meshes to the point of the cone, foreshortened by the setting angle.

The case for bottom trawls is more elaborate as the mouth of the bag is in the form of a flattish ellipse. The major axis of the ellipse is fairly estimated by proporrtion along the sides of the cone from the headline spread and the minor axis is similarly estimated from the headline height ($2Z_N$).



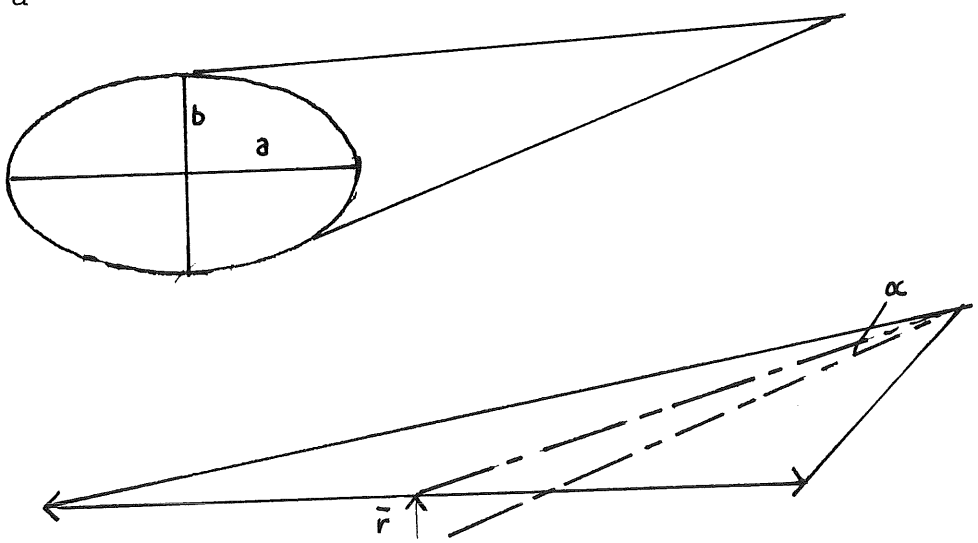
The lengthways measurements used in the proportion calculations are more readily taken from the net specification drawings than from actual measurements. The ellipse perimeter as determined from the major and minor axis is given by Spiegel (1962) as:

$$\text{Periphery } I(2\pi) = a\,2\pi\left[1\left(\frac{1}{2}\right)^2 k^2 - \left(\frac{1.3}{2.4}\right)^2 \frac{k^4}{3} - \left(\frac{1.3.5}{2.4.6}\right)^2 \frac{k^6}{5} - \left(\frac{1.3.5.7}{2.4.6.8}\right)^2 \frac{k^8}{7} - - - -\right]$$

where a = semi major axis
b = semi minor axis

and $k^2 = \dfrac{a^2 - b^2}{a^2}$

Mouth area nab



The elliptical cone may be considered as cut open and flattened out so that the perimeter is in a straight line. The setting angle of the meshes remains the same and for the area of the flattened surface presented to the waterflow to be the same as the mouth area of the cone the condition is

$$\tfrac{1}{2} \text{ perimeter} \cdot \bar{r} = \pi ab$$

The mean value of the angle (α) follows. The square and upper and lower wings are as before treated as forward extension of the cone.

Drag coefficients

The nominal developed area of twine in a netting panel is taken in the usual way as

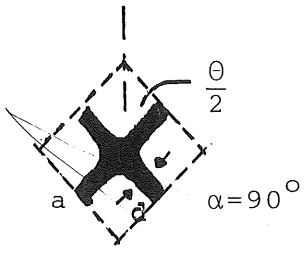
$$A = \frac{N + n}{2} \cdot H \cdot 2m \cdot d \times 10^{-6}$$

where m and d are mesh size and twine diameter in mm. Modification to this because of knots is taken into account within the drag coefficient.

An approach suggested by Crewe (1964) is now used where Cd_{90} i.e. (Cd at $\alpha = 90^{o}$) and Cd_0 (Cd at $\alpha = 0^{o}$) are calculated separately. Since in practice the plot of sheet netting drag appears to be nearly linear in the range ($\alpha = 0$ to $\alpha = 30^{o}$).

$$C_{d\alpha} = \tfrac{1}{2} (C_{d_{90}} - C_{d_0}) \frac{\alpha}{30^{0}} + C_{d_0}$$

Both $C_{d_{90}}$ and C_{d_0} are in different ways dependant on $\Theta/2$.



one mesh

The exit velocity through the mesh apertures must be larger than the approach velocity by a factor $\frac{U_e}{U} = \left(\frac{1}{1-s}\right)$ where s = the solidity.

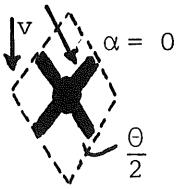
$$C_{d_{90}} = C_{dsc} \cdot C_t \cdot \left[\text{knot correction term}\right] \cdot \left[\frac{1}{1-s}^2\right]$$

$C_{d_{90}}$: Twine drag coefficient when formed into meshes

C_{dsc}: drag coefficient of a smooth cylinder allows for change with Reynolds number

C_t: allows for type of twine usually C_t = 1 to 1.2.

crossflow on bars



one mesh

the crossflow force on the bars in dependant on $\sin^3 \frac{\Theta}{2}$

In detail it can be shown that:

$$C_{d_{90}} = \left\{C_{dsc} \cdot C_t\left(1-\frac{d_k}{d}\cdot\frac{d}{a}\right) + C_k \cdot \frac{\pi}{8} \cdot \left(\frac{d_k}{d}\right)^2 \frac{d}{a}\right\} \cdot \left\{\frac{1}{1 - \frac{\frac{d}{a}\left(1-\frac{d_k}{d}\cdot\frac{d}{a} + \frac{\pi}{8}\left(\frac{d_k}{d}\right)^2 \cdot\frac{d}{a}\right)}{\sin\frac{\Theta}{2}\cdot\cos\frac{\Theta}{2}}}\right\}^2$$

bars — knots — solidity term

speed up term $\left(\frac{V_e}{v}\right)^2$

$$C_{d_0} = \left\{C_{dsc} \cdot C_t \cdot \left(\sin^3\frac{\Theta}{2} + C_f \cos^2\frac{\Theta}{2}\right)\left(1 - \frac{d_k}{d}\cdot\frac{d}{a}\right) + C_k \cdot \frac{\pi}{8}\left(\frac{d_k}{d}\right)^2 \cdot \frac{d}{a}\right\}$$

skin friction term

where in this instance $D_{dsc} \cdot C_t$ is put = 1

$\frac{d_k}{d}$ knot diameter/twine diameter is put = 3.16 and $\left(\frac{d_k}{d}\right)^2 = 10$

C_k the knot drag coefficient is put = 0.47 as for a sphere

C_f the twine skin friction coefficient is put = 0.07

The cone drag area of each panel is $A_c = C_{d\alpha} \cdot A$

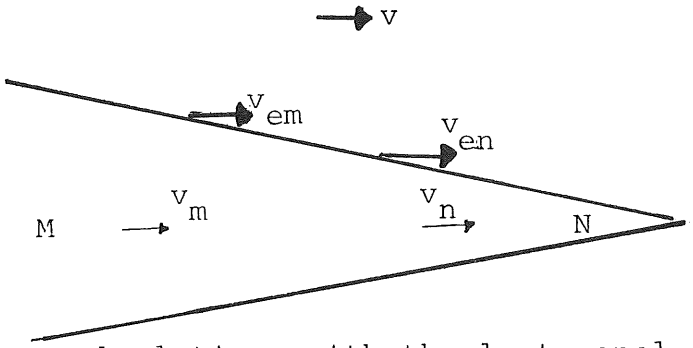
Effect of high solidity panels

When the solidity term S 0.3 then $\frac{v_e}{v} = \frac{1}{1-s} > \sqrt{2}$

and the frag coefficient dependant on $\left(\frac{1}{1-s}\right)^2$ would become >2.

This occurs for large $\frac{d}{a}$ and small $\frac{\theta}{2}$ and represents the commencement of form drag.

Such a condition can occur in the after part of midwater trawls and in front of and in the codend. The water will not escape by extra speed up locally within the restricted mesh openings and escapes rather by speeding up the waterflow through the meshes of preceding panels with lower solidity.



$v_e > v > v_m > v_n$

for $S_n > S_m$

Start calculations with the last panel of the netting cone.

Flux into panel N = Flux out of panel N

$$V_n \cdot A_N = V_{en} \cdot A_N (1-S_n)$$

$$V_n = V_{en} (1-S_n)$$

where A_N is the developed area of the panel.

The developed area of the twine in the panel is A_m and is simply related to A_M by:

$$\frac{A_m}{A_M} = \frac{d}{a} \cdot \frac{1}{\sin\frac{\theta}{2}\cos\frac{\theta}{2}}$$

(based on 2ad being the nominal area of twine in one mesh)

$$k_n = \frac{v_n}{v} = \frac{v_{en}}{v} (1-S_n) \quad \text{and} \quad \frac{v_{en}}{v} \quad \text{not} > \sqrt{2}$$

To get rid of as much water as possible put $\frac{v_{en}}{v} = \sqrt{2}$

The drag coefficient for such a panel becomes

$$C_{d90} = \left\{ C_{dsc}\, C_t \left(1 - \frac{d_k}{d} \cdot \frac{d}{a}\right) + C_k \frac{\pi}{8} \left(\frac{d_k}{d}\right)^2 \frac{d}{a} \right\} \cdot 2$$

Flux into Panels M and N = Flux out of panels M and N

$$V_m(A_M + A_N) = V_{em}\, A_M\, (1-S_m) + V_n A_N$$

$$K_m = \frac{V_m}{v} = \left(\frac{V_{em}}{v} \cdot A_M(1-S_m) + K_n A_N\right) \cdot \frac{1}{A_M + A_N}$$

After 2 (or more) panels have been considered in this way the value of $\frac{V_{em}}{v}$ will fall below $\sqrt{2}$ for $\frac{V_m}{v} = 1$

All preceding panels can then be considered as uninfluenced by the succeeding ones, the speed of the water within them also being the same as the trawl speed. The drag coefficient for the intermediate panel is given for example by

$$C_{d90} = \left\{ C_{dsc}\, C_t \left(1 - \frac{d_k}{d} \cdot \frac{d}{a}\right) + C_k \frac{\pi}{8} \left(\frac{d_k}{d}\right)^2 \frac{d}{a} \right\} \left(\frac{V_{em}}{v}\right)^2$$

where now $$\left(\frac{1}{1-S_m}\right)^2 < \left(\frac{V_{em}}{v}\right)^2 < 2$$

This a simplification because v_m and v_n cannot really change in jumps from panel to panel. When the water speed within and outside a panel are different this presumably affects the C_{do} value so that the value used is $C_{dol} = 0.5\, C_{do} \left(1 + \left(\frac{V_m}{v}\right)^2\right)$

and as before $C_{d\alpha} = 0.5\, (C_{d90} - C_{dol}) \frac{\alpha}{30^o} + C_{d01}$

Codend drag

The amount of twine in the codend is usually a substantial proportion of the total amount of twine in a trawl. Because it is in the form of a tube rather than a cone, the codend does not contribute anything like the same proportion to the total drag of the trawl and it therefor has to be considered separately as an appendage to the rest of the trawl.

From the Russian literature on the subject Fridman (1973) quotes the drag of a netting sheet parallel to the current as being

$$R_0 = 1.4\ell^{-0.14}\left(1 + \frac{5d}{a}\right)\left(0.9 + 0.04\,\frac{v_1}{v_2} + 0.55\,e^{-2.4\frac{v_1}{v_2}}\right) F_v^{1.96}$$

The term $^{-0.14}$ expresses the entrainment of the wake along the length of the sheet. The terms U_1 and U_2 are the hanging ratios in the two directions of the sheet. F is the development area of the sheet (length breath) and v is the velocity in m/s. The conversion from developed sheet area to area of twine in the sheet is:

$$\text{simplified solidity} = \frac{F_t}{F} = \frac{d}{a} \cdot \frac{1}{u_1\ u_2} \quad \text{same as} \quad \frac{A_m}{A_M} = \frac{d}{a} \cdot \frac{1}{\sin\frac{\Theta}{2}\cos\frac{\Theta}{2}}$$

Codend drags are worked out using the Russian formula and the codend twine drag coefficient appears to be in the region of 0.06.

Appendage drag

Appendages such as floats and bobbins are inflexible and their drag area simply determinable. Drag of spheres is taken as

$$D = 0.47\,\frac{\pi}{4}\,d^2 \cdot q$$

Bosom bobbins are considered as edge on to the waterflow, bunt bobbins are considered as side on to the waterflow and the drag coefficient is in each case taken as 1.2.

Friction

The total weight in water of the groundrope assembly is the sum of the weight in water of its component parts, rubber bobbins, rubber specers, iron lancasters, and bobbin wire. The ground friction coefficient is here taken as 0.7 although it is known to change with the nature of the bottom.

Results and discussion

In Table 1 the operational results of speed or hydrodynamic pressure headline spread and headline height are given in the first 4 columns. The other operational result, the net drag in the direction of motion is given in the second last column on the right. all the rest are derived results.

The last column, the cone drag area estimated from teinsion measurements, is obtained by subtracting the estimated friction, appendage and codend drags from the total measured drag and dividing by the hydrodynamic pressure.

An example of the computation of cone drag area is given in Table 2. The inputs are the nominal twine area of each netting panel A, the d/a value for each panel, normal twine drag coefficient C_t, ratio of knot diameter to twine diamter d_k/d, the knot drag coefficient C_k, and the twine hydrodynamic skin friction coeff. C_f. These remain the same for each set of calculations but $u_1 = \sin \frac{\Theta}{2}$, and AL = α are usually different each time the speed is changed so that they are input for each block. The output as well as repeating the A and d/a values for each panel gives the solidity S, the ratio of velocity inside the panel to water velocity Vp/v, the drag coefficient $C_{d\alpha}$, the drag area of each panel and the total cone drag area. The effect of S on $C_{d\alpha}$ is apparent.

The net drags obtained by tension measurements are compared with the geometrically derived net drag when plotted against hydrodynamic pressure in Figs. 1 to 5. Also included are plots of a knotless model of geometric drag which as might be expected fall somewhat below the knotted model-plots. The knotless model is simpler for hand calculation but generally follows the same argument as already outlined.

The agreement between geometrically designed and measured drag is generally fair except for nets with a high mesh solidity and rather flat attitude like the Granton where the knotted model is giving unrealistically high values of drag and even the knotless model is somewhat high. The difference between the knotless and knotted models decreases for those nets with low mesh solidity.

While the tension derived data may appear to be nearly linear with hydrodynamic pressure, the conclusion that it is linear leads to doubtfully high values for the bottom trawl friction obtained as the intercept. A small allowance of curvature allows for more probable values of ground friction. Furthermore the pelagic trawl data ought to extrapolate toward the origin and, as Figs. 4 and 5 show, requires some curvature to do so.

When what are considered to be reasonable values are substracted from the tension derived drag allowing for ground friction, appendage and codend drag, the residual cone drag converted into cone drag area (last column Table I) always shows an tendency to drop with increasing hydrodynamic pressure, more markedly even than the geometrically derived cone drag area (column 12 Table 1). This suggests that the computations are not giving enough change of cone drag area over the speed range and that some more attitude (α) dependance is required. Some allowance for this may be mode for this by change of C_t C_k and C_f within reasonable limits.

The ellipse area at the mouth of the bag appears always to fall with increasing speed, the ellipse perimeter mostly to fall except in the case of the lightweight net with low headline height where the increasing spread causes the perimenter to increase.

With the so far limited experience of using this approach, the predictions of net drag from the trawl geometry are perhaps no better as yet than could be obtained by other means e.g. scaling from existing designs whose performance is known. The formulae described are however more flexible in that they allow for change of shape.

Table 1. Summary of results.

speed v knots	a kg/m^2	net spread $2y_n$ m	headline height $2Z_n$ m	mouth area m^2	major axis 2a m	minor axis 2b m	ellipse area πab m^2	ellipse perim. m	setting angle $\sin\frac{\Theta}{2}$	attitude α_o	cone drag area m^2	cone drag kg	codend drag kg	appendage drag kg	friction drag kg	total geom. drag kg	total measr. drag kg	cone drag area measr. m^2
Granton developed twine area cone 47.1 m^2 codend 22.4 m^2																		
3.43	164	13.7	2.83	32	6.72	2.04	10.8	15.0	0.267	5.22	13.1	2140	220	558	202	3120	2340	8.3
3.93	215	13.1	2.86	31	6.42	2.07	10.4	14.4	0.257	5.28	14.1	3029	288	732	"	4250	3000	8.3
4.56	289	12.8	2.89	30	6.28	2.10	10.4	14.2	0.253	5.28	14.0	4055	387	986	"	5630	3930	8.1
Atlantic Western III developed twine area cone 39.7 m^2 codend 15.7 m^2																		
2.68	100	11.8	4.86	47	5.18	3.64	14.8	14.0	0.321	8.74	13.5	1352	139	374	144	2010	2200	15.6
3.06	130	10.5	4.55	39	4.62	3.40	12.3	12.6	0.291	7.99	13.0	1690	181	488	"	2500	2650	14.1
3.47	168	10.9	4.28	38	4.78	3.18	11.9	12.6	0.291	7.70	12.8	2145	234	627	"	3150	3150	12.8
4.00	223	10.6	4.01	35	4.66	2.98	10.9	12.1	0.279	7.35	12.5	2794	311	832	"	4080	3670	10.7
4.58	292	11.4	3.78	35	5.02	2.80	11.0	12.5	0.288	7.18	12.4	3607	407	1091	"	5250	4630	10.2
460 by 114 mm. lightweight trawl developed twine area cone 29.1 m^2 codend 1.4 m^2																		
2.17	65	13.0	2.1	22	8.12	1.81	11.5	17.5	0.334	3.73	4.2	271	25	74	20	390	430	4.8
2.56	90	13.5	1.8	20	8.45	1.53	10.2	18.0	0.343	3.04	4.0	358	34	111	"	520	530	4.0
3.08	131	13.8	1.6	18	8.65	1.34	9.1	18.3	0.350	2.69	3.9	510	49	160	"	740	680	3.4
572 by 560 mm pelagic trawl developed twine area cone 206 m^2 codend 46 m^2																		
2.61	94	27.0	24.8	670	21.3	24.8	415	72	0.226	8.40	55	5132	249	191	0	5570	5230	51
2.92	118	27.7	23.0	637	21.9	23.0	395	70	0.218	8.22	54	6407	312	239	"	6960	6110	47
3.19	140	27.3	22.2	606	21.5	22.2	375	68	0.213	7.99	53	7476	370	285	"	8130	6850	44
3.39	159	28.6	21.3	609	22.5	21.3	376	68	0.213	7.99	53	8491	420	322	"	9230	7450	42
264 by 2000 mm pelagic trawl developed twine area cone 310 m^2 codend 172 m^2																		
3.13	63	37.5	34.5	1290	28.0	34.5	758	98	0.186	7.18	71	4454	297	177	0	4930	5080	73
2.30	73	37.5	31.5	1180	28.0	31.5	692	94	0.178	6.78	69	5052	345	206	"	5600	5740	71
2.50	86	37.3	31.7	1180	27.8	31.7	692	93	0.176	6.89	70	6003	406	244	"	6650	6570	69
2.67	98	38.5	29.2	1120	28.7	29.2	658	90	0.170	6.72	69	6772	463	278	"	7510	7400	68