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A Net Drag Formula for Pelagic Nets

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Introduction

To a net designer, attempting to design a net to suit a specific power of vessel, the ability to predict the hydrodynamic drag of the net he is designing is essential. If he designs a net with too much drag, the boat will be unable to tow it fast enough. Alternatively, if the net he designs has less drag than can be comfortably overcome by the vessel, then there is a loss in efficiency, for the boat could be equipped with a larger net. Full scale engineering trials are expensive and time-consuming. Model tests are also expensive and we have not yet in this country the facilities to test models of pelagic trawls large enough to provide accurate net drag predictions. Thus, since the designer needs to be able to make a reasonable estimate of net drag when his net is still at the design and development stage, he requires a formula which will predict the drag of the net simply from the information contained in the net drawing.

A fisherman too, when choosing a new net, requires to know what drag the net will produce over the relevant range of towing speeds in order that he may choose the size of net that best matches his vessel's available towing power. It is also necessary to know the net drag to choose otterboards of a suitable size.

Discussion of Net Drag Formulae Developed So Far

Much research has been done into the problem of net drag prediction. Formulae developed, however, all require some knowledge of the net's full-scale performance before they may be evaluated.

Experiments have been conducted on panels and simple shapes of netting (Crewe and Arlotte, 1964; Fridman and Dvernik, 1973; Kowalski and Giannotti, 1974). A net may be expressed as a combination of netting panels or as a combination of simple sections of netting. If the assumption is made that the drag of the whole net is equal to the sum of the drags of the individual components, then, to calculate the total net drag, it is sufficient to know the drag of each section of the net.

The drag of a panel of netting is found to be dependent on the angle of incidence between the panel and the direction of fluid flow. Thus, if net drag is to be calculated by expressing the net as a collection of netting panels, detailed knowledge of the net shape as it is being towed through the water is required in order that the angle of incidence of each panel may be estimated. However, without full-scale trials of the net such information is not available. Similarly, if a net is to be expressed as a combination of standard shapes (such as conical sections) then again detailed knowledge of the total net shape is required.

To overcome this difficulty, attempts have been made to approximate the overall shape of the netting to one that can be conveniently handled mathematically. If this is done a more readily evaluated expression for net drag can be obtained than is produced by the method described above. Kowalski and Giannotti (1974) make the assumption that the net (excluding the wings) is conical in shape with eliptical cross section, the base of the cone having as major and minor axes the net spread and vertical net mouth opening respectively. Then, using results from wind tunnel tests on netting panels, they derive a net drag formula of the form

$$D = CV^2 \frac{R}{S} A_M \qquad (1)$$

where D = net drag, C is a constant, V = net speed through the water, R = total area of twine in the net (see Appendix), S = total surface area of netting (ie including the holes) and A_M = mouth area of net, defined as Π x net spread x vertical net mouth opening.

Crewe and Foster (1961), on the basis of experimental results from a Granton trawl, also made the assumption that net drag is linearly proportional to mouth area. Using theory combined with full-scale experimental results they derived a simple formula for a Granton trawl, taking the form

$$D = C_1 VR\ (1 + C_2 A_M) \qquad (2)$$

where C_1 and C_2 are constants and A_M = mouth area, defined as net spread x vertical net mouth opening.

To use either of these formulae it is necessary to have values of net spread and net mouth opening over the relevant range of towing speeds. These two parameters are, however, themselves dependent on net drag and otterboard spreading force and consequently are not available at the net-designing stage. Some full-scale trials of the net would therefore be necessary before these formulae could be evaluated.

It is interesting to note that both formulae (1) and (2) define a linear relationship between net drag and net mouth area, whereas experimental results collected by the Marine Laboratory have not shown the presence of such a linear relationship for pelagic trawls.

Another attempt to approximate the netting shape was made by Fridman and Dvernik (1973). They generalised the relationship between the drag of a panel of netting and its angle of incidence to the flow to one between the total net drag and the mean angle of incidence of the netting. To evaluate the formula they derive, it is necessary to be able to calculate $\bar{\alpha}$, the mean angle of incidence. To evaluate $\bar{\alpha}$, however, some quantitative knowledge (in terms of spreads and vertical heights) of the overall shape of the net as it is being towed is required. Again, this formula cannot be used until some full-scale trials of the net have been carried out.

Aim of Research

Since considerable data relating to the engineering performance of pelagic nets were available in the Marine Laboratory data bank, it was decided to make use of these data to determine whether an empirical net drag formula could be derived which would not require operational trials of the net for an evaluation of the validity of the formula to be made. That is, a formula which would model the relationship between net drag, net towing speed and net design and which could be evaluated using only information available from a net drawing.

Basic Hypothesis

The basic formula for the drag of a body in water takes the form

$$D = \tfrac{1}{2} \rho\ V^2 A\ C_D \qquad (3)$$

where D = drag, ρ = density of water, V = velocity of water flow past the body, A = projected area of the body perpendicular to the direction of flow and C_D is the coefficient of drag (see Richardson, 1950). This last parameter is an empirical constant depending on the shape of the body and on Reynolds number, $Re = VL/\upsilon$, where L = body length and υ = kinematic viscosity of water. The extent to which C_D varies with varying Reynolds number depends on the shape of the body and the nature of its surface (Hoerner, 1965).

A fishing net, however, is not a rigid body. Its shape and surface area vary with the speed of water flow through the net. Thus the parameter A varies with speed and the relationship between C_D and Re varies from net to net.

The net drag formula of Fridman and Dvernik (1973) takes the form

$$D = \tfrac{1}{2}\rho V^2 R\, C_D\, (\bar{\alpha}) \qquad (4)$$

where R = total twine area in the net (see Appendix) and the coefficient of drag C_D ($\bar{\alpha}$) is a function of $\bar{\alpha}$, the mean angle of incidence of all the netting panels which together make up the net. As mentioned, $\bar{\alpha}$ cannot be evaluated without first conducting some full scale trials of the net. To avoid the problem of the estimation of $\bar{\alpha}$ a further assumption concerning net performance would have to be made.

Many pelagic nets are similar in shape, and it was suggested that at the same speed these similarly shaped nets would be inclined at approximately the same mean angle to the flow. Thus the hypothesis was made that: for a range of nets of similar design the relationship between towing speed, V, and mean angle of incidence $\bar{\alpha}$, would be constant. If this hypothesis holds then, for such a range of nets, the coefficient of drag, C_D ($\bar{\alpha}$), will be a function solely of the towing speed, V.

Choice of Nets

To test the hypothesis outlined above, six pelagic nets of similar shape were chosen. Each of the nets was a four panel pelagic trawl, the dimensions of its four panels being roughly equal, and each was constructed of nylon twine. A generalised net drawing and rig diagram is shown in Figure 1 to illustrate the basic shape of these nets while a list of the basic dimensions of the nets is given in Table I.

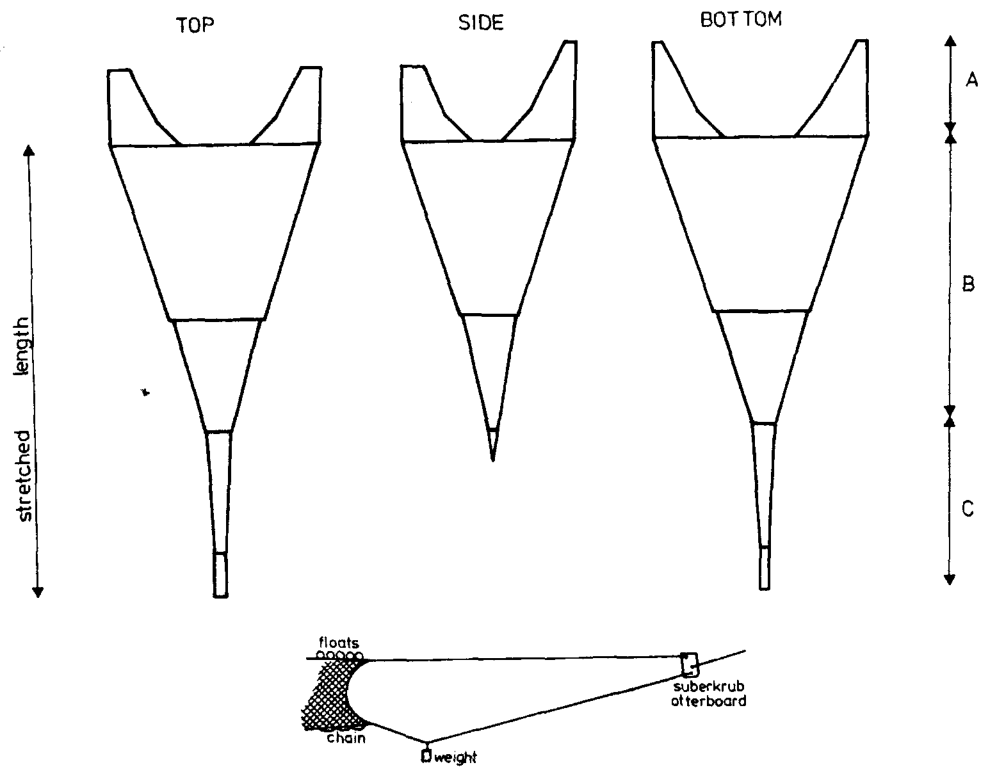

Figure 1 Definition of net sections as in Table I.

Table I

Basic dimensions of nets used in the derivation of the net drag formula

Net	Ship hp Range	Headline Length m	Footrope Length m	Side Panel Lines m	Stretched Length m	A Mesh Size mm	A Tex	B Mesh Size mm	B Tex	C Mesh Size mm	C Tex	Comments
Mk1M	100– 200	25	29	23	46.7	1000	2800	1000– 80	2800– 840	36	840–1260	Designed at the Marine Laboratory for use on FRV 'Mara'
Mk2C	400– 700	44	48	41	66.2	1000	2800	1000– 80	2800– 840	36	700–1120	Designed at the Marine Laboratory for use on FRV 'Clupea'
C600	600– 800	42.4	42.4	38.4	73.8	400	2240	400– 75	2240– 840	36	840–1260	Early Marine Laboratory design - designed along commercial lines of that time with smaller mesh sizes than Mk series.
Mk1E	700–1000	46	52	45	81.8	1000	2800	1000– 80	2800– 840	36	840–1260	Designed at the Marine Laboratory for use on FRV 'Explorer'
1000E (Cosalt 1424)	1000–1200	38.8	46.8	38.9	73.7	400	1960	400–100	1960–1050	36	1680–2240	Commercial net. Trials carried out on FRV 'Explorer'
Mk2S	1200–2000	68	72	68	86.8	1000	7000	1000– 80	7000–1400	36	2483	Designed at the Marine Laboratory for use on FRV 'Scotia'

Note Exact specifications of all six nets are contained in de Silva (1974)

A copy of this pamphlet may be obtained by writing to the author at the Marine Laboratory, P.O. Box 101, Aberdeen, AB9 8DB

Experimental data relating to the engineering performance of each of these six nets were available, these data having been collected over a period of three or four years on cruises of the Fishery Research Vessels 'Mara', 'Clupea', 'Explorer' and 'Scotia'. On such cruises the net being studied was fished with instruments attached to various parts of the gear. These instruments measure parameters necessary to quantify the engineering performance of the gear (Fig. 2).

Collection of Experimental Results

To calculate the net drag of a pelagic net the following parameters are measured:

1. Otterboard spread
2. Net spread
3. Otterboard depth
4. Net depth
5. Net mouth opening
6. Upper sweep tensions
7. Lower sweep tensions

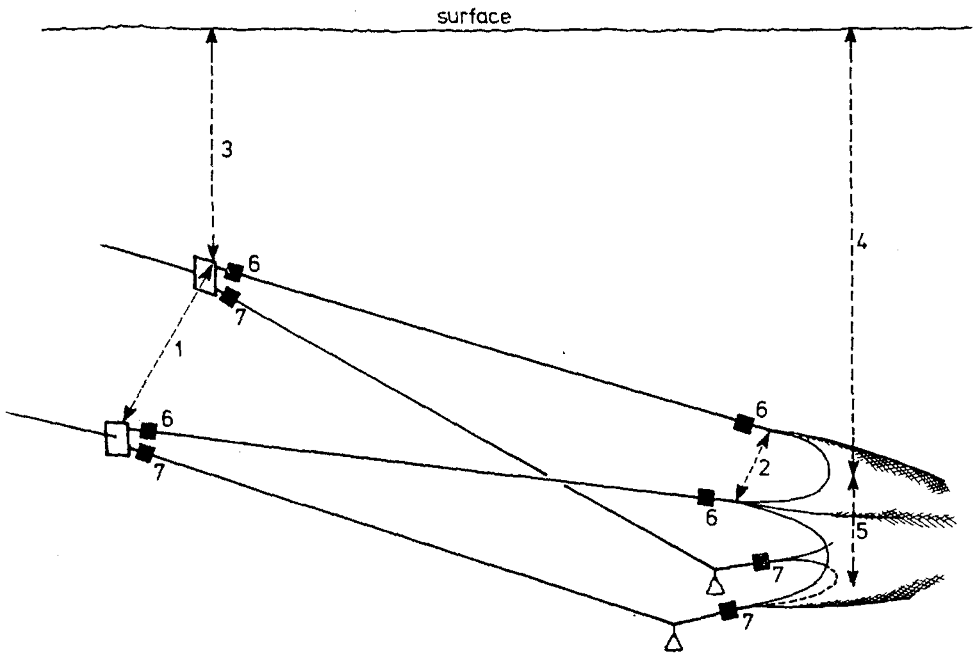

Figure 2 Parameters which are measured for the calculation of the net drag of a pelagic net. For key see text.

These measurements must be made when the net is being towed at constant speed through the water so that the system as a whole is in equilibrium and is not experiencing additional forces due to velocity changes. Given such a set of measurements, it is possible to calculate the geometry of the sweep system. The forces acting at the wing-ends can then be resolved in the direction of motion and the sum of these resolved forces should equal the net drag at that instant.

Figure 3 gives a fairly typical plot of experimental measurements, the net drag values having been calculated as indicated above. A large amount of scatter is immediately noticeable and this is due to various factors, as follows:—

(i) Inaccuracies in the measurements listed above will give rise to inaccuracies in net drag. Net drag is most sensitive to errors in the tension measurements and it is known that the load cells used for these measurements can be a significant source of error, especially when they are used to measure loads of less than one tonne.

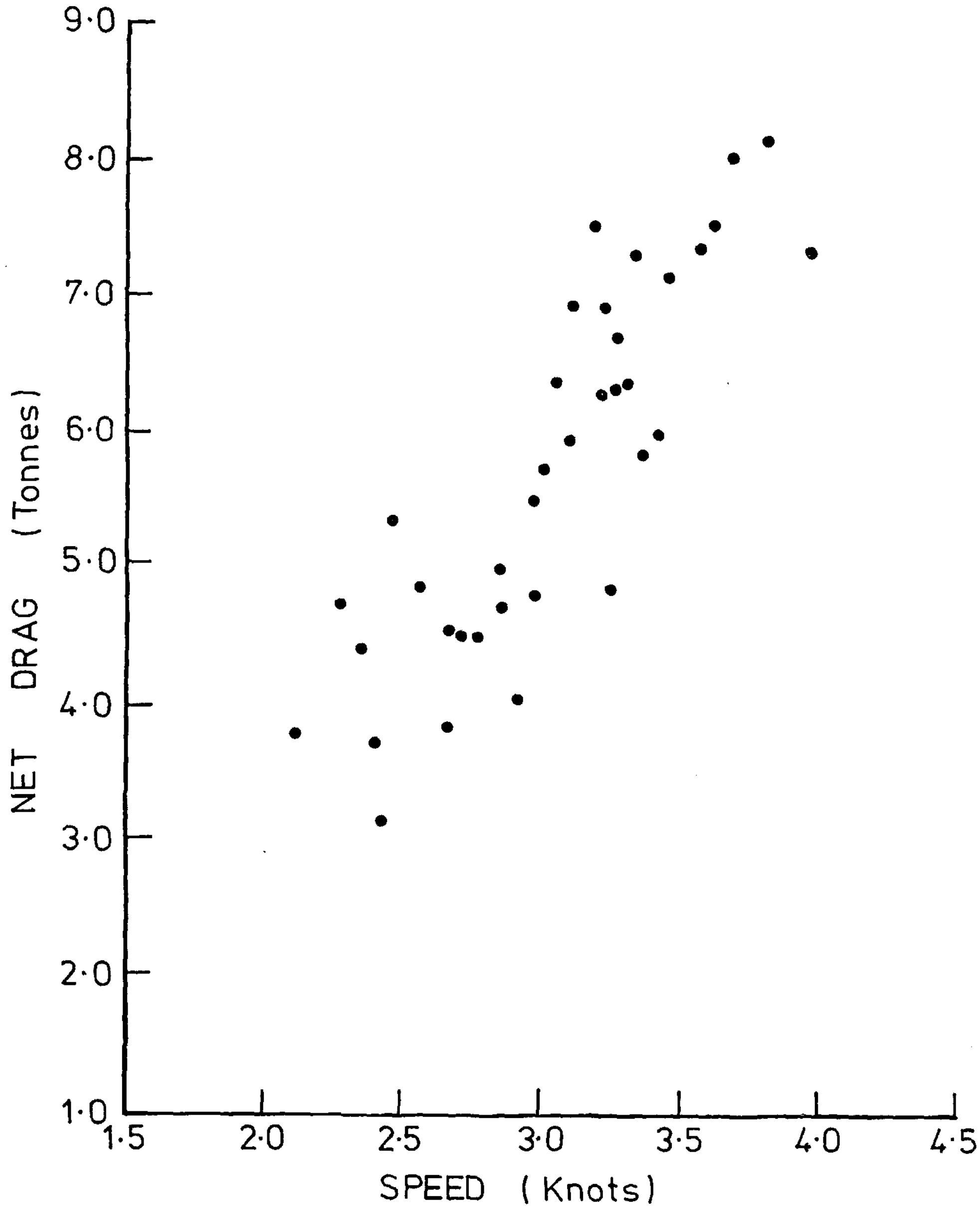

Figure 3 A typical experimental graph of net drag against speed for a 1000 hp net.

(ii) Inaccuracies in the net speed values also contribute to the scatter. As the net is being towed some depth below the surface it does not experience the same external forces of tide and wind as the vessel steaming along the surface. Wherever possible speed measurements are corrected for the effects of tide but, since no measurement of speed is made at the depth of the net, it is not always possible to perform such corrections exactly.

(iii) Sometimes load measurements are available for only one side of the gear. To ease handling problems instruments may have been put only on one side or, occasionally, one of the load cells may have failed to work properly. In either case, the assumption has to be made that the gear is symmetrical, but since, in practice, the gear is seldom exactly symmetrical, major errors might be introduced into the calculations.

(iv) The environment in which fishing gear trials are carried out is constantly changing and it is difficult to monitor fully the effect of such changes on net performance. Fluctuations in currents, tide flow, wind and wave conditions may cause asymmetries and imbalance which cannot be measured and consequently are not taken into account in the net drag calculations.

For each of the six nets under consideration suitable data had been collected. These were processed to obtain values of net drag and tide-corrected net speed, and for each net a graph of net drag against net speed was plotted (Fig. 5a - f). Also, from the net drawings, the total area R of each net was calculated using the method outlined in the Appendix.

Testing of Hypothesis

The hypothesis stated above requires that the relationship between the coefficient of drag, C_D, and net speed, V, should remain constant over the range of six similar nets chosen. It follows from equation (4) that

$$(\tfrac{1}{2}\rho)\ C_D = D/(V^2 R) \qquad (5)$$

Thus, to examine the relationship between C_D and V it is sufficient to consider the relationship between $D/(V^2 R)$ and V. For an individual net the value of R is constant and it is the variation of D/V^2 with V that is relevant.

From the experimental data an inverse relationship between D/V^2 and V was indicated, and so for each net a plot was made of $V^2 R/D$ against V. The resulting graphs suggested a linear correlation between these two parameters. The lines obtained by regressing $V^2 R/D$ against V for each of the six nets were sufficiently close to justify proceeding with the derivation of a mean linear relationship between $V^2 R/D$ and V for all six nets.

Derivation of Formula

Since the number of data points varied considerably from net to net, some kind of weighting of the points was necessary to ensure that each net contributed equally to the derivation of a mean linear relationship between $V^2 R/D$ and V. This was achieved by calculating a set of mean points $(V^2 R/D, V)$ for each net. These mean points were then used to calculate a mean relationship between $V^2 R/D$ and V; the relationship so obtained was

$$V^2 R/D = 54.72V + 115.2 \qquad (6)$$

where V is measured in knots, R in m^2 and D in tonnes.

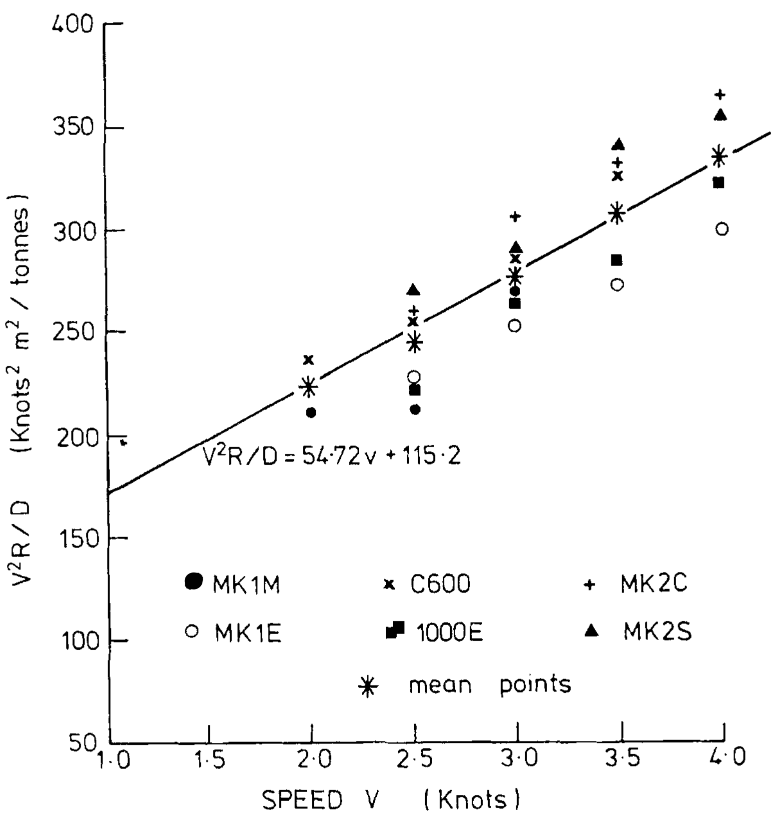

Figure 4 Relationship between V^2R/D and V.

Equation (7) expresses the equivalent relationship between C_D and V.

$$\tfrac{1}{2}\rho C_D = 1/(54.72V + 115.2) \qquad (7)$$

Substitution into equation (4) gives

$$D = V^2 R/(54.72V + 115.2) \qquad (8)$$

Equation (8) defines a relationship between net drag, net speed and net twine area which is independent of parameters derived from the net geometry. This formula can be readily evaluated from net specifications or a net drawing. It remains to show that this formula will give values of D close to drag values calculated from experimental results.

Checking of Formula against Experimental Results used in its Derivation

In Figure 5a - f comparisons are made between net drag as predicted by equation (8) and experimental net drag values for each of the six nets used in the derivation of the formula. The overall agreement obtained is within 10% of the average experimental drag values - that is, at a given speed V_O, the value of D calculated from equation (8) is within 10% of the mean net drag value at speed V_O, as estimated from the experimental results. Since this figure is within the order of accuracy of the experimental results, the level of agreement is felt to be acceptable.

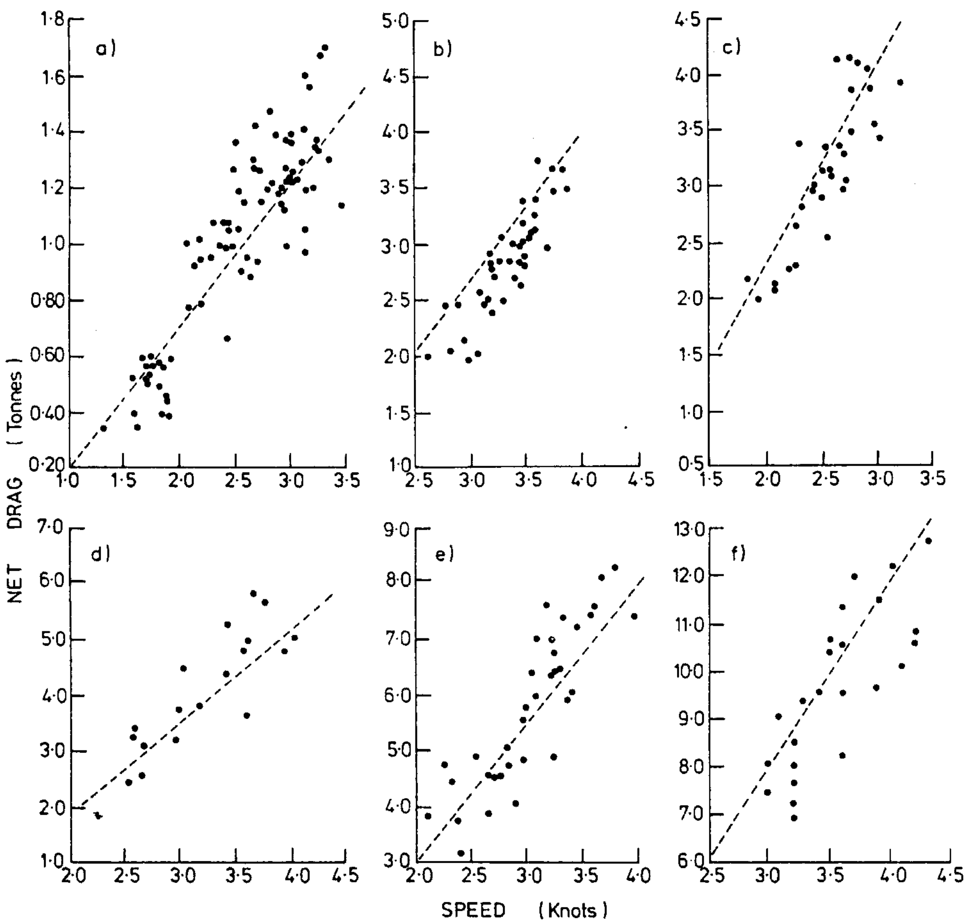

Figure 5 Comparison of formula predictions with experimental results. Individual points denote the experimental points whilst the dashed curves denote net drag as predicted by equation (8).

(a) Mk1M
(b) Mk2C
(c) C600
(d) Mk1E
(e) 1000E
(f) Mk2S

Comparison of Formula with Independent Experimental Results

To test the ability of the formula to predict net drag, further experimental results were collected and compared with the formula's predictions (Fig 6a, b, c).

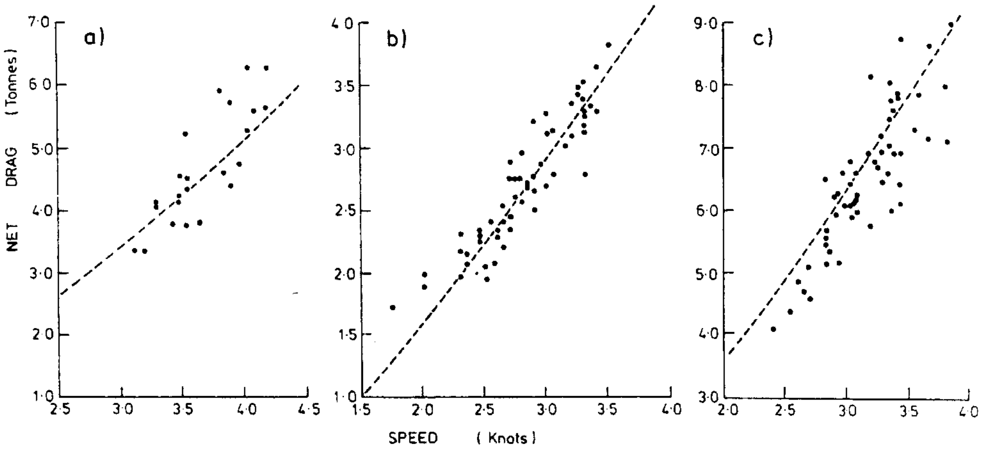

Figure 6 Comparison of formula with experimental results not used in the derivation of the formula.

(a) Mk1E (b) Mk1C (c) Delagic 1000 hp

The results plotted in Figure 6a are from the Mk1E, a trawl net already used in the formula's derivation. The points in this figure, however, represent data collected since the formula was derived and they extend the speed range of experimental results for this net (see Fig. 5d). The results shown in Figures 6b and 6c are from two nets, the Mk1C and the 1,000 hp Delagic, neither of which was used in the development of the net drag formula. The Delagic net is a new design, developed to fish just off the sea bed as well as in mid-water and a description and discussion of this net appears in de Silva (1975). The Mk1C is an older net, designed for use on a 600 hp vessel, which has since been superseded by the Mk2C. Specifications of the Mk1C may be found in MacLennan (1973).

The agreement between theoretical and experimental net drag values shown in Figure 6a, b and c is encouraging. From the experimental results plotted in these three figures average experimental drag values were estimated for a series of speed values, and in Table II these average drag values are compared with the formula's drag predictions. In the case of the Mk1E agreement is seen to be within 7% while in the case of the Mk1C and Delagic nets agreement with the mean points is within 2%.

TABLE II

Comparison of formulae drag with mean experimental drag taken from experimental data not used in the derivation of the formula

	Speed (Knots)	Average Experimental Drag (Tonnes)	Formula Drag (Tonnes)	Relative Error
Mk1E	3.1	3.36	3.59	0.07
	3.3	3.66	3.92	0.07
	3.5	4.29	4.25	0.01
	3.8	4.94	4.75	0.04
	4.0	5.33	5.10	0.05
	4.2	5.72	5.44	0.05
Mk1C	2.5	2.23	2.22	0.004
	2.7	2.44	2.49	0.02
	3.0	2.86	2.89	0.01
	3.3	3.27	3.30	0.01
Delagic	2.7	5.46	5.35	0.02
	3.0	6.15	6.22	0.01
	3.3	7.17	7.11	0.01
	3.5	7.65	7.71	0.01
	3.7	8.23	8.32	0.01

Sphere of Application

The net drag formula, equation (8), will be of use only for predicting the net drag of nets for which the relationship between C_D and V given in equation (7) is valid. This should apply to a net of design similar to the six nets used in the derivation of the formula - that is, a four panel pelagic trawl, made out of nylon twine, with the dimensions of its four panels roughly equal. The six nets used differ considerably in overall size, mesh sizes, and twine diameter (see Table I). All, however, are made from nylon twine. A net made of another material would be unlikely to exhibit exactly the same relationship between C_D and V as that derived for nylon nets. This relationship was an approximation of the variation of the coefficient of drag with the mean angle of attack of the netting and, consequently, will be highly dependent on the material from which the netting is made. It would, nevertheless, seem reasonable to expect an inverse linear relationship between C_D and V (as in equation (7)) to hold for a net of similar shape but made of a different material. Nevertheless, as pelagic trawls are almost always made of nylon, the confinement of the formula's use to those nets made of nylon should not be a significant restriction. More experimental data are required to test this formula further and do adapt it to cope with nets made of materials other than nylon. Also, if data were available on different shapes of pelagic nets, perhaps the relationship between drag coefficient and speed could be better understood.

Summary

Based on the assumption that a constant relationship between the net drag coefficient and net towing speed would exist for a set of nylon pelagic nets of similar design, a net drag formula has been derived:—

$$\text{DRAG} = \frac{(\text{SPEED})^2 \times \text{TWINE AREA}}{(54.72 \times \text{SPEED} + 115.2)}$$

(Drag in tonnes, speed in knots and twine area in m^2)

This formula has been found to agree with experimental values of net drag to within the level of accuracy of the experimental results. The advantage of this formula over previous net drag formulae is that it may be evaluated using only information available from a net drawing, so that the net drag of nylon pelagic nets of a fairly standard shape may be estimated at the design stage.

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Notation

A	surface area, projected into a plane perpendicular to the direction of flow.
A_M	net mouth area
C_D	coefficient of drag
D	drag
L	length of a body
R	twine area (see Appendix)
Re	Reynold's number = VL/υ
S	surface area of netting
V	velocity of water flow or towing speed of net
α	angle of incidence
$\bar{\alpha}$	mean angle of incidence
υ	kinematic viscosity of (sea) water
ρ	density of (sea) water

Appendix

The twine area of a net is calculated in the following manner:—

Partition the net into trapezium shaped panels, P_1, P_2, ...,P_n, each panel having constant mesh size and twine size.

Let

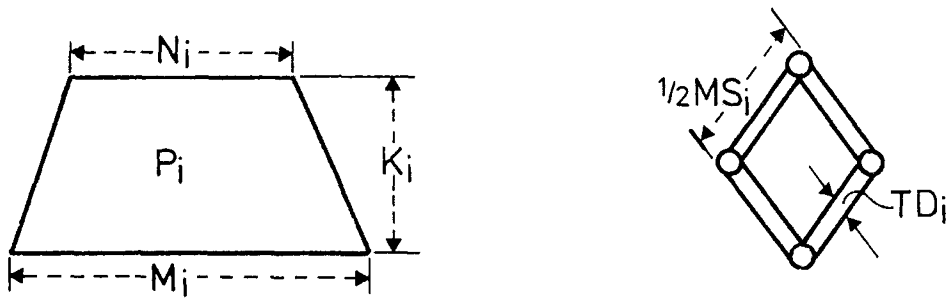
N_i = no of meshes along the top of panel P_i

M_i = no of meshes along the foot of panel P_i

K_i = no of rows (of knots) in the panel P_i

MS_i = mesh size in panel P_i

TD_i = twine diameter in panel P_i



Appendix Figure 1. Notation for the determination of net twine area.

Then

$$R_i = \text{twine area in panel } P_i = \frac{(N_i + M_i)}{2} \times \frac{K_i}{2} \times 2 \times MS_i \times TD_i$$

in units of mesh size x twine diameter. This must be converted into square metres before using the drag formula. Let C be the appropriate conversion factor*. Then the total twine area, R, is given by

$$R = C \times \sum_{i=1}^{n} (N_i + M_i) \times K_i \times MS_i \times TD_i/2 \;\; m^2$$

* If MS_i and TD_i are in inches then $C = 6.452 \times 10^{-4}$; if they are in mm then $C = 10^{-6}$.

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