The Drag Force of a Trawl Net Against a Stream

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Abstract

A general analytical method for the calculation of the drag force of a net which may form any shape was studied and some model experiments were carried out to verify the efficiency of the method. It was found that the method is efficient where the drag force formula of the plane net used is reliable.

Introduction

Various trawl nets are used in fishing. These nets are generally different not only in size but also in shape. In many cases, it becomes necessary to know the drag force of the net to be used or designed for maximum efficiency. For example, in designing a trawl net, fishing gear researchers often need to know the total drag force of the net to see if it fits the dynamic characteristics of the fishing vessel. This can be done generally in two ways: model experiments and theoretical analysis. There are often many problems with the first method, technical or financial. Some of the well known works are those of Tauti (1949, 1963). After a series of elaborated model experiments, Miyazaki (1964) and Miyazaki and Takahashi (1964) published

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several sound results. In this paper, we give a general method for calculating the drag force of a net moving in water which may form any shape but can be represented in an equation. We also did some model experiments and the results are discussed.

Methods

Tauti and Miyazaki's hydraulic resistance formulae are presented here as (T) and (M)

$$Rs\,(\theta) = A\,(D/L)\,\frac{(1-\cos^2 \phi \cos^2 \theta)}{(\sin \phi \cos \phi)} \qquad \dots T)$$

$$(A = 1/2 C_d \rho\, V^2\, (C_d = 2.0))$$

$$Rs\,(\theta) = 1/2\, \rho\, \lambda\, V^2\, (C_{d0} \sin^2 \theta + \qquad \dots M)$$

$$(1 - \lambda)^2 \sin \phi \cos^2 \theta / \sin \,(\pi/4))$$

$$(C_{d0} = 16\, (V^* h_d/\upsilon)^{-0.28})$$

Symbols (and their definitions) used in this paper are listed in Table 1.

Table 1. Symbols and their definitions.

Symbol	Definition
D	diameter of twine woven into net
L	length of mesh legs
θ	inclined angle of current to net plane
ϕ	half of angle between two mesh legs
λ	solidity of plane net
	$\lambda = \dfrac{D/L}{\sin \phi \cos \phi}$
V	flow speed
ρ	fluid density
ν	kinematic viscosity
h_d	hydraulic mean depth of plane net $h_d = 0.5L \cdot \sin \phi \cos \phi$

A net is considered to move through a uniform current and its surface is represented by the equation F (x, y, z) = 0 (Fig. 1). Take an arbitrary point S on the surface and suppose the tangent plane at S to be AX + BY + CZ + D = 0, a small part of the surface around S to be dS. Then we have

$$A = \frac{\partial F}{\partial x} (x, y, z)$$

$$B = \frac{\partial F}{\partial y} (x, y, z)$$

$$C = \frac{\partial F}{\partial z} (x, y, z) \qquad \qquad ... 1)$$

$$\sin \theta = \frac{|C|}{\sqrt{A^2 + B^2 + C^2}} \qquad \qquad ... 2)$$

where θ is the angle between z-axis and the tangent plane. dS is so small that it can be approximately regarded as plane and the drag force acted on dS, dR is thus given as

$$dR = Rs (\theta) dS$$

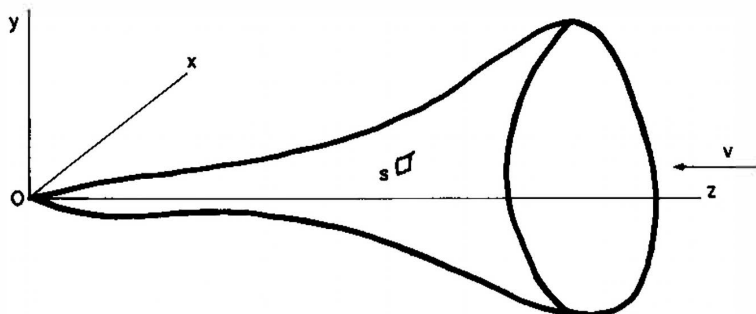where Rs (θ) is the drag force acting on a unit area of a plane net inclined to the current θ.

Fig. 1. Orthogonal coordinate system of a trawl moving in water.

If the whole net surface is represented as Σ, then the total drag force of the net, R, is calculated as follows:

$$R = \int_{\Sigma}\!\!\int d\,R = \int_{\Sigma}\!\!\int R\,s\,(\theta)\,d\,s$$

It is known that

$$dS = \frac{\sqrt{Fx^2 + Fy^2 + Fz^2}}{|F_z|}\,dxdy$$

then

$$R = \int_{Dxy}\!\!\int Rs\,(\theta)\,\frac{\sqrt{Fx^2 + Fy^2 + Fz^2}}{|F_z|}\,dxdy \qquad ...\,3)$$

where Dxy is the projected area (to xy-plane) of Σ. Fx is $\partial F/\partial x$, etc. and θ is determined from (1) and (2). Equation (3) may not be easily solved analytically, but some numerical methods are available in those cases.

It is considered that a trawl net is more like an elliptic cone than a simple cone when dragged through water. Therefore, an elliptic cone-shaped net is discussed here with its surface represented as:

$$(x/a)^2 + (y/b)^2 - (z/h)^2 = 0$$

By variable transformations with

$$x = arcos\,\Phi \qquad\qquad y = brsin\,\Phi$$

where r and Φ are new integral variables. Then:

$$R = \int_{0}^{1} rdr \int_{0}^{2\pi} Rs\,(\theta)\,\frac{\sqrt{Fx^2 + Fy^2 + Fz^2}}{|Fz|}\,|J|\,d\Phi$$

or

$$R = ab/3 \int_{0}^{2\pi} Rs\,(\theta)\cdot\sqrt{(h/a)^2\cos^2\Phi + (h/b)^2\sin^2\Phi + 1}\ \ d\Phi \quad ...\,4)$$

where

$$F_x = 2x/a^2 = 2r \cos \Phi/a,$$
$$F_y = 2y/b^2 = 2r \sin \Phi/b,$$
$$F_z = -2z/h^2 = -2r/h, \text{ and}$$

$$J = \left| \begin{array}{cc} \partial x/\partial r & \partial x/\partial \Phi \\ \\ \partial y/\partial r & \partial y/\partial \Phi \end{array} \right| = abr$$

are used and θ is obtained from formulae (1) and (2):

$$\theta = \sin^{-1} (1/ \sqrt{(h/a)^2 \cos^2 \Phi + (h/b)^2 \sin^2 \Phi + 1})$$

Substituting (T) and (M) for Rs (θ) in (4), we get two formulae (denoted as Rt and Rm):

$$Rt = Cv \cdot \int_0^{\pi/2} \frac{a^2b^2 + h^2 \sin^2 \phi (b^2 \cos^2 \Phi + a^2 \sin^2 \Phi)}{\sqrt{a^2b^2 + h^2 (b^2 \cos^2 \Phi + a^2 \sin^2 \Phi)}} \, d\Phi \quad \ldots 5)$$

$$Rm = \rho \lambda v^2 \cdot \int_0^{\pi/2} \frac{C_{do}a^2b^2 + C_{d90}h^2 (b^2 \cos^2 \Phi + a^2 \sin^2 \Phi)}{\sqrt{a^2b^2 + h^2 (b^2 \cos^2 \Phi + a^2 \sin^2 \Phi)}} \, d\Phi \quad \ldots 6)$$

where

$$C_{d90} = (1 - \lambda)^2 \sin \phi/\sin (\pi/4)$$

$$Cv = \rho C_d (D/L) v^2/(\sin \phi \cos \phi)$$

Equating a and b in (5) and (6), we get the drag force formulae for cone nets Rct and Rcm, respectively:

$$Rct = \pi a \, Cv/2 \cdot \frac{a^2 + h^2 \sin^2 \phi}{\sqrt{a^2 + h^2}}$$

$$Rcm = \pi \rho \alpha \, av^2/2 \cdot \frac{C_{do} a^2 + C_{d90} h^2}{\sqrt{a^2 + h^2}}$$

To verify these theoretical drag force formulae, some model experiments were carried out. If the ratio of minor axis to major axis of the net mouth changes from 0.6 to 1.0 (by 0.1 steps) while keeping the perimeter of the net mouth equal to 2 π · 20 cm and net height 80 cm, five different net models are obtained. With each net model, the relationships between drag forces and current speeds were examined. The details of webbing used in tailoring the model nets are as follows:

material	:	nylon
knot	:	single sheet bend
leg length	:	7.5 mm
twine diameter	:	0.394 mm
specifications	:	210 D/4 strands, 200 G/350 meshes

The model experiments were carried out in the Faculty of Fisheries, Nagasaki University. The water tank used was a circulating one with both width and depth of the channel at about 80 cm. The measuring device is as described by Nishinokubi et al. (1974).

It is difficult to tailor an elliptic cone net precisely, so we approximated it by sewing eight pieces of cut webbing (Figs. 2 and 3). The experimental procedure was as follows:
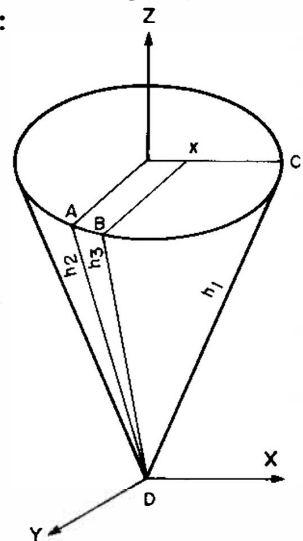
Fig. 2. Orthogonal coordinate system of an elliptic model net. (A, B, C, D are corresponding points in Fig. 3).
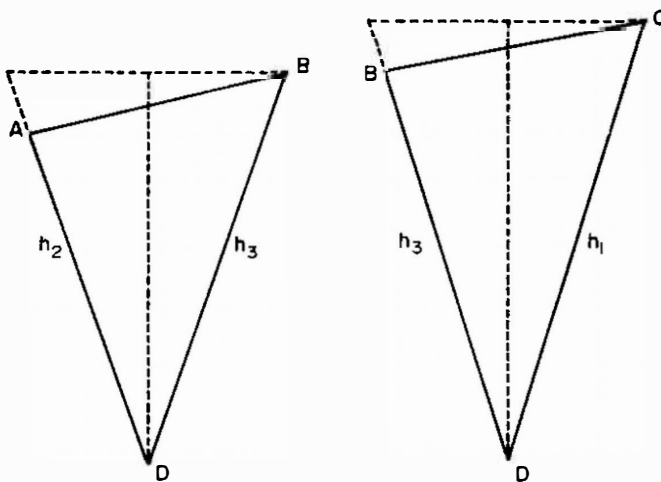
Fig. 3. Cutting pieces of the webbing to tailor an elliptic model net. (A, B, C, D are points corresponding to those in Fig. 2).

- pre-determining the relationship between the strains and loadings by the least-square method;
- covering the model net to an elliptic cone-shaped metal frame and fixing the frame to the experimental apparatus; changing current speed step by step, recording speeds and corresponding strains (Fig. 4);
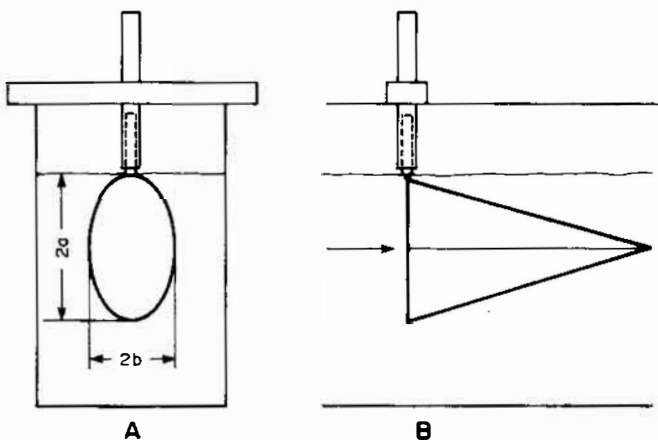- taking the model net off the frame and doing the same procedures to the frame alone.

Fig. 4. Schematic view of an experimental model net in a water tank. (A) front view, (B) side view.

By transferring strains into loadings using the least-square relationship, drag forces of the model net were obtained easily from the differences of drag forces of frame-net combination and that of the frame only.

Results and Discussions

Experimental results are plotted in Figs. 5-9. Two curves are also drawn in each of these figures according to the theoretical results calculated from equations (5) and (6). From these figures, it can be seen that the Rm theoretical values agree with the experimental ones very well while the Rt values become larger than the experimental ones with larger current speeds.
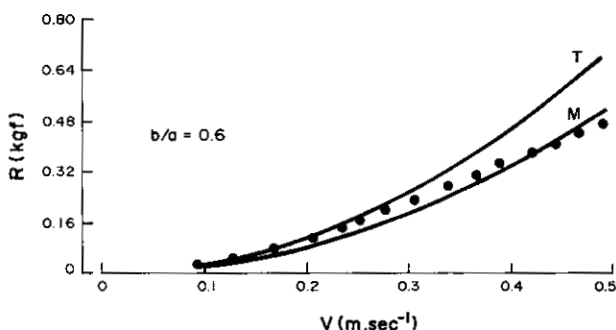

Fig. 5. Comparison between experimental and theoretical values (•) of water resistance when b/a = 0.6. (A and B are the major and minor axes of the model net mouth). T and M are the curves based on the values calculated from formulae (5) and (6).
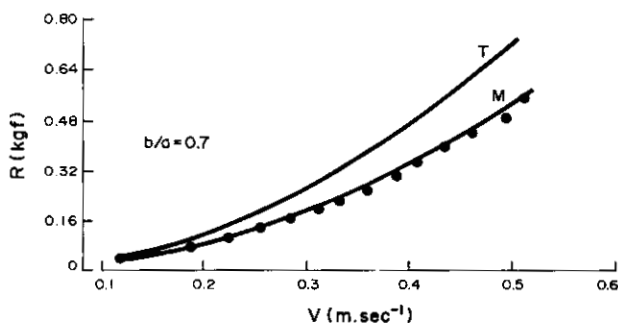

Fig. 6. Comparison between experimental and theoretical values (•) of water resistance when b/a = 0.7. (A and B are the major and minor axes of the model net mouth). T and M are the curves based on the values calculated from formulae (5) and (6).

Fig. 7. Comparison between experimental and theoretical values (•) of water resistance when b/a = 0.8. (A and B are the major and minor axes of the model net mouth). T and M are the curves based on the values calculated from formulae (5) and (6).
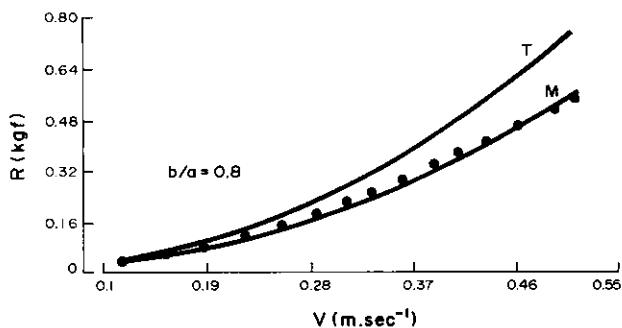

Fig. 8. Comparison between experimental and theoretical values (•) of water resistance when b/a = 0.9. (A and B are the major and minor axes of the model net mouth). T and M are the curves based on the values calculated from formulae (5) and (6).
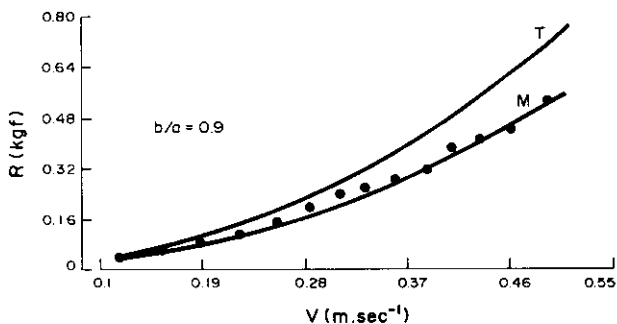

Fig. 9. Comparison between experimental and theoretical values (•) of water resistance when b/a = 1.0. (A and B are the major and minor axes of the model net mouth). T and M are the curves based on the values calculated from formulae (5) and (6).
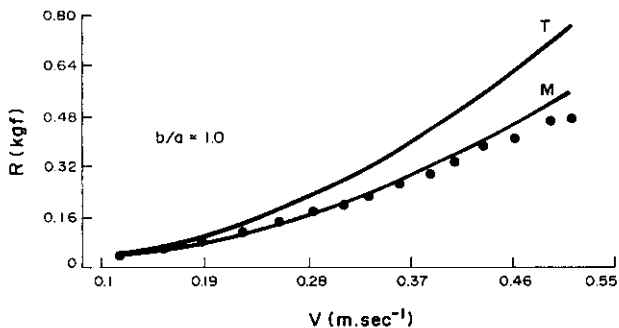
Formula (T) assumes that the hydraulic drag force acting on the mesh legs is proportional to the square of current speed (Tauti 1934). However, generally speaking, for cylinders, this assumption holds only when the Reynolds Number is in the range of 500-10^5, according to Newton's law, but when the Reynolds Number is very small, the hydraulic resistance becomes approximately proportional to current speed (Stoke's law), and the Reynolds Number range of 1-500 is said to be a region moving from Newton's law to Stokes' law (Kawakami 1981). In these model experiments, the maximal Reynolds Number is about 173 (max current speed: 0.5 m. sec^{-1}; $\nu = 1.19 \cdot 10^{-6}$ m^2 sec^{-1}), so the assumption of (T) may be violated and the observed discrepancy occurs.

From our theoretical analysis and model experiments, it appears that formula (3) is efficient in calculating the drag force when Rs (θ) for the plane net is reliable. Formula (T) seems to give a larger hydraulic resistance than the real one when the Reynolds Number is less than 500, and formula (M) should be used in these cases.

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