# Hydrodynamic Modeling of Nets and Trawls

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## ABSTRACT

Manufacture of nets and trawls has since early times been a highly sophisticated art. Today this art is being mated with modern technology in the form of laboratory net testing in model tanks in many of the world's fishing nations. Being able to test new design ideas relating to net construction on a small scale is of course advantageous when the cost of field testing of prototype nets and the high risk of losing or severely damaging such nets are considered. The benefits of actually seeing model trawls perform in the clear water of a model tank seem to be obvious to most skippers.

A very successful model tank is operated by the Chamber of Commerce of the city of Boulogne-Sur-Mer in France. This facility may be rented by the fishing industry for observation of model net behaviour. However, the observations made there and in similar tanks using models rather than prototype nets are mostly qualitative, i.e., forces and deformations cannot be transferred to the full scale net or trawl.

The present paper describes the development and verification of model laws which will allow a quantitative evaluation of models tested in hydraulic flumes and towing tanks. The influence of the properties of the twine made of polyamide or other natural or man-made fibers is taken into consideration. The model laws are verified by testing net models of different length scale in University of Florida's model tank and the corresponding prototypes in the ocean. It is expected that this model tank will be made available to test net designs for the fishing industry on a rental basis.

## INTRODUCTION

Production of nets and trawls in the USA is a highly sophisticated art which has been handed down from father to son through generations. While some successful laboratory model research and field research has been performed outside this country, mainly in the USSR (1), Europe (2,3,4), and Japan (5,6) and applied to the specific problems prevailing in these countries, relatively little has been done in this country to mate this art with the tools of modern analytical and experimental hydraulics.

Hydraulic models and the laws governing their use have been applied successfully in the solution of engineering problems related to the interaction between flowing water and rigid structures such as dams, spillways, energy dissipators and ships. Even in the study of fluvial phenomena, where the interaction between water and sediment is of a considerably more complex nature than in the case of nets and trawls, the hydraulic model has proved to be a powerful research tool (7). Therefore the fishing industry may expect to reap substantial benefits through improved net structure and performance by use of the hydraulic model concept in future net and trawl research. Future use of the model approach will also greatly reduce the loss of expensive full scale trawls often encountered in research today.

Field data accumulated in the Gulf of Mexico by the NMFS Exploratory Fishing and Gear Research Base at Pascagoula, Mississippi (8) indicate strongly that radical design changes are required to improve the performance of shrimp-separator trawls. Dutch investigators (9) show that the catch may be increased several times by use of gear which is rationally engineered for the specific problems of the North Sea. Such design changes and development of new gear may easily be accomplished in the clear waters of a laboratory towing tank or hydraulic flume using hydraulic model laws developed for the flexible trawl structures in flowing water. New gear resulting from the rational application of models may also result in increased harvests of currently unutilized stocks by allowing existing vessels to fish several times deeper than presently.

In the following, existing hydraulic model laws which may be applied to net and trawl models and new laws specifically needed for the proper modeling of the highly flexible structure of the mesh are presented. The assumptions made in the development of these laws require that the models must be at least one-tenth the size of corresponding prototype gear. This limits model net research to the relatively few large hydraulic laboratory facilities in the country. One such facility is the hydraulic flume at the University of Florida in which the research reported in this paper is conducted.

## MODEL LAWS

The term model scale used in the following is defined as a quantity in the prototype divided by the corresponding quantity in the model. Greek letters are used for the model scales while the subscripts p and m refer to prototype and model, respectively.

The fundamental model scales are:

length scale: $\lambda = L_p/L_m$ . . . . . . . . . . . . . . . . . . . . . . . . (1)

time scale: $\tau = T_p/T_m$ . . . . . . . . . . . . . . . . . . . . . . . . (2)

and force scale: $\kappa = F_p/F_m$ . . . . . . . . . . . . . . . . . . . . . . . . (3)

in which L, T, and F stand for a characteristic length, time, and force. All other model scales may be derived from these. E.g., the velocity scale is

$$V_p/V_m = \frac{L_p/T_p}{L_m/T_m} = \lambda/\tau \qquad (4)$$

where V is a characteristic velocity. Furthermore, it is possible to express the time scale and the force scale and thereby all other model scales by the length scale alone by requiring dynamic similitude between model and prototype, i.e. that all forces must have the same model scale.

When the flow of water through and around a trawl and its model is considered, the predominant forces are due to gravity, inertia and the viscosity of the water. If the model is not too small it may be assumed that the viscous forces have the least influence. Therefore this type of force is neglected in the following.

The inertia force scale is

$$\kappa_{\text{inertia}} = \frac{\rho_p \cdot L_p^3 \cdot L_p/T_p^2}{\rho_m \cdot L_m^3 \cdot L_m/T_m^2} = \frac{\rho_p}{\rho_m} \cdot \lambda^4/\tau^2 \quad \ldots\ldots\ldots\ldots\ldots (5)$$

in which $\rho_p$ and $\rho_m$ are the densities of the prototype water (sea water) and the model water (fresh water), respectively.

Neglecting the small variation of the acceleration due to gravity from prototype site to model site, if any, the force scale for gravity forces may be written

$$\kappa_{\text{gravity}} = \frac{\rho_p \cdot L_p^3}{\rho_m \cdot L_m^3} = \frac{\rho_p}{\rho_m} \cdot \lambda^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Requiring that the two force scales given by (5) and (6) must be equal yields the time scale

$$\tau = \lambda^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

and the corresponding velocity scale

$$V_p/V_m = \lambda/\tau = \lambda^{1/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

Equations (7) and (8) represent Froude's model law which is well-known among hydraulic engineers.

When constructing the model trawl, it is in most cases impossible to reduce the mesh to the size required by the length scale. However, a larger mesh size may be used in the model if the influence of this mesh size is compensated by the use of another twine diameter so that the hydrodynamic drag forces acting on any section of the prototype trawl and the corresponding section of the model have the correct force scale.

Two such sections are shown in an idealized form in Figure 1 where L, M, and D represent side length of the chosen square section of the trawl, mesh size, and twine size. The velocity of the water relative to the trawl is V while the resulting drag force on the considered section is F. This drag force is composed of the

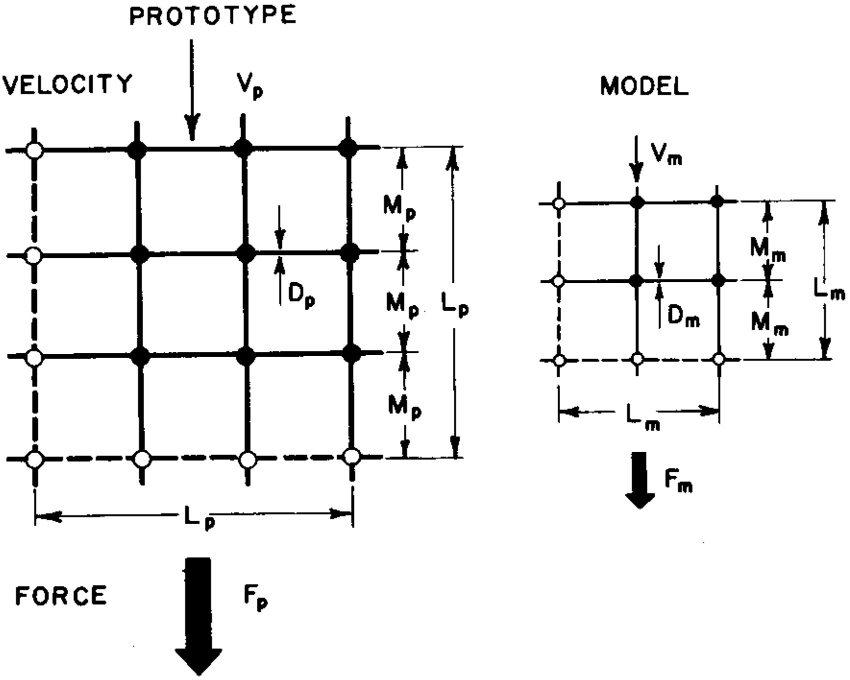

Fig. 1. Prototype and model mesh.

drag on the twine and the drag on the knots which may be considered to be fairly spherical.

The hydrodynamic drag force on the prototype section shown in Figure 1 may be written

$$F_p = C_1 \cdot \frac{L_p}{M_p} \cdot L_p \cdot D_p \cdot V_p^2 + C_2 \cdot \left(\frac{L_p}{M_p}\right)^2 \cdot D_p^2 \cdot V_p^2 \ldots\ldots \quad (9)$$

where the first term represents the drag on the twine and the second term stands for the drag on the knots. $C_1$ and $C_2$ are proportional to the drag coefficients of the twine, which may be represented by a long circular cylinder, and the more or less spherical knots, respectively.

The corresponding force in the model is

$$F_m = C_1 \cdot \frac{L_m}{M_m} \cdot L_m \cdot D_m \cdot V_m^2 + C_2 \cdot \left(\frac{L_m}{M_m}\right)^2 \cdot D_m^2 \cdot V_m^2 \ldots \quad (10)$$

where the values of $C_1$ and $C_2$ are assumed to be the same as in (9) provided that the model, and thereby the model Reynolds number, is not too small.

It may now be required that the force scale of the forces given by (9) and (10) must be equal to the force scale given by (6). Consequently

$$\frac{\rho_p}{\rho_m} \cdot \lambda^3 = \frac{C_1 \cdot \frac{D_p}{M_p} + C_2 \cdot \left(\frac{D_p}{M_p}\right)^2}{C_1 \cdot \frac{D_m}{M_m} + C_2 \cdot \left(\frac{D_m}{M_m}\right)^2} \cdot \left(\frac{L_p}{L_m}\right)^2 \cdot \left(\frac{V_p}{V_m}\right)^2 \quad \ldots\ldots\ldots\ldots \quad (11)$$

in which $L_p/L_m = \lambda$ and $V_p/V_m = \lambda^{1/2}$ according to (1) and (8). Introduction of these expressions and $C = C_1/C_2$ in (11) yields

$$\frac{\rho_p}{\rho_m} \cdot \frac{D_m}{M_m} \cdot \left[C + \frac{D_m}{M_m}\right] = \frac{D_p}{M_p} \left[C + \frac{D_p}{M_p}\right] \quad \ldots\ldots\ldots\ldots\ldots \quad (12)$$

A study of the curves giving the drag coefficients for long cylindrical bodies and spheres as a function of the Reynolds number based on diameter and towing velocity reveals that C maintains a fairly constant value for moderate to high Reynolds numbers. A realistic C-value may easily be found from Schlichting (10) or similar literature.

If the mesh size and the twine size of the prototype trawl are known and a model twine size is chosen the corresponding model mesh size may be found from (12). Neglecting the slight difference between the densities of seawater, $\rho_p$, and the fresh model water, $\rho_m$, it is seen that a solution to (12) is $D_p = D_m$ and $M_p = M_m$ showing that the same twine and mesh sizes may be used in model and prototype. However, it must be remembered that any model strain must be equal to the corresponding prototype strain if geometrical similitude between model and prototype is to be assured. In most cases this requirement makes it necessary to use different twine size in model and prototype. The model twine size is determined from the elastic properties of the prototype twine material and the usually different model twine material. The corresponding model mesh size is then found from (12).

## MODEL FLUME

The model laws are verified by observation of model behavior in the hydraulic research flume at the University of Florida and comparison with observations of the corresponding prototype trawl in the ocean.

Although the flume can be used as a towing tank it is found to be more convenient to use stationary models and let the water flow through and around them rather than actually towing the models through stagnant water.

The major dimensions and capacities of the flume are as follows: length, 140 ft; width of main flume, 8 ft; width of return flume, 4 ft; maximum depth, 3 ft; maximum rate of flow, 40 cfs; and water velocity, 1-5 fps.

Even though the flume is rather shallow it is possible to reproduce the conditions of deep trawling by special arrangement of the model trawl supports. Future installation of a moveable bed at the center part of the flume will allow studies of trawl-bottom interaction and problems related to oblique currents.

Figures 2 and 3 show the testing of a model trawl in this flume. The downstream gate used to regulate the water depth and the 4-foot wide return flume are clearly visible in Figure 3. The water velocity in the photos is about 2 fps, corresponding to a trawling speed of about 4 knots in the ocean. A prototype of this trawl was later tested at sea by the University of Rhode Island net research group and satisfactory agreement between field and laboratory observations was established.

Fig. 2. Trawl model during test in Hydraulic flume.

## CONCLUSION

Although the research reported in the present paper is in its initial stages, laboratory research and preliminary field observations made by the cooperating net research group of the University of Rhode Island seem to verify the applicability of the presented model approach to trawl testing. Future research will include an in-depth verification of the method, studies of trawl-bottom interaction and observation of the influence of oblique currents.

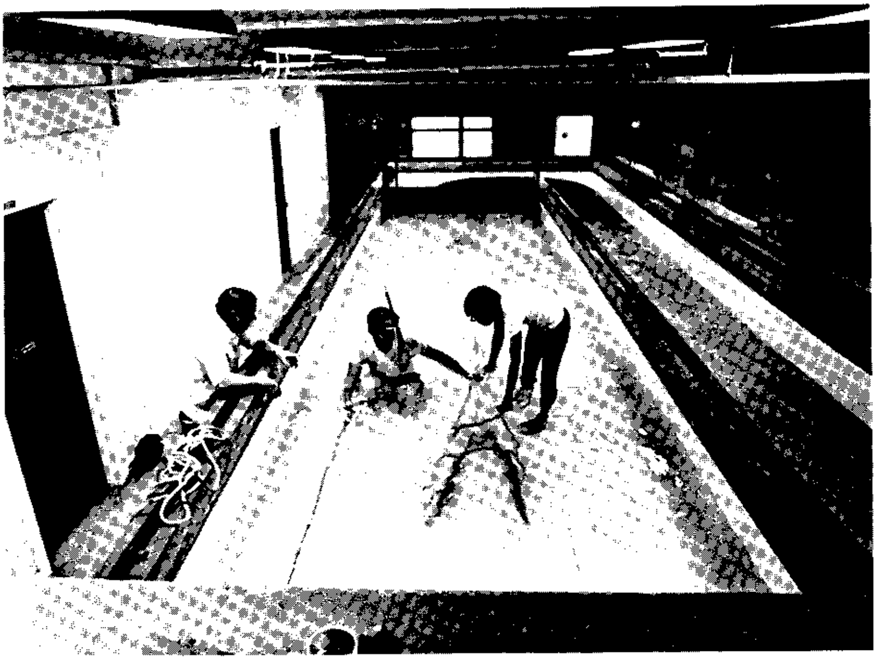

Fig. 3. Trawl model during test in hydraulic flume.

## LIST OF SYMBOLS

The following symbols have been used in this paper:

$C = C_1/C_2$ = constant

$C_1$ = constant

$C_2$ = constant

D = diameter of twine

F = force

L = length

M = mesh size

T = time

V = velocity

$\kappa$ = force scale = $F_p/F_m$

$\lambda$ = length scale = $L_p/L_m$

$\rho$ = fluid density

$\tau$ = time scale = $T_p/T_m$

Subscript m refers to model trawl
Subscript p refers to prototype crawl

## ACKNOWLEDGMENTS

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