Józef *ŚWINIARSKI,* Piotr *NOWAKOWSKI,* Henryk *SENDŁAK*

Fishing gear

MODEL STUDIES–BASED ANALYSIS OF EFFECTS OF PELAGIC TRAWL MOUTH CONSTRUCTION AND OPENING ON GEOMETRIC AND RESISTANCE–RELATED CHARACTERISTICS OF TRAWLS

ANALIZA WPŁYWU SPOSOBÓW ROZWIERANIA I KONSTRUKCJI WŁOKÓW PELAGICZNYCH NA ICH CHARAKTERYSTYKI GEOMETRYCZNO–OPOROWE NA PODSTAWIE BADAŃ MODELOWYCH

Department of Fishing Techniques, University of Agriculture, Szczecin, Poland

The technique of model studies on fishing gear, developed by the staff of the Department of Fishing Techniques, is employed in the field research carried out in a lake with the assistance of a catamaran as a gear model towing craft. A particular attention is paid to the functional coupling of a vessel, trawl, and rigging which makes up a complete trawl system.

The work presented was carried out at the Model Research Station in Ińsko, the Station being a unit of the Faculty of Marine Fisheries and Food Technology, Academy of Agriculture, Szczecin.

The paper introduces study techniques and some results of experiments on effects of pelagic trawl mouth construction and opening on geometry– and resistance–related trawl characteristics.

INTRODUCTION

In order for a fishery to be highly efficient, it has to use fishing gear adjusted to technical parameters of the fishing vessel and to the area as well as to specific features of biology and behaviour of target organisms.

In the process of fishing, a vessel serves a number of functions, that of catching fish being the most important one. A fishing vessel and her gear should be regarded as a fishing system (complete trawl system) which is a functional combination of a ship, a fishing gear (trawl) and rigging (Świniarski et al., 1979). The rational, reliable usage of the system and the desired effects of fishing operations are based on a selection of appropriate technical parameters of individual elements of the fishing system (vessel, gear, rigging).

Trawl studies in Poland are carried out with these problems on mind. At the initial stage, model studies are implemented, their results being later, at the final stage, verified at sea (Cetinić and Świniarski, 1980; Świniarski et al., 1989; Świniarski et al., 1990). The trawl fishing is highly energy consuming, thus trawl construction is being improved in order to improve gear hydrodynamic properties and netting material quality as well as to increase the sweeping range and fish trapping efficiency. In the work presented here, effects of pelagic trawl mouth construction and opening on geometry– and resistance–related characteristics were studied. Particular attention was paid to the resistance of a trawling system and the size of mouth area in several trawls differing in construction of their front part. The following trawl types were tested:

– 6–wing rope–mesh trawl,
– 4–wing rope–mesh trawl,
– big hexagonal mesh trawl.

Tests were run on 3 rigging systems:

1. Standard rigging (doors, floats, sinkers),
2. Standard rigging with flexible hydrofil floats (doors, floats, sinkers),
3. Hydrodynamic rigging with 4 doors.

Assessment of a trawling system performance and structure from direct underwater observations, photographs, and videotaping was an integral part of the study presented.

MATERIALS AND METHODS

The experimental work was carried out at the Model Research Station at Ińsko. The Station was formally established in 1975 as a unit belonging to the Department of Fishing Techniques of the Faculty of Marine Fisheries and Food Technology, Academy of Agri– culture, Szczecin. The Station is situated by the Ińsko Lake having numerous advantages for the research pursued, namely favourable hydrological conditions (mainly a high water transparency), elongated shape, easy access, and also picturesque landscapes. Trawl models tested are towed by a specially designed catamaran–type measurements platform (Kwidziński, 1986).

The platform is a motor (2 × 77 kW) two–hull craft (a catamaran), 11.7 m long, 8.3 m wide, 83.4 kN displacement. The maximum speed is 4.5 m/s; the maximum tracting effect is about 6 kN at 3 m/s speed. The platform's construction makes it possible to tow a trawl model in either of the two following ways:

1. The main body of the trawl, supported by two beams in the bow is towed underneath the platform (Fig. 1). The trawl mouth opening is pre–set and can be adjusted within the ranges of 0.5 – 7.6 m and 0.25 – 6.5 m horizontally and vertically, respectively. The model can be directly viewed in motion after removing the deck boards. The model resistance is measured with electric force gauges coupled with angle meters, mounted on the top of the beams;

2. A model with its rigging (towing ropes, doors, weights) is towed behind the stern on warps put out and hauled in by means of hydraulic winches. In this case, the process of trawling used on board stern trawlers is being modelled.

Measuring equipment

The platform is equipped with multi–channel electronic digital devices to control and record data describing the model's resistance and opening in water. The devices include (Fig. 2):

– an analog signals feeding and standardisation panel for the log and electric force gauges, each of the latter being coupled with electric protractors;

– an ultrasonic opening meter panel provided with 4 tubular ultrasonic transducers;

– a ZX Spectrum microcomputer with printer;

– an alpha numerical monitor;

– a PK–1 cassette memory;

– a multi–purpose measurement interface with 16 measurement channels of 8–bit digital impulse and 16 channels with 8–bit analog impulse.

The location of transducers to measure speed, forces, angles, and model opening is shown in Fig. 1.

The equipment described above allows to simultaneously measure up to 32 parameters and to record the data on magnetic tape by means of the cassette memory.

The microcomputer is also used to control the parameters being measured as the numerical values from various channels can be viewed on the screen. The correctly measured parameters are fed temporarily into the microcomputer memory. Once the measurements are completed, those data are recorded as 3–digit numbers (within 0 – 399 range) on the cassette memory magnetic tape, while the computer memory is cleared and the next set of measurements can be taken. An appropriate program is used to carry out those and other
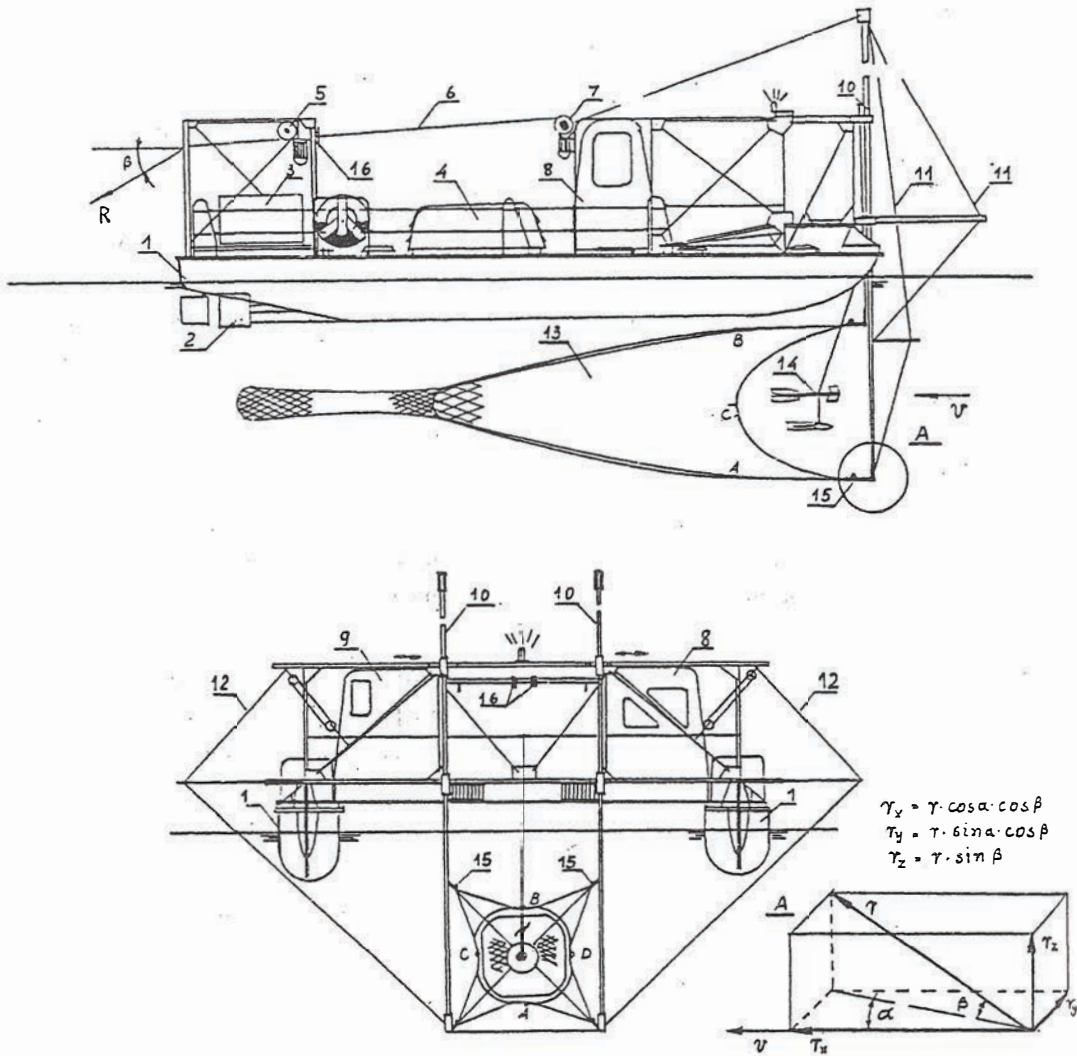
Fig. 1. The measurement platform (catamaran) for testing trawl models
1. platform float; 2. screw shielding; 3. electric generator; 4. engine room; 5. diver winch; 6. warp; 7. trawl winch; 8. steering room; 9. measurement room; 10. beam; 11. bow spring; 12. side spring; 13. trawl model; 14. log; 15. underwater dynamo‑meter coupled with angle‑meter; 16. on‑board dynamometer coupled with angle‑meter; r = hydrodynamic reaction; r_x, r_y, r_z = reaction components; v = speed; A, B, C, D = hydroacoustic spread – measuring transducers.

operations. The measurement repetition period and number of repetitions can be program-
med at will. In a typical measurement series, a 1 s repetition and 5 repetitions of measure-
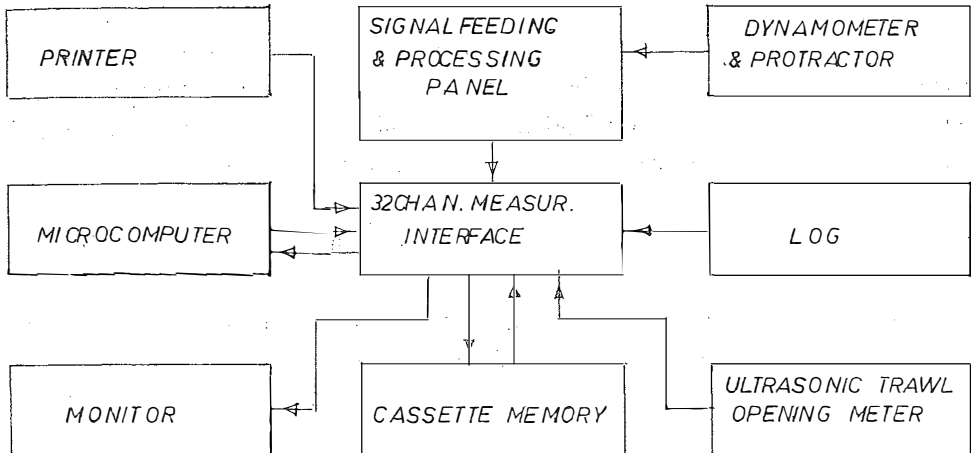ments at a defined speed and submersion depth of a model proved optimal.

Fig. 2. The catamaran electronic measurement equipment for trawl model testing

The following measurements on models towed on beams are made with the above-
described equipment (Fig. 1):

– towing speed, v, with the accuracy of 1% of the measured value;

– drag, r_i (where i = n = 4) at the points of mounting the model on the beams (Fig. 1),
  with the accuracy of 2% relative to the 1 kN range;

– angles between the catamaran symmetry plane and the reaction r_i direction α_i, with the
  accuracy of 2% relative to the 0.4 rad range;

The angles α_i and the distance between electric force gauge mounting points being
known, the angles β_i between the horizontal plane and the drag, r_i can be calculated.

The following parameters are measured on a model towed by warps:

– trawling speed, V (m/s);

– warp tension, R1 for the right warp and R2 for the left one, with the accuracy of 2.5%
  relative to the 3 kN range;

– warp spread angles relative to the catamaran symmetry plane axis, α_1 and α_2, with the accuracy of 2% relative to the 0.4 rad range;

– warp slope angles relative to the horizontal plane, β_1 and β_2, with the accuracy of 2% relative to the 0.4 rad range;

– vertical opening AB and horizontal opening CD, with the accuracy of 1% relative to the 19 m range.

When the field measurements are completed, the data are statistically processed in the laboratory. The processing is done by the computer previously coupled by means of the multi–purpose interface to a mosaic printer, cassette memory, and screen. Subsequently, the data processing program and the data themselves are fed into the computer.

Underwater observations and photographs of trawl models

The Station is provided with SCUBA diving gear and underwater photography equipment, the Station's staff having been trained in diving.

Preliminary, rather cursory, observations of a model towed by beams can be made, as already mentioned, from the catamaran's deck. Detailed observations on the shape of the model and its various elements in motion can be made and underwater pictures taken only by a diver towed along with the model. By using a special vehicle called the aquaplane the diver gets access to various elements of the model. The aquaplane is towed on the echo sounder cable, which makes it possible for the diver and the catamaran crew to commu–nicate via the underwater telephone. The cable is wound on the hydraulic winch drum on the deck. The winch operator, responding to the diver's signals by putting out or hauling in the cable, allows the diver to move along the model (Fig. 3).
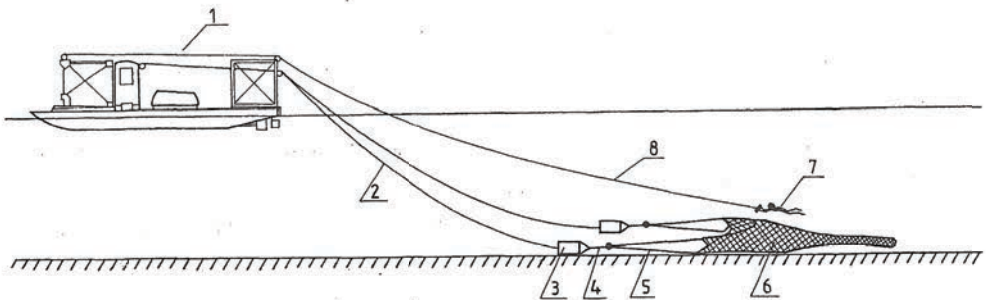

Fig. 3. Underwater observation of trawl model by diver
1. catamaran; 2. warp; 3. trawl door; 4. bridle; 5. leg; 6. trawl model; diver with aquaplane; 8. tow/phone cable.

The aquaplane is provided with a waterproof short lens objective (15 mm) photo-graphic camera, which makes it possible to photograph a relatively large model fragments from a short distance

Materials and principles of model construction

The basic construction was that of a WP–53/64 L pelagic trawling system used in Polish Baltic fishery by 419 kW (570 HP) trawlers fishing for herring, sprat, and even cod.

Fig. 4a and 5a present a 6–wing (basic) version of the construction with a standard rigging. Fig. 4b and 5b show a 4–wing version with the standard rigging. Fig. 4c presents a big hexagonal mesh trawl construction, its rigging with flexible hydrofil floats being presented in Fig. 5d. Fig. 5c shows a hydrodynamic rigging (4 doors) applied to a 4–wing construction version.

Trawl models were constructed and tested with the Newtonian criterion as the basic one (Nowakowski, 1980). The models, made of the same netting as that used in the full-scale trawls, were constructed to the U = 1:4 linear dimensions scale, hence a 16–fold reduction in the model's surface area (C_A = 1:16). To retain the C_A = 1:16 scale coeffi-cient for the belly ropes and bridles, their diameter was reduced by the factor of 4 (C_D = 1:4). The models were towed with a speed equal to that used at sea, i.e. the speed scale coefficient was C_V = 1. With this manner of modelling, the forces scale coefficient C_F should be equal to C_A:C_F = C_A = 1:16, therefore the buoyancy and sinking forces were reduced by the factor of 16, while the drag forces of doors and flexible floats were reduced by reducing their surface areas 16 times. Table 1 gives resistance areas (Atn) of trawling system models and their structure in %.

Table 1

Resistance area of trawling system models

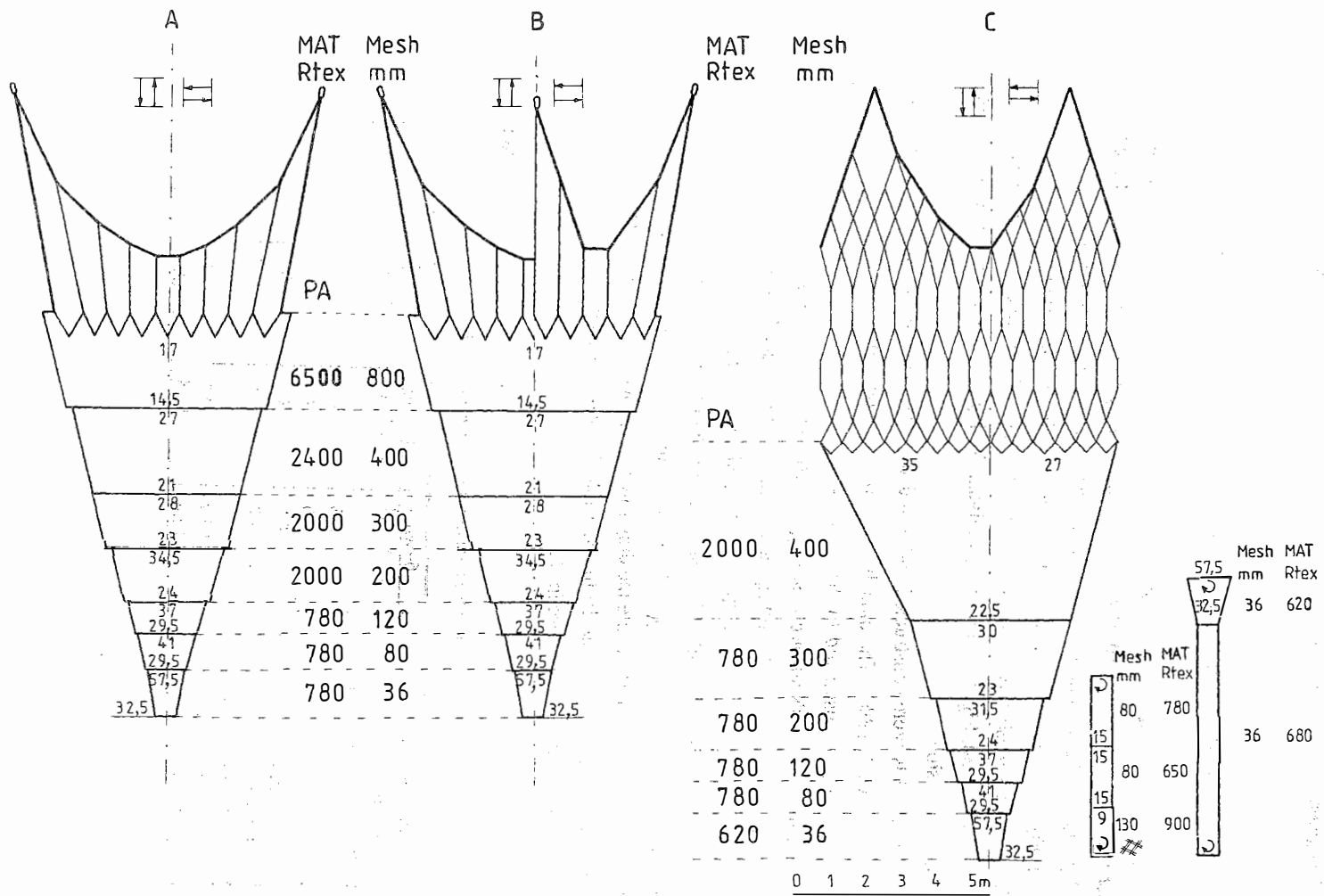| Model version	6–wing	4–wing	4–door	Big mesh
Resistance area	7.381 m^2	7.121 m^2	7.009 m^2	8.104m^2
Per cent contribution of;				
1. Warps	8.3	8.6	5.9	6.2
2. Doors	7.6	7.9	9.2	6.9
3. Bridles	6.5	4.5	4.6	5.5
4. Floats	1.5	1.6	1.6	
5. Hydrofil floats				1.4
6. Trawl main body	63.7	64.6	65.6	68.7
7. Codend + apron	12.4	12.8	13.1	11.3

Fig. 4. General view of 1:4 pelagic trawl model construction A – 6–wing trawl; B – 4–wing trawl; C – big mesh trawl.
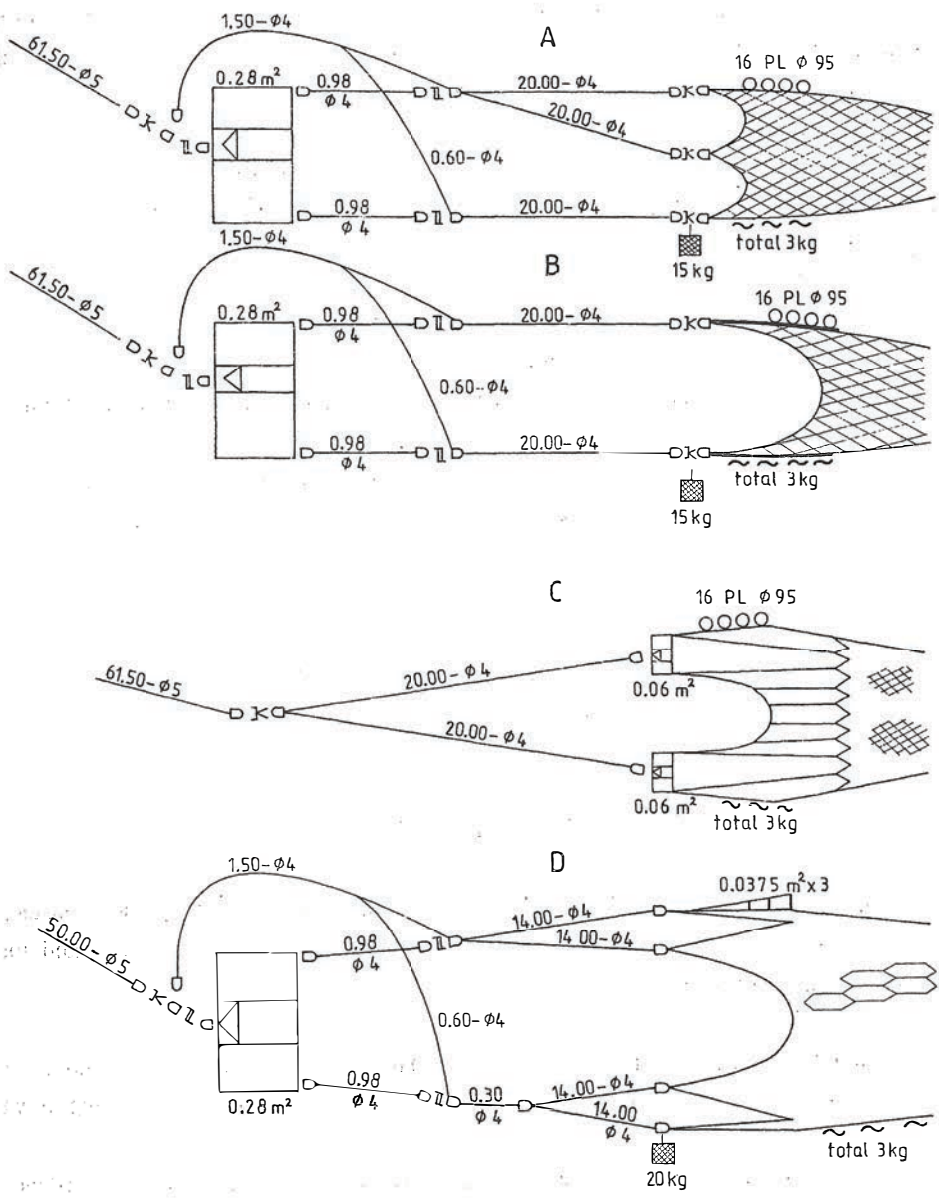
A

16 PL ⌀ 95

61.50 – ⌀5

1,50 – ⌀4

0.28 m²

0.98
⌀4

20.00 – ⌀4
20.00 – ⌀4

0.60 – ⌀4

0.98
⌀4

20.00 – ⌀4

1,50 – ⌀4

total 3kg

15 kg

B

16 PL ⌀ 95

61.50 – ⌀5

0.28 m²

0.98
⌀4

20.00 – ⌀4

0.60 – ⌀4

0.98
⌀4

20.00 – ⌀4

total 3kg

15 kg

C

16 PL ⌀ 95

61.50 – ⌀5

20.00 – ⌀4

0.06 m²

20.00 – ⌀4

0.06 m²

total 3kg

D

0.0375 m² x 3

1.50 – ⌀4

50.00 – ⌀5

0.98
⌀4

14.00 – ⌀4
14 00 – ⌀4

0.60 – ⌀4

0.98
⌀4

0.30
⌀4

14.00 – ⌀4
14.00
⌀4

0.28 m²

20 kg

total 3kg

Fig. 5   Rigging of the pelagic trawl models
A – 6–bridle trawl; B – 4–bridle trawl; C – 4–doors trawl
D – big mesh trawl with flexible hydrofoil float.

The results of measurements were approximated with the least squares method to a binomial in the form of $Y = A0 + A1 \, v + A2 \, v^2$, where A0, A1, and A2 are the binomial coefficients, and v is the towing (trawling) speed.

The following nomenclature is used:

L_z = vertical opening (m), measured between midpoints of headline and ground rope;

L_y = horizontal opening (m), measured between midpoints of left and right side lines;

A_m = surface area of the opening of the trawl mouth (conventional), (m^2), calculated as $A_m = L_z \, L_y$;

A_{tn} = resistance area (m^2) trawling system model;

RX   = trawling system hydrodynamic drag (kN):

   $RX = R1 \cos \alpha_1 \cos \beta_1 + R2 \cos \alpha_2 \cos \beta_2$ where R1 and R2 = forces pulling left and right warps;

α_1, α_2 =   horizontal angles between the trawling system symmetry axis and warps;

β_1, β_2 =   vertical angles between warps and horizontal plane;

ρ = specific weight of water in lake (1000 kg m^{-3});

CX   = trawling system resistance coefficient:

   $CX = 2 \, RX / (\rho \, v^2 \, A_{tn})$

CXA_m =   trawling system resistance coefficient relative to mouth area:

   $CXA_m = 2 \, RX / (\rho \, v^2 \, A_m)$

RESULTS AND DISCUSSION

Graphs in Fig. 6 and Fig. 7 show the results of trawl model geometry and resistance measurements, respectively. The analysis was made for 2 m/s trawling speed and for a 6–wing standard–rigged trawl as a reference gear.

The analysis shows that :

– the mouth area and resistance of a 4–wing standard–rigged trawl are by 25% and about 4% lower, respectively, than the corresponding characteristics of a 6–wing trawl model;

– a 4–door rigging produces a mouth area increase by as much as 50%, the resistance increasing by 10%;

– using 4 doors to hydrodynamically open the trawl mouth does not alter trawl geometry with increasing trawling speed;

- a big mesh trawl with standard rigging , flexible, and canvas hydrofil floats has vir-
  tually the same resistance as that of a 6–wing trawl. On the other hand, the mouth area
  in the big mesh trawl is increased by about 40%;
- the relationships described above are confirmed by changes in specific drag as a
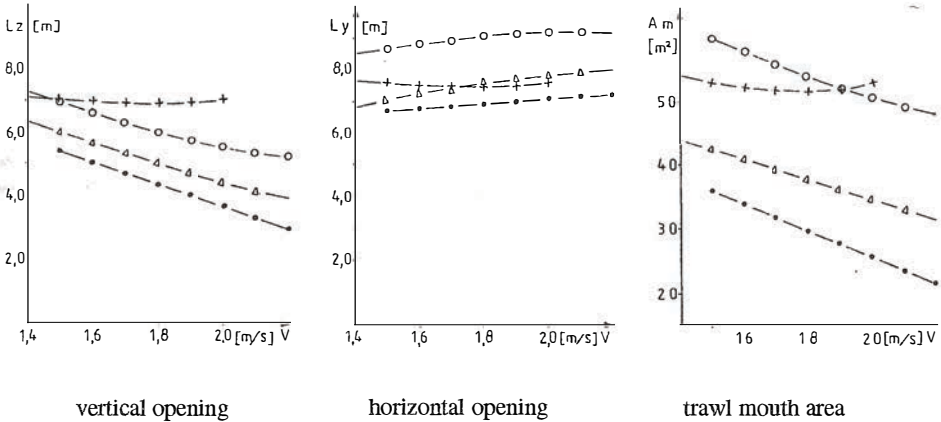 function of trawling speed.

vertical opening   horizontal opening   trawl mouth area

Fig. 6. The mouth opening of models

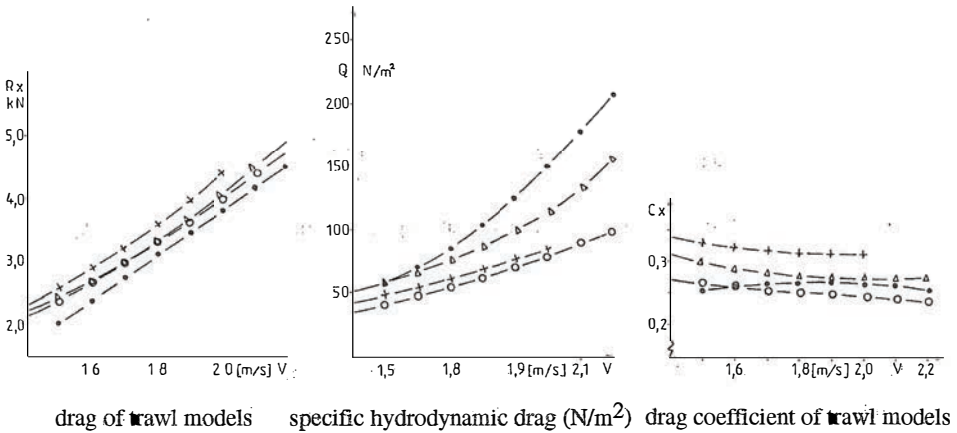drag of trawl models   specific hydrodynamic drag (N/m²) drag coefficient of trawl models

Fig. 7. Comparison of resistance characteristic of the pelagic trawl models

Fig. 7 shows the relationships between the resistance coefficient (CX) of the model s
tested and the trawling speed. As shown by the data, the coefficient remains basically
unchanged at the trawling speeds used in the Baltic fisheries (above 1.6 m/s). Earlier

studies demonstrated clear changes to occur at lower trawling speeds (Dudko et al., 1982; Nowakowski, 1980; Wagner et al., 1985).

Thus is possible to introduce a dimensionless independent variable expressed by a ratio between the resistance area (describing the construction size) and mouth area, i.e. A_{tn}/A_m. The dependent variable is the trawling system resistance coefficient relative to mouth area, CXA_m. The relationship is illustrated in Fig. 8.
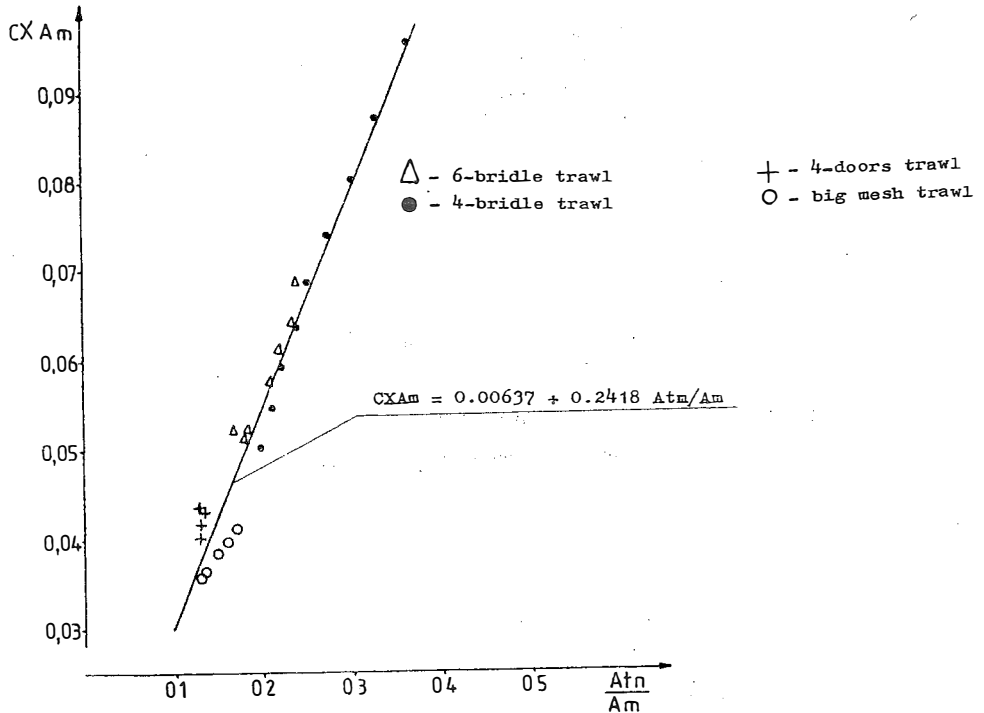

Fig. 8. Relationship between drag coefficient of trawl system model and values of A_{tn}/A_m

The scatter of data points suggests a linear relationship. Using the least squares as an approximation method, a linear empirical equation was obtained for $CXA_m = f\,A_{tn}/A_m$:

$$CXA_m = 0.00637 + 0.2418\,A_{tn}/A_m$$

Consequently, the drag of a pelagic trawling system can be calculated as

$$RX = 0.00637\,v^2/2\,A_m + 0.2418\,v^2/2\,A_{tn}$$

Thus, according to the assumptions adopted in the present work, the drag of a pelagic trawling system can be calculated using the trawl main body's opening area and the resistance area of the trawl.

CONCLUSIONS

1. Test on models of 6–wing, 4–wing, and big mesh trawls showed that:
   – change of a 6–wing trawl mouth construction from rope mesh to big mesh resulted in a 40% increase in the mouth area, the drag remaining unchanged;
   – a 4–wall construction used instead of a 6–wall one resulted in an about 25% decrease in the mouth area, the drag being slightly lower.
2. The empirical equation for calculating the trawling system drag,

$$RX = 0.00637 \; v^2/2 \; A_m + 0.2418 \; v^2/2 \; A_{tn}$$

seems to be a good methodological approach to solving the problem.

REFERENCES

Cetinić P., J. Świniarski, 1980: Analysis of the construction and resistance of pelagic trawls for catching pilchard in the Adriatic based on the model test and underwater observations. Acta Adriatica, **21** (1): 137–190.

Dudko S., J. Świniarski, Z. Przybyszewski, Z. Kwidziński, P. Nowakowski, H. Sendłak, 1982a: Effect of linear dimensions of conical netting constructions on properties of their resistance. Acta Ichthyol. Piscat., **12** (1): 117–126.

Dudko S., J. Świniarski, Z. Przybyszewski, Z. Kwidziński, P. Nowakowski, H. Sendłak, 1982b: Effect of mouth shape of conical netting constructions on properties of their resistance. Acta Ichthyol. Piscat., **12** (2): 101–111.

Kwidziński Z., 1986: A method studying trawl models in the experimental station of the Faculty of Sea Fisheries and Food Technology. Acta Ichthyol. Piscat., **16** (2).

Nowakowski P. 1980: Analiza wpływu sposobów rozwierania i prędkości holowania włoków na ich charakterystyki geometryczno–oporowe. PhD Thesis, Akademia Rolnicza w Szczecinie.

Świniarski J., M. Bykowski, Z. Kwidziński, P. Nowakowski, H. Sendłak, 1979: Wstępna analiza dynamiki zestawu trałowego (na przykładzie badań modelowych). [A preliminary analysis of trawling complex dynamics]. Zeszyty Naukowe Akademii Rolniczej w Szczecinie, **75**: 55–66.

Świniarski J., P. Nowakowski, H. Sendłak, Z. Kwidziński, 1989: Design, documentation and model studies of trawl for multipurpose WKR–25/III trawlers contracted by Iran. Department of Fishing Techniques, Akademia Rolnicza w Szczecinie.

Świniarski J., P. Nowakowski, H. Sendłak, Z. Kwidziński, P. Cetinić, 1992: Testing of technical parameters of bottom trawls designed for fishing in the Adriatic Sea. Acta Adriat. **32** (2): 899–936.

Wagner S., M. Meisel, H. Sendłak, Z. Kwidziński, 1985: Versuche zur Dynamik pelagischer Schleppnetze und Vergleich der Messungen mit theoretischen Berechnungsverfaren. Seewirtschaft, Nr 2: 95–98.

Józef *ŚWINIARSKI,* Piotr *NOWAKOWSKI,* Henryk *SENDŁAK*

ANALIZA WPŁYWU SPOSOBÓW ROZWIERANIA I KONSTRUKCJI WŁOKÓW PELAGICZNYCH NA ICH CHARAKTERYSTYKI GEOMETRYCZNO–OPOROWE NA PODSTAWIE BADAŃ MODELOWYCH

STRESZCZENIE

Opracowane przez zespół pracowników Zakładu Techniki Rybołówstwa metoda badania modeli narzędzi połowu dostosowana jest do badań prowadzonych na poligonie jeziorowym z wykorzystaniem pojazdu typu katamaran jako środka holującego. Dużą uwagę w badaniach modelowych zwraca się na funkcjonalne połączenie statku, włoka i elementów uzbrojenia, stanowiących układ połowowy.

Praca została wykonana w Stacji Badań Modelowych w Ińsku, stanowiącej jednostkę organizacyjną Wydziału Rybactwa Morskiego i Technologii Żywności AR w Szczecinie.

W pracy przedstawiono metodykę badań oraz niektóre rezultaty prac eksperymentalnych dotyczące wpływu konstrukcji wlotu włoków pelagicznych i sposobów ich rozwierania na charakterystyki geometryczno–oporowe.

Author's address:

Prof. tit. D.Sc. Józef Świniarski
Department of Fishing Techniques
University of Agriculture in Szczecin
Kazimierza Królewicza 4
71–550 Szczecin
Polska (Poland)