Fisheries Research 161 (2015) 217–225

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Computer simulation and flume tank testing of scale engineering models: How well do these techniques predict full-scale at-sea performance of bottom trawls?

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ARTICLE INFO

Article history:
Received 24 January 2014
Received in revised form 12 June 2014
Accepted 1 August 2014
Handling Editor Dr. P. He
Available online 6 September 2014

Keywords:
Bottom trawl
Dynamic simulation
Physical modelling
Flume tank

ABSTRACT

A Canadian demersal survey trawl (Campelen 1800) was used to investigate the differences in trawl geometry and resistance using dynamic simulation, flume tank testing, and full-scale at-sea observations. A dynamic simulation of the trawl was evaluated using DynamiT software. A 1:10 scale model was built and tested in a flume tank at the Fisheries and Marine Institute of Memorial University of Newfoundland (Canada). Full-scale observations of the Campelen 1800 in action were collected during the 2011 fall multi-species survey aboard the research vessel *CCGS Teleost*. The numerical and physical modelling data were assessed to determine their ability to predict full-scale at sea performance of the Campelen 1800 trawl. The numerical simulation data were also compared against scale model engineering performance under identical conditions. The study demonstrates that the ideal method with which to accurately predict full-scale at-sea performance of bottom trawls or used for designing a trawling system probably does not exist. Therefore, the importance of using two or three complementary tools should be encouraged as an ideal process for designing a trawling system and/or assisting the gear development circle.

1. Introduction

The method by which new fishing gears are designed and tested has dramatically changed and become more advanced and sophisticated over the last few decades. The major reasons for this continuing development in methodological process are rooted in the high cost of evaluating new gear designs at sea together with impressive improvements in the predictive abilities of computer simulation and physical models, both of which have been shown to reduce relevant expenses and potential risks for gear manufacturers and researchers (Winger et al., 2006; Prat et al., 2008; Queirolo et al., 2009). The driving forces of increasing regulations, bycatch restrictions, and concerns over ecosystem impact of bottom trawls have also been cited for significant improvements in the way new fishing gears are designed and tested (Winger et al., 2006).

The cycle of gear development proposed today should include the use of computer simulation, physical model testing, and at-sea evaluations in a complementary manner and in a logical sequence of work, as the ideal process for designing a new fishing gear system (Winger et al., 2006). Most importantly, the use of computer-based numerical modelling and simulation is encouraged during the early stages of design for validating simple design ideas, as a fast and convenient method. The recent rise in commercially available trawl design and simulation software has significantly improved the speed and quality of design work. Today, several commercial software packages are available for purchase and use on desktop computers and tablets (e.g., DynamiT, SimuTrawl, Trawl Vision Designer and Trawl Vision Simulator, CadTrawl, and CATS). Most of these software packages have the ability to simulate the effects of different materials and design features on trawl shape and performance under different rigging and towing scenarios, as well as calculate expected mechanical stresses on the seafloor (e.g., Vincent, 2000; Queirolo et al., 2009). By comparison, testing physical models in a flume tank, which is considered the *de facto* standard for evaluating new designs and forms the backbone of the modern fishing gear development cycle (Winger et al., 2006), is recommended in order to validate simulated values derived in previous simulation work (Queirolo et al., 2009). Benefits attributed to constructing and testing physical models include the ability to (1) explore potential defects in design; (2) examine the effect of

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http://dx.doi.org/10.1016/j.fishres.2014.08.007
0165-7836/

alterations in design and rigging; (3) examine the effect of speed and rigging changes on gear geometry and orientation; (4) measure forces acting on the gear; and (5) measure motions of fishing gear (see discussions by Dickson, 1959; Fridman, 1986; Winger et al., 2006). Finally, evaluation of full-scale prototypes at sea is always necessary for assessing the real fishing gear performance and identifying the most successful design features and trawl components of the new fishing gear system. The accuracy of measuring and predicting trawl geometry and performance of a new gear design plays an important role in gear development process. In real fishing conditions, trawl geometry and performance can vary from tow to tow and may be affected by various factors (e.g., towing speeds, water currents, bottom type) and increasing error in accuracy of measurements. The use of acoustic trawl monitoring sensors (e.g., SCANMAR acoustic trawl monitoring instruments) have permitted researchers to improve their monitoring of trawl performance at sea, identify any gear malfunctions and reduce variability in trawl geometry and performance (see, for example, Walsh and McCallum, 1995, 1997).

Given the high cost of evaluating new gear designs at sea, many trawl designers/researchers and manufacturers proceed with computer simulation followed by the testing of physical scale models in flume tanks. However, some might be tempted to speculate whether computer simulation might someday replace physical models or others could raise a question about how well do computer simulation and physical modelling predict full-scale gear performance at sea? Interestingly, few studies have been conducted to evaluate the accuracy/precision of numerical and physical modelling techniques in the comparison with full-scale trawl performance during the last decade. In some cases, data from physical models have been compared to full-scale trawls (e.g. Morse et al., 1992; Fiorentini et al., 1991, 1992, 2004; Sala et al., 2009), and in other cases data from computer simulations have been compared to physical models (e.g., Queirolo et al., 2009), but no clear studies exist in which all three techniques are compared, or any comparison between software, or between flume tanks. Hence, this study represents a unique and novel piece of research.

The objective of this study was to assess the accuracy of computer simulation and physical modelling approaches in predicting the full-scale at-sea performance (geometry and resistance) of the Campelen 1800 trawl. In addition, this study also investigated the ability of computer simulation to predict performance of physical models. The results are discussed in relation to the commonly used methodological approach for fishing gear design described by Winger et al. (2006).

2. Materials and methods

2.1. Trawl design and scale engineering model specifications

The Campelen 1800 was selected as the trawl design for this study. This is the standard demersal survey trawl widely used by Fisheries and Oceans Canada on the east coast of Canada since 1995, replacing earlier versions of the Engel 145 otter trawl and the Yankee 41 shrimp trawl (Walsh and McCallum, 1997). This trawl design is known as a four panel design with cut-away lower wings and is rigged with three bridles and 4.3 m^2, 1400 kg Morgère Polyvalent trawl doors. The Campelen 1800 trawl is rigged with a 35.6 m rockhopper footgear and uses 356 mm diameter rubber disks. Trawl construction is of 4.0, 3.0 and 2.0 mm diameter polyethylene twine varying in mesh size from 80 mm in the wings to 60 mm in the square and the first bellies and 44 mm in the remaining bellies, extension and codend (see Fig. 1 for details). The design has changed very little over time as a result of stringent standardization of construction and operational protocols (Walsh et al., 2009).

A linear scale of 1:10 was selected as the best balance between the limitations of the test facility (i.e., flume tank size), objectives of the test programme, and the ability to extrapolate model results to full-scale performance. The majority of the components were custom ordered and/or fabricated in-house and the model was assembled by hand using standard trawl construction practices (see Winger et al., 2006).

2.2. Dynamic simulation tests

Trawl simulation software (i.e., DynamiT) developed by the French Research Institute for the Exploitation of the Sea (IFREMER) was utilized to simulate the mechanical behaviour of the Campelen 1800 trawl. The software has the ability to calculate and simulate the dynamic behaviour of virtually any trawl type, commonly referred to as dynamic simulation (Vincent, 2000; Queirolo et al., 2009). For this study, the simulations were performed for different door spreads, depths, and towing speeds. Output parameters included door spread, wing-end spread, headline height, and towing resistance (i.e., warp/bridle tension).

In order to facilitate comparison to the physical modelling, the dynamic simulations were conducted at the same door spreads as the flume tank tests in order to eliminate bias in trawl performance when comparing the two datasets. The simulations were constrained for the desired door spreads by deploying the appropriate warp and simply attaching a rope of diameter 0.0 mm between the trawl doors as a restrictor rope (referred to as restrictor rope based simulation). Specifically, we conducted a series of dynamic simulations for six different door spreads of 45.0, 50.0, 55.0, 60.0, 65.0, and 70.0 m at four different towing speeds of 2.0, 2.5, 3.0 and 3.5 knots. The trawl geometry parameters (i.e., wing-end spread, headline height) and resistance (i.e., bridle tension) of each combination of treatments were obtained.

To facilitate comparison with the full-scale observations of the Campelen 1800 trawl, the dynamic simulations were performed at a standardized towing speed of 3.0 knots and varying towing depths or we simply replicated all the tows as conducted aboard the *CCGS Teleost* during the 2011 fall multi-species survey (referred to as depth based simulation). The trawl geometry parameters (i.e., door spread, wing-end spread, headline height) and resistance (i.e., warp tension) of each combination of treatments were documented.

2.3. Flume tank tests

A 1:10 scale model was constructed by the Fisheries and Marine Institute of Memorial University of Newfoundland using mainly Froude scaling principals (Tauti, 1934; Dickson, 1959; Fridman, 1973; Hu et al., 2001). The scaled model was constructed in a manner that approximates the geometric, kinematic, dynamic, and force laws of full-scale trawls. The modelling laws may be summarized as:

$$\lambda = \frac{L_f}{L_m} \quad (1)$$

$$A_m = \frac{A_f}{\lambda^2} \quad (2)$$

$$F_m = \frac{F_f}{\lambda^3}\frac{\rho_m}{\rho_f} \quad (3)$$

where L, A, F and ρ are length, area, force and water density, the subscripts m and f refer to model and full-scale, respectively. To compensate for differences with respect to the full-scale trawl due to available twine diameter, an area scale and force scale are also used. The velocity scale is given by:

$$\lambda^{1/2} = \frac{v_f}{v_m} \quad (4)$$