Ocean Engineering 149 (2018) 238–244

Contents lists available at ScienceDirect

Ocean Engineering

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

Otterboard hydrodynamic performance testing in flume tank and wind tunnel facilities

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ARTICLE INFO

Keywords:
Wind tunnel
Flume tank
Otter board
Hydrodynamics

ABSTRACT

Two pelagic otterboards, previously tested in a wind tunnel, have been tested in a flume tank prior to their analysis in real working conditions in sea trials. This intermediate step aims at providing guidance for sea trial planning and a basis for otter board performance analysis from real campaign data. The doors were rigged in working-like conditions in the flume tank, with onboard-mounted attitude sensors to provide at the same time a noisy environment as expected in sea trials and accurate measurement of all quantities relevant to precise determination of hydrodynamic angles and forces. The trends found in flume tank experiments closely match wind tunnel results, although systematic offset has been observed that can be ascribed to deviations between nominal and real water velocity, due to inhomogeneous velocity distribution in the cross-section.

1. Introduction

The effective and efficient use of a trawl gear, be it bottom, pelagic or semipelagic, relies on the adequate choice, sizing and rigging of one of its key components: trawl doors (Paschen and Lee, 2006; Notti et al., 2013a). In ordinary trawling, these under water devices, also known as otter boards, fulfill the crucial task of ensuring a suitable horizontal net opening, and this is to be achieved with minimum drag for optimal trawler fuel consumption (Sala et al., 2007; Buglioni et al., 2012; Notti et al., 2013b). They are also responsible for keeping the right net depth in pelagic trawling and must be designed for minimal sea bottom disruption in case of bottom trawling. Stable handling of the full gear must also be guaranteed while manoeuvering, deploying and stowing (FAO, 1974).

There exist a wide range of numerical models that simulate net dynamics (Bessonneau and Marichal, 1998; Niedzwiedz and Hopp, 1998; O'Neill, 1999; Wan et al., 2002; Priour, 2003; Suzuki et al., 2003; Lee et al., 2005), and a few extend to include complete gears, exploiting a sometimes crude (Lee and Lee, 2000), sometimes fair (Folch et al., 2007; Prat et al., 2008) description of trawl door behaviour. The only full trawl gear simulation to date embodying a complete and detailed modelling of the otter boards was undertaken by (Reite, 2006).

Traditional flume tank tests provide drag and lift coefficients as a function of the yaw orientation angle of the door (notice that the terminology usually employed -angle of attack- is a misnomer in this context) in allegedly no-heel and no-pitch conditions (Authority, 1993; Strickland, 1995). The coefficients are usually obtained via reduced-scale tests that not always preserve dynamic similarity (Park et al., 1996; Fukuda et al., 1999). Although this procedure might suffice to the needs of the trawl fishing industry, it has shortcomings that render it inappropriate for the detailed analysis of otterboard performance and the intimate understanding of its behaviour in real conditions that is crucial to optimising both design and rigging as well as off-design operation. Preventing stability issues in non-standard realistic conditions or exploiting control systems to dynamically pilot the full gear require an accurate modelling of the hydrodynamic forces acting on the trawl doors along with the rest of gear components and their interactions (Reite, 2006; Paschen, 1981). It is therefore essential that moments and forces in all three axes can be predicted for any possible attitude of the door, as given by its two hydrodynamic angles (angle of attack and sideslip). Dynamical effects derived from acceleration or rotation in the three axes also play a role, but accurately assessing their influence is beyond the scope of the test methods here presented.

Clever exploitation of traditional flume tank facilities, using door-mounted sensors, has allowed a more detailed analysis of bottom otter board performance (Sala et al., 2009). In these experiments, both heel and pitch angles were set to prescribed values. The inclusion of load cell sensors on the shoe allowed measurement of the bottom normal reaction thus providing a means of calculating all three force components

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https://doi.org/10.1016/j.oceaneng.2017.12.034
Received 6 April 2017; Received in revised form 21 July 2017; Accepted 10 December 2017

alongside quantitative assessment of potential seabed impact (Sala et al., 2009).

Modern flume tank facilities (SINTEF Fisheries, Hirtshals) have improved on traditional techniques by suspending the otter board from a 6-component balance (three-axes force and moment measurement) that can accurate orient the model in any desired attitude. The downside is their operation cost, as compared with general-purpose wind tunnel testing, which has been seldom used in analysing trawl door hydrodynamics (Reite and Sorensen, 2006; Mellibovsky et al., 2015), despite a number of evident advantages.

Numerical modelling with Computational Fluid Dynamics tools is a powerful alternative that can potentially provide hydrodynamic coefficients in all detail, but its computational cost makes it still inadequate for large parametric studies and, due to the complex unsteady hydrodynamics at the operating flow regimes at which otter boards work, which require turbulence modelling, experimental validation is unavoidable (Vincent et al., 2006; Jonsson, 2012; Takahashi et al., 2013).

Otter board hydrodynamics are extremely difficult to test at sea in full-scale experiments and very few studies have attempted at measuring attitude and forces in real operation (Sala et al., 2009). It is however of the utmost importance to understand trawl door behaviour in real operating conditions to relate back to more controlled wind tunnel or flume tank experiments.

The most comprehensive otter board measurements at sea (Sala et al., 2009) up to date assimilate trawler velocity to door velocity, which is a reasonable approximation in steady trawling in the absence of depth-dependent sea currents. Forces acting on the otter board are inferred from accurate tension measurements on warp and bridles close to their attachment points on the door (just upstream and downstream), door spread and depth and cable deployment lengths, yet with crude cable bending assumptions in determining force orientation. Otter board pitch and roll angles are measured with an accelerometer-based attitude sensor, leaving yaw as the only unknown orientation angle. This alone prevents reliable assessment of the operating hydrodynamic angles, which is fundamental to estimating the expected hydrodynamic forces for comparison with measurements.

The main objective of the present study is to exploit traditional flume tank tests as an intermediate step to carrying fully controlled tests in wind tunnels or modern flume tanks to realistic operating conditions at sea. The aim here is therefore to bridge the gap between precise experiments (wind tunnel and modern flume tank facilities) and the uncertainties faced in actual operation (sea trials) by realistically rigging the otter-board in an environment in which sufficiently accurate measurement is still feasible (traditional flume tanks with door-mounted attitude sensors). While wind tunnel and modern flume tank experiments constitute a reference for accuracy, traditional flume tank tests are still useful to realistically reproduce sea conditions by mimicking actual rigging, and results can be cross-checked against wind tunnel and modern flume tank results.

One aim is therefore to assess the capability of traditional flume tank facilities to conduct the kind of parametric studies that are feasible in modern flume tanks and wind tunnels, relinquishing the precise variation of the hydrodynamic angles but retaining a somewhat accurate measurement of door orientation and the resulting forces.

An accessory goal is then to validate the use of attitude probes, based on accelerometers for pitch and roll and on a magnetic compass for yaw (or a gyro-based inertial reference system), for their use in sea trials. Again, a traditional flume tank provides the adequate framework for validation, as force measurement and projection is accurate enough while the rigging method provides a sufficiently noisy environment to test measurement stability of the orientation probe in realistic conditions. Balances used in wind tunnels and modern flume tanks are too stable for being representative of the noisy conditions the probes will experience in sea trials.

Wind tunnel and traditional flume tank tests of two models of pelagic otter boards will be compared in order to provide insight as to the way full-scale sea trials must be undertaken.

The paper is then structured as follows: wind tunnel and flume tank tests are described in §2. Test results for two production otter boards are presented in §3 and comparison between flume tank and wind tunnel results discussed in §4. Finally, in §5 we summarise the main results and briefly analyse their relevance to full scale sea trials.

2. Methods

Two models of flying (pelagic) trawl doors, Thyborøn type 15 vf and Grilli Fly, have been tested in both wind tunnel and flume tank facilities for comparison (Fig. 1). The geometric parameters of the models, which are made of the same materials as real scale doors (steel) for their suitability for sea trials, are given in Table 1. Reference for roll is taken with the span-line (tip-to-tip) in the upright position, such that the body z-axis runs parallel to the span-line. Note that the relevant parameter to unambiguously set a reference for roll is ϕ^e, defined as the angle between the tip-to-tip span line and the earth vertical when the door is standing flat on its shoe. The effects of the upper and lower panel dimensions and respective dihedral angles on the definition of the roll reference are all encompassed by this single parameter. For details on how to relate the geometric parameters of the trawl door to ϕ^e, see Fig. 1 in (Mellibovsky et al., 2015).

Wind tunnel experiments were done at the MariKom wind tunnel facilities (http://www.marikom.uni-rostock.de/en/), located at Rostock University campus in Germany. The wind tunnel is of the Göttingen construction type (also known as Prandtl type or closed return wind tunnel) with an open test chamber of square cross-section of 1.4 m side and provides an accurate three-axes positioning system and a six-component balance for forces and moments measurement. Tests were conducted on 20 October 2013, and a detailed account of the data analysis procedure and results for the Thyborøn type 15 vf is available at (Mellibovsky et al., 2015).

Flume tank tests were conducted on 10 September 2014 at the Marine Institute in St John's, Newfoundland, Canada. The flume tank has a test section of 8 m × 4 m × 22.25 m width, depth and length, respectively (https://www.mi.mun.ca/facilities/flumetank/).

Three pumps or impellers located in the return section circulate the water around the tank. Each impeller or pump is driven by a 125 hp DC motor. The tank is fitted with flow straighteners in the lower section last turn to remove swirl. Downstream from the guide vanes, the flow crosses a honeycomb grid to make the flow as uniform as possible across the test chamber cross-section. The tank is calibrated for mean velocity, as averaged across 200 equispaced individual measurements on a grid covering the full cross-sectional area of the chamber. Mean velocity is correlated with pump rotational speed (rpm), such that flume tank nominal speed during experiments is inferred from pump speed. Individual pumps are regularly calibrated for accuracy and repeatability, but actual average speed in the test section is checked less frequently and no guarantee is provided of uniform velocity distribution in the cross-section. The maximum nominal speed of the flume tank is slightly short of 1 m/s.

Doors were weighted in air (W_a) and in water (W_w) and rigged within the flume tank as in real working conditions for the tests, pulled by the warp at the front and by two lines connected to the bridle at the back. The flume tank was operated at a constant nominal water speed V, set to 0.7 m/s for the Grilly door and to 0.95 m/s for the Thyboron door, corresponding to chord-based Reynolds number $Re \simeq 2.3 \times 10^5$ in both cases (water density and viscosity estimated at $\rho \simeq 10^3$ kg/m^3 and $\nu \simeq 1.2 \times 10^{-6}$ m^2/s for $T \simeq 15$°C).

Warp (T_w) and bridle (T_b) tensions were measured at their respective ends and their attitude geometrically measured from top (ψ_w^t and ψ_b^t) and side views (ψ_w^s and ψ_b^s) as shown in Fig. 2a and c. The yaw angle (ψ) of the door was measured from a top view as shown in Fig. 2b, while pitch (θ) and roll (ϕ) were recovered from an accelerometer-based attitude sensor