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Testing otter board hydrodynamic performances in wind tunnel facilities

Fernando Mellibovsky [a,*], Joana Prat [b], Emilio Notti [c], Antonello Sala [c]

[a] Castelldefels School of Telecom and Aerospace Engineering, Universitat Politécnica de Catalunya, Castelldefels 08860, Spain
[b] EPSEVG-SARTI, Universitat Politécnica de Catalunya, Dept. Matemática Aplicada 4, Vilanova i la Geltrú 08800, Spain
[c] National Research Council (CNR), Institute of Marine Sciences (ISMAR), 60125 Ancona, Italy

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ABSTRACT

The feasibility and potential advantages of wind tunnel testing of otter board designs are assessed. Traditional flume tank tests incur high operational costs and present some limitations in terms of flexibility and accuracy. Modern flume tanks, despite more flexible and accurate, are still expensive to operate or hire. Wind tunnel facilities are widespread, with a potential for low budget tests, and allow for an accurate control of velocity, angle of attack and sideslip as well as precise measurement of forces and moments in all three axes. A complete description of otter board hydrodynamics is paramount to optimising design and rigging and for the design of active control strategies that allow for stable trawling at a target speed and depth. We describe in detail the methodology of wind tunnel tests applied to general otter board designs, exemplify it with a commercial pelagic otter board and provide a comparison with existing flume tank results for the same design.

1. Introduction

Otter boards or trawl doors are key components of trawl gears for their effective and efficient use (Paschen and Lee, 2006; Niedzwiedz and Hopp, 1998). Their main role consists in keeping the net open at the required wing-end spread – and depth in pelagic trawling – while producing the minimum possible impact in terms of trawler fuel consumption (Sala et al., 2007b; Buglioni et al., 2012; Notti et al., 2013) and, in the case of bottom otter boards, sea bottom disruption. Otter boards must also ensure stable shooting and handling of the gear (FAO, 1974).

Trawl doors fulfil their net-opening part through the generation of an hydrodynamic lift force at the cost of introducing a drag force that adds to the total resistance the trawler must overcome. As a result, a low lift to drag ratio of the otter board results in high trawler consumption. The trawl door lift is mainly used in keeping the net open and, when fishing in shallow waters, also in overcoming its own weight. In deep waters, the warp takes most of the responsibility for balancing the otter board weight. Drag can be mainly ascribed to three sources: friction, wake and wing tip vortices. Friction drag is chiefly dependent on the laminar or turbulent nature of the boundary layer. Wake drag, also known as pressure or form drag, is a consequence of boundary layer separation due to adverse pressure gradients on the outer surface recompression area when generating lift. It is thus also critically dependent on the laminar or turbulent nature of the boundary layer, which conditions separation, and increases with the square of lift. Finally, wing tip vortices are responsible for the so-called lift-induced drag, which is also proportional to lift squared and inversely proportional to the aspect-ratio of the otter board. It is therefore clear that drag can be reduced both through diminishing lift requirements or by increasing the hydrodynamic efficiency through increasing the aspect-ratio. In shallow water fishing, minimising lift requires light otter boards, while in deep water heavy otter boards are preferred to enforce depth upon the net. The aspect-ratio is not only limited by practical and technical issues, but also because friction is negatively influenced by slenderness. All in all drag minimisation for the required lift is then achieved through careful hydrodynamic design and optimal rigging. While classic otter boards used to work with the outer surface in complete stall to ensure stability (Patterson and Watts, 1985, 1986), modern otter boards tend to feature slotted cambered airfoil shapes deployed in high aspect-ratio wings to stably operate in conditions closer to that of optimal efficiency. In pelagic systems, otter boards may also serve a trawl gear pilot/control task (Paschen, 1981; Reite, 2006), which renders accurate modelling essential to anticipate stability issues under realistic conditions. Other processes such as seabed impact or capture targeting are

* Corresponding author.
E-mail address: fernando.mellibovsky@upc.edu (F. Mellibovsky).

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strongly affected by the dynamic interactions of vessel, rigging, otter board and net interactions, with the otter boards having a first order effect.

Trawl net opening and depth control, system stability to manoeuvring, trawl gear response to external perturbations such as currents or underwater gusts, rely on a deep understanding of the dynamics of the system as a whole and a realistic model of the otter boards must necessarily include an accurate description of their hydrodynamic behaviour (Schumacher, 1974). Moving parts aside, as may be devised for control purposes, this translates into the precise knowledge of how forces and moments in all three axes depend on the two relevant hydrodynamic angles: the angle of attack and the sideslip angle.

Most experimental efforts have been devoted to analysing net hydrodynamics both by means of sea trials (Valdemarsen et al., 1995; Sala et al., 2007a; Fiorentini et al., 1999, 2004; Dremière et al., 1999; Brčić et al., 2014; Lucchetti and Sala, 2012) and flume tank experiments of scaled net models (O'Neill, 1993; Ferro, 1996; Hu et al., 2001). There also exist studies that compare flume tank results with full-scale sea trial data for both isolated nets and full gear (Ward and Ferro, 1993; Fiorentini et al., 2004; Kumazawa et al., 2009). In addition, a number of numerical models to simulate net dynamics have been developed (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 also some models of complete gears, including a crude (Lee and Lee, 2000) or somewhat fair (Folch et al., 2007; Prat et al., 2008) description of trawl door behaviour, have been devised. A careful literature search shows that the first and only full trawl gear simulation embodying thorough modelling of the otter boards was undertaken by Reite (2006).

Traditionally, the study of otter board hydrodynamics has been limited to the mere determination of the drag and lift coefficients as a sole function of the angle of attack (IFREMER, DIFTA, 1993; Strickland, 1995). These coefficients are usually obtained via reduced-scale tests in flume tank facilities (Park et al., 1996; Fukuda et al., 1999; Sala et al., 2009). The traditional rigging in flume tanks, with the otter board held in place by cables, results in low positioning accuracy and force measurements lack in precision. Modern flume tank facilities have improved on traditional techniques (SINTEF Fisheries, Hirtshals) by plunging the otter board in a precise orientation and measuring forces and moments with a six component balance. The downside is their operation cost and the inability of reaching water speeds that ensure dynamical similarity with real conditions. Wind tunnel testing has seldom been used in analysing trawl door hydrodynamics (Crewe, 1964; Stengel and Hartung, 1964; Patterson and Watts, 1986; Reite and Sorensen, 2006; Mellibovsky et al., 2014), despite a number of evident advantages. The use of wind tunnel facilities is a natural step that follows the analysis of trawl doors in the framework of underwater flight mechanics (Crewe, 1964; Schumacher, 1974; Paschen, 1981; Patterson and Watts, 1985).

To achieve dynamic similarity with a given otter board model, the balance in a flume tank has to endure forces six times those in a wind tunnel. Although the power required to drive the water through the flume tank is about half that required in a wind tunnel of equal cross-section, the fact is that flume tanks are invariably much larger in order to be able to accommodate tests of other marine equipment, such as fishing nets, making them oversized for otter board testing, which entails unreasonably large power consumption.

Otter board hydrodynamics at sea are extremely difficult to test and very few studies have attempted at measuring forces in real operation (Sala et al., 2009). Numerical modelling with CFD is a powerful alternative to produce hydrodynamic coefficients, but is computationally very costly and still needs experimental validation (Vincent et al., 2006; Jonsson, 2012; Takahashi et al., 2013).

In this paper we explore the potential benefits of exploiting wind tunnel facilities in analysing trawl door hydrodynamics, taking advantage of the ability to accurately set wind velocity and otter board orientation and to measure forces and moments in all three axes. We set up a methodology that can be exploited generally and exemplify it with a production pelagic otter board that we test at the wind tunnel facility of MariKom in Rostock, Germany. The paper is then structured as follows: the methodology for wind tunnel operation and data obtention is described in Section 2.1, together with reference frame definitions and similarity considerations for experimental validity. Section 2.2 is devoted to data processing and hydrodynamic performance parameters extraction. Test results for a production otter board are presented in Section 3 and compared with flume tank results available in the literature. Finally, in Section 4 we summarise the pros and cons of wind tunnel exploitation and provide some recommendations for future development.

2. Material and methods

2.1. Wind tunnel testing methodology

Analysing otter board designs via wind tunnel testing requires careful planning. Geometrical data of the trawl door model that will be tested sets the basis for deciding on how the wind tunnel is to be operated. This data, along with wind tunnel and balance specs, must be used to exploit experimental data in a meaningful way.

In this section we provide the model and wind tunnel data that is relevant to such tests, along with some similarity considerations that must be taken into account to guarantee the validity of the experiments. The analysis procedure is described in detail.

While most of the methodology discussed is generic to any wind tunnel test of an otter board, some details are specific to the particular wind tunnel setup. In our case, the experiments were performed in the MariKom (http://www.marikom.uni-rostock.de/en/) wind tunnel facilities, located at the Rostock University campus in Germany. The wind tunnel is of the Göttingen construction type (also known as Prandtl type or closed return wind tunnel) and provides a three-axes positioning system and a six-component balance for force and moment measurement.

2.1.1. Trawl door model data

The model is a scaled faithful version of the full-size trawl door. A number of geometrical parameters of the model need be considered for data processing. These parameters are summarised in Table 1 and shown in Fig. 1a. Our tests will be demonstrated on a Thyborøn vf 15 pelagic trawl door (http://www.thyboron-trawldoor.dk/), whose specific dimensions will be duly introduced in Section 3.

The span line (b) is defined as the straight line connecting both flap tips at their respective trailing edges. The pseudo-symmetry plane is then the plane orthogonal to the span line that contains the intersection of the flaps. The chord line (l) is the straight line connecting leading and trailing edge on the pseudo-symmetry plane.

2.1.2. Reference frames and wind tunnel test data

Three different frames of reference are required to properly analyse trawl door hydrodynamic behaviour and wind tunnel results. The Earth or, in our case, wind tunnel reference frame is defined as $\mathcal{E} = \{\mathbf{E}; \mathbf{x}_e, \mathbf{y}_e, \mathbf{z}_e\}$, with the origin $\mathbf{E}$ on the balance attachment point and, to construct the orthonormal basis, $\mathbf{x}_e$ follows the streamwise direction of the wind tunnel, pointing forward, $\mathbf{y}_e$ follows the horizontal spanwise wind tunnel direction,