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Phase-averaged mean properties of turbulent flow developing around a fluttering sheet of net

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ABSTRACT

Time-Resolved Particle Image Velocimetry (PIV) measurements are performed to investigate the hydrodynamic flow interaction with a representative piece of fishing net structure. Using the advanced post-processing mathematical tool based on Proper Orthogonal Decomposition, the phase averaged mean properties of turbulent flows are extracted from PIV database, demonstrating the existence of a Turbulent Boundary Layer (TBL) flow developing all around the sheet of net. The results also show that the mesh opening and so the turbulent flow passing through the structure are strongly influenced by the structure oscillations. This work allows us to demonstrate that the drag computation of fishing gear, commonly based on uniform velocity, needs to consider not only the local velocity deficit near the horizontal part of the net but also the instantaneous oscillations of the sheet of net.

1. Introduction

The mesh fishing structures and their flow interactions play an important role in the fishing vessel energy efficiency due to the impact of the drag force on fuel consumption (Germain et al., 2010). Commonly, computations of drag force have been carried out by using empirical formulations using the towing velocity as a reference water velocity (Priour, 2009), assumed that water flow inside the net is equal to the corresponding towing speed, even if it is well admitted that the flow speed inside the cod-end is smaller than the one outside the cod-end and also than the towing speed. These small velocity differences may lead to some modifications in local drag force estimations. The fishing structure drag force determination remains today complex due to the fluid/structure interactions that induce large deformation and oscillations of the net and modifies instantaneously the local drag force (Zheng and Zhang , 2008; Liu et al., 2012).

It is also now clear that turbulent flow developing inside cod-end structure has a significant impact on fish behavior and then on selectivity. Engaas et al. (1999) showed that a modification of water flow in the trawl cod-end leads to improve the fish escapement. They also showed that the trawl geometry has a non-negligible effect on selectivity. This can be related to the work of O'Neill et al. (2003) who illustrated the effect of cod-end pulsing on selectivity. Previous analyses mainly based on one point measurement (Kim, 2012, 2013) shown the effect of turbulence on maneuvering of fish swimming and also on potential use of active stimulating device. Very recently, Time Resolved PIV (Particle Image Velocimetry) measurements have been carried out to investigate the flow around an oscillating cod-end model (Bouhoubeiny et al., 2011). It has been emphasized the turbulent flow interaction with the fluttering cod-end structure. Nevertheless, the analysis of the turbulent flow inside a cod-end is quite complex. In a realistic flow configuration, a full investigation of the 3D turbulent flow interacting with the fishing net structure is not possible not only numerically but also experimentally.

We propose in this study to experimentally investigate the turbulent flow interacting with a representative piece of fishing net structure, even if such structure does not correspond to any real fishing gear. However, such preliminary study will permit to elucidate the hydrodynamic behavior of such a simplified structure which is not fully understood and for which accurate predictions still remain today difficult. It is then expected that present results would have several implications in a more realistic flow configuration. Present analysis related to a simplified piece of fishing net structure allows the investigation of different turbulent flows developing around an arbitrarily oscillating fishing net structure: (1) the boundary layer developing around the horizontal part and (2) the turbulent flow passing through the inclined one. Using the advanced post-processing tool based on Proper Orthogonal Decomposition (POD) (Druault et al., 2012; Lumley,

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1967), the phase averaged mean properties of these flows are examined as a function of multiple parameters such as structure oscillations and porosity.

After the description of the experimental facility in Section 2, preliminary analyses of instantaneous velocity measurements are presented and the POD phase-averaged operator is briefly detailed. In Section 3, POD analysis is detailed. Then in Sections 4 and 5, TBL flows and turbulent flow passing the curved part of the fishing structure are successively analyzed as a function of structure motion.

2. Description of PIV measurements and post-processing tools

2.1. Experimental set-up

Experiments are carried out in the IFREMER (French Institute for the Exploitation of the Sea) wave and current circulation flume tank (Pichot et al., 2009; Bouhoubeiny et al., 2011). A rectangular sheet of net of 3 m length by 2 m width (120 meshes length by 80 meshes width) is used. The sheet of net is made of polyamide twine of 2.2 mm diameter and diamond-shaped meshes $l=22$ mm (the length of the meshes between two knots). It is maintained in the tank only by two ropes, so the structure is free to move in the water flow (Fig. 1, top). In order to obtain a shape having incidence changes encountered on real trawl, the sheet of net is mounted on a rectangular rope canvas like shown in Fig. 1 (bottom). Even if the

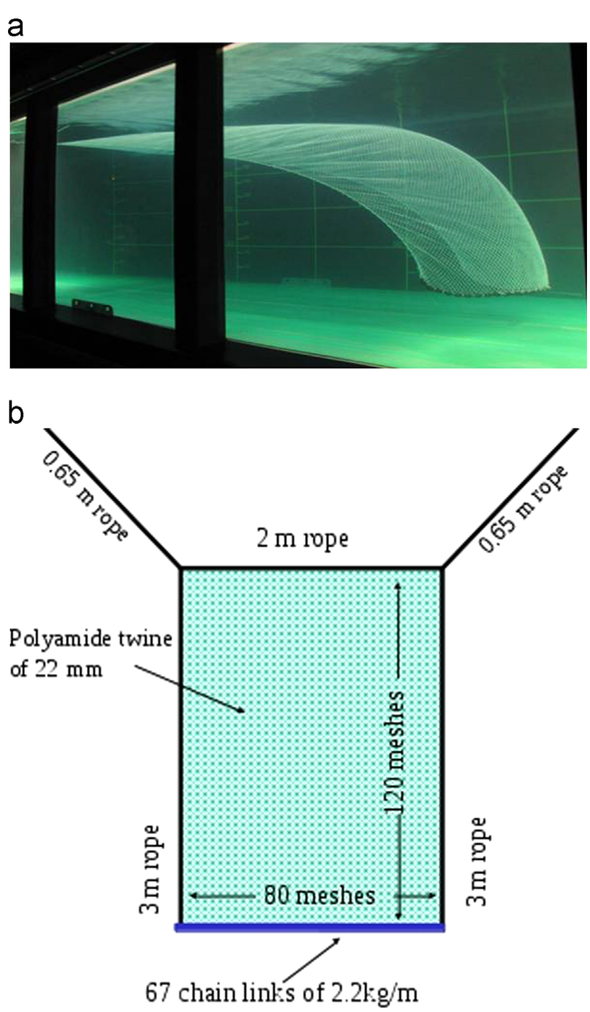

Fig. 1. Top: sheet of net located in the flume tank during trials at 0.85 m/s. Bottom: description of the sheet of net assembly.

free downstream end of the sheet of net plays a dominant role in the oscillatory behavior of the structure, the structure motion is mainly two-dimensional with a maximum vertical amplitude less than 10 cm. The 3*D* deformation of the sheet of net leads mainly to a 2*D* motion of the net knots in the vertical measurement plane (symmetrical axis of the structure).

An input streamwise velocity of $U_\infty = 0.85\ \mathrm{m\,s^{-1}}$ is imposed with a turbulence intensity rate (*TI*) of 3%, with:

$$TI = \frac{\sqrt{\frac{1}{3}(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})}}{U_\infty} \quad (1)$$

where an overbar indicates the classical Reynolds time average and the fluctuating parts of the velocity field are indicated with a prime index. Note that the time average transverse and spanwise velocity component are null. The corresponding data have been measured with a 2D Laser Doppler Velocimetry system in two steps to acquire the three velocity components, in the far field where the flow is uniform.

The corresponding Reynolds number based on the diamond-shaped meshes and the upstream velocity U_∞ is given by

$$Re_\infty = \frac{U_\infty l}{\nu} \quad (2)$$

where ν denotes the fluid kinematic viscosity, $\nu \approx 10^{-6}\ \mathrm{m^2\,s^{-1}}$. The studied Reynolds number is then 17,600.

2.2. PIV measurement system

The two-dimensional PIV system is used to determine the streamwise u and transversal v velocity components along respectively the x and z directions. Seeding particles (silver-plated glass spheres of 15 μm diameter) are introduced in the water and illuminated by a standard, frequency-doubled, double-cavity Nd: YAG laser (NewWave, Gemini PIV) with a pulse energy of up to 120 mJ per pulse at 532 nm, and a maximum repetition of 15 Hz. A CCD camera with a 60 mm focal lens coupled to a PC running image acquisition software is used to acquire images. The physical area of approximately 0.38 m by 0.28 m is imaged onto 1600 by 1200 pixels^2. The final interrogation window size is 16×16 pixels^2 with a 50% overlap. Then, an interpolation based on the 3×3 neighbors replaces false vectors. In each instantaneous PIV image, $n_x \times n_z = 199 \times 149$ instantaneous velocity vectors are finally provided with a spatial resolution of 1.9 mm in both directions. Details about the PIV system and its associated post-processing algorithms can be found in Bouhoubeiny (2012).

PIV measurements are carried out in several 2D planes shown in Fig. 2. These overlapped planes are located in the vertical median plane of the sheet of net. Note that along the horizontal

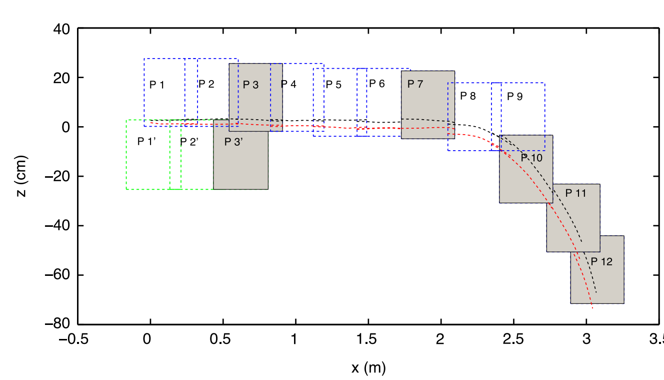

Fig. 2. PIV measurement planes with the highest (black dashed line) and lowest (red dashed line) locations of the fluttering structure. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)