PDG/REM/RDT/LCSM
Maria Ikhennicheu • Grégory Germain • Benoît Gaurier
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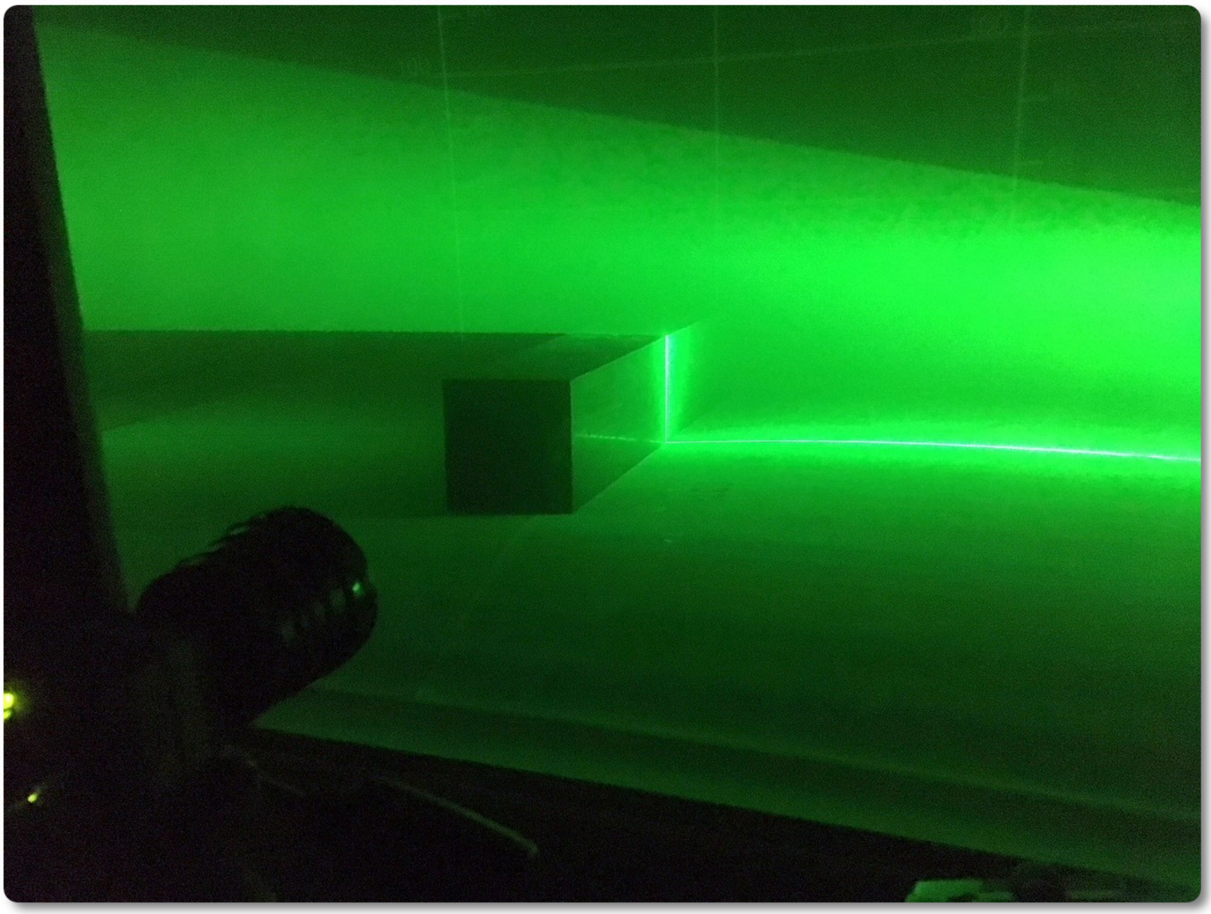
EXPERIMENTAL DATABASE OF THE FLOW PAST A WALL-MOUNTED SQUARE CYLINDER

Description of the dataset



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In high flow velocity areas like those suitable for tidal applications, turbulence intensity is high and flow variations may have a major impact on tidal turbines behaviour. Large boils that can be observed at the sea surface are emitted from the sea floor and may interact with the tidal turbine. These boils have then to be characterized. The Reynolds number, based on the rugosity height and mean flow velocity, is rather high in this context: $R_e = 2.5 \times 10^7$. For that purpose, experiments are carried out in a flume tank with R_e as high as achievable in Froude similitude (in the tank: $Re = 2.5 \times 10^5$ and $Fr = 0.23$) in order to study coherent flow structures emitted behind seabed obstacles. The obstacle is here a canonical square wall-mounted cylinder chosen to be representative of specific *in-situ* bathymetric variations. Using PIV and LDV measurements, the flow past the cylinder is investigated. The database created is presented in this report.

Mots clés / Key words :
turbulence, tidal turbine, wall-mounted square cylinder, wave and current flume tank, IFREMER, PIV, LDV

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Introduction

Turbulence can have a major impact on the tidal turbines behaviour, on their production [2] and on the structural fatigue [6]. Before trying to reproduce complex bathymetric structures, we chose to introduce the topic by studying elementary obstacles representative of real life condition.

The present report details the database used for the article [4] where the wake of a wall-mounted cylinder representative of seabed element is studied. Large turbulent events, generated in the cylinder wake are such that they can rise up to the surface and create a boil. The database has been achieved for PIV and LDV measurements in order to characterize the flow past the cylinder is investigated. Using a POD filter, large coherent structures can be identified and their trajectories can be analysed. By means of a Lamb-Oseen profile approximation, properties of these structures can be determined. The formation mechanism of such structures is discussed in a specific paper and their behaviour is characterized [4].

1 Experimental facility

The tests are carried out in the wave and current circulating flume tank of IFREMER located in Boulogne-sur-Mer (France) and described in [3]. The test section is: $18m$ long $\times$ $4m$ wide $\times$ $2m$ high. In this work, the three instantaneous velocity components are denoted (U, V, W) along the (X, Y, Z) directions respectively (Fig.1). The incoming flow $(\overline{U_\infty}, \overline{V_\infty}, \overline{W_\infty})$ is assumed to be steady and constant. By means of a grid and a honeycomb (that acts as a flow straightener) placed at the inlet of the working section (see Fig.1), a turbulent intensity of $I = 1.5\%$ is achieved for a flow velocity of $1m/s$. Turbulence intensity I in the incoming flow is defined as follows:

$$I = 100\sqrt{\frac{\frac{1}{3}(\overline{u'^2} + \overline{v'^2} + \overline{w'^2})}{\overline{U_\infty}^2 + \overline{V_\infty}^2 + \overline{W_\infty}^2}} \tag{1}$$

The obstacle of interest in this study is a wall-mounted cylinder of aspect ratio $A_R =$ Width/Height $= 6$, its dimensions are $H \times 6H \times H$ with $H = 0.25m$. This element represents a key bathymetric element in the area of interest at a 1:20 scale. As there is no obstacle upstream of the cylinder: the upstream flow is a simple boundary layer (δ) developing over the tank floor. At the obstacle position, the boundary layer height δ is calculated as $\delta_{95} = z(\overline{U} = 0.95\overline{U_\infty})$. It yields $\delta/H = 1.3$. Experiments are achieved at $F_r = 0.23$, $F_r = \frac{U_\infty}{\sqrt{gD}}$, with g the gravity and D the tank depth and at $R_e = 2.5 \times 10^5$, $R_e = \frac{HU_\infty}{\nu}$, with ν the kinematic viscosity of water.

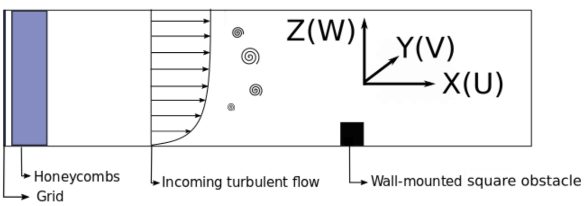


Figure 1 – Schematic view ot the experimental set-up

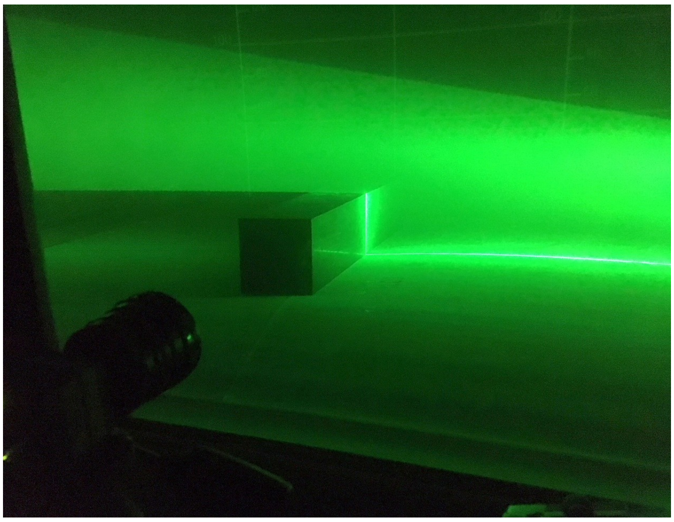


Figure 2 – Cylinder during PIV measurements

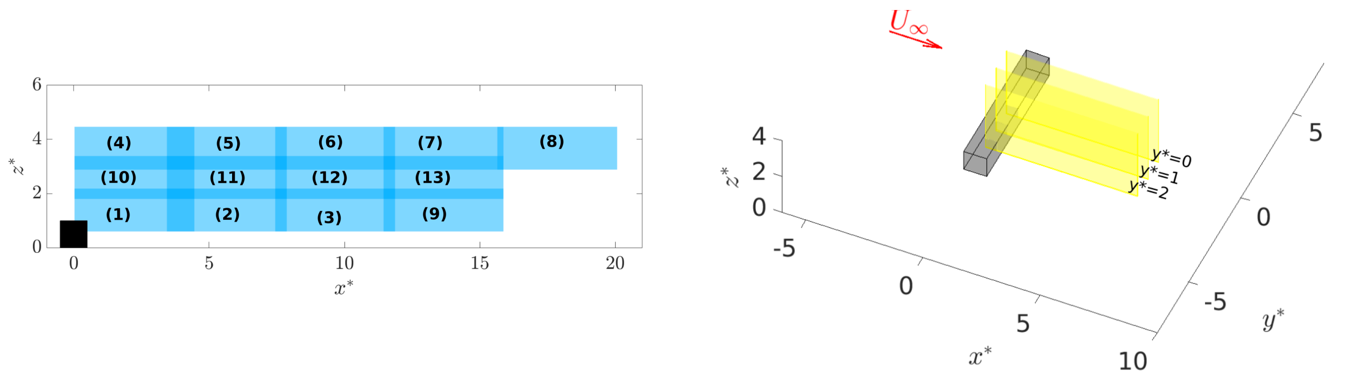
2 Instrumentation

To characterize the flow, two Laser Velocimetry techniques are used: LDV (Laser Doppler Velocimetry) and PIV (Particle Image Velocimetry): see Fig.2. Beforehand, the tank is seeded with $10\ \mu m$ diameter silver coated glass micro-particles. For the PIV measurements, a Nd-YAG Laser GEMINI-LIKE is used: power is $200\ mJ$ per probe and wavelength is $532\ mm$. The laser is synchronized with a Camera FLOWSENS EO-2M 1600pix $\times$ 1200pix that makes double images with a time step of $1600\ \mu s$. PIV acquisitions are made for $150s$, hence 2250 double images are taken with a $15H_z$ acquisition frequency. The data are post processed with the software DYNAMIC STUDIO. The displacement of particles is calculated using a Cross-Correlation on 32pix $\times$ 32pix interrogation windows with 50% overlap [5]. Outliers are replaced with the Universal Outlier Detection [7]. Depending on the plane, from 1% to 13% of the total vectors number are substituted. Single-pass method is used as, in our case, multi-pass adaptive PIV leads to errors generating artefacts rather than improving resolution. PIV measurements are carried out at various transverse positions: $y/H = 0$, $y/H = 1$ and $y/H = 2$ summarized in table 1 and represented in Fig.3(b). Fig.3(a) shows the 13 measurement planes carried out for each transverse position. In the tank, using a wide angle lens for a large surface detection, only vertical PIV measurement planes can be achieved. Hence, only 2D measurements of (U, W) are performed in this study. The experimental set-up allows measurements for $z/H \in [0.5; 7]$.

Plane	Field $[pix^2]$	Field $[mm^2]$	Spatial discretization $[mm]$
$y/H = 0$	1600×600	1153×430	11.6
$y/H = 1$	1600×600	1250×470	12.6
$y/H = 2$	1600×600	1360×510	13.7

Table 1 – PIV measurement characteristics

The LDV measurements are made using a 2D DANTEC FIBERFLOW system with wavelengths of 532 and $488nm$. The probe is positioned horizontally for (U, V) measurements at various streamwise positions along the Z axis. With LDV measurements, the acquisition frequencies are not constant. It depends on the number of particles passing through the measurement volume. Then, a re-sampling is done in the post processing. Based on previous works performed in the tank [1], the re-sampling is done using the mean sample rate of the set of



(a) **(b)**

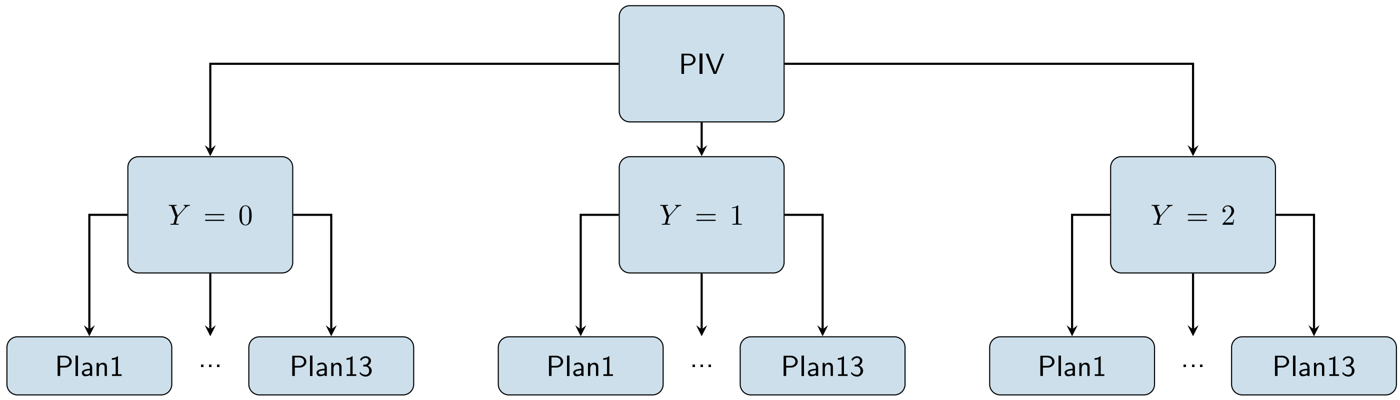
Figure 3 – PIV measurement planes locations (in the symmetry plan $y/H = 0$ for (a)) in the wake of a wall-mounted cylinder. Origin is taken at the middle of the bottom face of the cylinder

measurements considered. At a specific streamwise position, f_e varies from 70 to 270 H_z depending on the turbulent agitation. For the measurement techniques, uncertainty is estimated to be around 2% for LDV and 2.6% for PIV [4].

3 Available database

3.1 PIV

PIV repertory is organized as follow:



Each of the "Plan*i*" repertory contains 2250 *.dat, one for each acquisition. Every file contains information obtained after Cross-Correlation and Universal Outlier Detection. Every file contains a (3564×4) matrix, 3564 is the number of data point in the measurement plane (99×36) and 4 corresponds to (X, Z, U, W) calculated at each data point. Distance are given in mm and velocities in m/s.

In order to properly position the planes, one must add the following matrix for origin position (in $[mm]$):

X	1470	2350	3380	1420	2300	3330	4221	5300	4271	1420	2300	3330	4221	900
Y	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Z	25	25	25	595	595	595	595	595	25	440	440	440	440	140

3.2 LDV

LDV profiles are performed at the following streamiwse positions: $x/H = 0, 1, 3, 5, 7, 9, 11$ and z/H positions are listed in the following table and represented in the figure:

$x/H = 0$	$x/H = 1$	$x/H = 3$	$x/H = 5$	$x/H = 7$	$x/H = 9$	$x/H = 11$
	0.1	0.1	0.1	0.1	0.1	0.1
	0.2	0.2	0.2	0.2	0.2	0.2
	0.4	0.4	0.4	0.4	0.4	0.4
	0.6	0.6	0.6	0.6	0.6	0.6
	0.8	0.8	0.8	0.8	0.8	0.8
1	1	1	1	1	1	1
1.1						
1.2	1.2	1.2	1.2	1.2	1.2	1.2
1.3						
1.4	1.4	1.4	1.4	1.4	1.4	1.4
1.5						
1.6	1.6	1.6	1.6	1.6	1.6	1.6
1.8	1.8	1.8	1.8	1.8	1.8	1.8
2	2	2	2	2	2	2
				2.2		2.2
2.4	2.4	2.4	2.4	2.4	2.4	2.4
				2.6		2.6
2.8	2.8	2.8	2.8	2.8	2.8	2.8
				3		3
3.2	3.2	3.2	3.2	3.2	3.2	3.2
				3.4		3.4
3.6	3.6	3.6	3.6	3.6	3.6	3.6
				3.8		3.8
4	4	4	4	4	4	4
				4.2		4.2
4.4	4.4	4.4	4.4	4.4	4.4	4.4

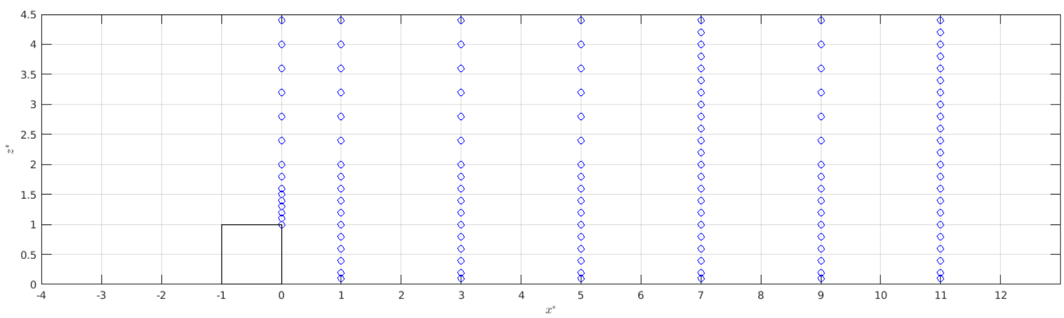


Figure 4 – LDV measurement points

Repertory LDV is simply divided into 7 repertories for each streamwise position. In these repertories, *.txt files are organized from the lowest z/H to the highest. Every file contains a $(N_t \times 7)$ matrix, N_t the number of data point which varies depending on the datarate. The 7 rows correspond to: the line number, the time step for V, the datarate for V, the V value, the time step for U, the datarate for U and the U value. Time is given in ms and velocity in m/s. Note that U and V acquisitions are not synchronized (choice of the author to have a higher datarate). Hence, U and V vectors lengths is different.

4 Example of results

Using PIV measurements , velocity maps can be plotted. LDV measurements are rather used for temporal and spectral analysis due to the higher frequency resolution. Results and further analysis on this specific test case can be found in [4].

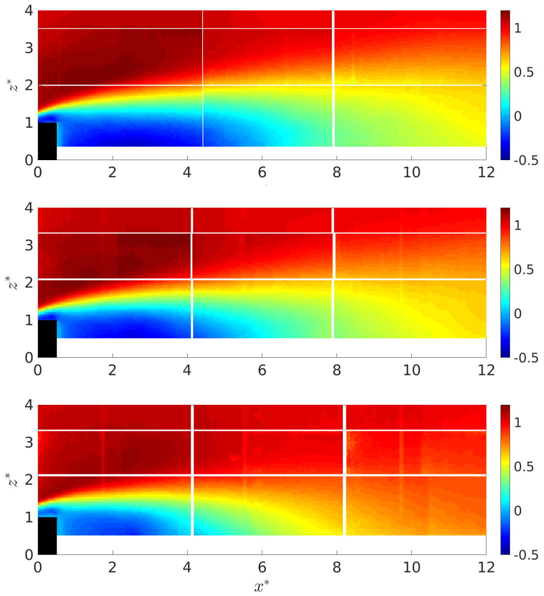


Figure 5 – $\overline{U}/U_\infty$ maps in plane $y0$ **(top)**, $y1$ **(middle)** and $y2$ **(bottom)**. White parts indicate the different PIV measurement planes separation.

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