PDG/REM/RDT/LCSM
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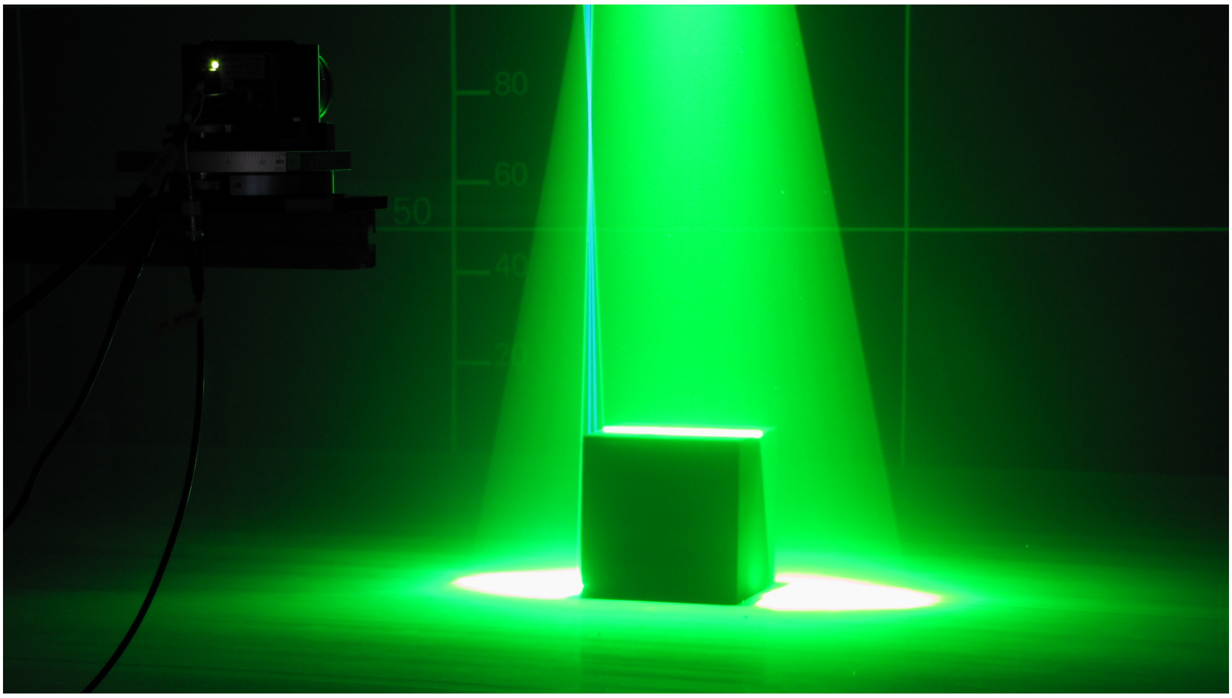
# EXPERIMENTAL DATABASE OF THE FLOW PAST A WALL-MOUNTED SQUARE CUBE

## Description of the dataset



# Fiche documentaire

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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 turbulent structures are present in the water column and may interact with the tidal turbine. 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 the wake past seabed obstacles. The obstacle is here a canonical square wall-mounted cube chosen to be representative of specific *in-situ* bathymetric variations. To represent the variability of turbulent *in-situ* conditions, different upstream turbulence rate are achieved. Using PIV and LDV measurements, the flow past the cube is investigated. The experimental database is presented in this report.



**Mots clés / Key words :**
turbulence, tidal turbine, wall-mounted square cube, 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 [7]. 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 cube representative of seabed element is studied. The database has been achieved for PIV and LDV measurements in order to characterize the flow past the cube.

# 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. The origin is taken at the centre of the bottom face of the cube. Turbulence intensity $I$ in the incoming flow is defined as follows:

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

According to the experiments carried out in the same tank [7], the natural ambient $I$ in the tank is $14\%$ (this case has to be considered as a degraded case). By means of grid and honeycomb (that acts as a flow straightener) placed at the inlet of the working session (see fig. 1), lower $I$ can be achieved: $I = 1.5\%$ using the grid and the honeycomb and $I = 4\%$ using only the honeycomb.

The obstacle of interest in this study is a wall-mounted cube of height $H = 0.25m$. 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 $(\delta)$ developing over the tank floor. At the obstacle position, the boundary layer height $\delta$ is calculated as $\delta_{95} = z(\overline{U} = 0.95\overline{U_\infty})$. It yields $\delta/H = 1.3$. Experiments are achieved with an upstream velocity of $1\ m/s$, hence $F_r = 0.23$ ($F_r = \frac{U_\infty}{\sqrt{gD}}$, 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 $\nu$ the kinematic viscosity of water).

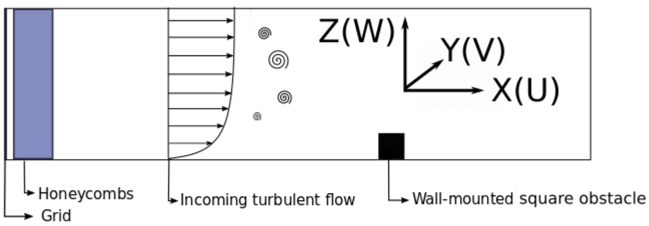



**Figure 1** – Schematic view of the experimental set-up

**Figure 2** – Cube during simultaneous PIV and LDV measurements, flow coming from the left.

# 2 Instrumentation

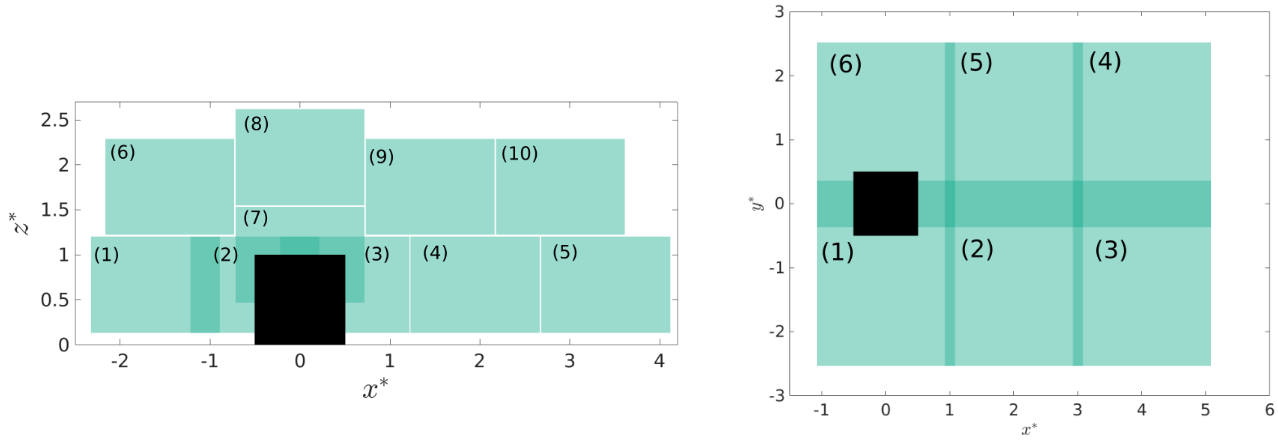
To characterize the flow, a Laser Velocimetry technique is used (see fig. 2(b)), the tank is seeded with 10 $\mu m$ diameter micro-particles. For the PIV (Particle Image Velocimetry) measurements, a Nd-YAG Laser GEMINI-LIKE is used with a Camera FLOWSENS EO-2M 1600pix $\times$ 1200pix that makes double images with a time step of 800 $\mu s$. A particle is detected on 3 to 5 pixels. PIV acquisitions are made for $150s$, hence 2250 double images are taken with a $15H_z$ acquisition frequency. In [4], the data are post processed with the software DYNAMIC STUDIO. To get rid of noise, the mean image is first subtracted to all images. Then, the displacement of particles is calculated using a Cross-Correlation on a 32pix $\times$ 32pix interrogation windows with 50% overlap [6]. Outliers are replaced with the Universal Outlier Detection [8], depending on the plane, from 1% to 13% of the vectors are substituted. Single-pass method is used as, in our case, multi-pass adaptive PIV leads to errors generating artefacts rather than improving resolution. Full post-processing process is detailed in [5]. Two configurations are used for the PIV measurements:

- for horizontal planes, the laser lightens the $(z/H = 0.7)$ plane of the fluid and the camera is placed above the obstacle, perpendicularly to the laser plane, trials were performed at $I = 1.5\%$ and $I = 15\%$,
- for vertical planes, the laser lightens the $(y/H = 0)$ plane of the fluid and the camera is positioned beside the obstacle, trials were performed at $I = 1.5\%$, $I = 4\%$ and $I = 15\%$.

| Plane | Field $[pix^2]$ | Field $[mm^2]$ | Spatial discretization $[mm]$ |
|---|---|---|---|
| Horizontal | $1600 \times 600$ | $400 \times 150$ | 4.04 |
| Vertical | $1600 \times 600$ | $350 \times 275$ | 3.53 |

**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 vertically for $(U, V)$ measurements at various streamwise positions along the Z axis and horizontally for $(U, W)$ measurements. With LDV measurements, the acquisition frequencies are not constant. It depends on the number of particles passing through the measurement volume. Based on previous works performed in the tank [1], re-sampling can be done using the mean sample rate of the set of measurements considered. At a specific streamwise position, $f_e$ varies from 20 to 200 $H_z$ depending on the turbulent agitation.




**(a)** Vertical measurement planes **(b)** Horizontal measurement planes

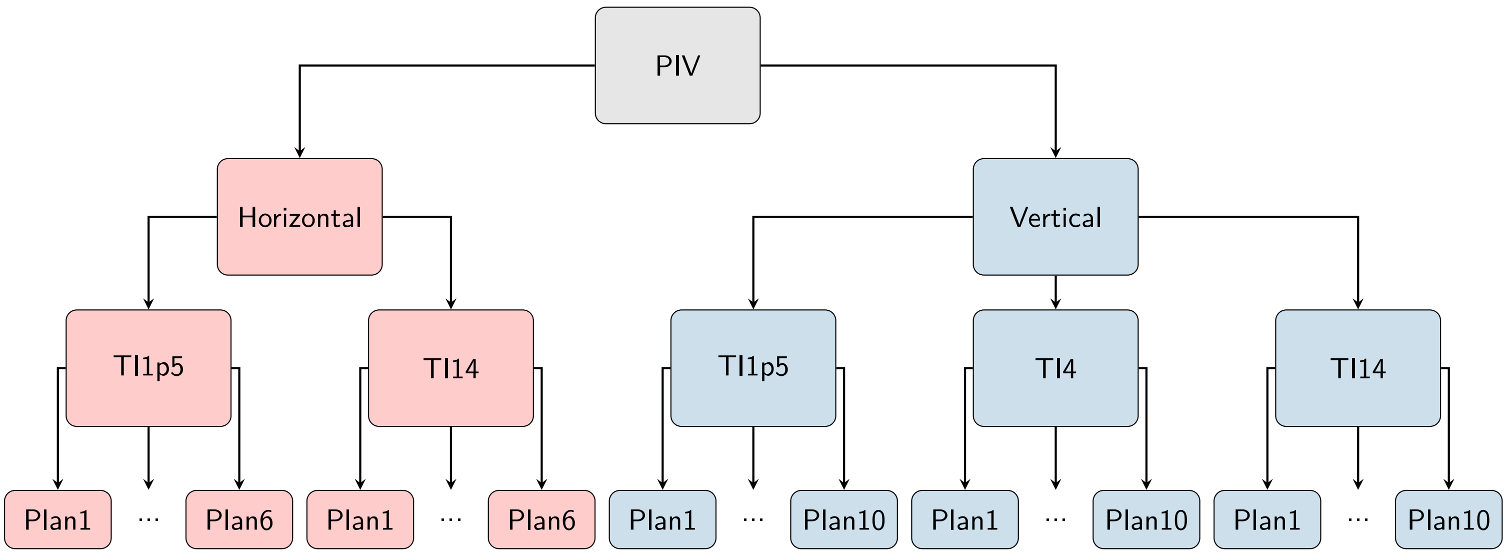
**Figure 3** – PIV measurement planes locations

For the measurement techniques, uncertainty is estimated to be around $2\%$ for LDV and $2.6\%$ for PIV [5].

# 3 Available database

## 3.1 PIV

PIV repertory is organized as follow (with TI1p5, TI4 and TI14) for respectively: 1.5, 4 and 14 % of turbulent intensity):




Each of the "Plan*i*" repertory contains 2250 files "*.dat": one for each acquisition. Every file contains information obtained after Cross-Correlation and Universal Outlier Detection. Every file contains a $(3564 \times 4)$ matrix, $3564$ is the number of data point in the measurement plane $(99 \times 36)$ 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 vertical planes, one must add the following matrix for origin position (in $[mm]$):

$$\begin{bmatrix} X & -460 & -183 & 67 & 429 & 792 & -420 & -58 & -58 & 304 & 666 \\ Y & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ Z & -220 & -220 & -220 & -220 & -220 & 51 & -137 & 134 & 51 & 51 \end{bmatrix}$$

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

$$\begin{bmatrix} X & 250 & 750 & 1250 & 250 & 750 & 1250 \\ Y & 85 & 85 & 85 & 625 & 625 & 625 \\ Z & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

## 3.2 LDV

LDV measurements are summed up in table 2. Points reference refers to the positions at which measurements were achieved. They will be detailed later on, all positions are given in $[mm]$. V (Vertical) means measurements along the $z$ direction in the symmetry plane of the tank and H (Horizontal) means measurements along the $y$ direction in the $z/H = 0.7$ plane. $UV$ (resp. $UW$) acquisitions means than the probe is positioned vertically (resp. horizontally) and the components $U$ and $V$ (resp. $W$) are measured. Acquisition time varies depending on the turbulent agitation at the measurement point.

| $I$ | H or V | $UV$ or $UW$ | Points reference |
|---|---|---|---|
| 1.5 % | V | $UV$ | Points1 |
| 1.5 % | H | $UV$ | Points3 |
| 1.5 % | H and V | $UW$ | Points5 |
| 4 % | H | $UV$ | Points2 |
| 14 % | V | $UV$ | Points2 |
| 14 % | H | $UV$ | Points4 |
| 14 % | H and V | $UW$ | Points5 |

**Table 2** – LDV measurements database

Points1 are performed for positions $x = -500, -375, -250, -125^*, 0^*, 125^*, 187, 250, 375, 500, 750$ and points2 for $x = -500, -250, 0^*, 250, 500$. For positions upstream or downstream of the cube, measurements are achieved at $z = 5, 10, 25, 50, 75, 100, 125, 150, 175, 200, 225, 250, 275, 300, 325, 350, 375, 400, 425, 450, 475, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, 1000$ and for measurements over the cube (indicated with a $^*$), measurements are achieved at $z = 225, 250, 275, 300, 325, 350, 375, 400, 425, 450, 475, 500, 550, 600, 650, 700, 750, 800, 850, 900, 950, 1000$. For all data points in Points1 and Points2, acquisitions last 2 minutes at $I = 1.5\%$ and $I = 4\%$ and 3 minutes at $I = 14\%$.

Points3 are performed at $x = 250, 500$ and for $y =$ **-50,0,25,50,75,100,125,150**, $200, 250, 300, 350, 400, 500, 600$. Acquisitions at positions in bold last 6 minutes and others last 4 minutes.

Points4 are performed at $x = 250, 500$ and for $y = -600, -500, -400, -350, -300, -250, -200, -150,$ **-125,-100,-75,-50,-25,0,25,50,75,100,125,150,200,250,300**$, 350, 400, 500, 600$ and again in the positive direction. At $x = -750$, acquisitions are performed at $y =$ **-600,-500,-400,-300,-200,-100,0**. Acquisitions at positions in bold last 6 minutes and others last 4 minutes.

Points5 is more complex and is summed up in the following array. **Bold** indicates an acquisition time of 6 minutes for $I = 1.5\%$ and $I = 14\%$, highlight indicates an acquisition time of 4 minutes for $I = 1.5\%$ and 6 minutes for $I = 14\%$ and underline indicates an acquisition time of 6 minutes for $I = 1.5\%$ and 4 minutes for $I = 14\%$.

Points5 =

| $x = -750$ | $x = 250, 500$ | |
|---|---|---|
| $z$ | $y$ | $z$ |
| **60** | −600 | **60** |
| 100 | −500 | **100** |
| 150 | −400 | **150** |
| 200 | −350 | 200 |
| 250 | −300 | 250 |
| 300 | −250 | 300 |
| 350 | −200 | 350 |
| 400 | −150 | 400 |
| 450 | −125 | 450 |
| 500 | −100 | 500 |
| 600 | **−75** | 600 |
| 700 | **−50** | 700 |
| 800 | **−25** | 800 |
| 900 | **0** | 900 |
| | **25** | |
| | **50** | |
| | **75** | |
| | **100** | |
| | **125** | |
| | **150** | |
| | **200** | |
| | **250** | |
| | 300 | |
| | 350 | |
| | 400 | |
| | 500 | |
| | 600 | |

Repertory LDV is divided into 5 repertories for each Points reference. Then, user can choose the turbulence rate and, for some cases, the direction of the measurements (Horizontal or Vertical). In final repertories, *.txt files are organized from the lowest $z/H$ (or $y/H$) 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 are 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].

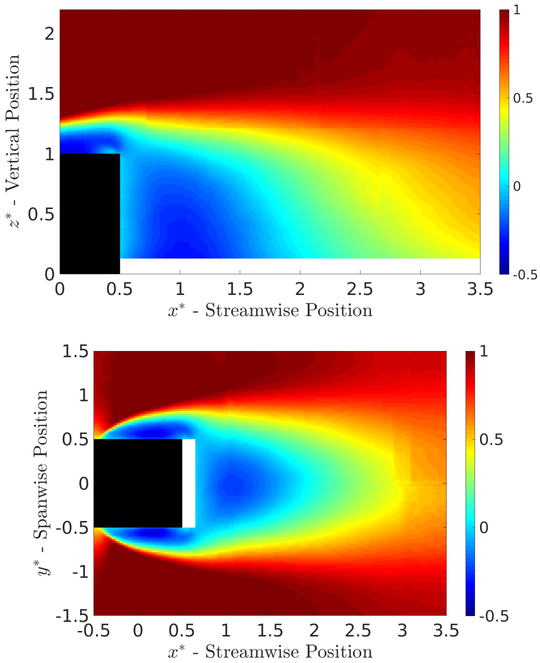



**Figure 4** – Vertical (top) and horizontal (bottom) averaged streamwise velocity at $1.5\%$ around the cube. Measurements planes are interpolated.

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