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STUDY OF DIFFERENT KIND OF TIDAL BORES IN LABORATORY

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ABSTRACT

Tidal bores stay the object of many investigations and some aspects remain always unknown. In this paper, we generate such type of flow in a laboratory to investigate the influence of different parameters as the water depth, the upstream velocity and initial conditions of boundary layer. Different kinds of moving bores have been generated for one Froude number Fr=1.29 and three initial boundary layer conditions. The water depth evolution does not seem to be affected by the boundary-layer conditions while the internal flow is significantly altered during the passage of the whelps depending on these conditions. The time evolution of the velocity fields is shown inside the water column and quantities like Reynolds stresses, the turbulent kinetic energy, and acceleration and pressure fields are evaluated from the TR-PIV and spatio-temporal filters of the data. The results show the influence of the different conditions and suggest that different kind of tidal bores could be measured on the field.

Keywords: *Tidal bores, Time-resolved PIV, Acceleration, Pressure, Boundary Layer.*

1. INTRODUCTION

Tidal bores in nature are well known in such places like the Dordogne river, the bay of Mont-Saint-Michel (France), the Dee River (United Kingdom), the Daly River (Australia) for examples. This natural phenomenon is characterized by a brutal rise of water level followed by series of waves propagating upstream for kilometers. Different approaches have tried to better understand the main parameters governing this physical event which appears only in some conditions. Historically, theorical and experimental studies have considered the evolution of the free surface to characterize the wave propagation. The amplitude and shape are function of the Froude number calculated from the initial conditions (water depth and upstream velocity) and the wave celerity (Barré de Saint-Venant, 1871, Lemoine, 1948, Benjamin and Lighthill, 1954, Chanson, 2010). In laboratory, the bore is more generally considered like a jump in translation which is generated by different ways like a rapid partial closure of a sluice gate situated at the downstream end of the flume or an opening of a reservoir which creates a reverse flow. These laboratory experiments allow the control of different parameters like the flow regime, the water depth, the boundary layer thickness, the initial flow turbulent condition. Several velocity measurements with the Acoustic Doppler Velocimetry (Koch and Chanson, 2009, Chanson, 2011, Chanson and Docherty, 2012, Huang et al, 2013) and the Particle Image Velocimetry (Hornung et al, 1995, David et al, 2014) are carried out coupled with water depth recording. Experiments are still necessary to better understand the wave propagation inside the water column. In this paper, time-resolved PIV measurements in an open channel are carried out to study the undular tidal bore (Fr=1.29) in laboratory conditions. Different flow conditions as the water depth, the upstream velocity and initial conditions of boundary layer are generated to see the influence on the Reynolds stresses, the turbulent kinetic energy, the acceleration and pressure fields evaluated from the TR-PIV and spatio-temporal filters.

2. EXPERIMENTAL SETUP

Experiments were performed in the L=8m long and B=0.4m wide flume built with glass walls of Pprime Institute. The details of the channel and the generation of flows could be found in David et al. (2014). Different inlet conditions of the flow have been generated: three boundary layer thicknesses, two water depths for two flow discharges and two flow turbulent states. The positive surge is generated by the rapid partial closure of a sluice gate situated at the downstream end of the flume. The sluice gate is operated from a monitored electro-pneumatic actuator and the water depth and the PIV measurements are trigged with the motion of the gate to synchronize the different acquisitions. At the gate closure, the water depth increases and induces the positive surge propagating upstream into the flume. The generation of the bore is established after 5m and the repeatability of the generation for different Froude numbers, different initial water depths and initial velocities have been validated (David et al., 2014). All the parameters are adjusted to obtain a Froude number of 1.29 based on the upstream velocity, the bore celerity and the initial water depth.

The water depth was measured with acoustic displacement meters (Microsonic mic+25/IU/TC) placed at -750, -125, 200, and 750 mm from the center of the PIV field (located at 1200mm from the end of the convergent). The accuracy of such sensors is 0.1mm. Both systems were synchronized with the gate closure. Four sensors were used for ensuring that the bore is well established and that its velocity is constant in the zone of measurement. Velocity measurements were made by a TR-PIV system composed of a mega-pixel fast camera (Photron SA-1) with a 50mm focal lens and a 527nm double pulsed 20mJ Nd:YLFQuantronix® laser with 250 Hz repetition rates were used. The vertical laser sheet was aligned with the center plane of the flume. The field of view was a 300mm wide square window. A period of 16 second was recorded; each run was also synchronized with the gate motion, providing 4000 images per run. To avoid the reflection of light on bubbles which causes the saturation of the camera sensors, the flow was seeded by 20µm PMMA particles of density 1.18 doped with Rhodamine-b and a high pass filter is placed on the camera's lens to record only the signal from the particles.

3. DATA PROCESSING

3.1 TR-PIV processing

The PIV image processing is composed by different steps. First, a masking procedure to blacken unnecessary parts due to some reflections close to the free surface is used. The water depth signals of the two probes just placed upstream and downstream the region of interest are employed to create a dynamic mask which is applied successively on the images. Then, the velocity fields are calculated from a TR-PIV algorithm (Jeon et al., 2014) based on a sequence of images and an ensemble fluid trajectory correlation (FTEE). A sequence of 9 images with a final window size of 32x32 pixels and 75% overlapping is used for the evaluation of a second order polynomial which allows also the acceleration estimation during the same processing.

3.2 Post-treatment of the velocity fields

From the velocity fields, Reynolds stresses, the turbulent kinetic energy, and pressure fields are evaluated. For the two first quantities, a spatio-temporal filter based on both the Variable-Time Interval Average and the local spatial average is defined to extract the components of the Reynolds tensor and for the evaluation of the turbulent kinetic energy in the plane of measurements. The total acceleration is estimated directly from the algorithm of the TR-PIV but the Eulerian acceleration is deduced from the velocity. Finally, the pressure field is calculated by integration from the pressure gradient Eq. [1] and by the atmospheric pressure condition in the free surface.

$$\nabla p = -\rho \frac{D\vec{V}}{Dt} + \mu \nabla^2 \vec{V} \qquad [1]$$

where p is the pressure and $\vec{V}$ the velocity vector.

4. RESULTS

The water depth evolution is not affected by the three different boundary-layer conditions. Time-resolved velocity measurements allow the observation of the flow during the arrival of the bore. Before the arrival of the bore, the boundary layer thickness is very different with the initial conditions and varies between 10% and 50% of the initial water depth. When the bore arrives in the field of view, a roller is present in the upper part of the wave. The increase of the water depth during the passage of the bore creates a pressure gradient which allows the development of the boundary layer. At the end of the passage of the wave, the pressure gradient is reversed and the thickness of the boundary layer decreases progressively but stays larger than its initial thickness. For the different conditions of the boundary layer, the expansion of the boundary layer is larger in the case of the more extended initial boundary layer. The flow seems to be more affected by the turbulence in this case and the velocity increases and decreases in the water column less progressively. In the case of the less developed boundary layer, the variations of velocity are very progressive during the passage of the bore.

Close to the bottom, no inversion of the flow is observed in this case (some other experiments for different flow conditions and Froude numbers have revealed an inversion of the flow) but when the boundary layer is larger, some vortices appear along the flume bed during the passage of the different whelps. The most intense vortex structure appears for the first water raise (Figure 1) but others occur for the successive whelps in the case of the larger initial boundary layer.

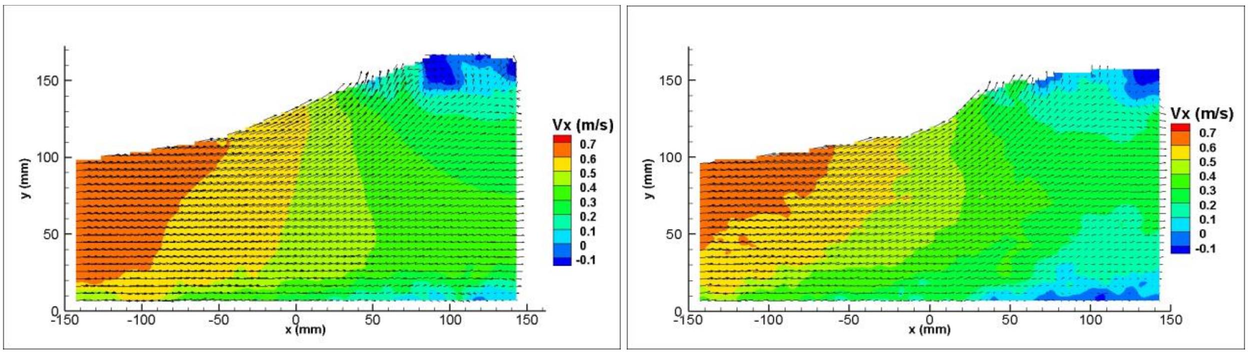

Figure 1. Streamwise velocity component for the two most developed boundary layers during the arrival of the bore

The Eulerian and Lagrangian acceleration fields have been calculated from the time-resolved velocity measurements. For these two quantities, the range of the values varies between -10 to 10 m/s². The streamwise component of the material acceleration (Figure 2) shows the deceleration of the flow in front of the bore and a small vertical acceleration followed by a deceleration when the first wave is created. This material acceleration could be directly linked to the pressure gradient.

The contributions of the different Reynolds stresses, of the turbulent intensity are also highlighted for the different boundary conditions.

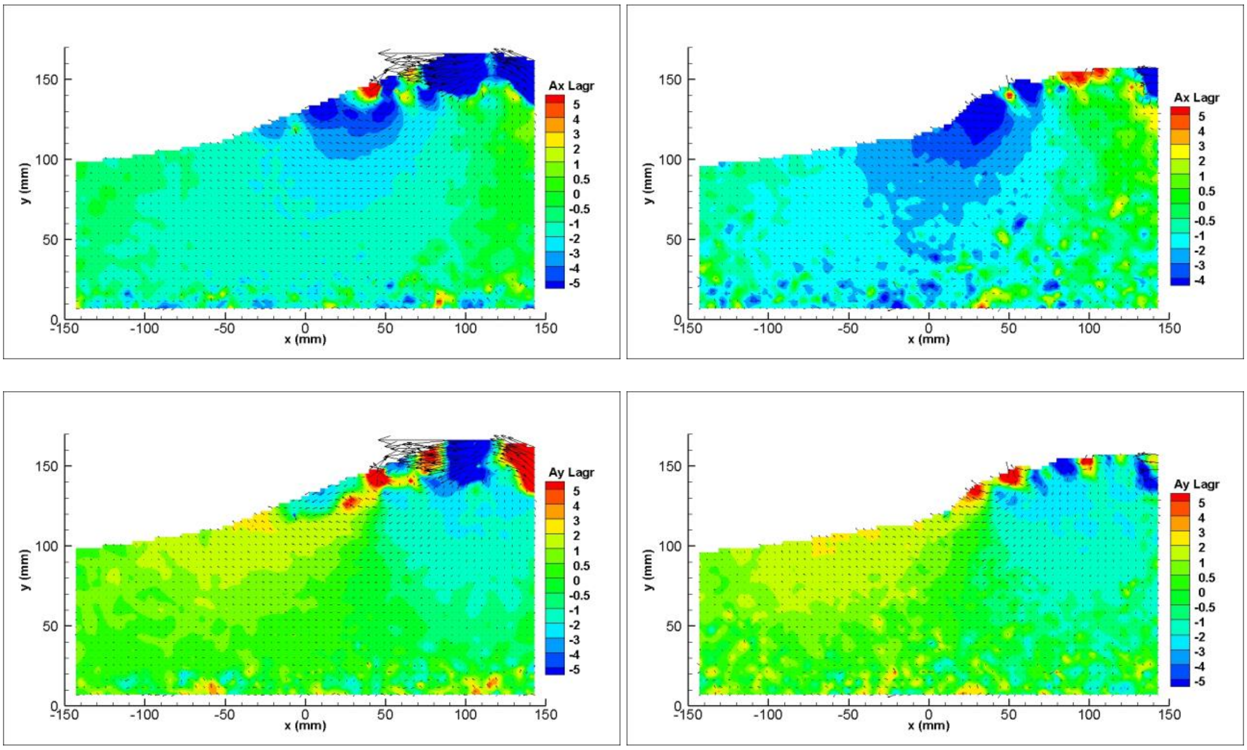

Figure 2. Material acceleration components for the two most developed boundary layers during the arrival of the bore

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