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PARTICLE IMAGE VELOCIMETRY CHARACTERIZATION OF ULTRASONIC TRANSDUCER-INDUCED FLOWS IN A WATER TANK

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Fluid: *water*
Visualization method(s): *Particle Image Velocimetry*
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ABSTRACT : *An experimental study of the determination of the velocity field in a water tank generated by an ultrasonic transducer is presented for different positions and input power values in order to estimate the intensity of convection heat transfer between water and the transducer. Particle Image Velocimetry has been used for its ability to deal with the transient character of the flows and for its non intrusive character. Results highlight the influence of the input power value on the intensity of the velocity field and also the great influence of the acoustic effect on the flow structure. This influence is more important for a focused transducer that generates an axial jet in the focusing zone. This study shows the prevailing influence of the acoustic effect on free convection effect when the transducer is powered and consequently the necessity of modeling the convection heat transfer with correlations for forced convection flow regimes.*

1 Introduction

Ultrasound is nowadays widely used in medicine as a diagnosis tool (scan) as well as a treatment tool for various internal surgical operations [1]. Two types of transducers are found depending on the shape of the ultrasonic waves: planar waves generator used for diagnosis devices and focused waves generator used for treatment devices. Transducers are made up of piezoelectric elements (ceramic) which are bound with a polymer. Ultrasonic waves are generated by monitored periodic electrical pulses applied to electrodes in contact with the piezoelectric elements. Electric energy is converted in this way into both mechanical and thermal energies. Production of thermal energy leads to the heating of the transducer and constitutes a source for mechanical stresses and deformations inside its heterogeneous structure, this harmful effect for the accuracy of the transducers' geometry being increased by the transient character of the heat production. So the control of the thermal behavior constitutes a major task for the improvement of the working safety of these devices.
Modeling the transient thermal field for various input conditions can help predict the stress distribution inside the transducer. For that purpose, it's essential to determine the thermal boundary conditions for the transducer in contact with fluids like air or water. Heat convection between the transducer walls and

the surrounding fluids can be modeled using correlations for the heat transfer coefficient, this one depending on the structure and intensity of flow and above all on its transient or developed character. Flow inside the water tank can be generated by free convection effects due to temperature difference between the transducer and the fluid, and also by acoustic effects in the vicinity of the transducer.
The aim of this paper is the experimental characterization of the velocity fields in the surrounding of a transducer in contact with water in a tank for different transducer positions and different input power values. This study constitutes the first step toward the final objective, i.e. the accurate determination of the convection heat transfer coefficient between the transducer and water. The transient character of the flow in the water tank when ultrasound begins to be emitted, the size of the domain where convection takes place and its non-intrusive character, have led to the choice of a PIV -Particle Image Velocimetry- system to perform these velocity fields determination [2,3].

2 Material and methods

2.1 Experimental setup

Ultrasound generation and propagation

The monitoring of the ultrasonic transducer (Fig. 1) consists of a current generator that generates a 1 MHz low level sine signal connected to a power amplifier with a 150W maximal output power. The transducer is connected to the power amplifier and to a power meter for the determination of the absorbed power.
The ultrasonic transducer has an active diameter of 35 mm, i.e. a 962 mm² active area. Its plastic housing is 50 mm in diameter and 20 mm long. Two kinds of transducers have been used: a planar one and a focused one with an 80 mm curvature radius concave face. The water tank is 50 cm long, 40 cm wide and 30 cm high and has been filled up with gas-free water, in order to avoid bubble formation during ultrasound emission. A hole in the middle of its lateral face allows to settle the transducer for horizontal emission. The water tightness is obtained with gasket. Once fixed on the tank, the emitting face of the active part is in the water while the rear face is in the open air (Fig. 2). For the vertical set up, the transducer is put on the tank lid and half immerged with a dedicated support (Fig. 4).

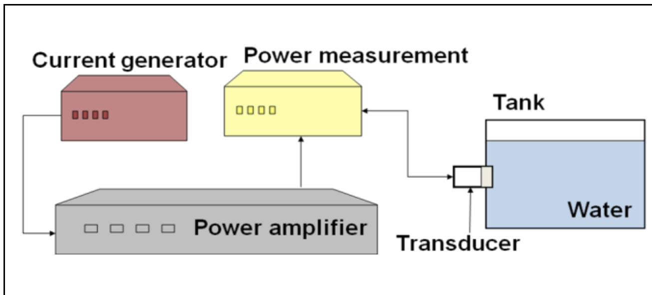

Fig. 1 : Sketch of the monitoring device

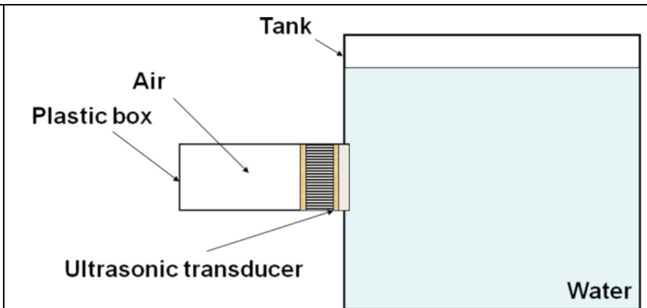

Fig. 2 : Water tank and transducer

Velocity measurements

The PIV system used to performed velocity field maps in the water tank consists of the following parts (Fig. 3):
- 40 µm in diameter Rilsan particles added to water as tracers.
- A Nd-Yag, double cavity, 532 nm pulsed laser which provides 25 mJ and 7 ns pulses.
- A combination of spherical and cylindrical lenses in order to create adjustable laser light sheets for the illumination of the measurement plane. This plane is vertical and passes through the transducer axis for both vertical and horizontal positions (Fig. 4).
- A 1024 X 1024 pixels intercorrelation camera which performs two 70 X 55 mm pictures corresponding to the double laser pulse and placed at right angles to the laser sheet.
- A computer for the setting of the emission and reception parameters, the image processing and the velocity field computation.

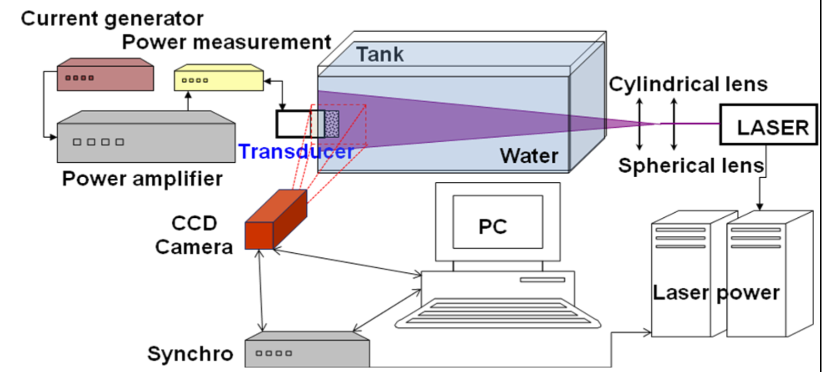

Fig. 3 : Sketch of the entire experimental setup

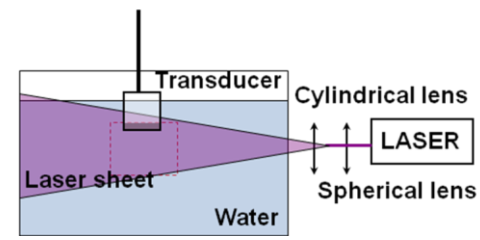

Fig. 4 : Laser arrangement for vertical transducer

2.2 Measurements

Velocity field determination has been performed for both planar and focused transducers, for both vertical and horizontal positions, corresponding to the direction of the transducer axis. Several input power values have been applied to the transducers and measurements have been performed for different time delays between the acoustic power release and the images capture. 25 image pairs have been recorded with a 4 Hz acquisition frequency for each parameters combination. Each pair has been used to extract an instantaneous velocity field. A post-treatment (filtering and mean values computation) of these fields leads to the determination of a mean velocity field for each configuration.

3 Results and discussion

3.1 Influence of the delay between ultrasound generation and image capture

For the testing of each set of parameters the water contained in the tank was initially at rest (Fig. 5). The use of different delays between the triggering of the planar acoustic transducer and the images capture has allowed us to evaluate the time necessary for the setting of the velocity field inside the water tank. Results have shown that steady state conditions are reached after 5 s. Figures 6, 7 and 8 present 0 s delay velocity fields for three electrical power values: 6.3 W, 12.4 W and 23.6 W. In each case the velocity field is already detectable even for the lowest power value. The velocity field corresponds to a horizontal symmetric jet flowing from the left wall of the tank wherein the transducer is mounted and the intensity of velocity vectors increases with the electrical power. Figures 9 and 10 present velocity fields after a 5 s delay. One can observe the greater diffusion of the velocity field around the central part of the jet when compared with the 0 s delay measurements. The thermal effect on the velocity fields remains low after 5 s.

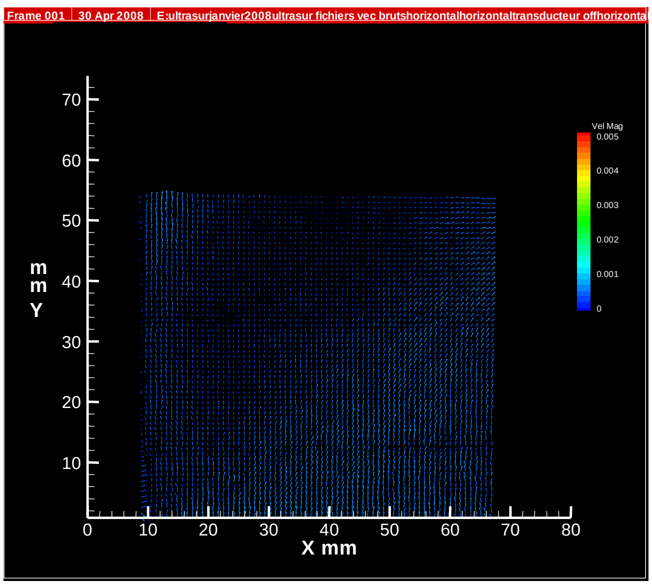

Fig. 5 : Fluid at rest

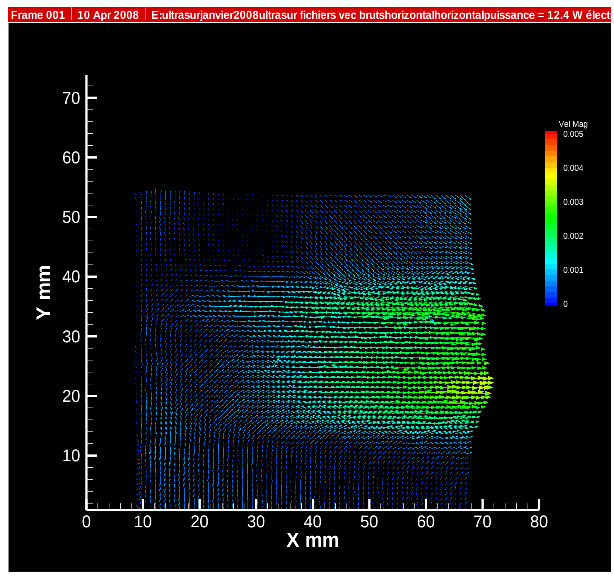

Fig. 6 : 0 s delay acquisition (6.3 W)

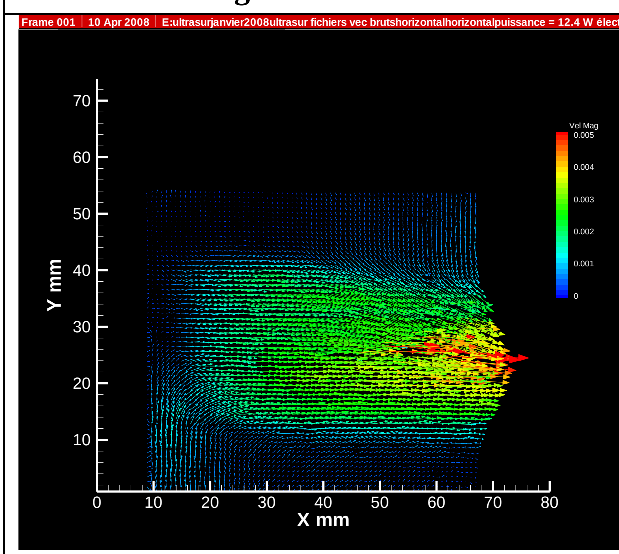

Fig. 7 : 0 s delay acquisition (12.4 W)

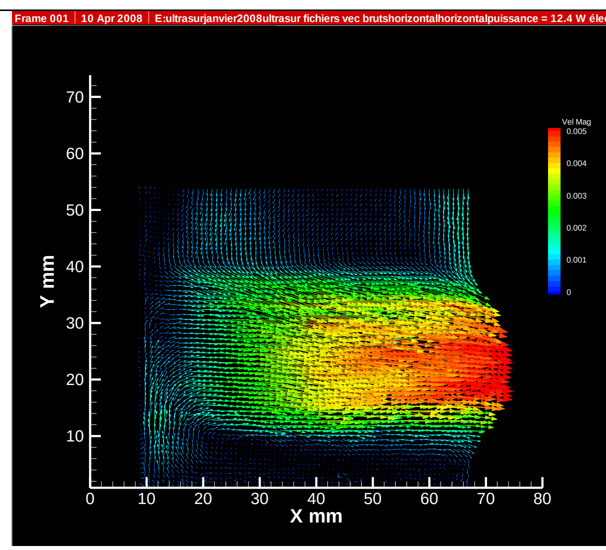

Fig. 8 : 0 s delay acquisition (23.6 W)

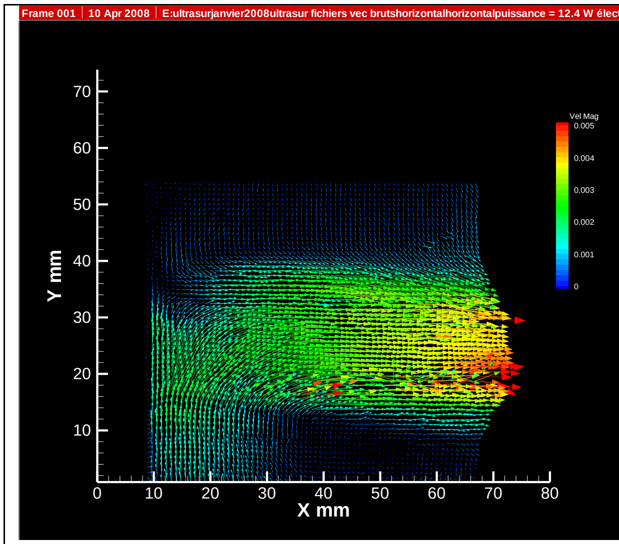

Fig. 9 : 5 s delay acquisition (12.4 W)

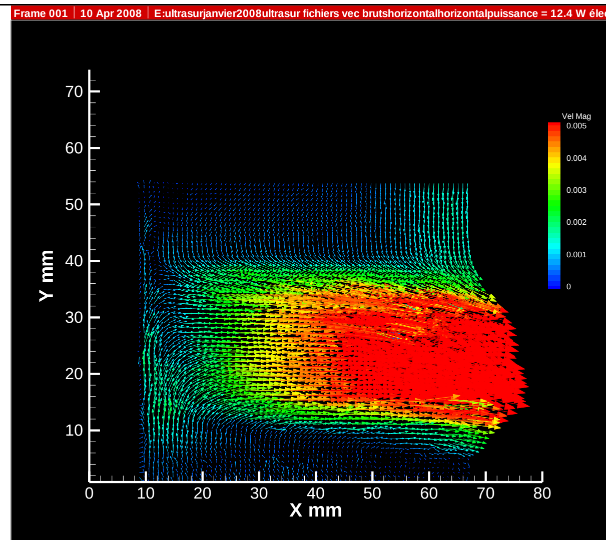

Fig. 10 : 5 s delay acquisition (23.6 W)

3.2 Influence of the input power

Different input power values have been applied to the focused acoustic transducer in horizontal position in order to evaluate their influence on the velocity field. For each power value, the water contained in the tank was initially at rest and a 5 s delay has been respected before the image captures. Velocity fields are presented on Fig. 11 to 14 for different input power values (from 6 W to 48 W). The extent of the horizontal jet and the velocity values increase with the power value but the shape of the flow keeps unchanged and one can't detect a vertical component (positive Y-direction), sign of free convection effects near the left wall.

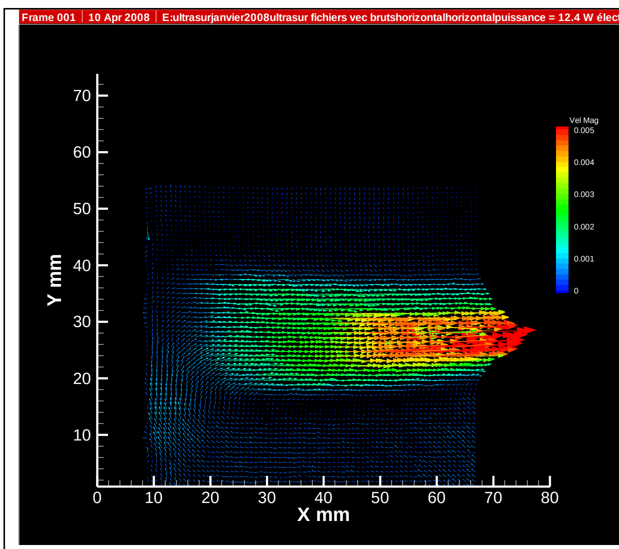

Fig. 11 : Focused transducer (6 W)

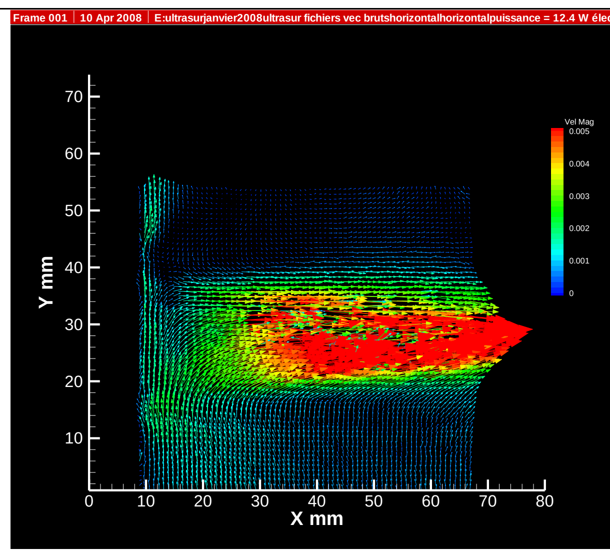

Fig. 12 : Focused transducer (23 W)

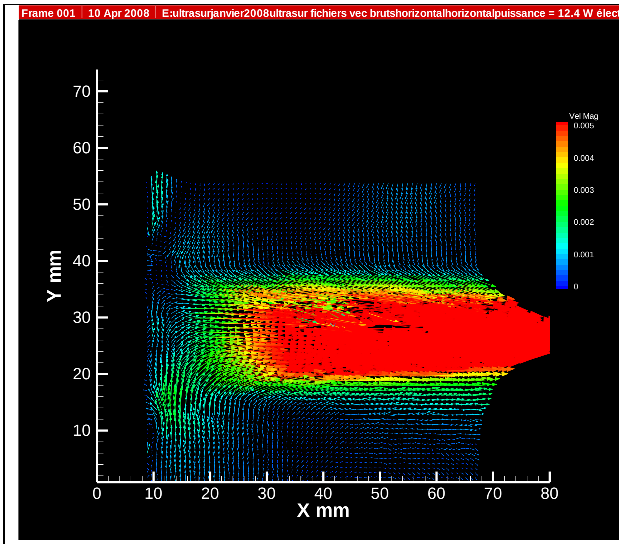

Fig. 13 : Focused transducer (35.3 W)

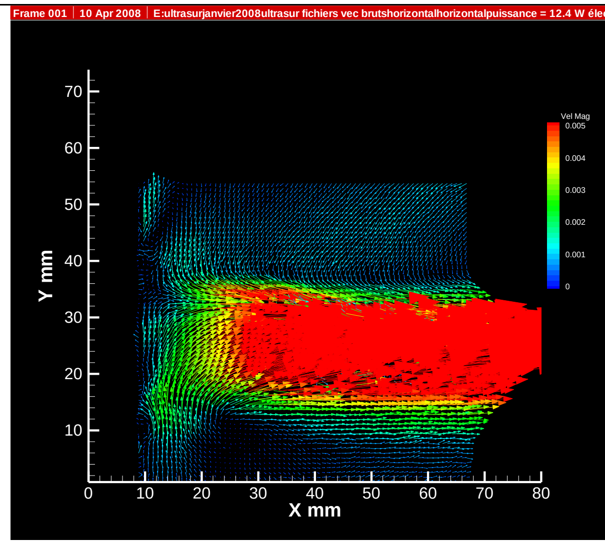

Fig. 14 : Focused transducer (48 W)

3.3 Influence of the transducer's shape

A comparative study has been performed between the planar and the focused transducer for similar input power conditions (12 W, horizontal position). The influence of the transducer's shape on the water flow is significant. Fig. 15 presents the velocity field obtained with the planar transducer while Fig. 16 presents the velocity field for the focused one: higher velocity values can be observed near the focusing zone but the spread of the jet is lower when compared with the planar configuration.

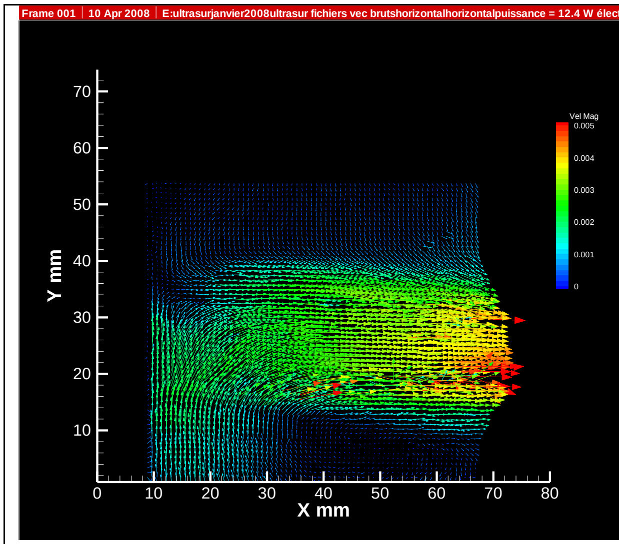

Fig. 15 : Planar transducer (12.4 W)

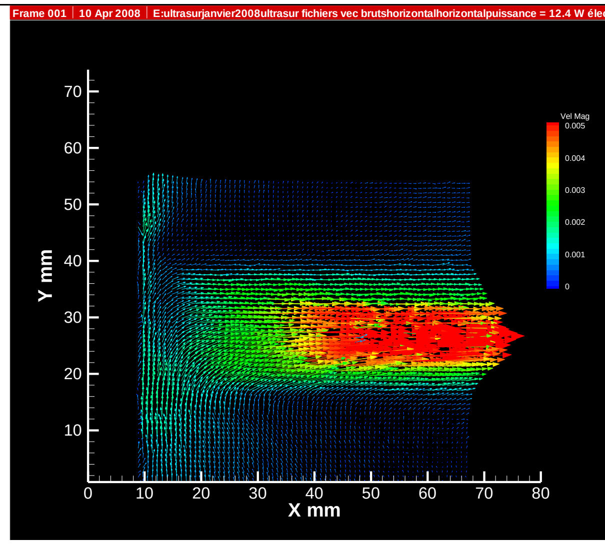

Fig. 16 : Focused transducer (12.4 W)

3.4 Comparison between horizontal and vertical emission

Two geometrical configurations have been tested for the focused transducer: the horizontal position which has been already described and the vertical position where the transducer and its body are mounted vertically in the middle of the tank lid. The velocity fields are presented on Fig. 17 for horizontal position and on Fig. 18 for vertical position. The input power has been set to 23 W for both cases and similar jet-shaped flows are encountered. The image processing and the velocity vectors computation were more delicate for the vertical velocity field due to a greater instability in the flow. Nevertheless it can be established that the similarity of the flows leads to the conclusion that free convection effects don't have a significant influence on the flow.

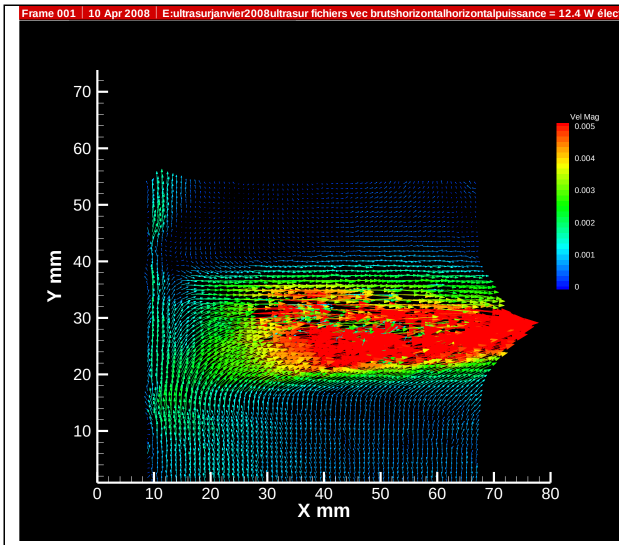

Fig. 17 : Horizontal transducer (23.4 W)

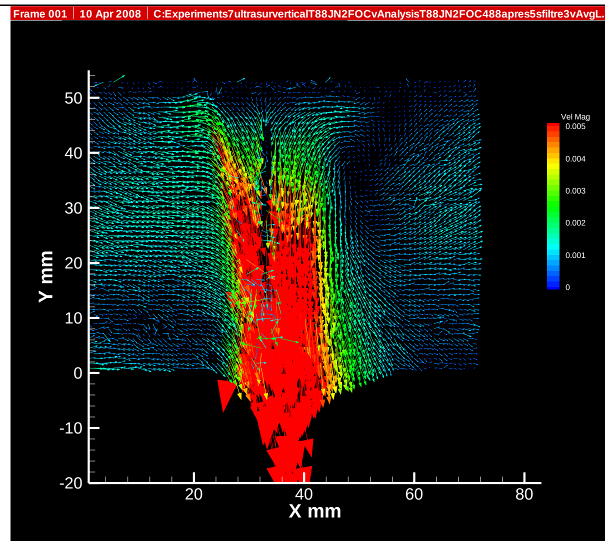

Fig. 18 : Vertical transducer (23.4 W)

4 Conclusion

Particle Image Velocimetry has been applied in order to determine velocity fields in a water tank submitted to ultrasound emission. Results highlight the influence of the parameters of the ultrasonic transducer on the motion in the water tank. Ultrasound generates an axial jet-shape flow in the vicinity of the transducer and the magnitude of velocity depends on the input electrical power. The development of flow is quasi simultaneous to the triggering of the transducer. The shape of the transducer also affects the velocity field: when a focused transducer is used the concentration of energy leads to a refinement of the moving area in the water tank and to higher velocity values in the focusing zone. Results also show the lack of free convection effects in the flow patterns: vertical gravity governed flows are not encountered for any input power values. Consequently, when regarding the final objective of this study, the modeling of the convection heat transfer coefficient needs the taking into account of correlations for forced convection flow rather than for free convection flow.

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