Acoustic Streaming Induced by a 20kHz Transducer: Comparison between PIV and Numerical Simulation

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The objective of this work is to study, experimentally and by numerical modelling, the acoustic streaming flow generated by 20 kHz high power ultrasound.

Experimental setup

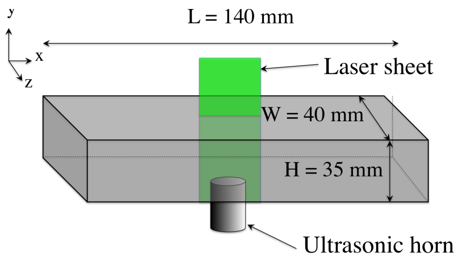

Figure 1: Experimental setup.

The experimental setup (Figure 1) consists of a polypropylene parallelepipedic cell (40x35x400 mm^3) with flat edges and which is part of a liquid loop [1-2] filled with water. In the present study, there is no fluid circulation in the loop, the flow is only induced by ultrasound activity. A 20 kHz transducer (Sonics and Materials) is located near the center of the test cell, on the bottom part. Its acoustic intensity was determined experimentally by a conventional calorimetry method [3]. For a given power, velocity vector fields were determined by PIV (Particle Image Velocimetry). The 532 nm laser beam (double pulsed Nd:YAG) was spread into a 2D sheet of light in the median plan of the test cell. Hollow glass beads (8-12 μm)were used as tracers. Two consecutive images of the flow were recorded using a camera (TSI 13-8 PIVCAM) with a pulse delay of 100ms. A total of 100 pairs of images were recorded. PYV software [4] was used to pre-process images (to correct relative displacements due to vibrations and images orientations) and to process PIV calcultation using a cross-correlation analysis with discrete window offset [5]. From the hundred vector fields processed, an average velocity vector field was calculated. Velocity vector fields obtained highlight the streaming contribution induced by the transducer.

Model

The acoustic field is computed by a non-linear model developed recently, accounting for the energy dissipation by inertially pulsating bubbles, assumed present in the liquid zone where the acoustic pressure is larger than the Blake threshold [6,7] . The predicted acoustic pressures range between 0 and 3.5 bar, contrarily to linear acoustics models, which predict huge non-physical values. Acoustic streaming is then computed by deducing the driving volumetric force from the computed acoustic field, and injecting this force into the full Navier-Stokes equations [8]. The latter are then solved by using a turbulence $k - \epsilon$ model [9].

Results

Figure 2 shows the mean velocity vector field with its streamlines obtained by PIV (on the left) and by numerical simulation (on the right). On the PIV velocity vector field, the region in the close vicinity of the transducer (where velocities are almost null) corresponds to where cavitation occurred: the high amount of bubbles caused defaults in the PIV process there. The experimental and numerical velocity fields and streamlines shapes are in quite good agreement, so that the model yields a reasonable prediction of the flow. The order of magnitude of the velocity flow is correct, which is not the case when using to simpler streaming models, like Eckart's one [8,9]. This is also due to the correct estimation of the acoustic field attenuation [9].

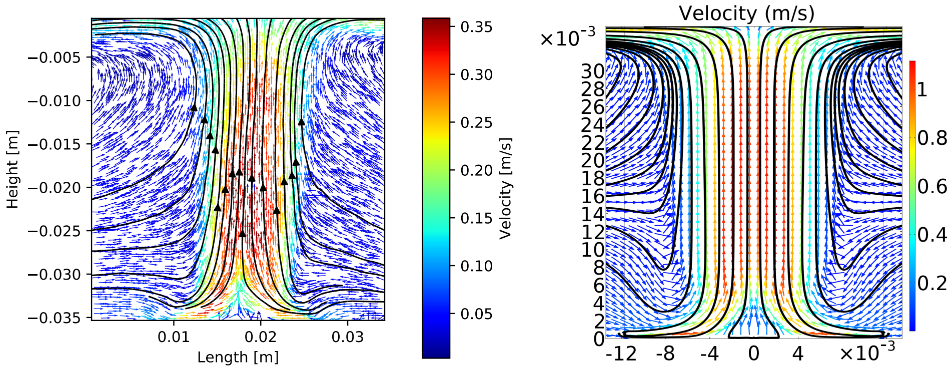

Figure 2: Velocity vector field and streamlines : PIV (left) and numerical simulation (right).

More explicit comparisons can be made by sketching the velocity profiles along horizontal lines, located at various distances from the transducer. Figure 3 displays such comparisons of the vertical component of the velocity. The simulation velocities (solid lines) have been multiplied by an arbitrary factor 0.31. Thus, while the experimental and numerical profiles of the velocity vertical component are in pretty good agreement, the numerical prediction is still in excess by a three-fold factor compared to experimental velocities. This discrepancy might be attributed to experimental uncertainties (due to the material used for the calorimetry method), systematic errors linked with the turbulence $k-\epsilon$ model, and more probably to a (known and yet unsolved) tendency of the acoustic model to slightly overestimate dissipation of acoustic energy .

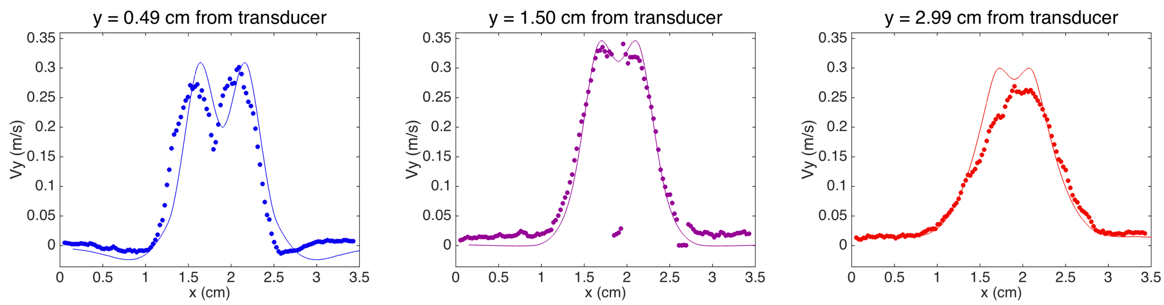

Figure 3: Vertical component of the velocity profiles for three vertical positions: rescaled numerical simulation (line) and PIV results (dots).

References

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