Vortex stretching in vibration induced streaming at high forcing

S. Amir Bahrani[1,2], Nicolas Périnet[3], Maxime Costalonga[1,2], Laurent Royon[2] & Philippe Brunet[1]

[1] Laboratoire Matière et Systèmes Complexes, UMR 7057 CNRS, Université Paris Diderot, Paris, France.
[2] Laboratoire Interdisciplinaire des Energies de Demain, UMR 8236 CNRS, Université Paris Diderot, Paris.
[3] Departamento de Fisica, Facultad de Ciencias Fisicas y Matematicas,Universidad de Chile, Casilla 487-3, Santiago, Chile.

seyed-amir.bahrani@univ-paris-diderot.fr

Oscillations of bodies immersed in fluids are known to generate secondary steady flows (streaming) [1], which originate from mechanisms similar to those generated by acoustic fields interacting with solid boundaries [2]. Streaming flows have applications in fluid homogenization and mixing especially in microfluidics [3], in heat transfer enhancement [4], in particle sorting [5] or in fluid pumping [6].

Streaming flow can be evaluated by writing a balance between the viscous dissipation (diffusive) forces and the inertia (convective) term via a perturbative approach of the Navier-Stokes equation.

$$\rho \left(\frac{\partial \boldsymbol{v}}{\partial t} + (\boldsymbol{v} \cdot \nabla)\boldsymbol{v} \right) = -\nabla P + \mu \nabla^2 \boldsymbol{v} \qquad \text{with} \qquad \mathcal{R} = \frac{\text{Convective}}{\text{Diffusive}}$$

We study the secondary time-averaged flow (streaming) generated by an oscillating cylinder immersed within a fluid. These vibrations generate two pairs of counter-rotating vortices within the viscous boundary layer (*inner streaming*), and by transfer of momentum, larger eddies are generated outside the boundary layer (*outer streaming*). Our study aims to quantify the spatial range and strength of the outer streaming, with both Particle Image Velocimetry (PIV) measurements and numerical simulations, within a large range of frequencies (f = 5–100 Hz) and amplitudes (A up to 2.5 mm, nearly half the cylinder diameter d). More specifically, our study evidences a so far unreported stretching of the secondary external vortices along the direction of vibration, occurring as the acceleration of vibrations is increased. This stretching can be of great interest to induce mixing and resuspension of particles.

From this information, we propose possible mechanisms for the growth and stretching of these secondary vortices (*outer streaming*) along the direction of the vibration with the increase of the vibrations amplitude and frequency. To validate our experimental observations, we have developed a finite-difference code solving the Navier-Stokes equations in an two-dimensional homogeneous fluid (experiments have shown that the flows were essentially two-dimensional). The size of this outer flow is usually that of the object diameter d, but when streaming Reynolds number $\mathcal{R}_s = A^2 f/\nu$ is larger than a few units, the outer flow grows and stretches out, becoming several times (up to 8) the size of the object. Outer vortices get closer to the vibration axis. In applied prospectives, these results show the potentiality to mix fluids or resuspend particles within a large space, via the streaming flow.

Références

1. N. Riley, *Annu. Rev. Fluid Mech.*, **33**, 43-65 (2001).
2. W. L. Nyborg, *J. Ac. Soc. Am.*, **30**, 329 (1958).
3. C. Suri et al., *Ultrasonics***40**, 393-396 (2002).
4. B. Tajik et al., *Int. J. Heat Mass Transf.* **60**, 230-235 (2013).
5. C. Devendran, I. Gralinski, A. Neild, *Microfluid. Nanofluid.* **17**, 879-890 (2014).
6. L. Schmid et al., *Microfluid Nanofluid* **12**, 229-235 (2012).