The influence of fluid viscoelasticity on steady streaming generated by an oscillating cylinder

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Oscillations of bodies immersed in fluids are known to generate secondary steady flows (streaming) [1]. These flows have strong similarities with acoustic streaming induced by sound and ultrasound waves, although such flow can be generated if the fluid is incompressible. Such streaming is actually similar to Rayleigh acoustic streaming [2] induced in the vicinity of an oscillating boundary layer around the body, due to the non-linear interactions between first order viscous forces and second order inertial ones. Lighthill [3] modeled these volume forces as results of Reynolds stresses near the boundary layer, induced by the non-zero acoustic momentum averaged over one period. As a result, stationary vortex flows are generated both inside and outside the boundary layer. Such streaming flow have potential applications to fluid homogenization and mixing, to heat transfer enhancement, to particle sorting in microfluidics or fluid pumping.

The generation of such secondary flows was theoretically investigated first by Rayleigh, then later by Batchelor [4] and Schlichting [5] in the context of oscillating boundary layers. Let us consider an object moving at velocity $U = A\ exp\ i\phi t$ within a fluid, forcing the fluid particles to follow this motion. Due to the no-slip boundary condition along the body, within a layer of typical thickness $\delta = \frac{2\nu}{\omega}$, the vorticity is created within this boundary layer. By conservation of momentum, this vorticity induces large-scale vortices outside the boundary layer.

A typical situation is that of an cylinder oscillating perpendicular to its axis, generating two pairs of counter-rotating vortices due to the transfer of vorticity from a inner boundary layer. While most studies so far investigated the situation of newtonian fluids, it is often required to achieve mixing in fluids with complex, non-newtonian properties for various practical applications [6]. Here, we consider the situation of a viscoelastic fluid : by using PIV, we carry out an experimental study of the flow structure and magnitude over a range of amplitude and frequency. As shown previously qualitatively [7,8,9], we evidence the effect of elasticity in streaming by systematic comparison with a purely newtonian case.

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