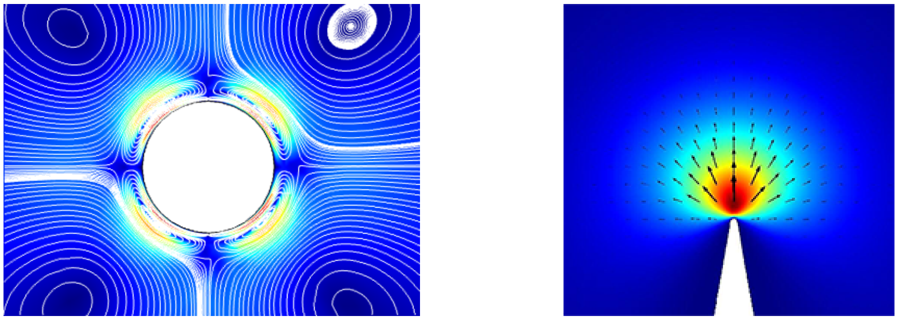

Figure 1: Streaming driven by a vibrating cylinder (left) and vibrating sharp edge (right).

GFD Project: Acoustic Streaming meets GFD

–Greg Chini (with Stefan Llewellyn Smith and Guillaume Michel)

Acoustic streaming is a technologically important wave-driven mean flow phenomenon. Viscous effects play a crucial role in classical forms of acoustic streaming, with streaming speeds being small compared to the oscillatory velocities directly induced by the sound waves.

The Effect of Baroclinicity

A novel form of *strong* acoustic streaming recently has been identified [1] in which streaming speeds are comparable to oscillatory particle velocities. The enhanced streaming speeds arise because wave (fluctuating) vorticity is produced *baroclinically* throughout the physical domain in the presence of an imposed background temperature/density gradient. Our theoretical investigations of baroclinic acoustic streaming in internal (channel) geometries demonstrate that, unlike classical Rayleigh streaming, there is fully two-way coupling between the sound waves and time-mean flow [2,3]. The aim of this GFD project is to re-examine (using asymptotic analysis and numerical simulation) a related problem: streaming-enhanced heat transfer from an oscillating hot sphere to a cooler ambient gas. Crucially, *all* prior analyses [e.g. 4] of this canonical problem tacitly but incorrectly presume that the heat transfer can be computed by treating the mean temperature as a passive scalar field advected by a pre-computed classical viscous (Rayleigh) streaming flow.

The Effect of Surface Roughness

In Rayleigh streaming, wave vorticity is generated in oscillatory Stokes boundary layers adjacent to solid surfaces. Interestingly, recent studies [5] have demonstrated the possibility for anomalously large streaming speeds emanating from a *sharp edge*. To date, however, there has only been a single compelling theoretical investigation of this "sharp-edge Rayleigh streaming" [6]. Accordingly, the aim of this GFD project is to further develop the theory, expose the underlying physical mechanisms and devise efficient numerical algorithms for simulating this novel phenomenon.

1. G. P. Chini, Z. Malecha & T. Dreeben (2014), "Large-amplitude acoustic streaming," *J. Fluid Mech.* **744**, pp. 329–351.

2. G. Michel & G. P. Chini (2019), "Strong wave–mean-flow coupling in baroclinic acoustic streaming," *J. Fluid Mech.* **858**, pp. 536–564.

3. N. Nama (2019), "Mixing hot and cold with sound," **JFM Focus on Fluids 866**, pp. 1–4.

4. B. J. Davidson (1973), "Heat transfer from a vibrating circular cylinder," *Int. J. Heat Mass Transfer* **16**, pp. 1703–1727.

5. N. Nama, P. H. Huang, T. J. Huang & F. Costanzo (2014), "Investigation of acoustic streaming patterns around oscillating sharp edges," *Lab on a Chip* **14**, pp. 2824–2836.

6. M. Ovchinnikov, J. Zhou & S. Yalamanchili (2014), "Acoustic streaming of a sharp edge," *J. Acoustical Soc. America* **136**, pp.22–29.