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Axisymmetric and azimuthal waves on a vibrated sessile drop

D. Panda,[1] L. Kahouadji,[1,*] L. S. Tuckerman,[2] S. Shin,[3] J. Chergui,[4] D. Juric,[4,5] and O. K. Matar[1]
[1]*Department of Chemical Engineering, Imperial College London, London SW7 2AZ, UK*
[2]*Physique et Mécanique des Milieux Hétérogènes, CNRS, ESPCI Paris,*
Université PSL, Sorbonne Université, Université de Paris, 75005 Paris, France
[3]*Department of Mechanical and System Design Engineering,*
Hongik University, Seoul 04066, Republic of Korea
[4]*Université Paris Saclay, Centre National de la Recherche Scientifique (CNRS),*
Laboratoire Interdisciplinaire des Sciences du Numérique (LISN), 91400 Orsay, France
[5]*Department of Applied Mathematics and Theoretical Physics,*
University of Cambridge, Cambridge CB3 0WA, UK

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There is a growing interest in understanding the dynamics of vibrated sessile drops due to technological innovations in adaptive liquid lenses [1] and drop atomisation in heat transfer cells [2]. Noblin et al. [3] observed that at low forcing amplitudes, the drops exhibited axisymmetric standing waves with pinned contact lines on polystyrene surfaces. At higher amplitudes, the drops exhibited azimuthal (non-axisymmetric) modes punctuated by stick-slip contact line motion. Vukasinovic et al. [4] found that vibration-induced drop atomisation follows the appearance of the azimuthal waves along the contact line beyond a threshold acceleration. They also observed that the contact line was pinned, irrespective of the acceleration amplitude. The axisymmetric and azimuthal waves exhibit harmonic and subharmonic responses, respectively.

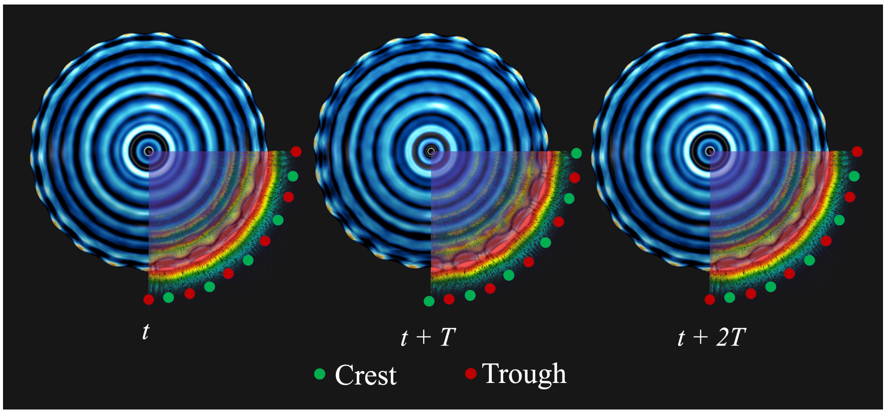

FIG. 1: Top-view of drop (100 μL) oscillations with $f = 1040$ Hz and $a = 1000$ m/s^2 at $t = 32T + T/2$, where $T = 1/f$.

We performed 3D numerical simulations of a drop of volume $\mathcal{V} = 100\mu$L using an in-house multiphase solver, *BLUE* [5] previously used to study spherical Faraday waves [6]. The computational domain, a cube encompassing water and air, is decomposed into $12 \times 12 \times 6$ cores each of resolution 64^3, leading to a global mesh structure of $768 \times 768 \times 384$ grid cells of size $\Delta x = 15.625$ μm sufficient to capture the axisymmetric and azimuthal waves. The density of water and air is set to 998 kg/m^3 and 1.205 kg/m^3 and their dynamic viscosities to 10^{-3} kg/m.s and 1.82×10^{-5} kg/m.s, respectively. The surface tension is equal to 0.0714 N/m. The substrate is vibrated at a frequency $f = 1040$ Hz. As an initial condition, we used a perturbation proportional to the 10th axisymmetric spherical harmonic $Y_{10}^{(0)}$. We ramped up the acceleration by 100 m/s^2 up to $a = 1000$ m/s^2 every 20 forcing time period to avoid numerical divergence.

We imposed periodic and Neumann boundary conditions on the velocity at the lateral and top faces of the water-air cubical domain, respectively. Near-contact line azimuthal waves were observed only when a generalised Navier (rather than a Dirichlet) boundary condition was imposed on the substrate, with hysteresis characterised by advancing and

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[*] Electronic address: l.kahouadji@imperial.ac.uk

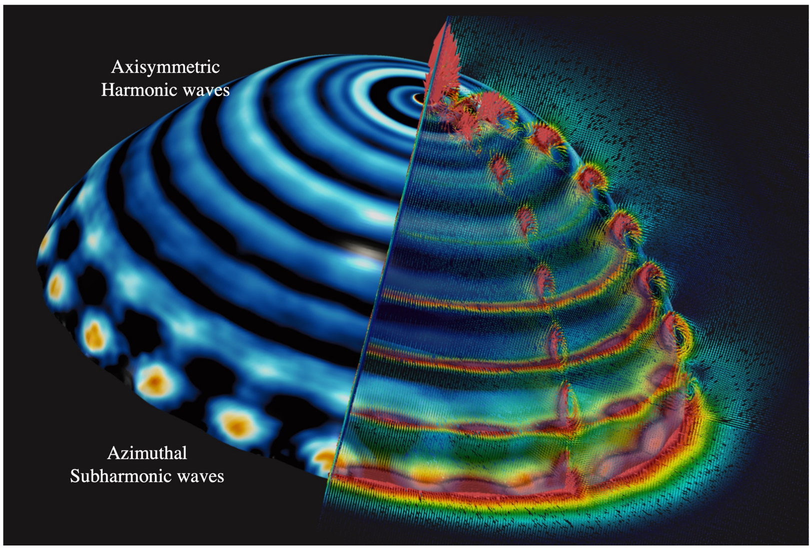

FIG. 2: Snapshot of vibrated drop at $t = 32T + T/2$. The velocity glyphs illustrate the vortices on the axisymmetric waves and the strong influx at the contact line. Pressure contours on the interface show high pressure zones at the crests on the drop apex and in the vicinity of the contact line. The parameter values remain unaltered from figure 1

receding contact angles of $\theta_a = 90°$ and $\theta_r = 84°$, respectively. This contradicts the experiments of Vukasinovic et al. [4], in which the contact line remained pinned.

Figure 1 shows that the near-contact line wave crests (green) and troughs (red) occur at the same locations at $t+2T$, but not at $t + T$, demonstrating that these are subharmonic standing waves. Conversely, the axisymmetric waves repeat after each time period T, exhibiting a harmonic response. These observations agree well with the experiments [4]. Although a subharmonic response is a classic signature of Faraday waves [7], such waves oscillate in the same direction as the imposed oscillation. Thus, if the radially oscillating azimuthal waves near the contact line result from a Faraday-type instability, the instability is not engendered by the vertically oscillating substrate, but by the radially oscillating axisymmetric waves, as proposed in [4]. However, the azimuthal waves might be caused instead by a modulation of the axisymmetric waves brought about by the proximity of the substrate to the contact line.

Our observations await a more detailed understanding of the physics of vibrating sessile drops. Although the harmonic axisymmetric waves may be the cause of the subharmonic azimuthal waves, a number of crucial questions need to be addressed. Among these are (i) the role of the contact line in the formation of subharmonic azimuthal waves; (ii) the role of the vibrating substrate in the growth of these waves on the interface; and (iii) an understanding of such subharmonic waves when the external vibrations are parallel to the interface, e.g., oscillatory Kelvin-Helmholtz instability [8]. Addressing these issues will be the subject of future work.

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