Liquid Dancing in a Singing Bowl
Team Third Report

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Context and Purpose

This is a report for the Team Third assignment, conducted as part of the MCEN 5151 Flow Visualization course in the fall of 2023. The team embarked on capturing the mesmerizing "dancing" of a liquid within a singing bowl. A singing bowl, or a standing bell, is a unique instrument typically used in meditation practices for its soothing sound[1]. Each bowl, being handcrafted, possesses distinct resonant frequencies. The phenomenon of interest in this project was the formation of Faraday waves[2] within the liquid as the bowl resonated, and droplets were seen to break off from the walls of the bowl which then bounce on the surface of the liquid. Faraday waves serve a useful functions in multiple fields not limited but including material sciences, biomedical application, acoustic research, non-destructive testing, chemical processing, as well as astrophysics. I would also like to thank Alexandr Vassilyev and Haotian Chen for their inputs and support for this assignment.

Flow Apparatus

The flow apparatus consisted of a handmade 6-inch brass alloy singing bowl, a mallet for playing the singing bowl, a fabric ring as a dampening stand, and 70% concentration isopropyl alcohol. The singing bowl, when played, resonated at specific frequencies, this singing bowl specifically resonates at 310Hz and 818Hz, generating Faraday waves in the liquid. Isopropyl alcohol was chosen due to its lower surface tension and viscosity of 22 dyne/cm and 2.4 cP at room temperature as compared to 72 dyne/cm and 1 cP for water, which leads to a higher probability of droplets breaking off at the walls of the resonant singing bowl. The Faraday waves and oscillating walls of the bowl led to the ejection of droplets from the liquid's surface, which intriguingly floated for an extended period before rejoining the main body of liquid upon cessation of the bowl's vibration. This unique behavior raised questions about the interaction of surface tension, fluid dynamics, and the bowl's oscillatory motion.

Visualization Technique

For capturing this phenomenon, isopropyl alcohol was chosen due to its clear nature and lower viscosity than water, which helped clearly capture the droplets that were forming as well as provided enough shadows and highlights on the waves surface to see its formation. The alcohol was roughly filled to 60% of the bowls capacity. 3 diffused white light sources were employed to adequately illuminate both the bowl and the liquid with one led bulb placed directly above the singing bowl. The high-speed photography was conducted using a Pixel 6 primary camera, which allowed for 4K recording at 60fps. The multiple light sources were crucial for capturing the fast-moving droplets and the fluid's surface dynamics in detail with minimal light strobe effect. The 3 light sources were placed around 2 feet above the subject, and the fourth light source was placed above the bowl at a height of around 4inches from the upper edge of the bowl.

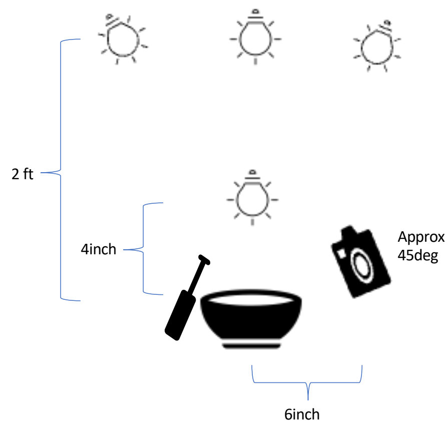

Figure 1 Photographic and Visualization Setup

Photographic Technique

The camera was placed on the side of the bowl 6inches away and at an angle of around 45deg to capture the bowl and the liquid surface. A Pixel 6 was utilized due to its capability of capturing 4k resolution at 60fps to facilitate a slow-motion playback at 2.5x rate. The Pixel 6 primary camera, with its 50MP 1/1.31" sensor and fixed aperture of f/1.85, provided the necessary resolution and depth of field. The focal length equivalent was 24mm. The video was recorded in 4K resolution (3840x2160 pixels) at 60fps, and the slow-motion playback at 2.5x (24fps) helped in visually dissecting the fluid behavior.
Below is a snapshot showing the droplets ejecting from the walls of the bowl and floating on the waves formed on the liquids surface.
Here is a link to the video: https://youtu.be/X6jJGNl8X38

Figure 2 A snapshot of the video showing the droplets

Technical Analysis

To understand the fluid dynamics at play, we can analyze the Faraday wave phenomenon. Faraday waves are surface waves that emerge when a fluid layer is subjected to periodic vertical oscillations[3][4]. The wavelength (λ) of Faraday waves can be approximated using the dispersion relation for gravity-capillary waves:

$$\lambda = 2\pi \sqrt{\frac{\gamma}{(\rho g + 4\pi^2 \rho f^2)}}$$

where,

- Surface tension of isopropyl alcohol, γ: 22 dyn/cm (converted to 0.022 N/m).
- Density of isopropyl alcohol, ρ: Approximately 786 kg/m³.
- Acceleration due to gravity, g: 9.81 m/s².
- Resonant frequencies of the bowl: 310 Hz and 818 Hz.

Using the common values for each parameter, the wavelength can be calculated for both the observed resonant frequencies of 310Hz and 818Hz as:

$$\lambda_{310Hz} \approx 1.71 \times 10^{-5}\ meters$$

$$\lambda_{818Hz} \approx 6.47 \times 10^{-6}\ meters$$

The kinetic energy (KE) introduced into the liquid by the vibrating bowl can also be crudely estimated using:

$$KE = \frac{1}{2} m v^2$$

Where v is the velocity of the bowl's wall, given by:

$$v = 2\pi f A$$

Here, f is the frequency of the bowl and A is the amplitude of vibration of the bowl.
Assuming:

- Mass of the liquid in the bowl, m: 0.5 kg (500 grams), roughly 500ml of liquid in the bowl
- Amplitude of vibration of the bowl, A: 0.001 meters (1 millimeter).

The velocity of the bowl's wall and kinetic energy introduced in the liquid can be tentatively calculated as:

$$v_{310Hz} = 2\pi \times 310 \times 0.001\ m/s$$

$$KE_{310Hz} = \frac{1}{2} \times 0.5 \times {v_{310Hz}}^2 \approx 0.95\ joules$$

$$v_{818Hz} = 2\pi \times 818 \times 0.001\ m/s$$

$$KE_{818Hz} = \frac{1}{2} \times 0.5 \times {v_{818Hz}}^2 \approx 6.6\ joules$$

These calculations provide insight into the dynamics of the liquid we see when playing the singing bowl. Upon starting to play the bowl, Faraday waves start to form in the liquid due to the vibrational energy of the bowl being transferred to the liquid, and when resonance is reached, around 6.6 joules of energy is suddenly being imparted on the liquid around the inner walls of the bowl which results in droplets breaking off from the liquid and ejected inwards in the bowl. These droplets then continue to bounce and linger on the liquids surface due to the momentum of the liquid's surface not letting the droplets coalesce. As soon as the bowl stops resonating, when stopped ringing, the droplets coalesce into the liquid, as can be seen at the end of the video.

Observations

The captured footage revealed fascinating aspects of fluid physics. The persistence of droplets on the liquid's surface before coalescing highlighted the interplay between surface tension, fluid inertia, and the vibrational energy imparted by the singing bowl. This observation leads to further questions about the threshold of vibrational energy required to maintain these droplets and the role of fluid viscosity in this phenomenon. Further study can be performed looking into the interaction of different liquid solutions in the singing bowl, as well as having what effects arise by having multiple immiscible liquids. The fluid dynamics displayed were both visually appealing and intellectually stimulating, offering a rich field for further exploration in fluid mechanics which can be applicable in material science, fluid dynamics, chemical processing, and acoustic research.

References

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