Exploration of Locally-Induced Waves

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1 Introduction and Prior Work

Faraday waves are nonlinear standing waves that are most often generated by vibrating a system vertically and globally. The phenomenon was first observed by Michael Faraday in 1831 [1]. A noticeable effect of Faraday waves is the formation of interesting patterns on the liquids surface. These patterns var from concentric circles to complex polygon geometries. Prior research has shown that the formation of these patterns is dependent on various factors, including the fluid's viscosity, the depth of the fluid, the frequency of the container's oscillations, and the amplitude of the oscillations [2]. Figure 1 demonstrates the fascinating patterns that emerge as a result of the Faraday wave phenomenon.

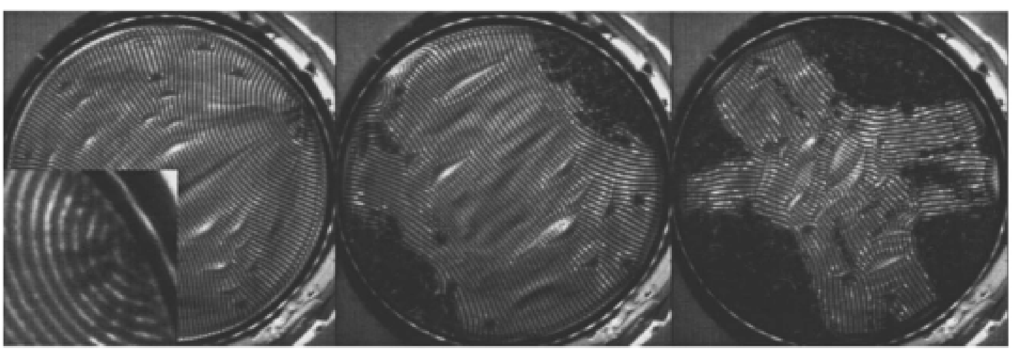

Figure 1: Faraday waves observed in a container undergoing global vibrations.

Researchers have rigorously studied the reasons for Faraday wave formation. Notably, Douady [5] recreated Faraday's experiments and demonstrated Faraday waves' sensitivity to boundary conditions. He also derived an early version of the equations that govern Faraday waves. Bechhoefer et al. [4] went on to more rigorously describe the formation of Faraday waves, and thereby decreased the discrepancies between previous theory and experimental results in their study of Faraday Instability. With the advent of computers, researchers have begun conducting numerical and analytical analyses for the Faraday wave pehnomenon. Kudrolli [3] explored the formation of spatiotemporal chaos on surface waves, and documented the existence of a "mixed state" for these waves. Chen and Viñals developed methods to determine the type of pattern formed when standing waves are generated in various fluids [2]. Additionally, Périnet et al. [9] developed one of the first numerical simulations of Faraday waves.

While prior research has ventured to explain the formation of globally induced Faraday waves, there is little research that explores the formation and dynamics of locally induced Faraday waves. This includes the effect of variables such as viscosity, container width, boundary conditions on the formation of globally induced Faraday waves. What's more, locally driven frequencies are more applicable to real life examples. For instance, Moriarty et al. [7] demonstrated that alligators generate standing waves in water as part of their mating ritual. These kinds of standing waves are locally induced, and are not explained by previous literature.

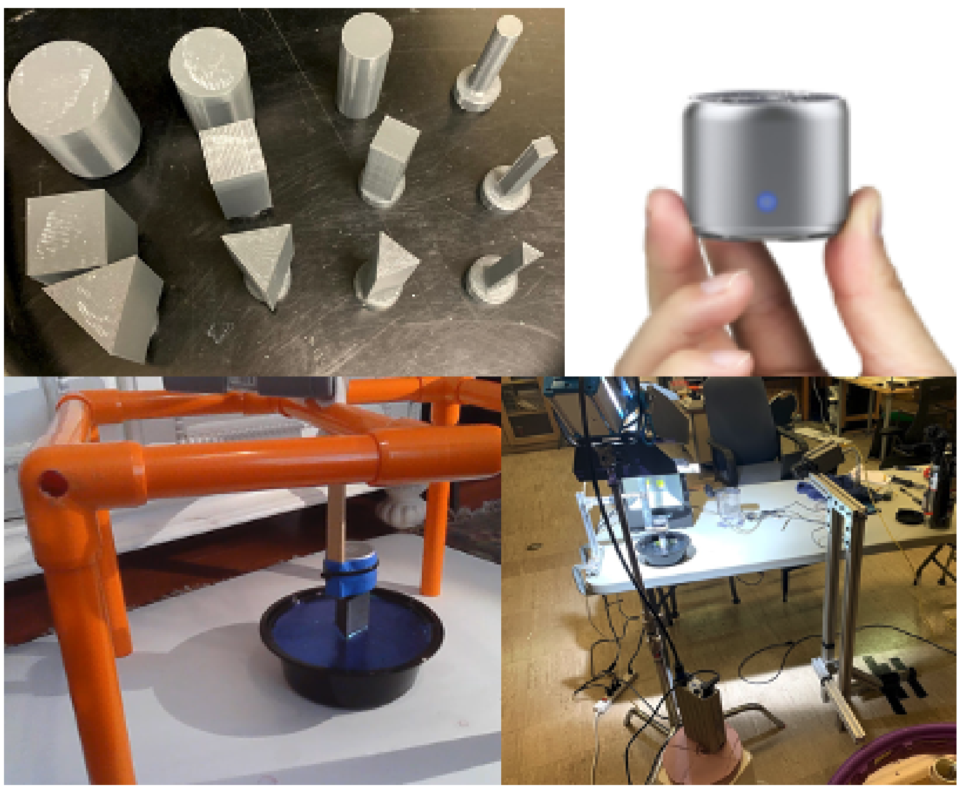

Figure 2: Setup used to measure the effects of locally-induced Faraday waves. Top left: The various piston shapes and sizes used in our experiment. Top right: The EWA A106 bluetooth speaker used to apply local oscillations to generate waves. Bottom left: Ashley Barnes experimental setup, with the piston-driver assembly submerged in the water. Bottom right: Steven Tarr's experimental assembly.

2 Experimental Setup

In this work, we aim to better understand how locally forced Faraday waves behave. Specifically, we are interested in observing the patterns that emerge as a result of local forcing, and to understand whether locally induced oscillations in fact lead to standing waves. To this end, each member of the group assembled a testing rig to evaluate the three piston shapes studied in the triangle. Namely, we studied circular, triangular, and square pistons. Four variants of each piston were printed; each with a different cross-sectional area. Pistons of 5, 10, 15, and 20mm radius were used, where the inscribed policy was used to measure the radius of squares and triangles. The pistons were then rigidly attached to an EWA A106 Bluetooth speaker using rubber cement.

We then filled a 6" diameter container with 0.9L of water at 50mm depth to serve as our testbed. The piston-drive assembly was attached to a rigid stand, enabling submersion of the piston to different depths. The control parameters for our assembly were the piston shape, submersion depth, and driver frequency. Figure 2 visualizes the piston shapes, speaker, and test rigs used in our experiment.

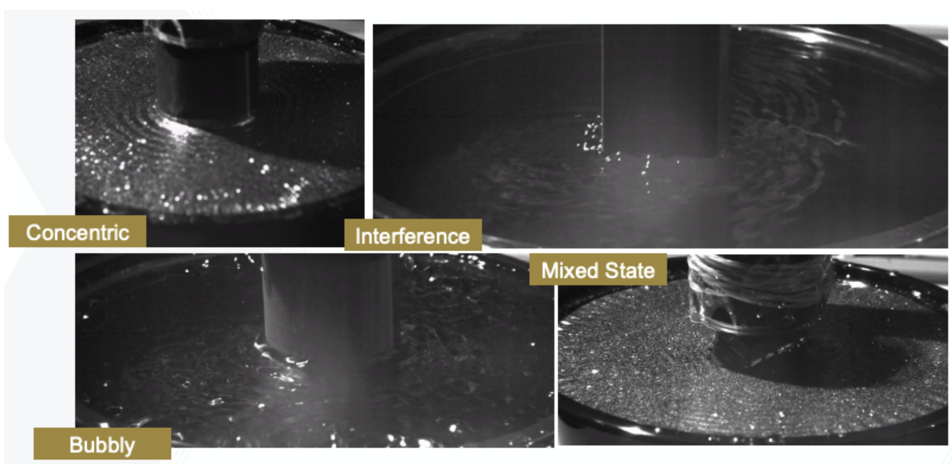

Figure 3: Emergent wave patterns. Top left: Concentric waves. Top right: Interference wave pattern. Bottom left: Bubbly waves. Bottom right: Mixed state waves.

3 Results

With the experimental setup described above, we conducted a thorough exploration to observe which wave patterns emerge as a function of the control parameters. To our delight, our experiment revealed that standing waves do indeed occur as a result of locally induced oscillations. Figure 3 displays some of the wave patterns which emerges as a result of our experiment. We observed four different kinds of waves: concentric, interference, bubbly, and mixed. Concentric waves were the most prominent, and usually happen at higher frequencies. This wave pattern is defined by concentric circular, triangular, or square patterns emanating from the local oscillation.

An interference pattern is defined by various smaller waves which appear to interfere with each other. In some regions of the liquid, waves appear whereas in others they collide and disappear. A bubbly wave pattern is chaotic and contains waves with large amplitudes. Finally, a mixed state pattern contains various kinds of wave formations. Figure 3 visualizes the various kinds of wave patterns we observed during our experiments.

4 Analysis

To our delight, we observed a variety of sophisticated wave patterns emerge. For instance, we were able to recreate the surface wave patterns explored by Sheldrake et al. [8] (Figure 4). Their work identified a few main patterns of waves that merge when the container is globally oscillated. We were able to recreate some of these patterns in our experiments with locally-induced waves.

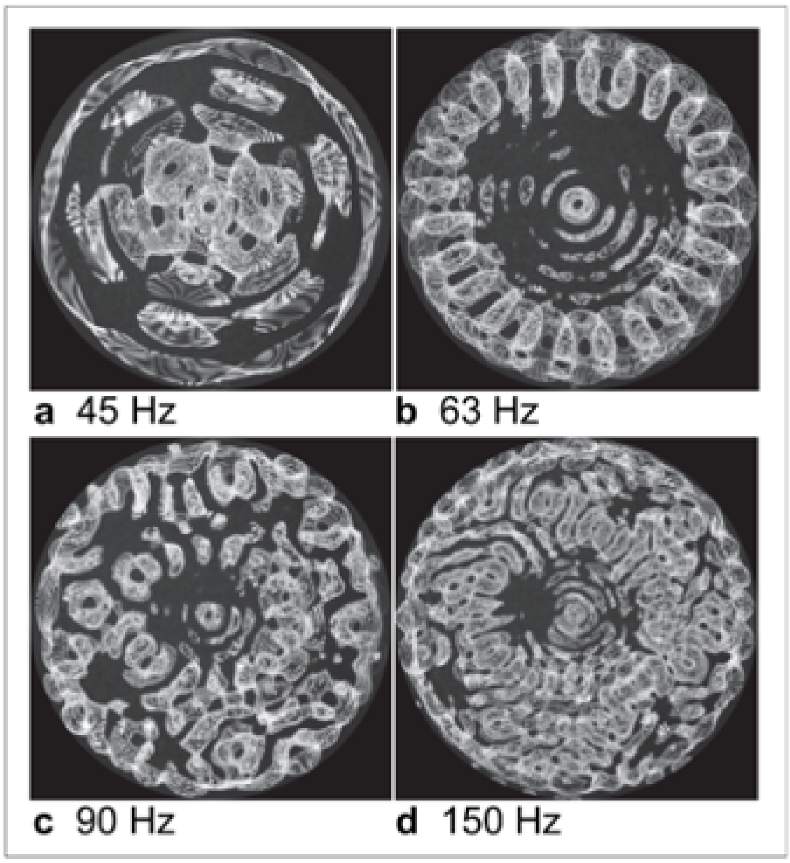

Figure 4: Wave patterns observed by Shaldrake et al. In our experiments, we were able to replicate these observed patterns.

We also found a correlation between the complexity of the standing waves, and the different variables which were observed. First, there was a start correlation between the patterns observed and the area of the driving piston. Pistons with a larger surface area seemed to produce more complex patterns. In Figure 6 we explore the types of wave patterns that emerge as the piston size and submersion depth are varied. Note that the pistons with larger radius generally produce more sophisticated wave patterns than those with smaller radius. The authors also observed a correlation between the piston shape and the complexity of the standing waves. Namely, depending on the piston shape, the edges of the piston would cause interesting boundary condition problems. These boundary conditions would lead to interesting patterns in experiments where glitter was added. In experiments with glitter, we noticed that the triangular piston led to sinks in the edge midpoint and repellors at the corners. As such, glitter particles would be attracted to the face of the piston then would be repelled at the corners. Finally, we observed that deeper submersion of the piston led to more complex wave patterns.

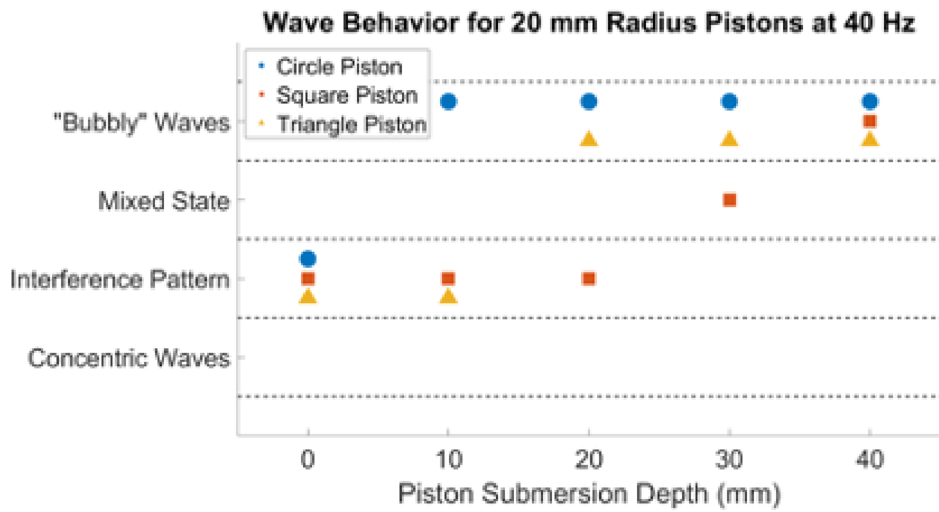

Figure 5: Effect of piston shape and submersion depth on the emergent wave patterns. As submersion depth increased, the complexity of the wave pattern increased. Additionally, some shapes produced more complicated wave patterns at the same frequency as other shapes.

In Figure 5, we study the effect of piston shape and submersion depth on the produced wave patterns. As mentioned in the previous paragraph, increasing the piston submersion depth leads to the formation of more complicated wave patterns. Note also that the piston with the largest cross-sectional area, the circle, produced the most complex wave patterns. This coincides with our observation that there is a correlation between the piston's cross-sectional area and the complexity of the emergent wave patterns.

We also ventured to explore properties of the waves themselves, such as their frequency. In figure 7, we explore the effect of submersion depth and piston shape on the wave patterns and their frequency. We find that, initially, the pistons produce concentric waves with high frequency. However, the steady state waves are complex, indicating that boundary effects may give rise to the observed complexity.

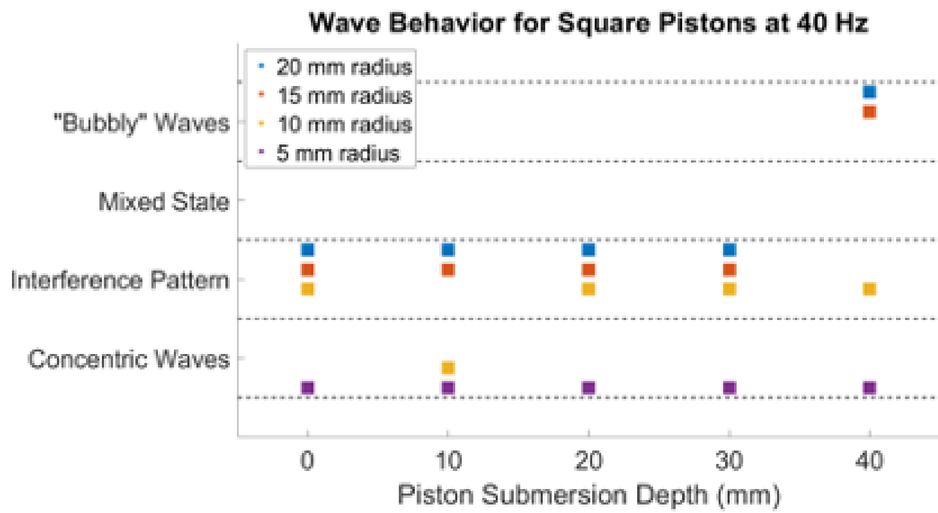

Figure 6: Effect of submersion depth and piston radius on the emergent wave patterns.

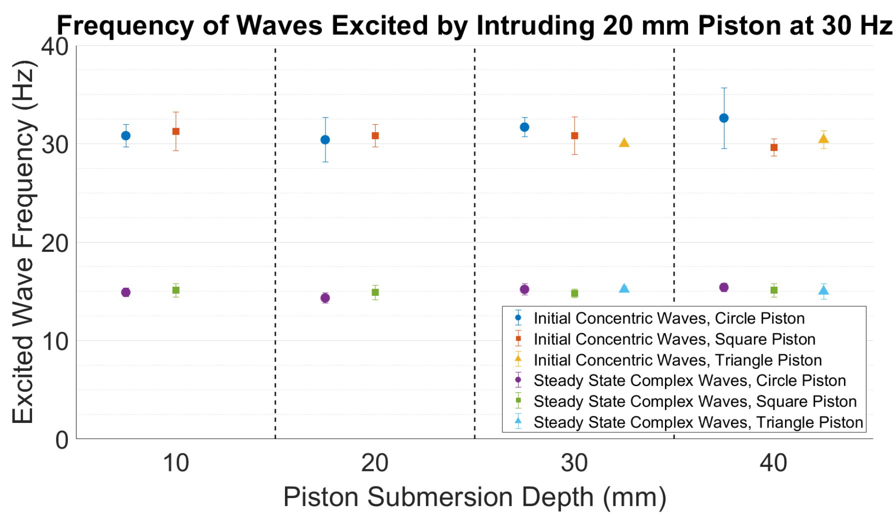

Figure 7: a nice plot

5 Conclusion

In conclusion, this project explored the effect of locally-induced oscillations on a container of fluid. Namely, we analyzed the impact of piston shape, piston frequency, and submersion depth on the resultant wave formation. It is clear that induced standing waves are a complex nonlinear dynamical phenomenon that can be easily created and observed. However, there is a lot of future work that remains to be done. For instance, we need to be sure that the locally induced standing waves are truly local, and not a result of container resonance. This would require modifications to the existing experimental set up that limit the impact of the container's walls on the liquid. Additionally, We could invert the experimental setup by using global forcing and holding various shapes to the water surface. Finally, we need to re-evaluate the established theory and see how it holds up when the waves are instead locally induced.

References

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