Summer 2021

Droplet Impact, Part 2: Engineering a Droplet Generator

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Droplet Impact

Part 2: Engineering a Droplet Generator

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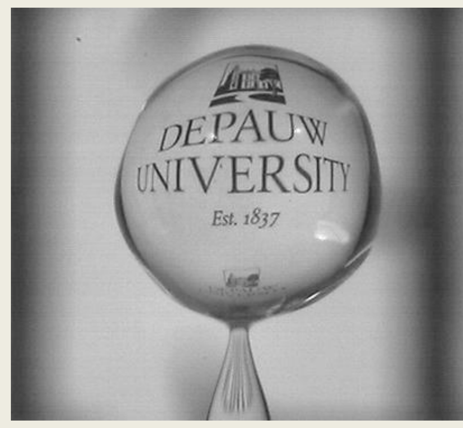
Science Research Fellows

J. WILLIAM ASHER & MELANIE J. NORTON ENDOWED FUND IN THE SCIENCES



Introduction

Prior droplet impact research at DePauw used a syringe to pump fluid through a tube to create a droplet. This method generated ~2.5mm diameter droplets with secondary satellite droplets that formed during pinch-off and influenced rupture upon collision with the main droplet. Furthermore, the large diameter caused the droplet to experience significant oscillation as it fell, making it difficult to control impact shape without changing impact velocity. Part of this summer's research focused on adapting pre-existing designs for droplet generators to build our own version that creates small, consistent droplets without interference from satellite droplets or jets (which form at high speeds/large diameters)[1,2].

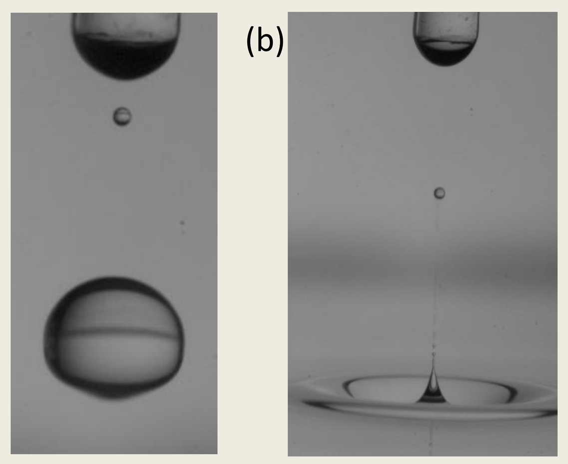


Figure 1: (a) Picture of a droplet right after pinch off with a satellite droplet. (b) Picture of jet forming after impact.

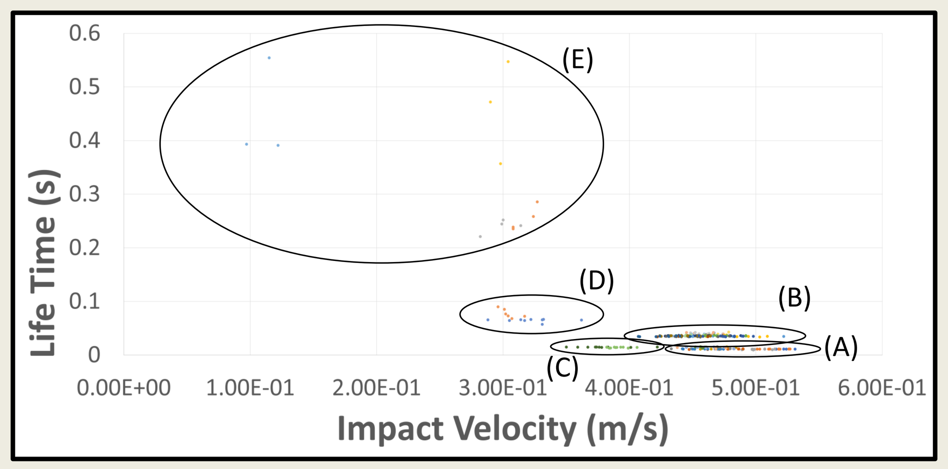
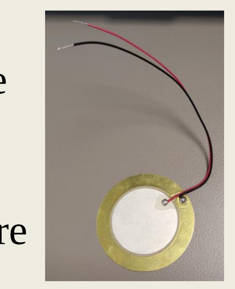


Figure 2: Lifetime vs impact velocity with original droplet generator. Droplets ruptured in distinct groups: at impact (A), during satellite droplet collision/jet formation (B), shape inconsistencies (C), on post-bounce impact (D), and at rest (E).

Piezoelectric Disk

Issue/Challenge: Producing droplets of highly repeatable size without interference from satellite droplets

Innovation/Solution: Placed a piezoelectric disk on the top of the fluid chamber in direct contact with the fluid and used Arduino Nano to create and control a pressure pulse in the fluid chamber by the voltage-induced flexure of the disk.



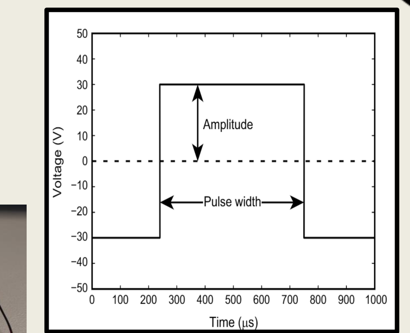
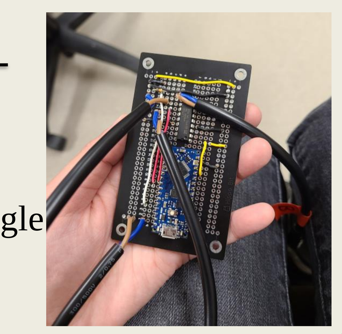
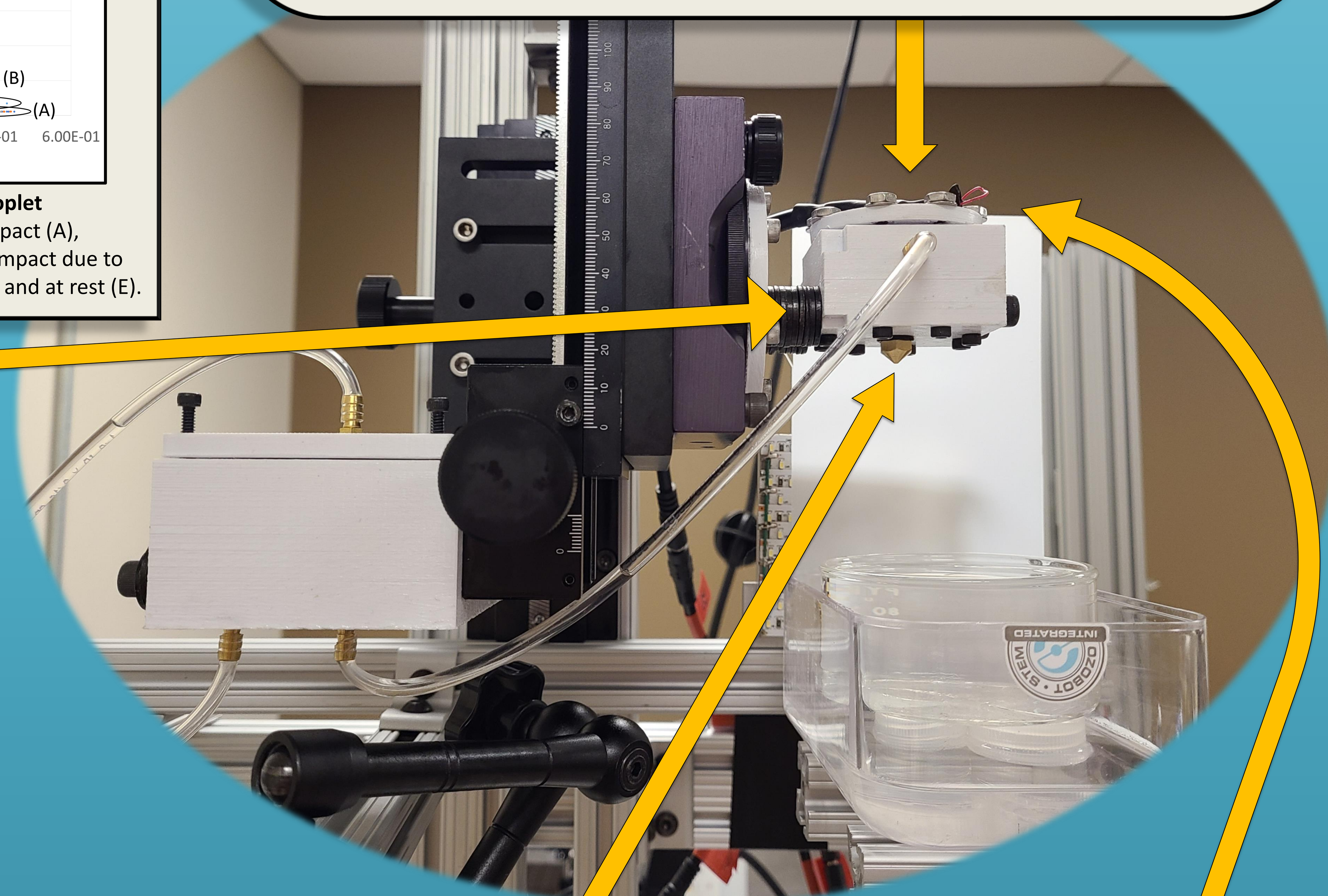


Figure 3: Example of a typical waveform used to drive the piezoelectric element.

- Positive voltage → the piezoelectric contracts → a positive pressure pulse in the chamber that forces liquid through the nozzle
- Negative voltage → the piezoelectric expands → a negative pressure fluctuation that draws liquid back into the chamber

This sequence of expansion and contraction expels a single droplet from the nozzle.

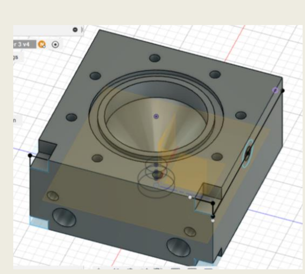




Fluid Chamber

Issue/Challenge 1: Eliminating all air bubbles in the system to make sure that the applied pressure pulse leads to liquid ejection rather than gas compression.

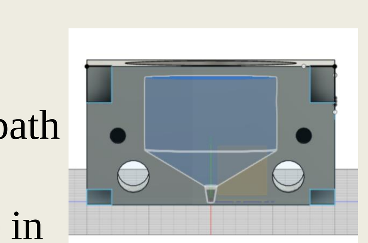
Innovation/Solution 1-1: Created a watertight and airtight seal between the piezoelectric and fluid chamber orifice by designing a recess on the top of the fluid chamber to put an O-ring on and attached a clamping ring by using a through-hole design instead of threading into the fluid chamber, which causes a separation.



Innovation/Solution 1-2: Set the 3D printing infill percentage to be 100% and put glue on the surface.

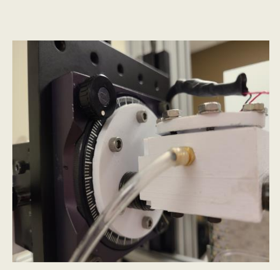
Issue/Challenge 2: Attaching the nozzle to the base of the fluid chamber, keeping the smooth path for the fluid.

Innovation/Solution 2: Designed a cone shape in the chamber that leads to a tapped hole in the bottom where the 3D printer extruder nozzle is attached and sealed with an O-ring.



Bleeding Procedure

The fluid chamber is inverted using the turntable and held lower than the reservoir until fluid bleeds from the nozzle. The nozzle tip is then sealed until the chamber is restored to the upright position. A height-adjustable fluid reservoir is used because the height of the reservoir relative to the nozzle outlet determines the hydrostatic pressure at the outlet.



Nozzle

Issue/Challenge:

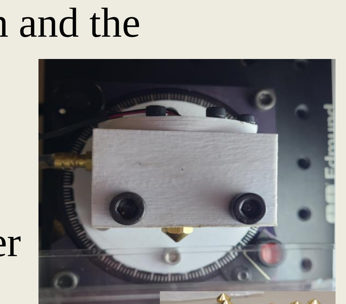
We designed and 3D printed a nozzle that fit a pipette tip so that we could cut a pipette tip to change droplet diameter.

→ It was so long and thin that a pressure pulse from the piezoelectric could not reach the tip of the nozzle properly.

We glued a fine metal tube onto the fluid chamber and used it as a nozzle.

→ Glue does not make it watertight enough and the fluid came out from the side.

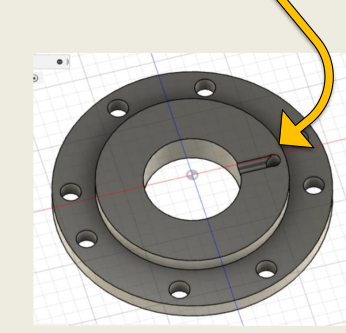
Innovation/Solution: Used a 3D printer extruder nozzle with a diameter ranging from 0.2 mm to 1.0 mm.



Clamping Ring

Issue/Challenge: Creating an airtight seal between the piezoelectric and fluid chamber orifice.

Innovation/Solution: Designed a clamping ring so that it provides a sufficient clamping force on the edges of the piezoelectric equally and made a hole for the wires of the piezoelectric to go through.



Conclusion

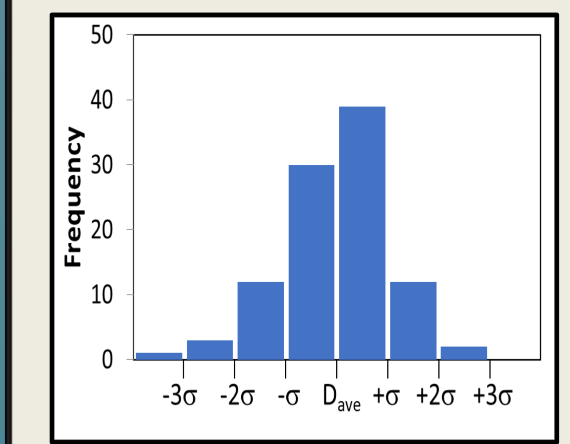


Figure 4: Frequency vs average droplet diameter. The new droplet generator consistently produced small droplets with an average diameter of 0.634 ± 0.015 mm.

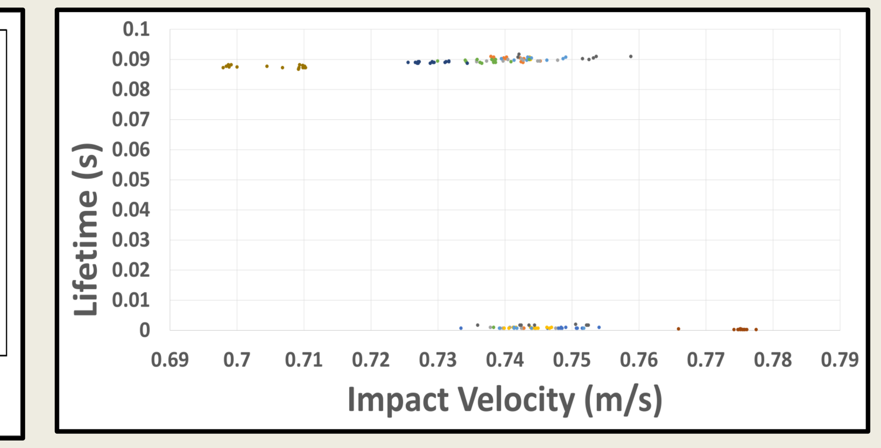


Figure 5: Lifetime vs impact velocity with new droplet generator. Without interference from satellite droplets, jets, or large diameters (i.e., shape), droplet lifetime is distinctly bimodal. That is, the droplet either ruptures on impact or survive to achieve rest.

The droplet generator we constructed achieved most of its goals (Figure 5). It consistently produced small (~0.6 mm) droplets (Figure 4) and eliminated the interference caused by satellite droplets (and occasionally eliminating the satellite droplet altogether). The small droplet diameter causes droplet oscillations to occur rapidly and thus the droplet stabilizes into a sphere quickly, ensuring that the shape as the droplet impacts the bath is practically identical every time (this also limits the likelihood of jets occurring).

Next Steps

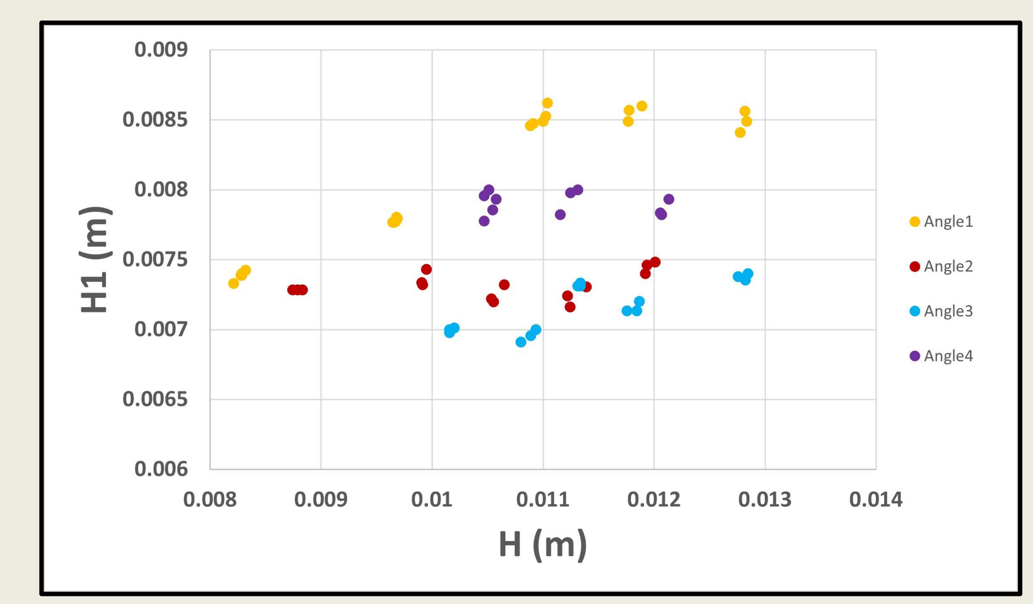


Figure 6: Slide height vs droplet generator height. Because the slide was not adjusted between various trials of the same angle, slide height (H_1) should be the same for any one angle. This is not the case, suggesting that we need a better way to control H_1 and, by extension, slide angle.

The new droplet generator does not solve all our problems. When using the droplet generator on oblique impacts with a glass slide, we discovered two weak areas. First, our design does not leave much room for additional objects (e.g., slides) to be placed underneath the nozzle. This made it difficult to maneuver the slide during our experiments, resulting in inconsistent slide angles and heights (Figure 6). Second, the fluid chamber is attached directly to the turntable. Ideally, the fluid chamber and nozzle would be suspended directly over the fluid bath, but the proximity of the fluid chamber to the turntable limits our nozzle range. The next steps for this research would be to redesign the fluid chamber and nozzle such that we can easily and consistently determine slide position and angle, as well as to extend the chamber from the turntable for more clearance over the fluid bath.

References: [1]D.M. Harris, T. Liu, J.W. M. Bush (2015) A low-cost, precise piezoelectric droplet-on-demand generator. Exp Fluids 56:83,
[2]N. Ionkin, D. M. Harris (2018) Note: A versatile 3D-printed droplet-on-demand generator. Review of Scientific Instruments 89, 116103

Funding for this project is by the Science Research Fellows at DePauw University and the J. William Asher and the Melanie J. Norton Endowed Fund in the Sciences