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Droplet Impact, Part 1: Controlling Skirting Velocity

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Droplet Impact

Part 1: Controlling Skirting Velocity

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QR Code
for Droplet Video

Abstract

Droplet skirting occurs when a fluid droplet rolls over a bath of the same fluid without merging. To achieve skirting, we introduced a ~0.6 mm-diameter droplet of 1 cSt silicone oil into a bath of the same fluid by bouncing it off an angled glass slide coated with 100,000 cSt silicone oil. Our work suggests that initial skirting velocity increases as a function of slide angle and, to a lesser degree, droplet generator height. Furthermore, we conclude that the droplet lifetimes (initiation of skirting until rupture) and corresponding τ values (rate of decay of motion) appear consistent with theoretical predictions for such droplets based on previous research (which did not address >0.75 mm-diameter droplets).

Objectives

Our overall objective is to characterize and control the factors that cause droplet skirting (i.e., the rolling of a droplet over a fluid bath of the same material without merging) in order to reliably reproduce this fluid dynamic phenomenon. Specifically, we seek to better refine our understanding of the physics behind droplet coalescence/noncoalescence during skirting motion, which is primarily prescribed by droplet velocity (controlled by slide angle and droplet generator height in our apparatus) and by droplet geometry (controlled by droplet size and shape; see "Droplet Impact Part 2: Engineering a Droplet Generator" for more detailed information).

Methods

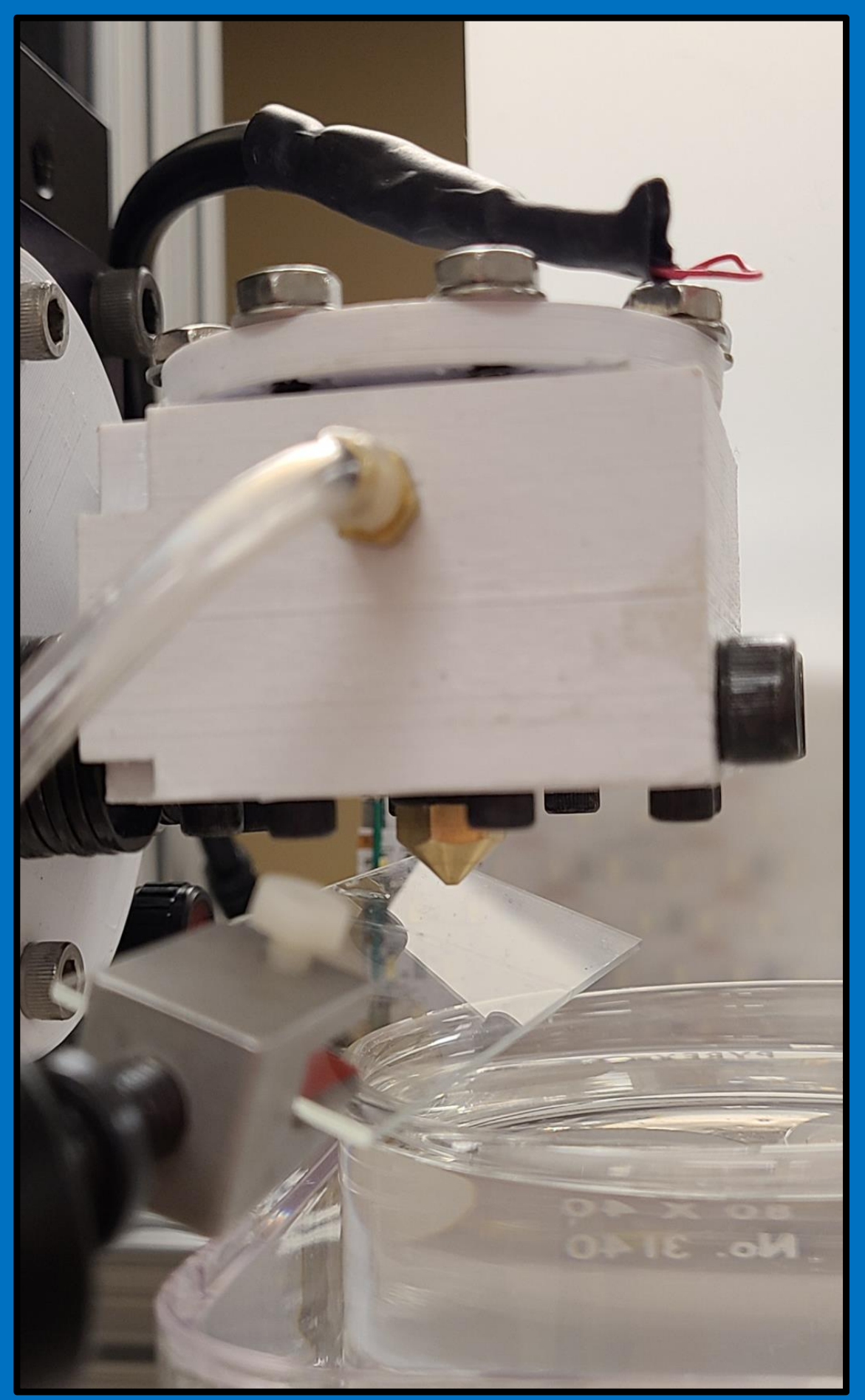

Figure 1 – Droplet apparatus and process. Generated droplet and fluid bath were made from 1 cSt silicone oil. Angled glass slide was coated with 100,000 cSt silicone oil. Droplets were bounced off the angled slide to convert vertical drops into projectile motion with vertical and horizontal velocities (horizontal motion is necessary to achieve skirting over the bath surface). Drop height was adjusted by moving the droplet generator up and down. Slide angle was changed by rotating the slide. Data were collected and analyzed by recording videos of droplet motion using a high-speed camera and retrieving information from specific frames.

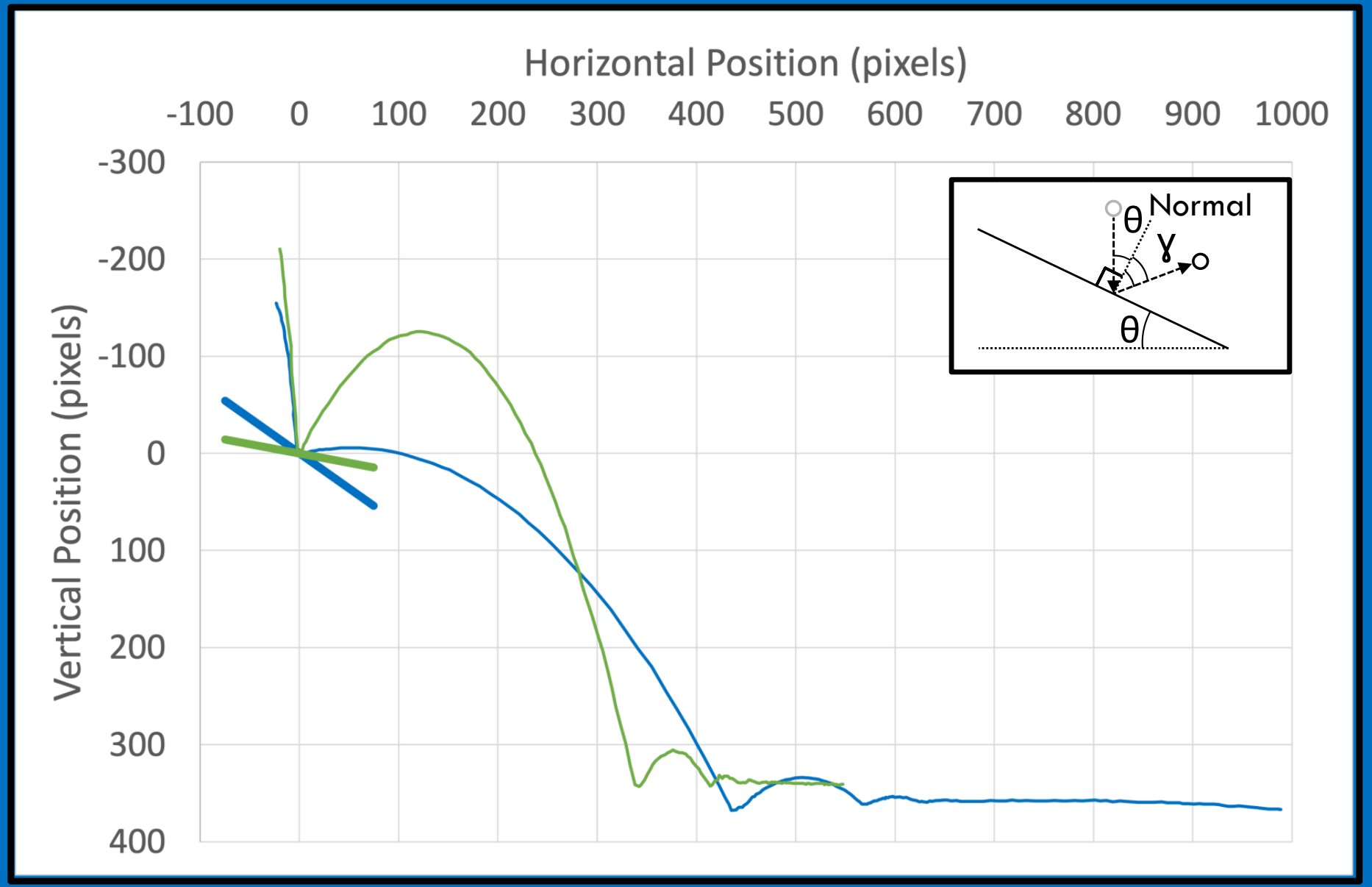

Figure 2 – Droplet position over time for minimum and maximum slide angles. Green lines illustrate droplet path (thin) for the minimum slide angle of ~8° (thick); whereas blue lines represent droplet path (thin) for the maximum slide angle of ~40° (thick). Skirting occurs where slope flattens. See inset diagram for definitions of slide (θ) and rebound (γ) angles.

Results

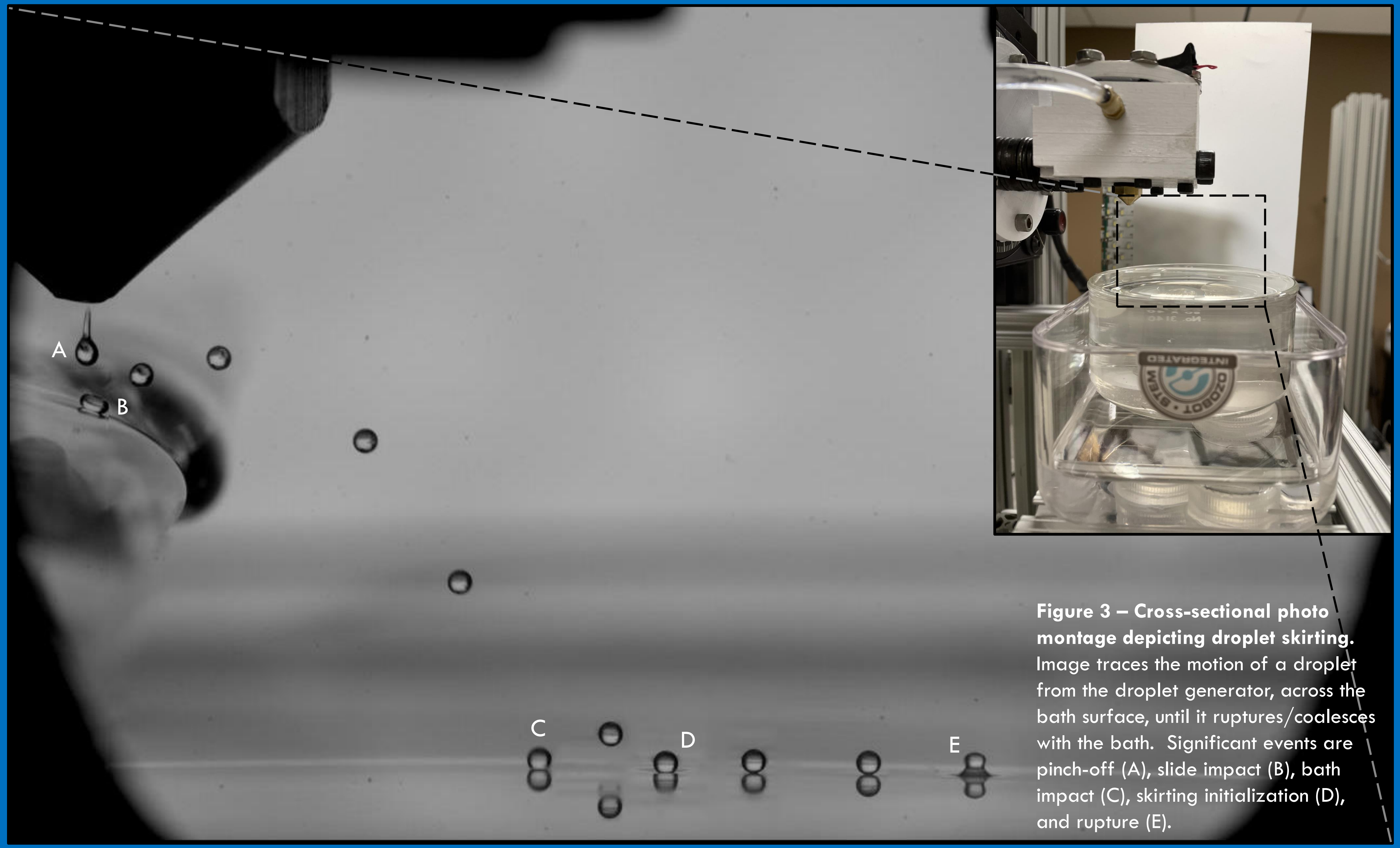

Figure 3 – Cross-sectional photo montage depicting droplet skirting. Image traces the motion of a droplet from the droplet generator, across the bath surface, until it ruptures/coalesces with the bath. Significant events are pinch-off (A), slide impact (B), bath impact (C), skirting initialization (D), and rupture (E).

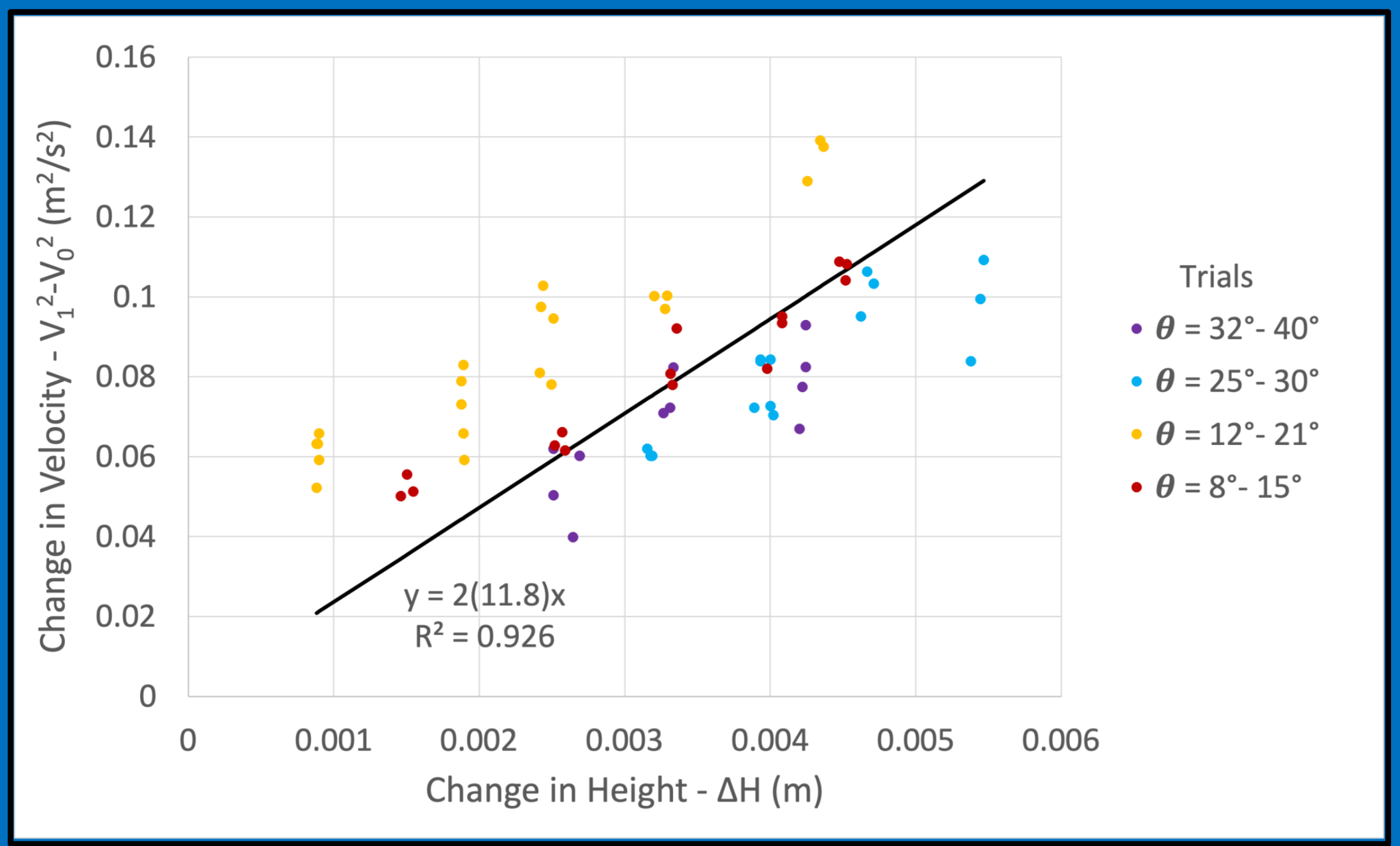

Figure 4 – Change in velocity vs change in height from pinch-off (A) to slide impact (B). Excel Solver calculated g for theoretical line of best fit to be ~11.8 m/s^2. Slide angles from each trial (for reference only) do not affect velocities prior to slide impact.

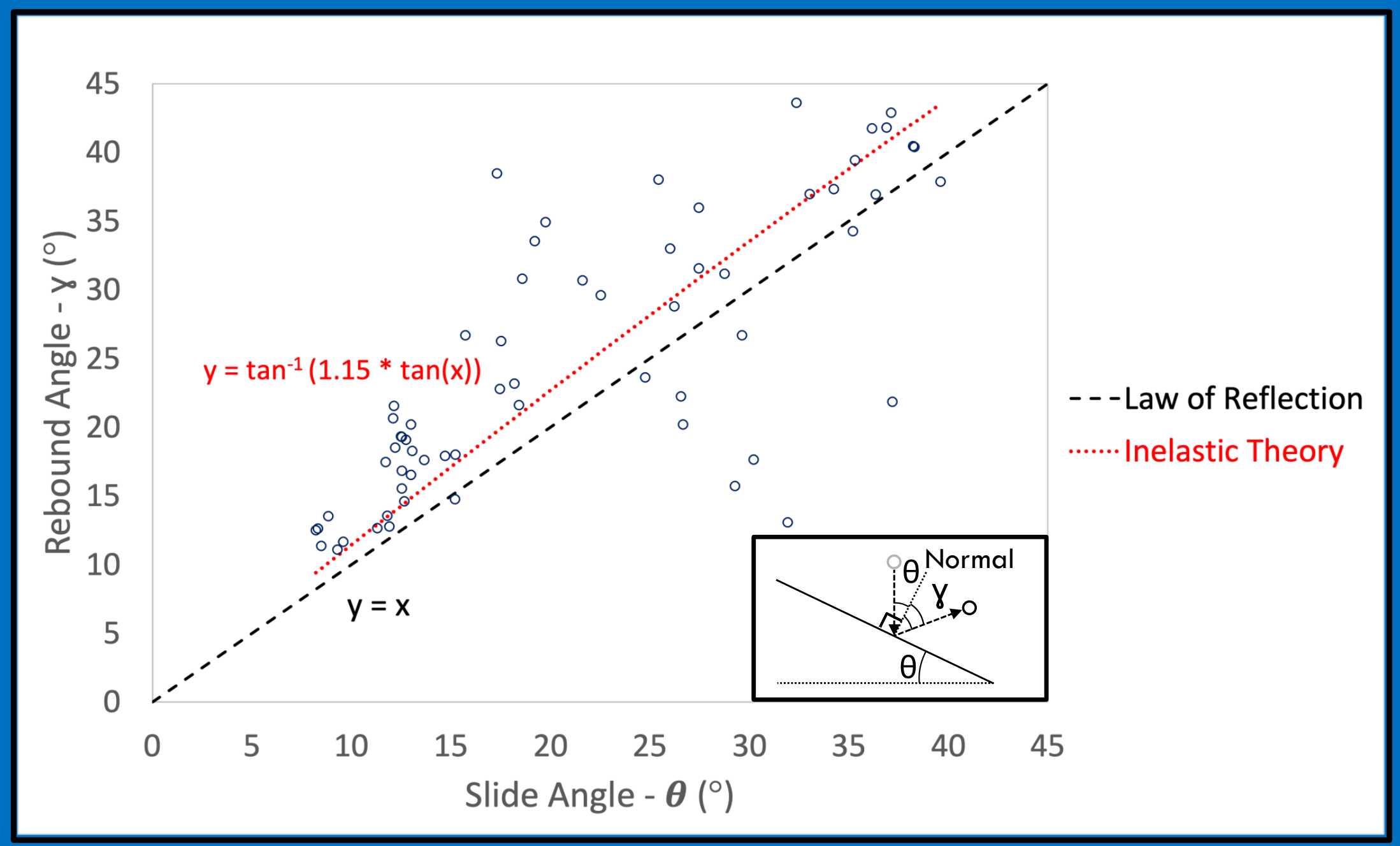

Figure 5 – Rebound angle vs slide angle at slide impact (B). Data were compared with the Law of Reflection (perfectly elastic collisions), which would predict that rebound angle (γ) equals slide angle (θ). Inelastic theory better fits the data, suggesting that γ is a product of inelastic collisions[2]. See inset diagram for definition of θ and γ.

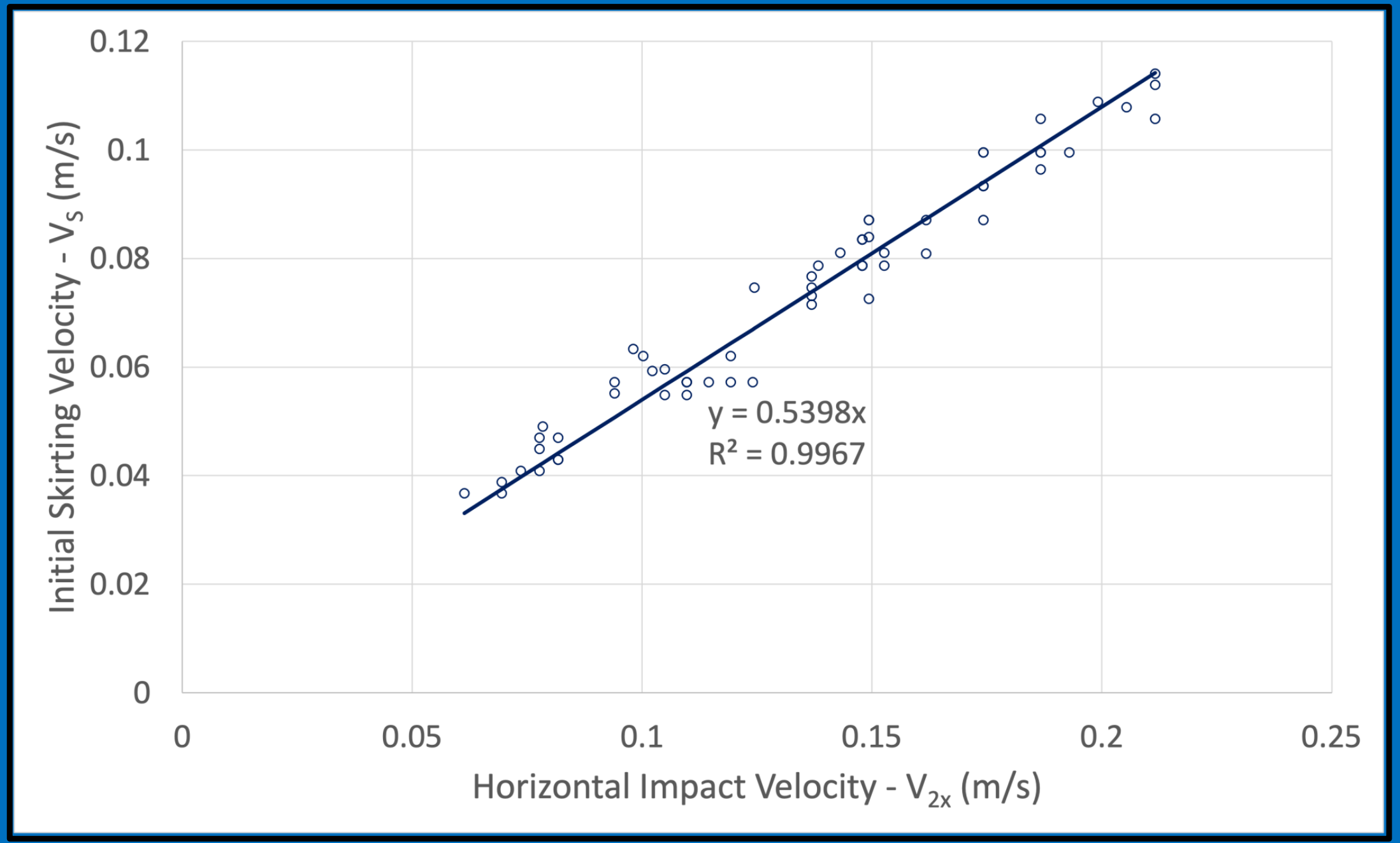

Figure 6 – Initial skirting velocity (D) vs horizontal impact velocity (C). Theoretical line of best fit for data was calculated using Excel Solver based on a directly proportional relationship between initial skirting velocity (V_S) and horizontal impact velocity (V_{2x}).

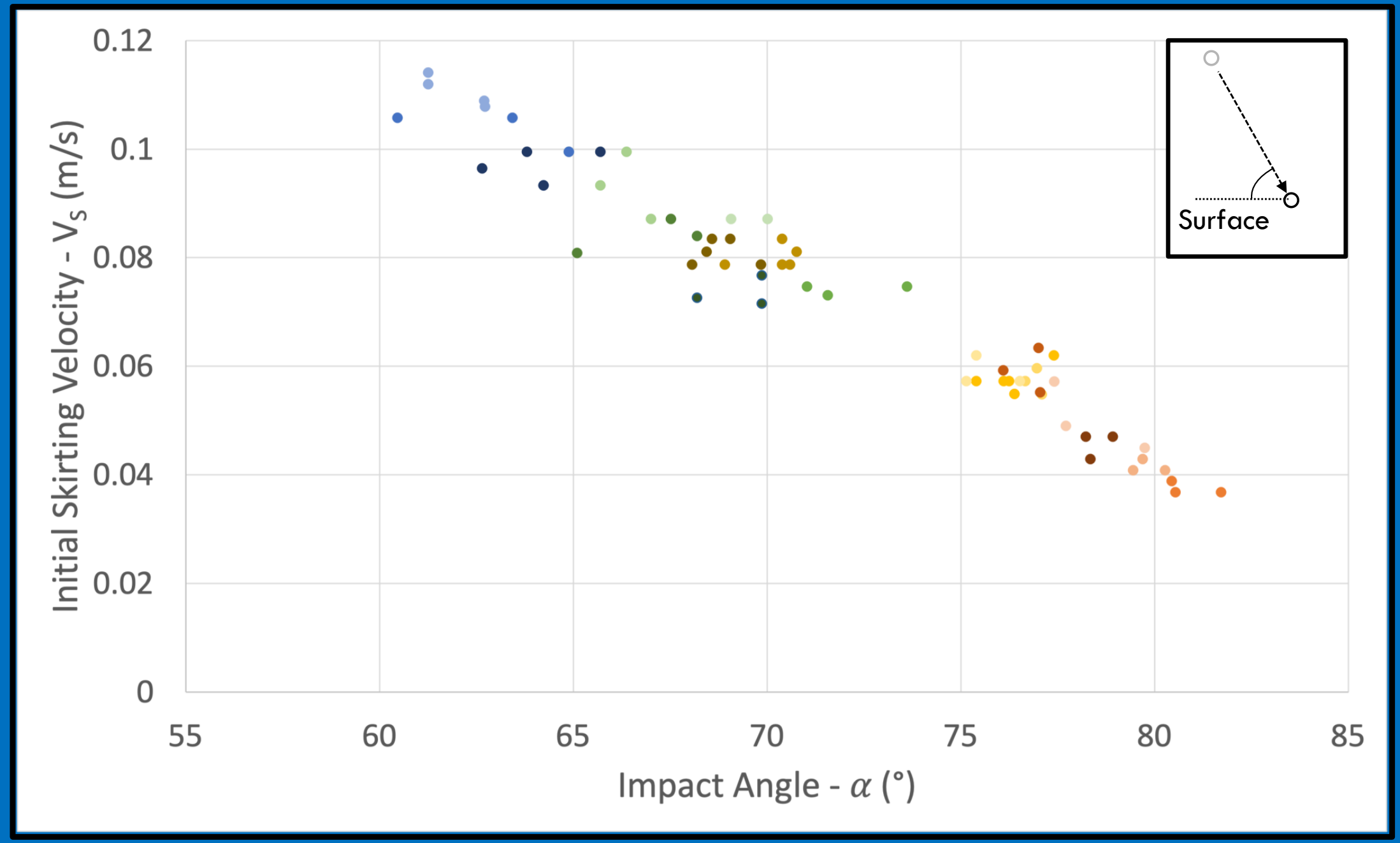

Figure 7 – Initial skirting velocity (D) vs impact angle (C). As slide angle (θ) decreased (blue to orange), the horizontal impact velocity decreased and impact angle (α) became steeper (i.e., steeper α result in slower initial skirting velocities). See inset diagram for definition of α.

Interpretation

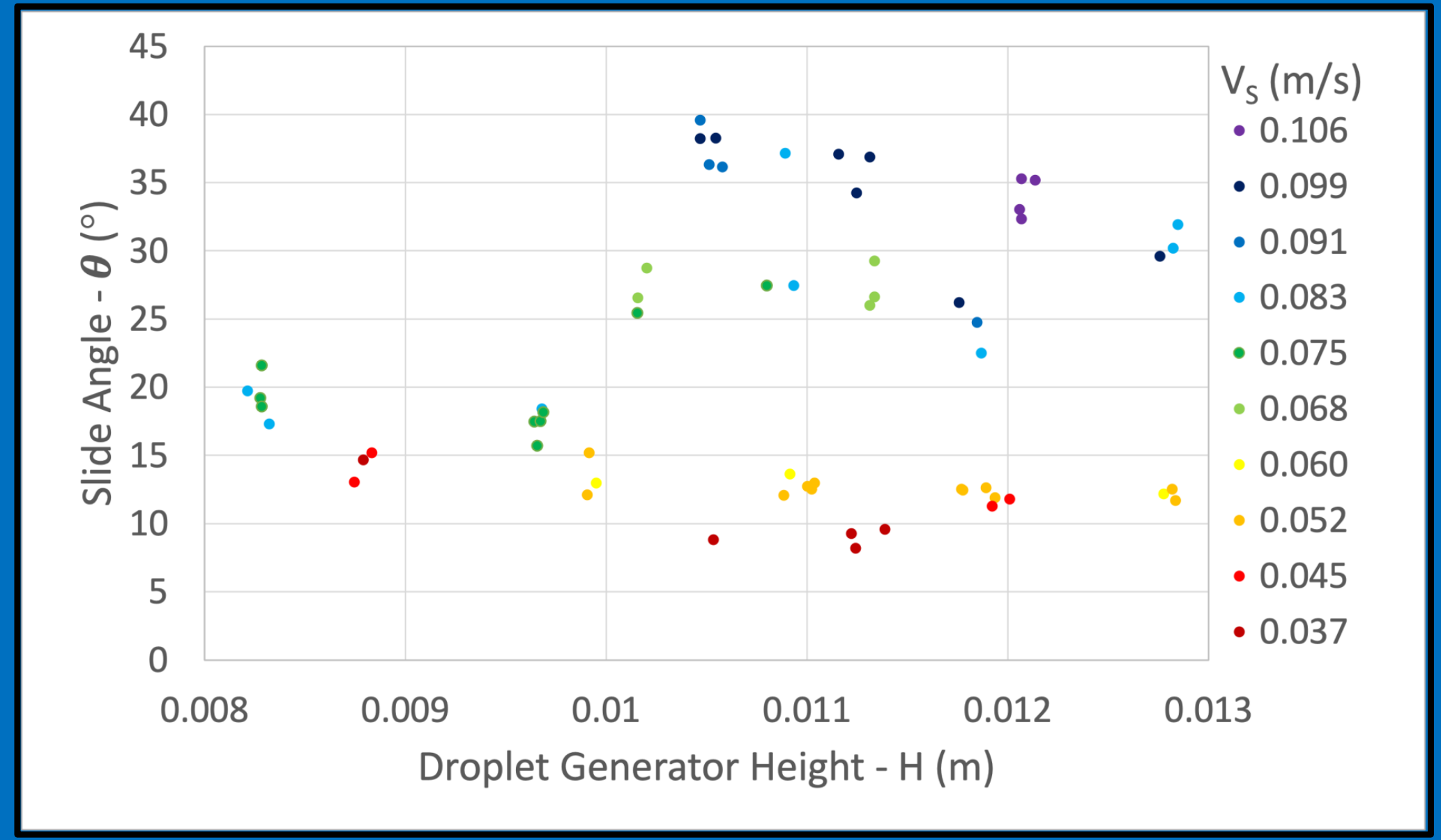

Figure 8 – Effect of slide angle and height on initial skirting velocity. Generally, initial skirting velocity (V_S) increases with slide angle (θ). Height (H) does not seem to have as much of an effect on V_S, although there is a slight indication that V_S might increase with H.

Initial skirting velocity (V_S) is controllable by manipulating slide angle (θ). As θ approaches 45° (droplet rebound with no initial vertical velocity), the impact angle (α) approaches a minimum (i.e., the droplet impacts the bath at the shallowest angle possible), producing the maximum horizontal velocity at impact, and thus the **largest initial skirting velocity.**

Similarly, droplet generator height (H) also affects V_S, but its influence is of substantially lesser magnitude than θ (i.e., for a given range of θ, V_S increases slightly with H, but not as significantly as when θ is changed).

In addition to looking at the relationships between V_S and θ/H, we also compared droplet lifetimes to previous research[1]. Specifically, our τ value (rate of decay of motion) from the exponential decay equation,

$$\frac{L}{V_S} = \tau(1-e^{\frac{T}{\tau}})$$

where L is skirting length and T is lifetime, was similar to the predicted value of τ for our droplet diameters even though previous research did not study small diameter droplets[1]. This corroboration not only supports previous research, but it also attests to the effectiveness of our ability to control the factors that influence droplet skirting using our droplet generator apparatus.

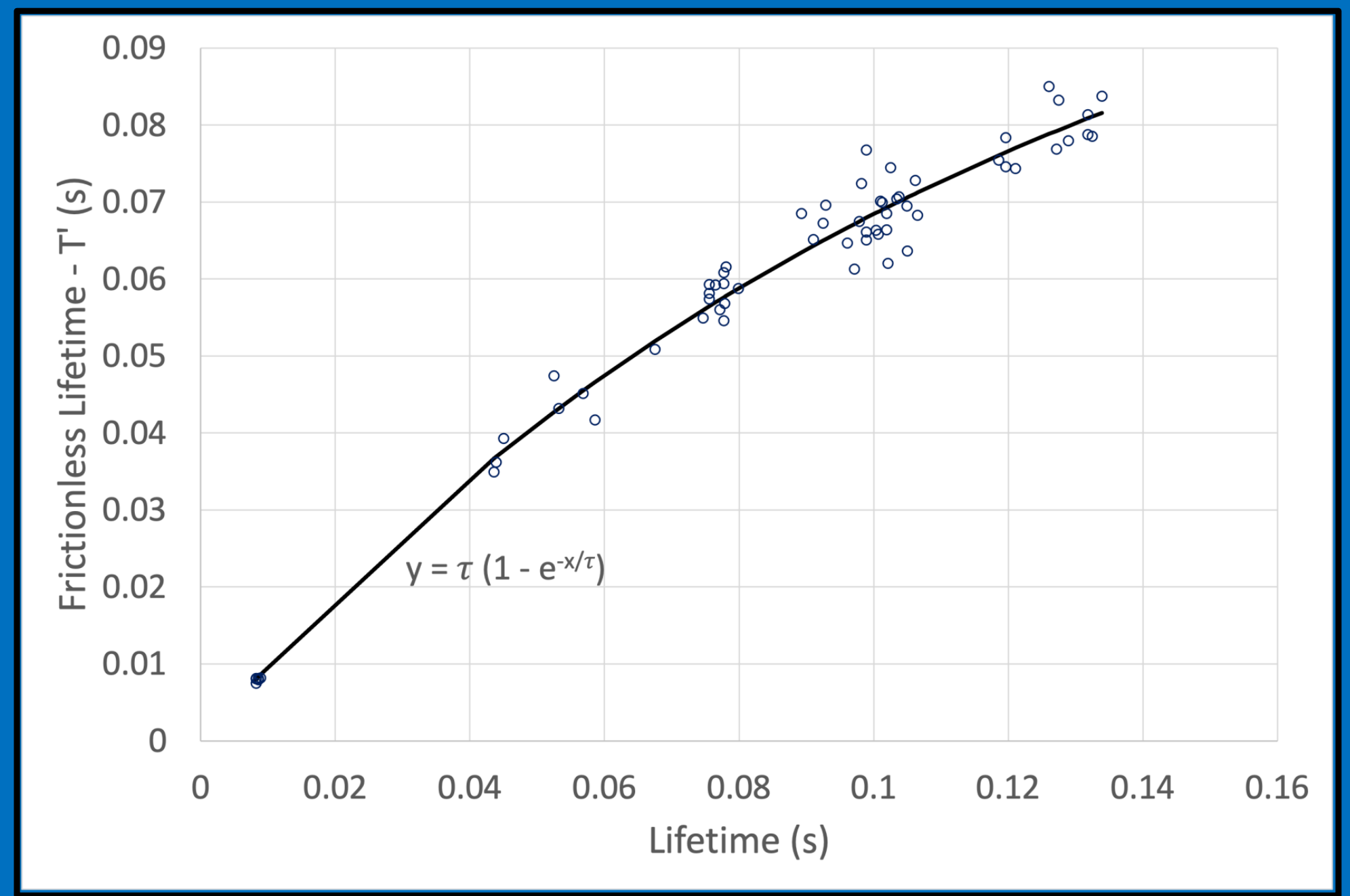

Figure 9 – Frictionless lifetime vs droplet lifetime. The lifetime of the droplet if friction were not present (T') represents skirting length (L) divided by initial skirting velocity (V_S). Data were compared with the exponential decay equation relating V_S to lifetime (T)[1]. The exponential decay constant (τ) calculated in our experiment (0.122) matches predicted values for our droplet diameter.

Acknowledgements

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[1] Hale, Akers, 2016 Deceleration of droplets that glide along the free surface of a bath, *J. Fluid Mech.*

[2] Gilet, Bush, 2012 Droplets bouncing on a wet, inclined surface, *Phys. Fluids 24*, 122103