DEPARTMENT OF ENGINEERING SCIENCE
UNIVERSITY OF OXFORD

The interface dynamics of drops impacting onto a different liquid

Ben Fudge

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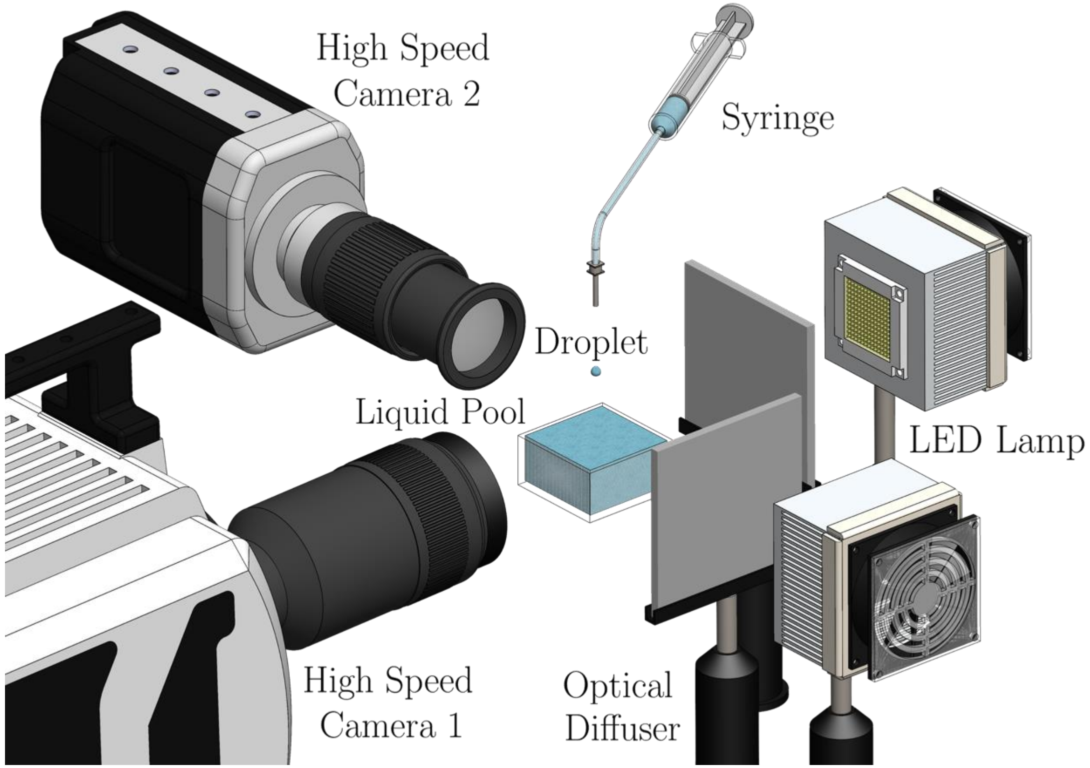
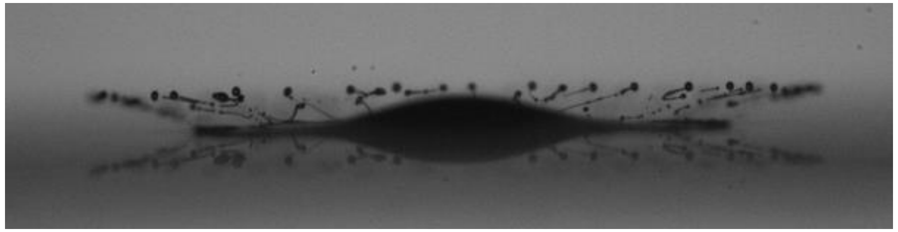
Experimental Setup

- Either single or twin camera setup to capture impacting droplet, pool motion or impact on sphere from both directions.
- Post-processing in Matlab to extract features such as droplet impact and pool velocity, splashing outcome etc.
- Example image shows impact of 1.8 mm diameter FC-770 droplet onto 500 cSt silicone oil pool at 2.7 m/s.





Numerical Setup

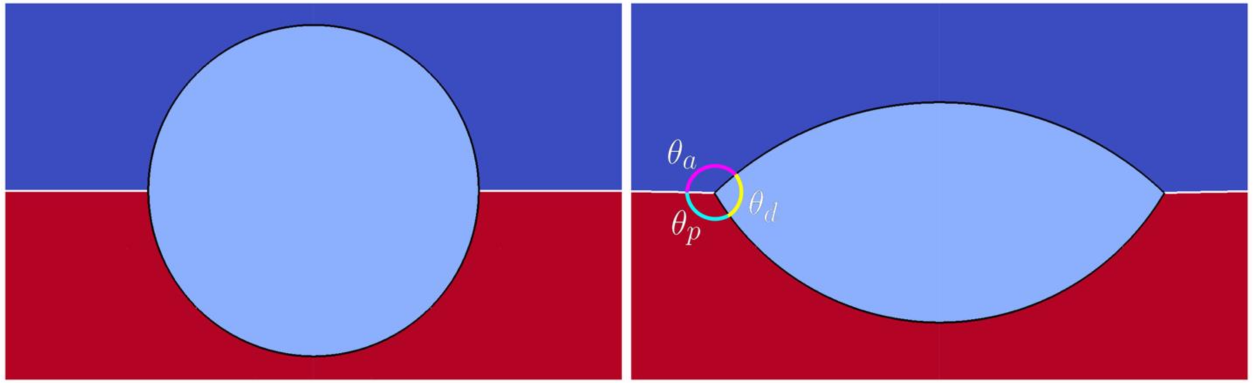
- Used Basilisk to solve the full non-linear Navier Stokes equations including the effects of surface tension, gravity and viscosity.

$$\rho(\partial_t \mathbf{u} + \mathbf{u} \cdot \nabla \mathbf{u}) = -\nabla p + \nabla \cdot (2\mu \mathbf{D}) + \sigma\kappa\delta_s \mathbf{n} + \mathbf{f_e},$$

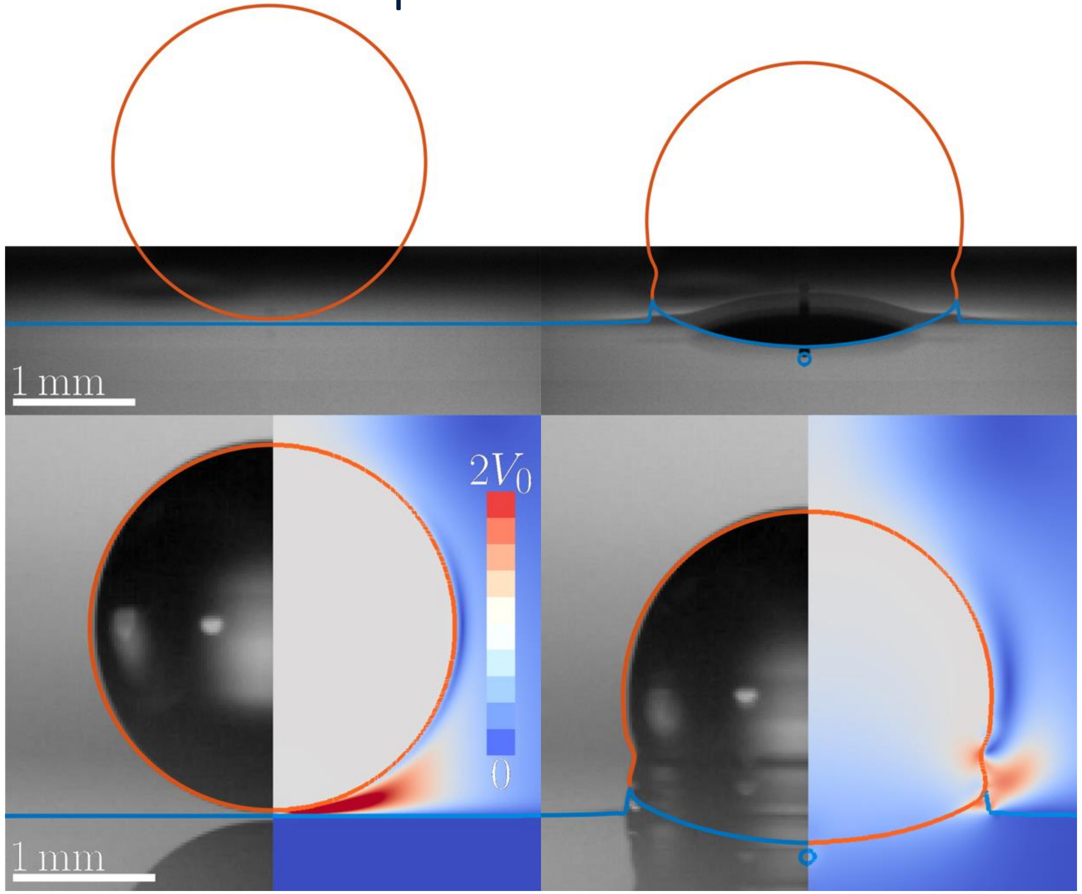
$$\nabla \cdot \mathbf{u} = 0,$$

- To vary the pool and droplet properties the three-phase method of Chizari (http://basilisk.fr/sandbox/chizari/threephase/) was used.

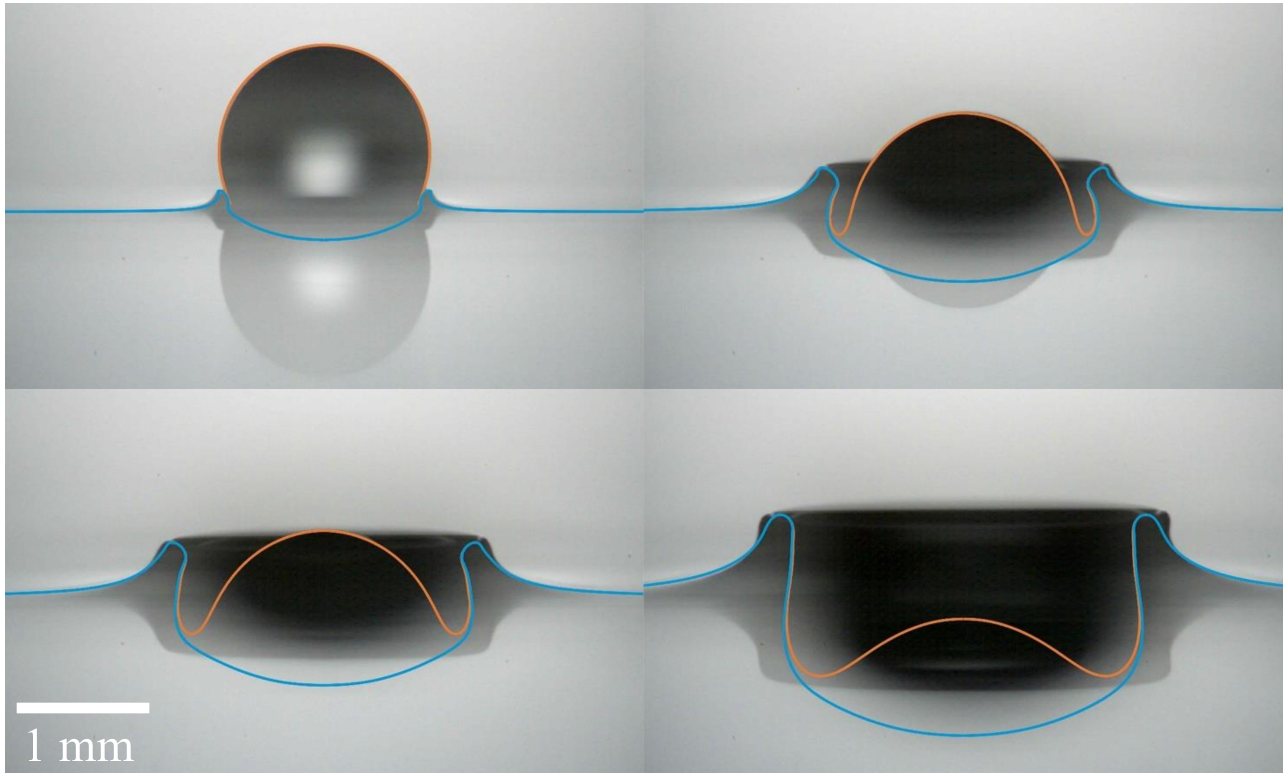
- The three-phase implementation was validated by comparing to canonical liquid lens final steady state analytical solutions based on Neumann triangles.



Experiment-Simulation Comparison

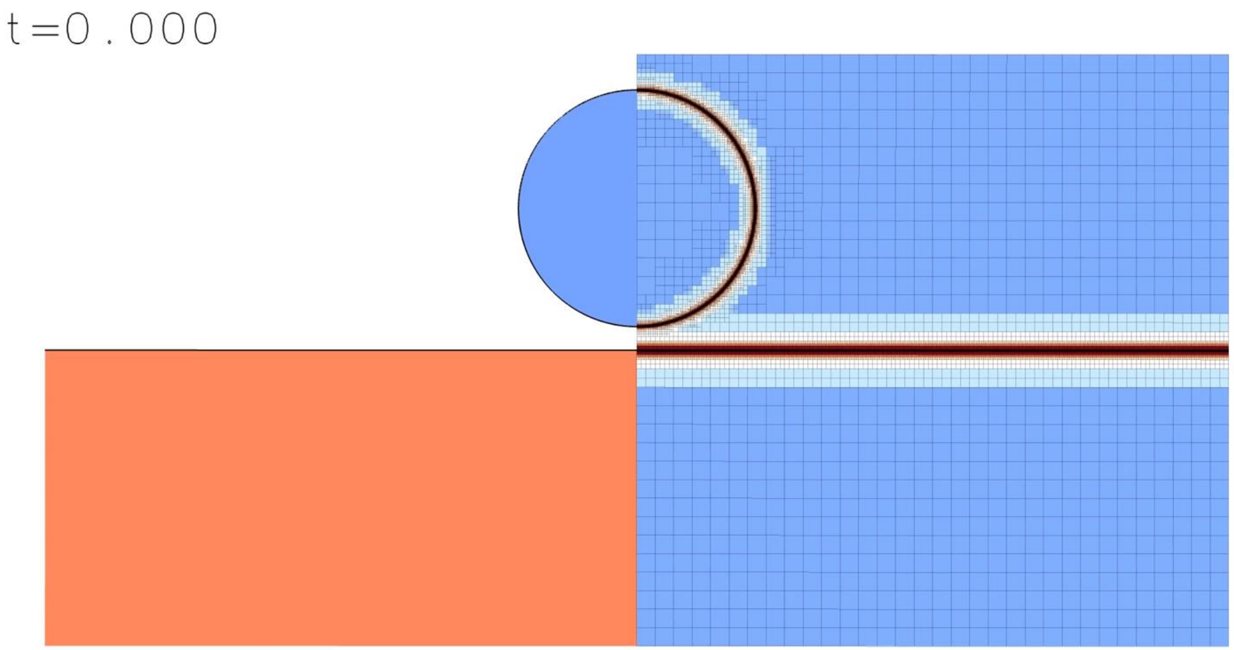


Impact of a 5cP Water-Glycerine Solution Droplet onto a FC-40 pool



Simulation and Experimental snapshots for the impact of a FC-770 droplet onto a 50 cSt Silicone Oil Pool

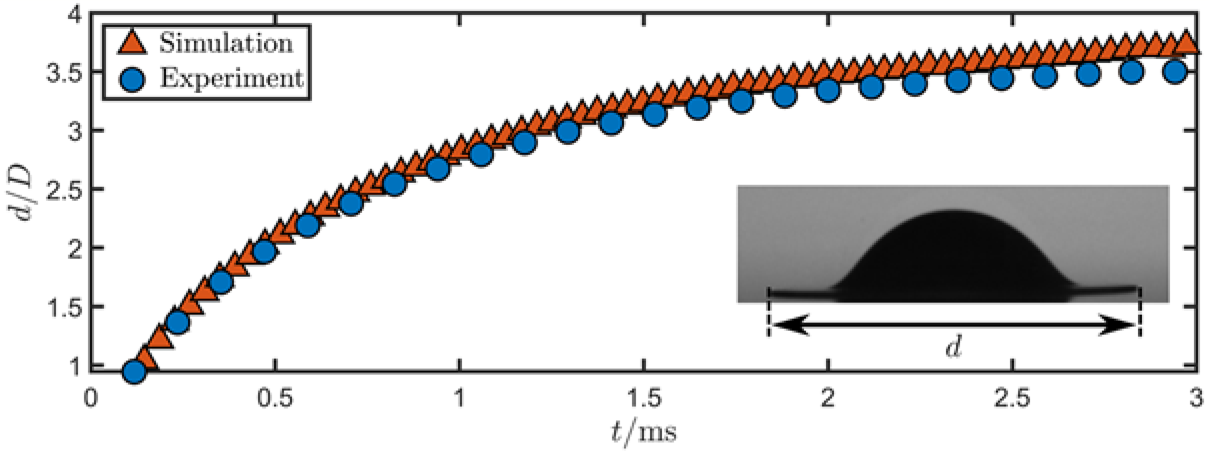
Experiment-Simulation Comparison



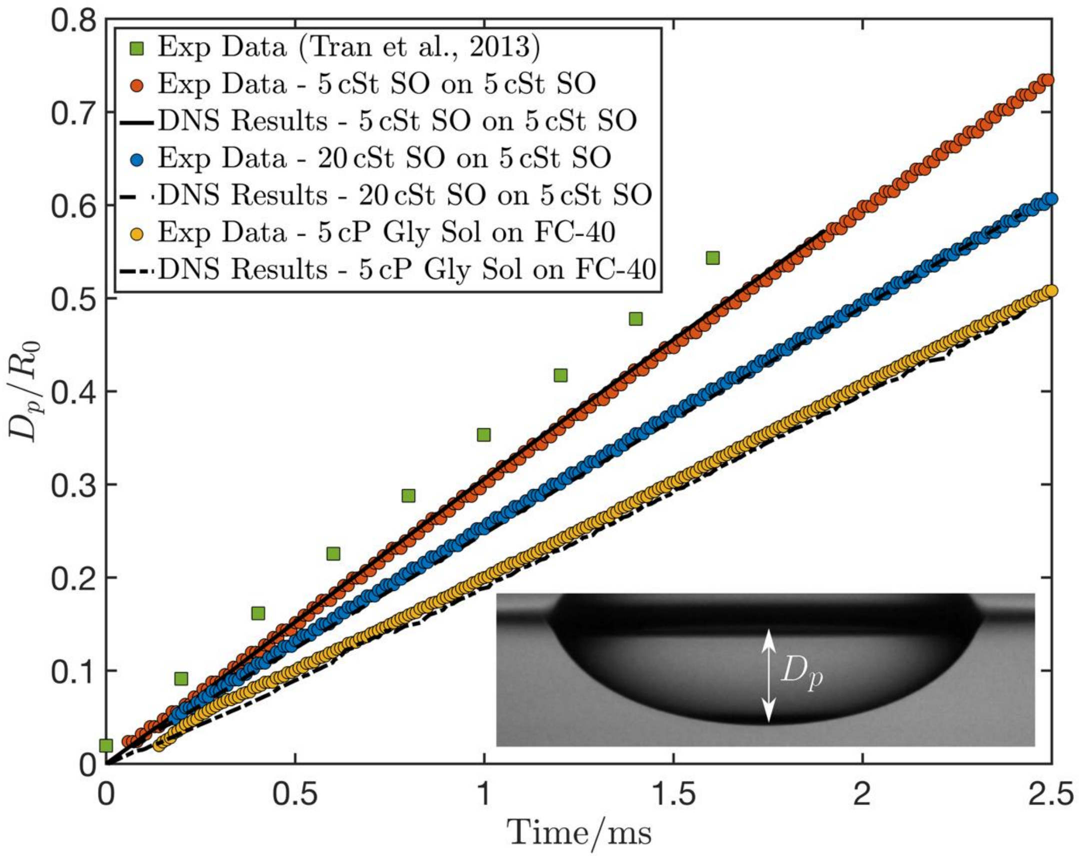
Impact of a 1.6 mm diameter FC-770 drop on a 50 cSt silicone oil pool at 3.2 m/s (Re=6660, We=2020, Fr=25.9). Experimental video captured at 25,000 fps but displayed at 20 fps.

Experiment-Simulation Comparison

- Performed quantitative and qualitative comparisons between the experiments and simulations to check for accurate capturing of the dynamics.



1.4 mm diameter FC-770 droplet onto a 1000 cSt silicone oil pool at 1.72 m/s



Various fluid combinations given in the legend demonstrating different density and viscosity ratios

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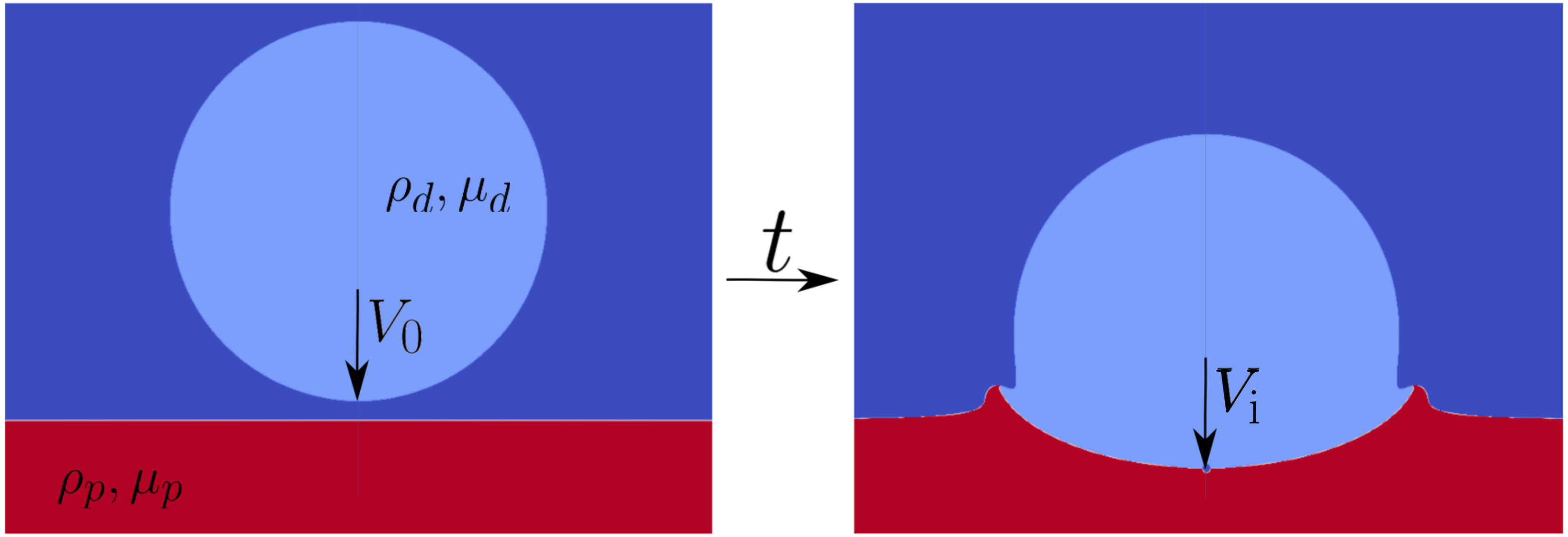
Pool Displacement Velocity

- Interested in how the speed of the common interface between an impacting droplet and a deep pool of another fluid varies with the difference in properties between the two fluids.

- For the case of same fluid impacts the speed of the common droplet interface is commonly considered to be one half of the impacting droplet speed.



Pool Displacement Velocity

- Droplet initial has kinetic energy $E_d^0 = \rho_d \Omega V_0^2/2$ and later has kinetic energy $E_d^t = \rho_d \Omega V_{\mathrm{i}}^2/2$ once moving with the pool.

- Assuming that the pool has a radially outward velocity field from the common interface with the droplet it has kinetic energy $E_p^t = 3\rho_p \Omega V_{\mathrm{i}}^2/2$.

- Equating the sum of the two energies with the initial droplet energy we find

$$\bar{V} = \frac{V_{\mathrm{i}}}{V_0} = \frac{1}{\sqrt{1+3\rho_r}},$$

where $\rho_r = \rho_p/\rho_d$ is the pool to droplet density ratio.

Pool Displacement Velocity

- Viscous dissipation rate per unit volume scales as $\epsilon \sim \mu V^2/D^2$ and we can thus write the energy dissipated in the pool as

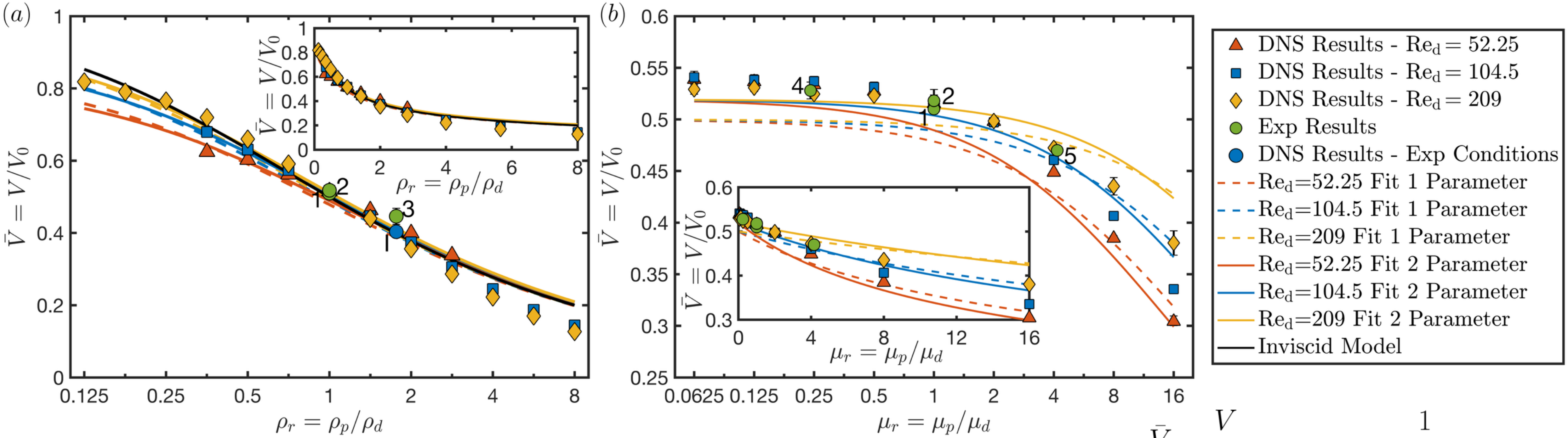
$$E^t_{\mu,p} = \frac{C\mu_p\Omega}{2DV_0}V_{\mathrm{i}}^2 .$$

- Incorporating this into our energy balance and relaxing the assumption on the pool velocity field we get

$$\bar{V} = \frac{V_{\mathrm{i}}}{V_0} = \frac{1}{\sqrt{1 + A\rho_r + \frac{C}{\mathrm{Re_d}}\mu_r}} .$$

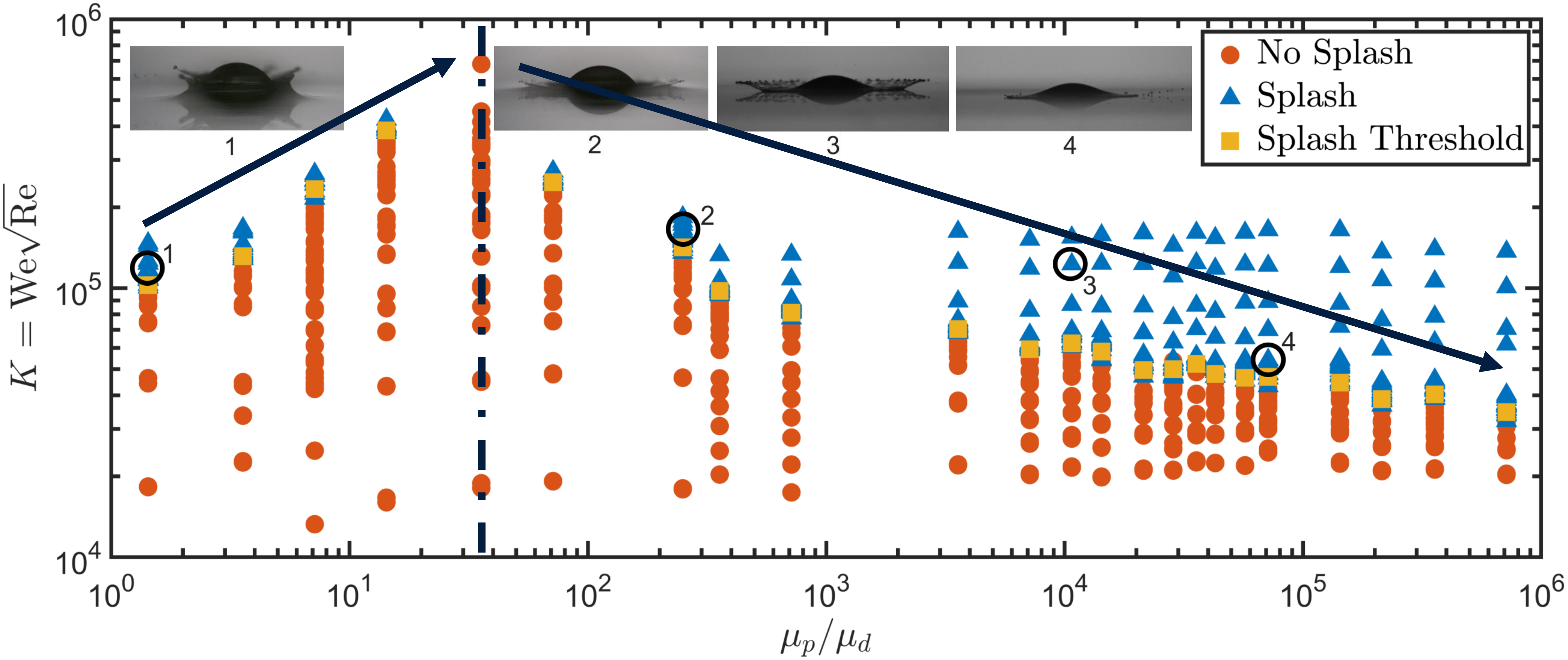
Pool Displacement Velocity

- Performed a wide range of experiments and simulations across a large range of density and viscosity ratios and found a significant change from the simple half droplet speed for same fluids.



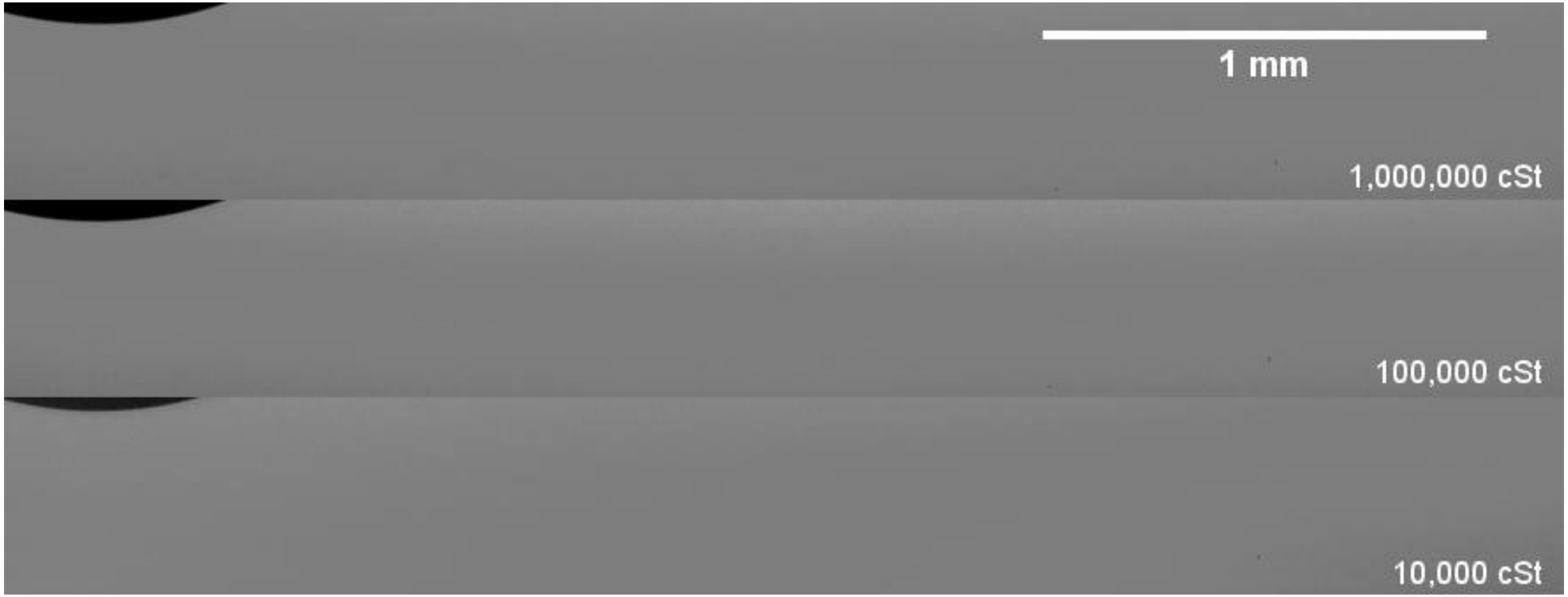
$$\bar{V} = \frac{V}{V_0} = \frac{1}{\sqrt{1 + A\rho_r + C\mathrm{Re_d}^{-1}\mu_r}}$$

Splashing on a Viscous Pool



Splashing on a Viscous Pool

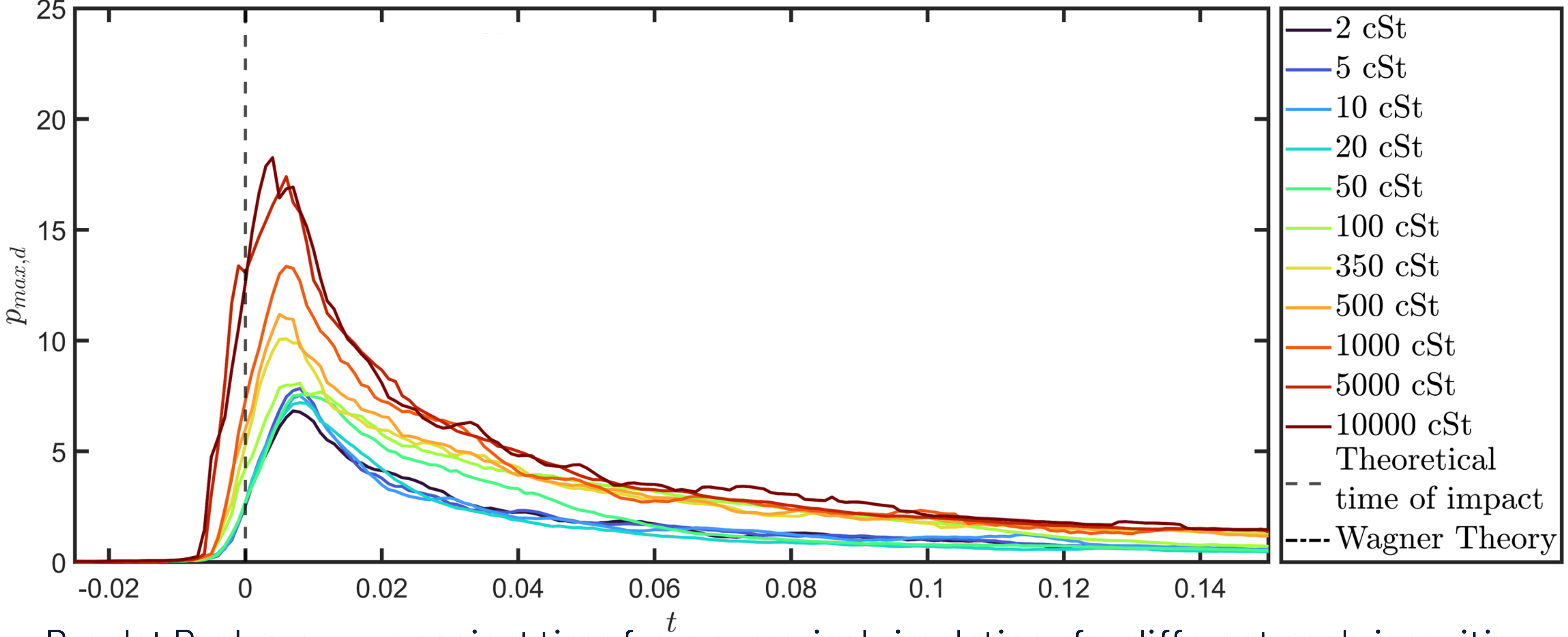
- A similar phenomena was observed for impact onto soft solids, being explained by the substrate motion cushioning the impact leading to a reduction in the maximum pressure in the droplet.



Impact of a 1.6 mm diameter FC-770 droplet onto three different silicone oil pools (10k, 100k, 1M cSt) at 2.5 m/s. Captured at 220,000 fps but displayed at 15 fps.

Splashing on a Viscous Pool

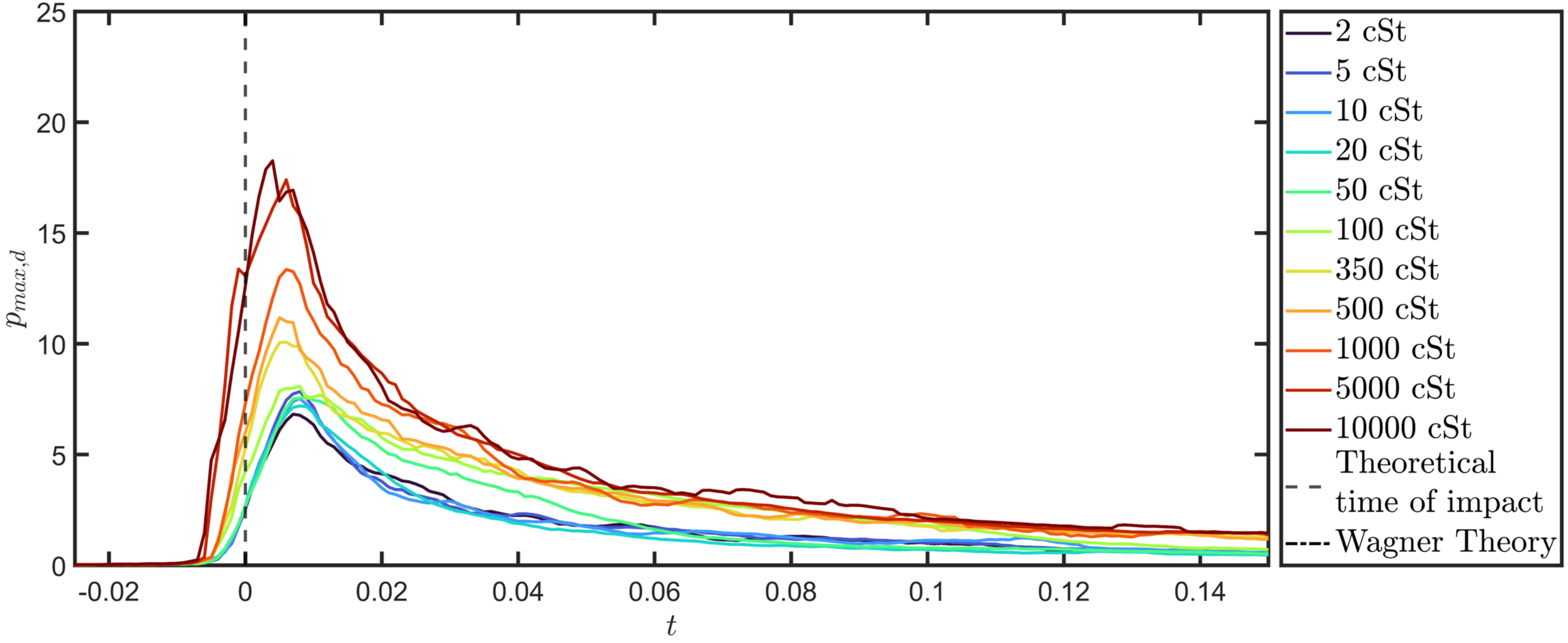
- A similar phenomena was observed for impact onto soft solids, being explained by the substrate motion cushioning the impact leading to a reduction in the maximum pressure in the droplet.



Droplet Peak pressure against time from numerical simulations for different pool viscosities with the impact velocity being the same in all cases

Splashing on a Viscous Pool

$$p^{\text{Wagner}}_{\text{max,d}} = \frac{3\rho_d R V_0}{8\delta t} \qquad p_{\text{max,d}} = \frac{3\rho_d R (V_0 - V_i)}{8\delta t} = \frac{V_0 - V_i}{V_0} p^{\text{Wagner}}_{\text{max,d}} = \left(1 - \bar{V}\right) p^{\text{Wagner}}_{\text{max,d}}$$



Splashing on a Viscous Pool

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- Considering that splashing will occur when the droplet maximum pressure exceeds a certain threshold, we arrive at the following criteria to splash.

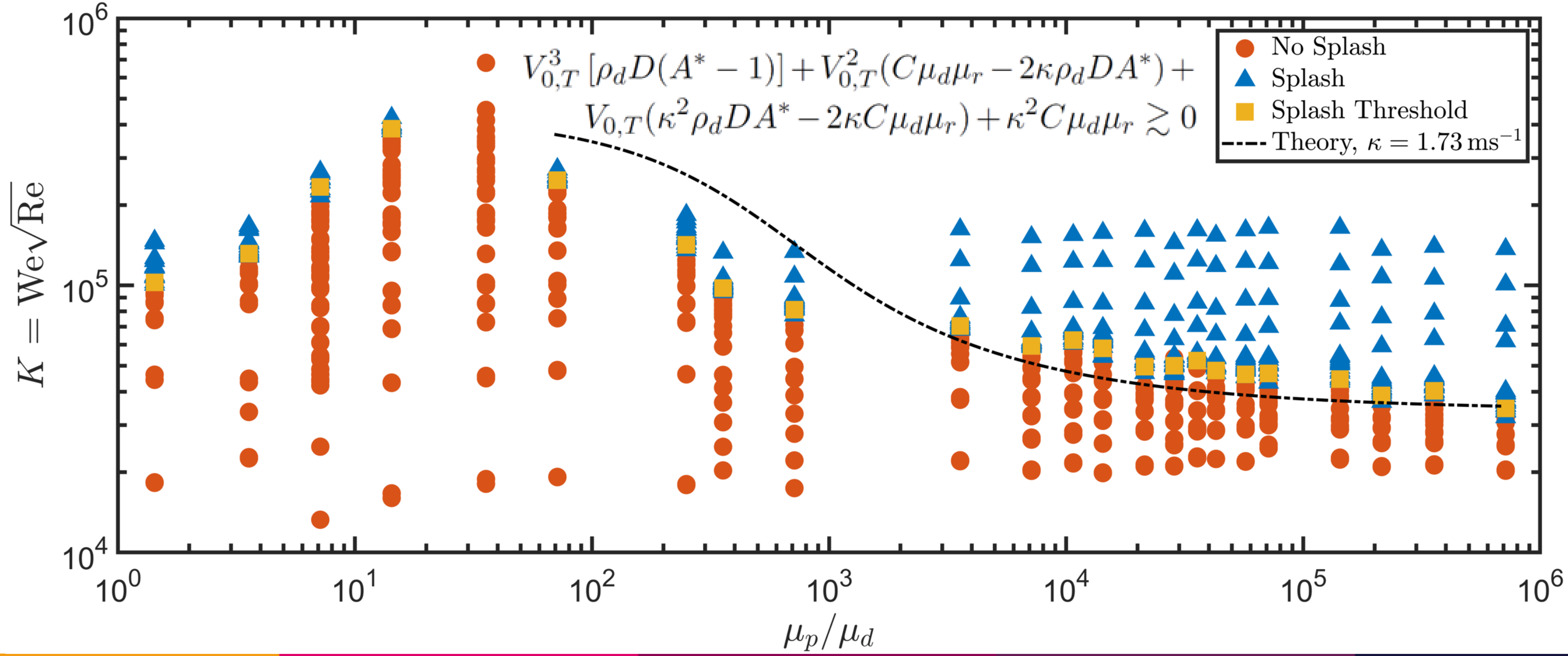
$$p_{\mathrm{max,d}} \gtrsim p_{\mathrm{T}} \longrightarrow V_{0,T} - V_i = V_{0,T}(1-\bar{V}) \gtrsim \frac{8p_T\delta t}{3\rho_d R}$$

- The term $\frac{8p_T\delta t}{3\rho_d R}$ which we hereafter denote as κ is equivalent to the speed to splash on a solid surface.

Splashing on a Viscous Pool

- From this an equation was derived for the splashing threshold, showing excellent agreement with the experimental data.

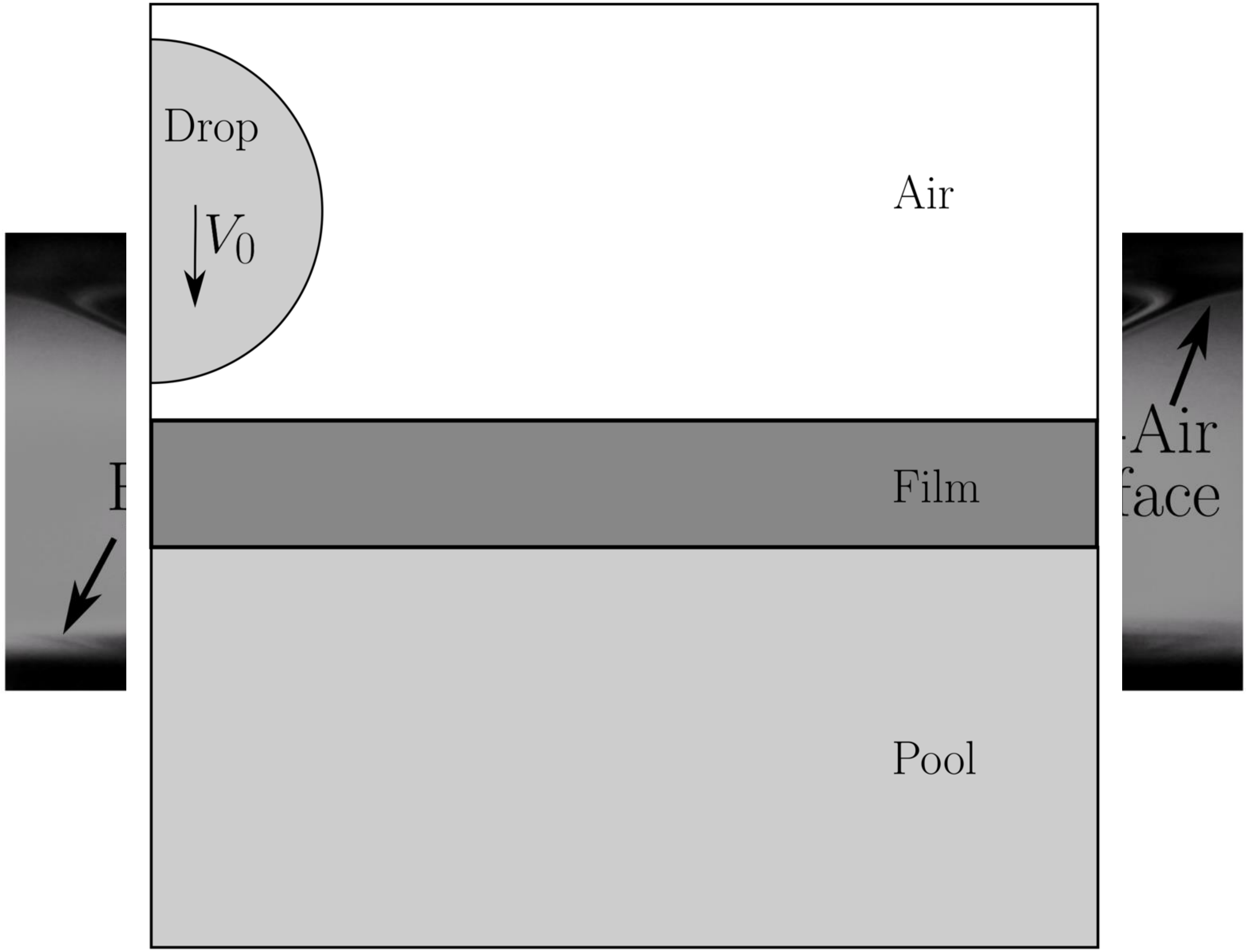
$$V_{0,T} - V_i = V_{0,T}(1-\bar{V}) \gtrsim \frac{8 p_T \delta t}{3 \rho_d R}$$



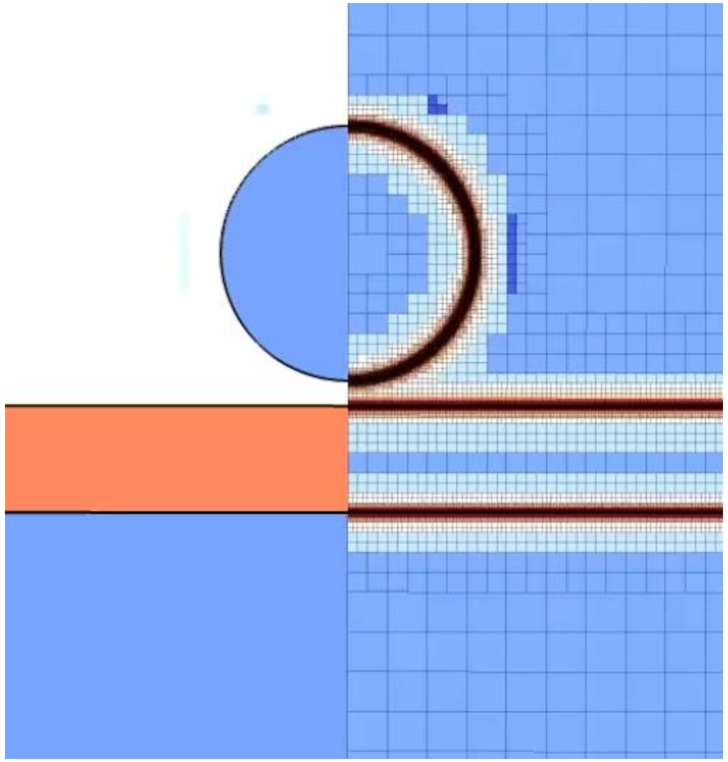
Film Displacement Velocity

- Here the case of a droplet impacting a deep pool of the same fluid coated by a thin layer of a different was investigated.

- The thickness and varied and there were two notable limits for zero and infinite film thicknesses.



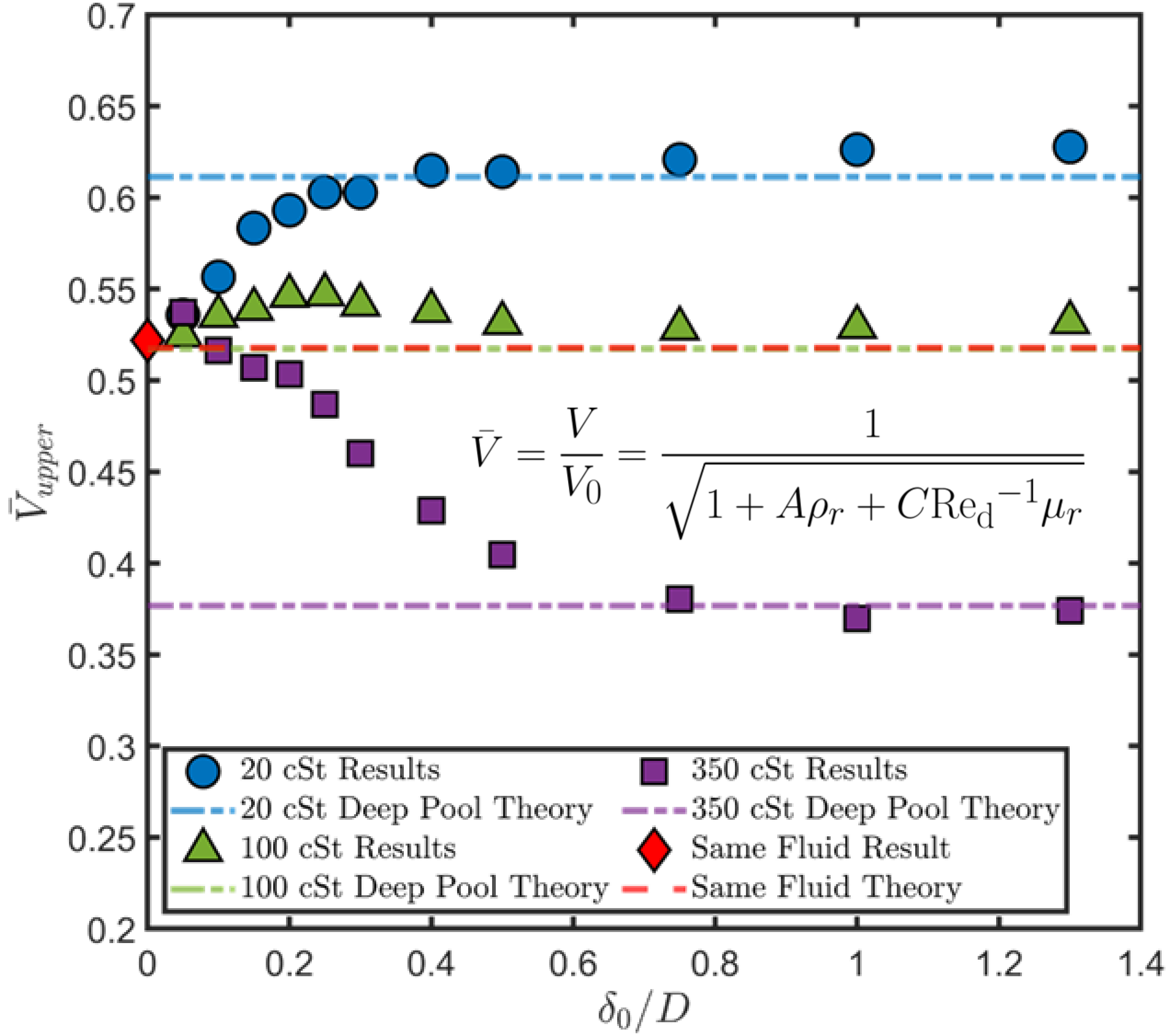
Film Displacement Velocity



Impact of a 2.6 mm diameter water droplet onto a 1.1 mm thick 350 cSt silicone oil film atop a water pool at 0.58 m/s . Experimental video captured at 34,000 fps but displayed at 25 fps for a duration of 4.9 ms.

Film Displacement Velocity

- Both increasing and decreasing trends in the velocity of the upper film-droplet interface were found.
- Some deviation in the trend was observed at low film thicknesses.
- We also observed different trends for the lower film-pool interface.



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Thank you for listening

BDF was supported by a UK-EPSRC DTA Studentship (2118171). AAC-P was supported by a Royal Society University Research Fellowship URF/R/180016 and USA-CBET/UK-EPSRC grant EP/S029966/1. RC and AAC-P further acknowledge support from USA-CBET/UK-EPSRC grant EP/W016036/1.