The Flow of Thin Liquid Film Past Obstructions

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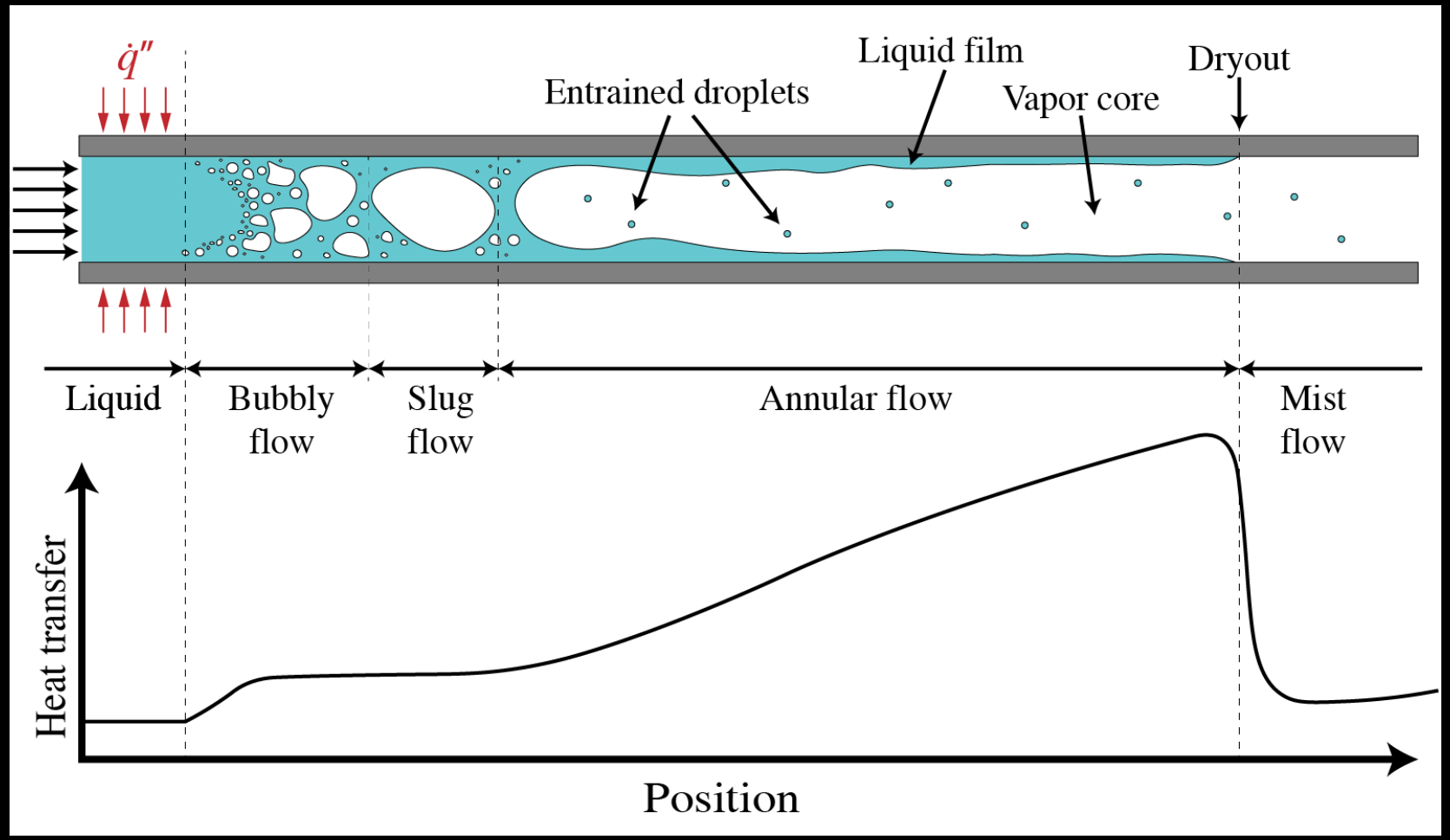
October 26, 2021

SEL Seminar

Captured: 200 fps
Playback: 24 fps

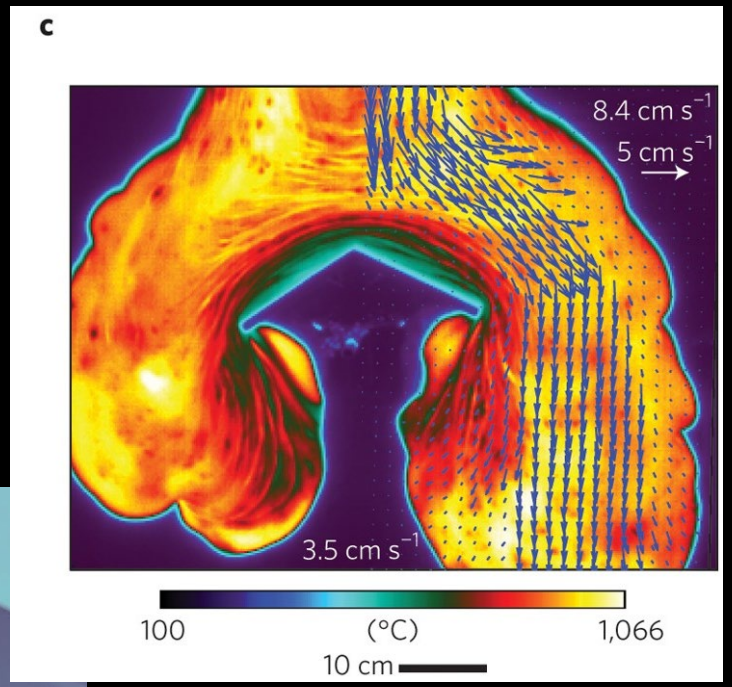
What's going on?



Common applications of obstructions in thin liquid films

Lubrication

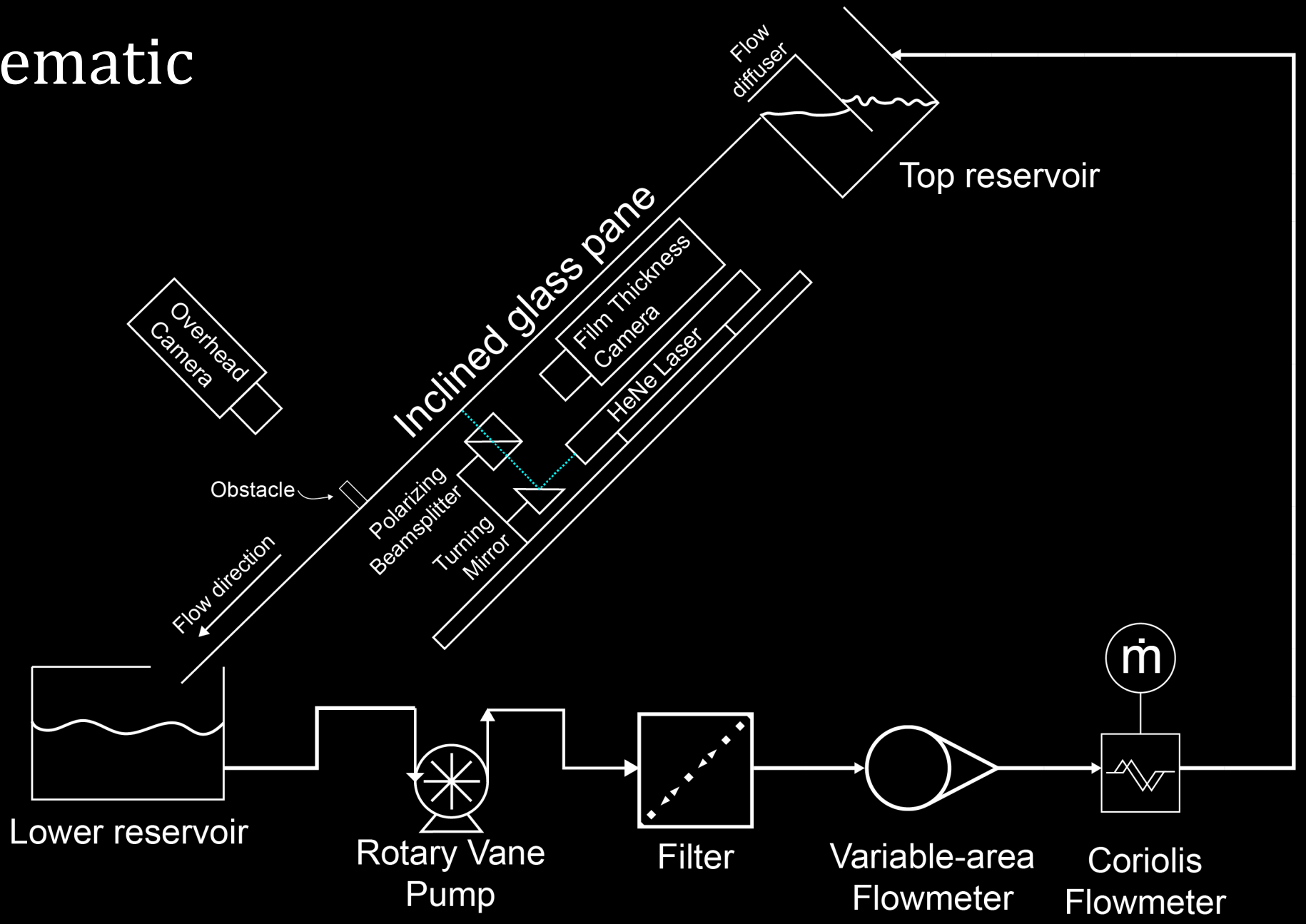
Spin-coating



Shelter in lava flow

Why build a separate facility?

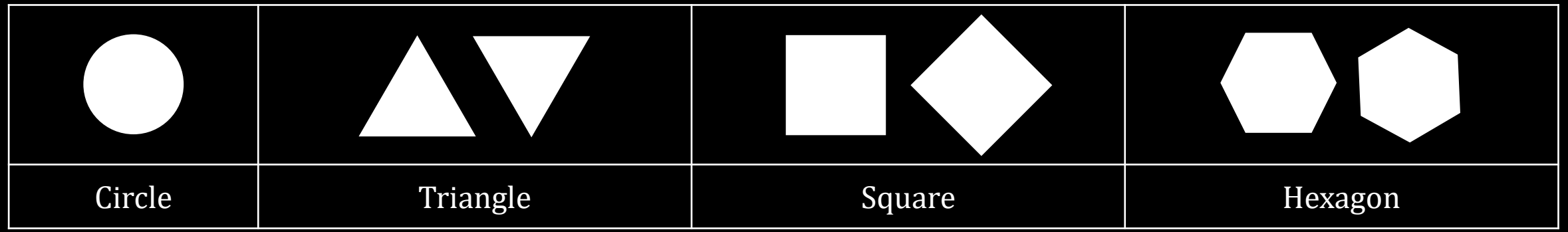
Schematic


Flow diffuser
Top reservoir
Inclined glass pane
Overhead Camera
Film Thickness Camera
HeNe Laser
Obstacle
Polarizing Beamsplitter
Turning Mirror
Flow direction
Lower reservoir
Rotary Vane Pump
Filter
Variable-area Flowmeter
Coriolis Flowmeter
ṁ

Real-life analogy: flow around bridge pylon/pillar

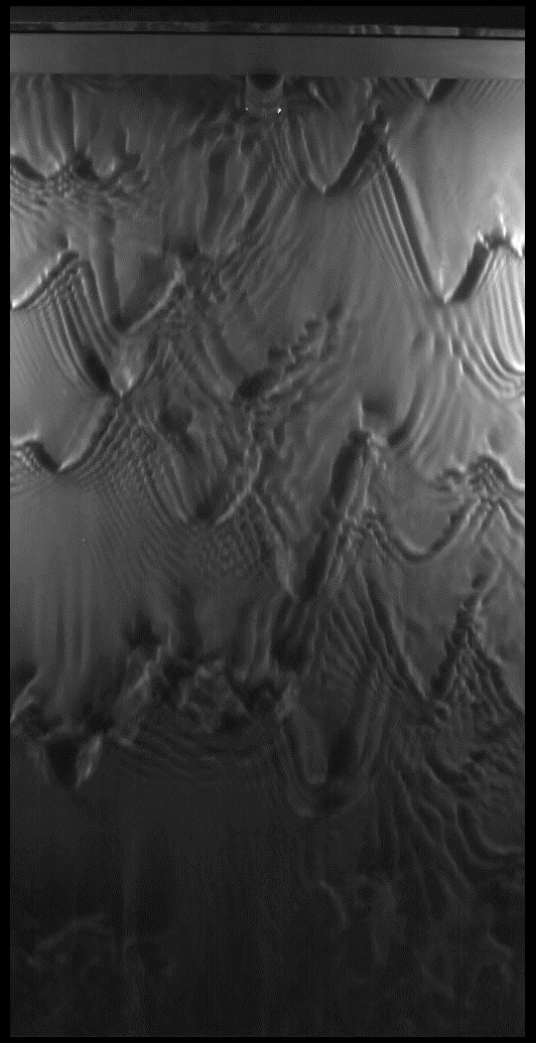
Obstructions

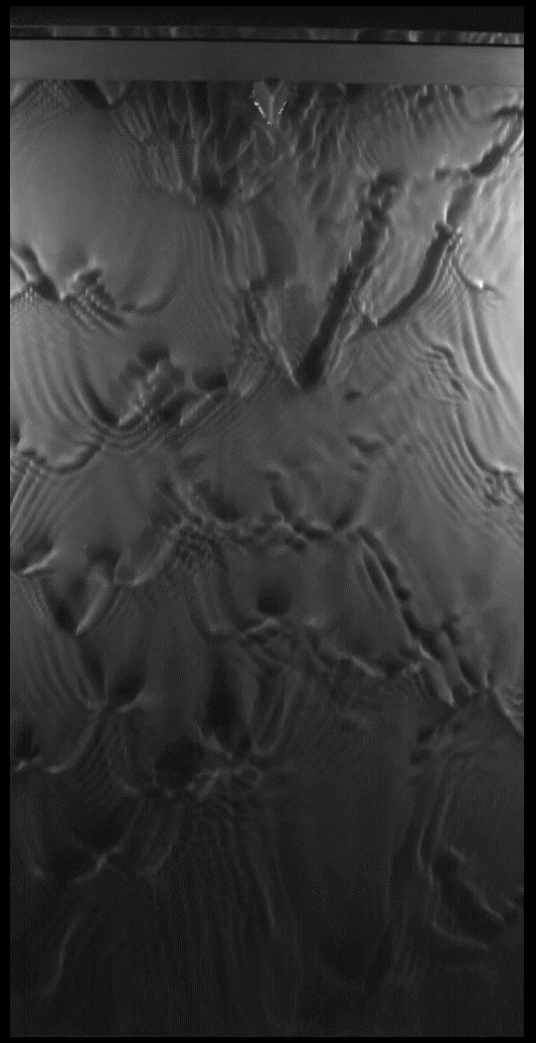
Flow

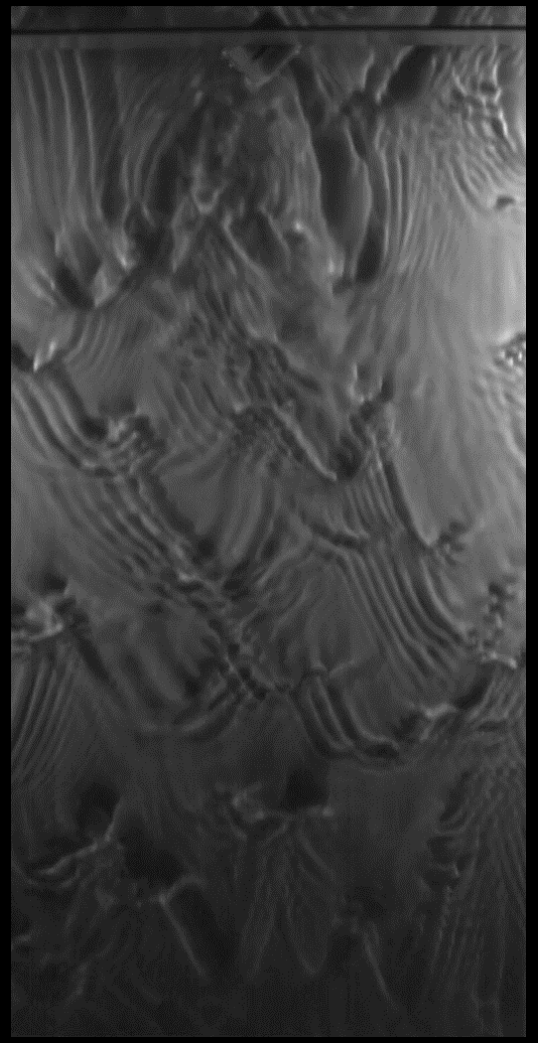


Circle	Triangle	Square	Hexagon

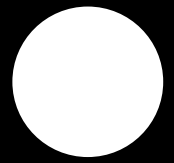
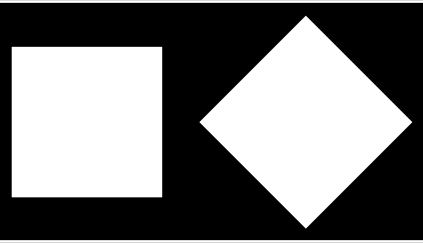
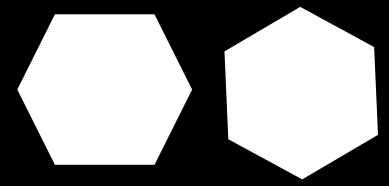
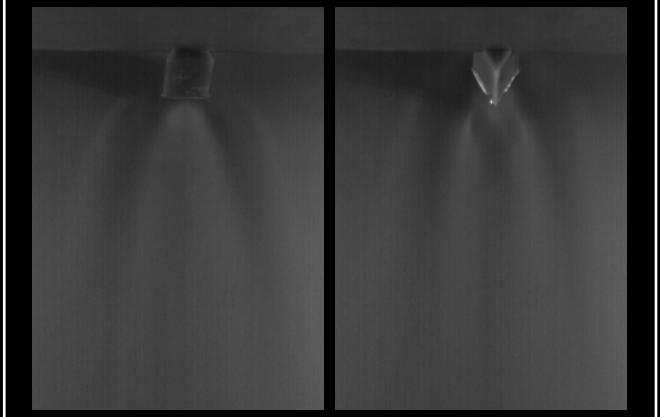
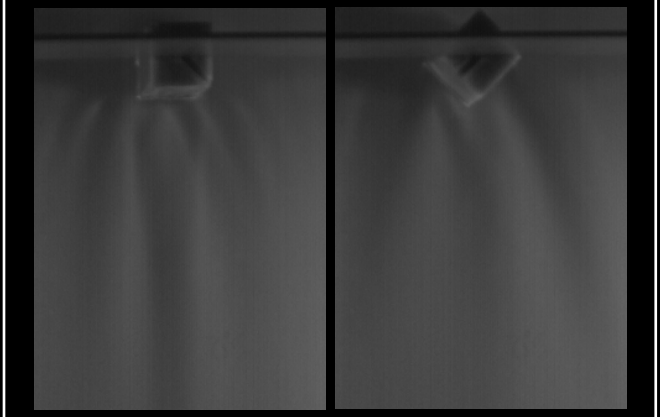
- Material: FormLabs Gray Pro resin
- Parametric Study
  - Sizes: 5, 10, 15 mm (1.25%, 2.5%, 3.75% of channel width)
  - Incline angle: 30, 45, 60 degrees
  - Flow Rates: 20, 40, 60 g/s
  - Geometry shapes





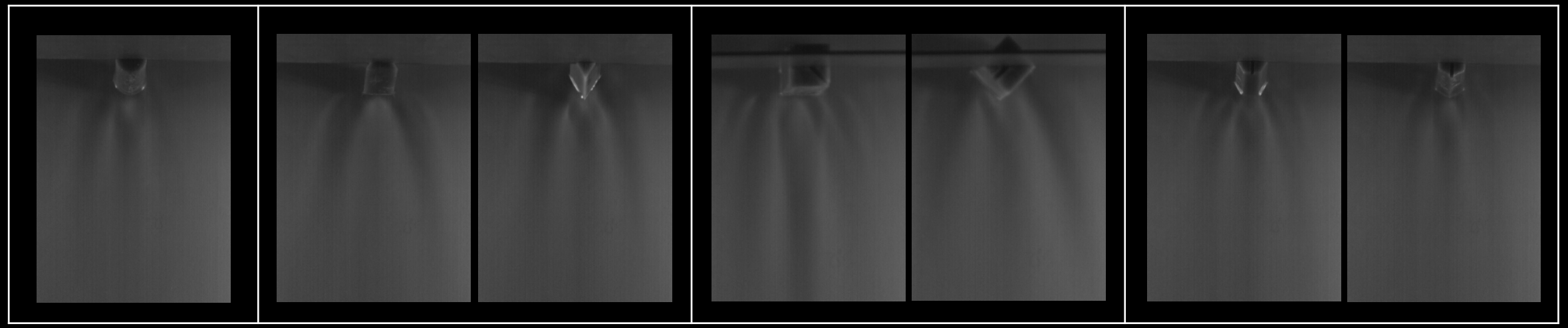


Obstructions - Time averaged images

			
Circle	Triangle	Square	Hexagon
			

- Material: FormLabs Gray Pro resin
- Sizes: 5, 10, 15 mm (1.25%, 2.5%, 3.75% of channel width)
- Shown: 60 g/s, 30 deg incline angle, 15 mm obstructions

Obstructions – Takeaways



- No dry patch
- No obvious change in downstream film thickness
- A wake profile exists

- Next steps:
  - Increase obstruction size
  - Measure wake profile film thickness

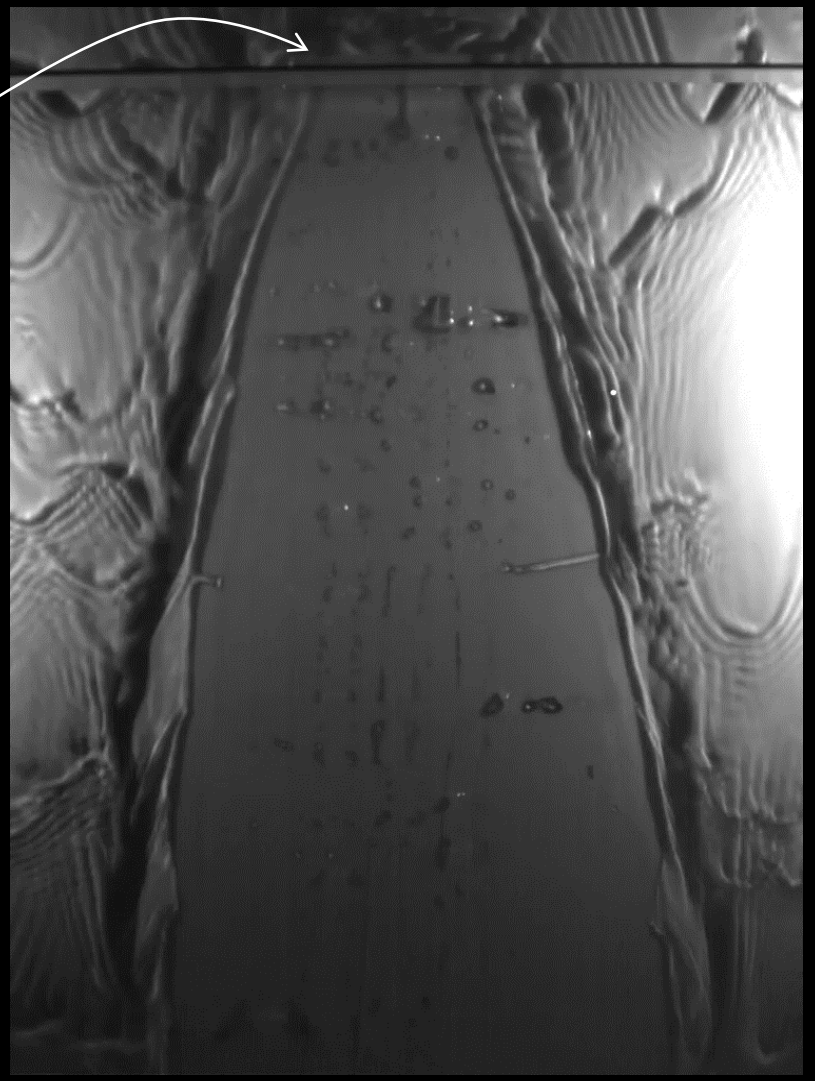
Plate Obstructions

th: 3 mm

Width: 20 to 105 mm
@ 5 mm increments

- Material: Acrylic
- Parametric Study
  - Widths: 25 – 105 mm @ 5 mm increments
  - Incline angle: 30, 45, 60 degrees
  - Flow Rates: 20, 40, 60 g/s

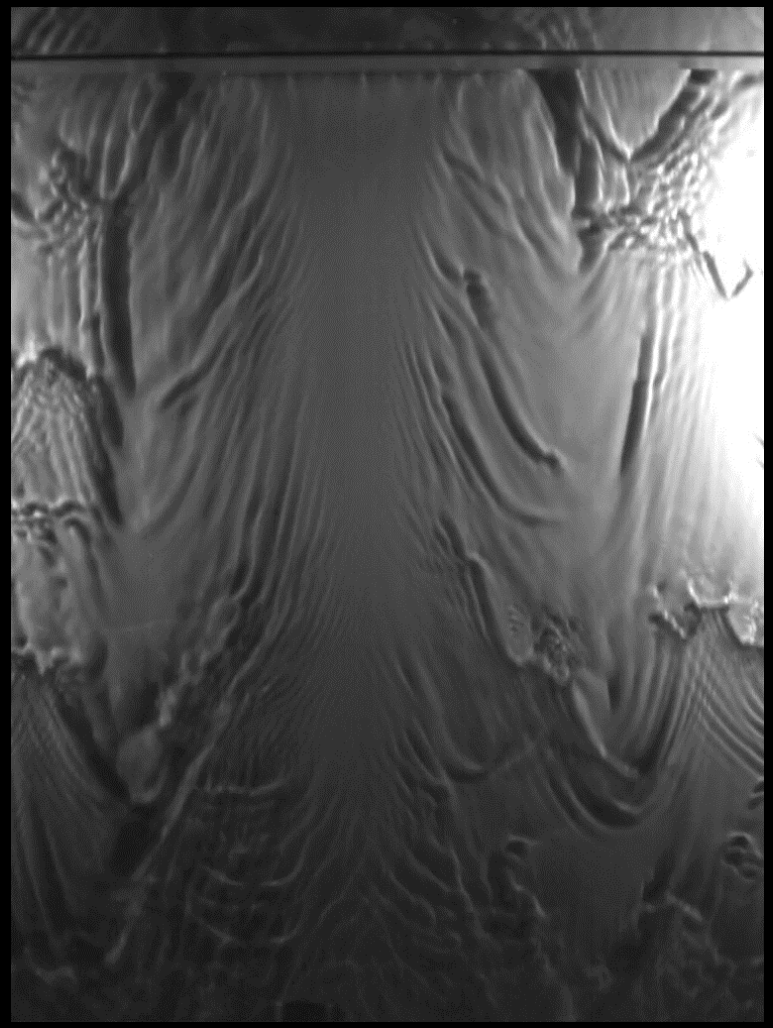
Plate Obstructions – Two regimes



Experimental procedure

Stop flow
↓
Install obstruction
↓
Restart flow
↓
Downstream film ruptures
↓
Spray water on dry patch immediately downstream of the obstruction
↓
Record whether the dry patch recovers (rewets)

Plate Obstructions – Two regimes



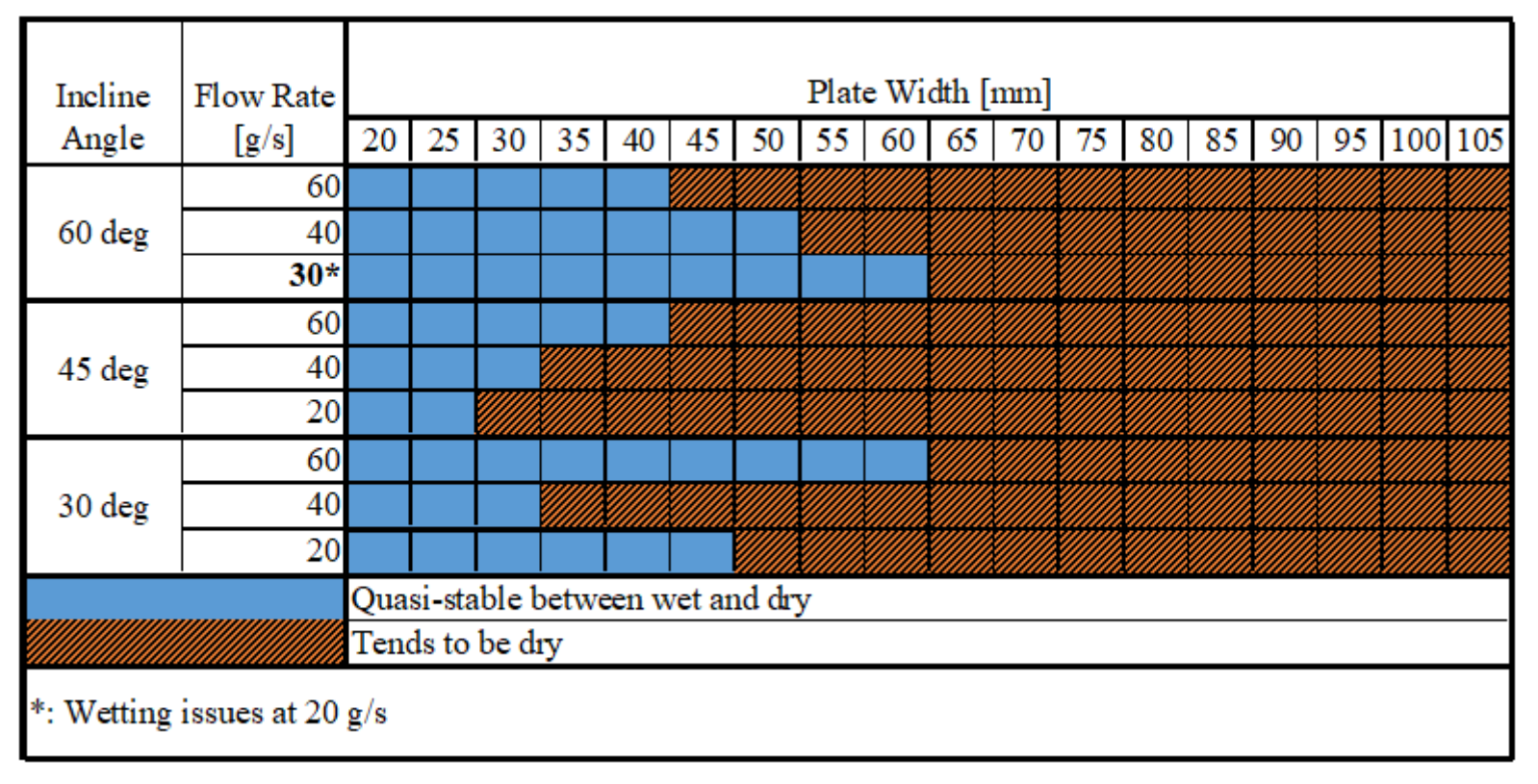
Recovers

Does not recover

Experimental procedure

Stop flow
↓
Install obstruction
↓
Restart flow
↓
Downstream film ruptures
↓
Spray water on dry patch immediately downstream of the obstruction
↓
Record whether the dry patch recovers (rewets)

Plate Obstructions – Regime map V1



60 deg Plate Obstruction

Plate Width (20mm – 90mm) →

60 g/s

40 g/s

30 g/s

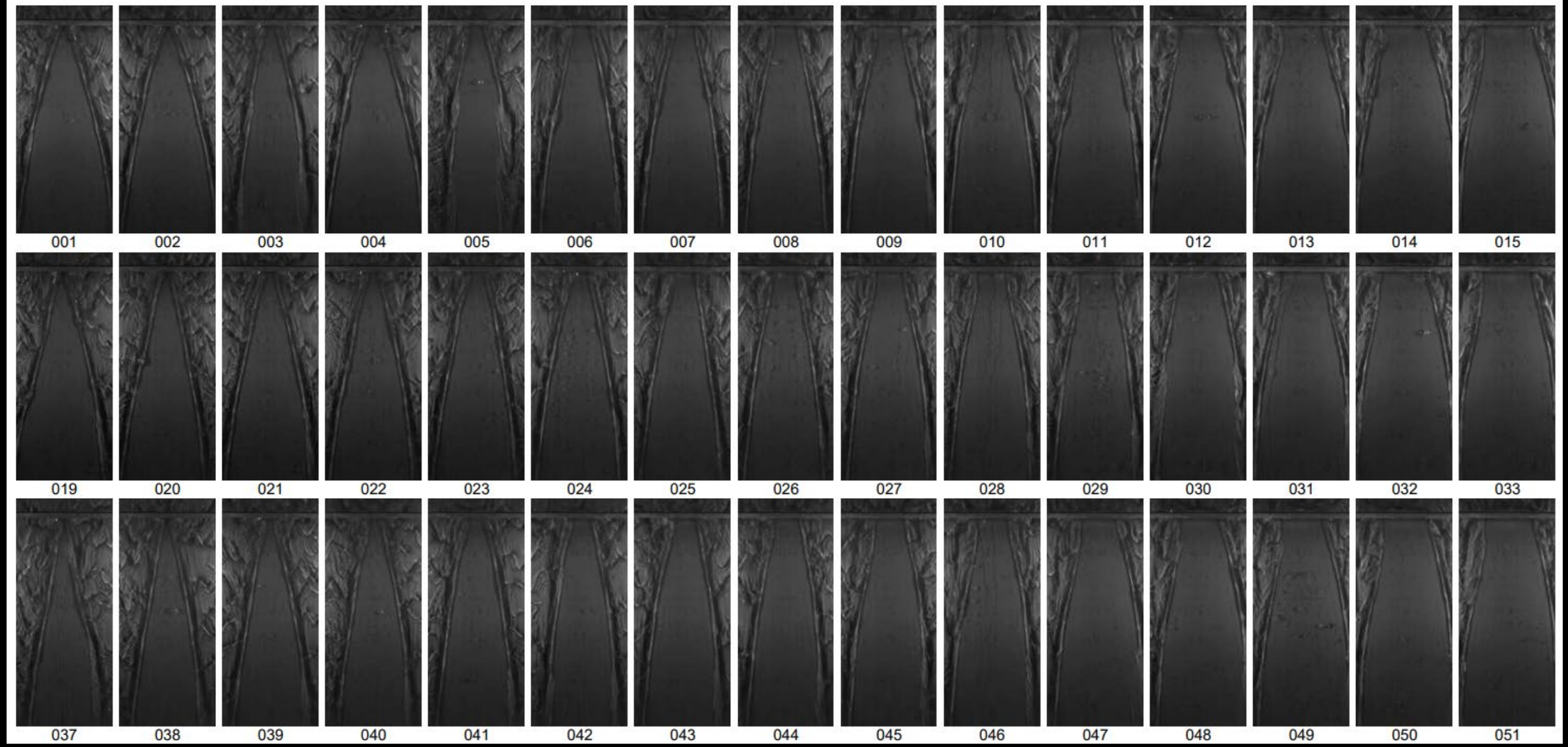
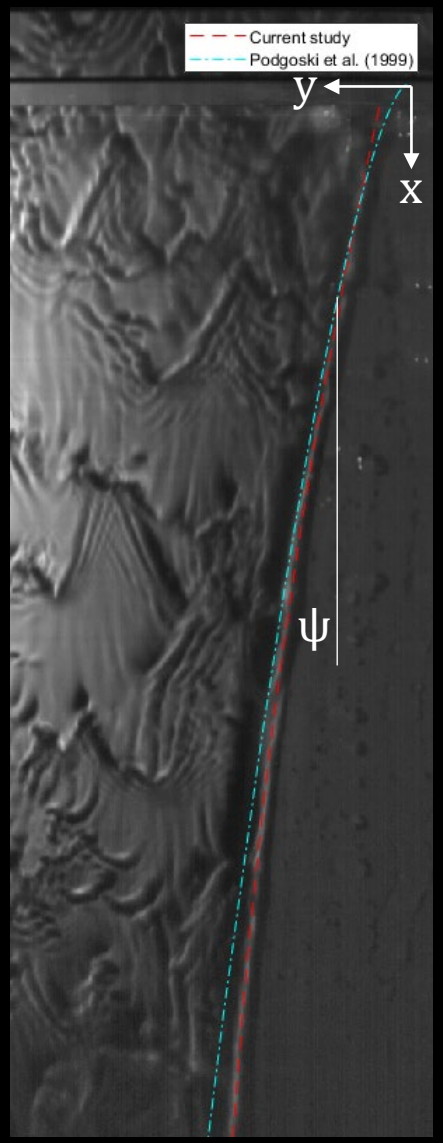
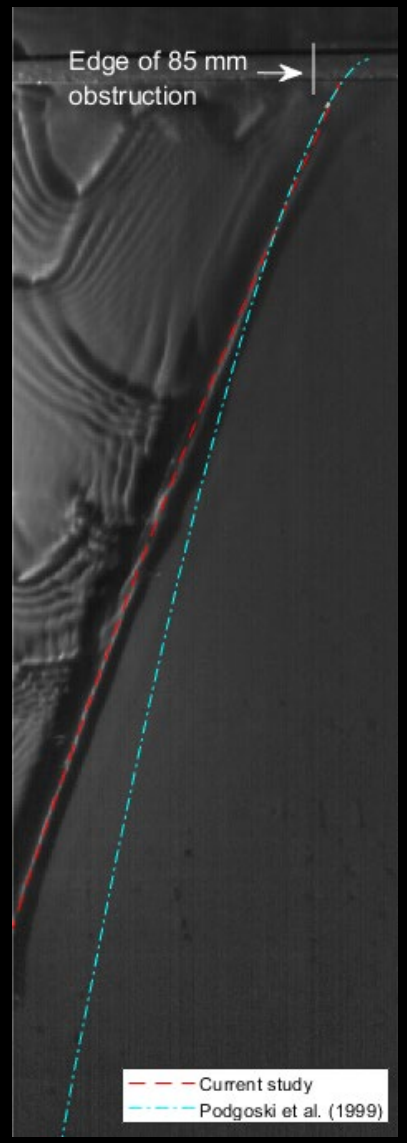


Plate Obstructions – Wet/Dry boundary

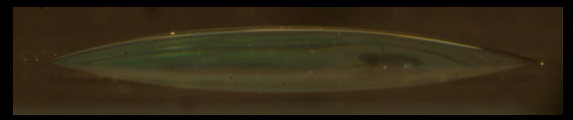




$$x = -\frac{r}{3}\left(\frac{1-3\cos^2(\psi)}{\sin^3(\psi)} - 1\right), \quad y = r\frac{\cos(\psi)}{\sin^2(\psi)}$$

$$r = mf_2(\theta_s)\frac{L_c^2}{\sin(\alpha)}\frac{U_c}{\Gamma}, m = 0.23$$

$$f_2(\theta_s) = \frac{(1-\cos(\theta_s))^4}{\theta_s - \sin(\theta_s)\cos(\theta_s)}$$



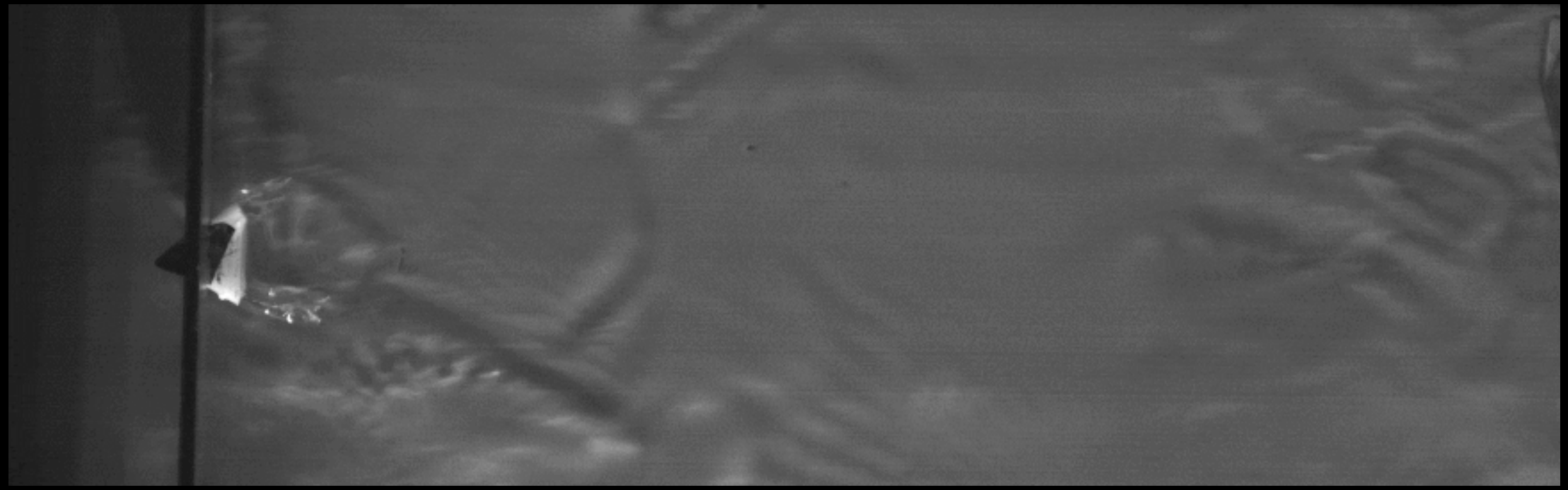
$\theta_s \approx 21°$

Boundary location is a function of :

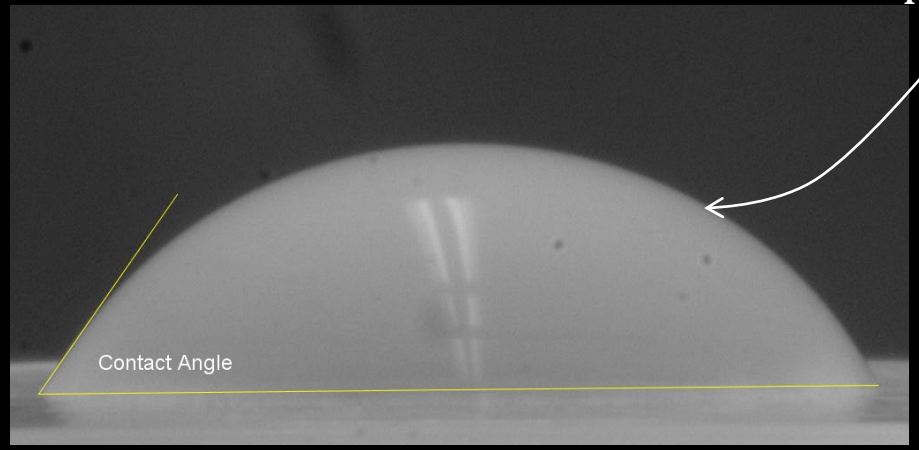
- θ_s , **contact angle** between water and incline pane
- $L_c = \sqrt{\left(\frac{\sigma}{\rho g}\right)}$, capillary length (**surface tension**, **density**)
- $U_c = \frac{\sigma}{\mu}$, capillary velocity (surface tension, **viscosity**)
- α, **incline angle** wrt horizontal
- Γ, **flow rate** per unit **film width** (~0.1E-3 m^2/s)

What now…?

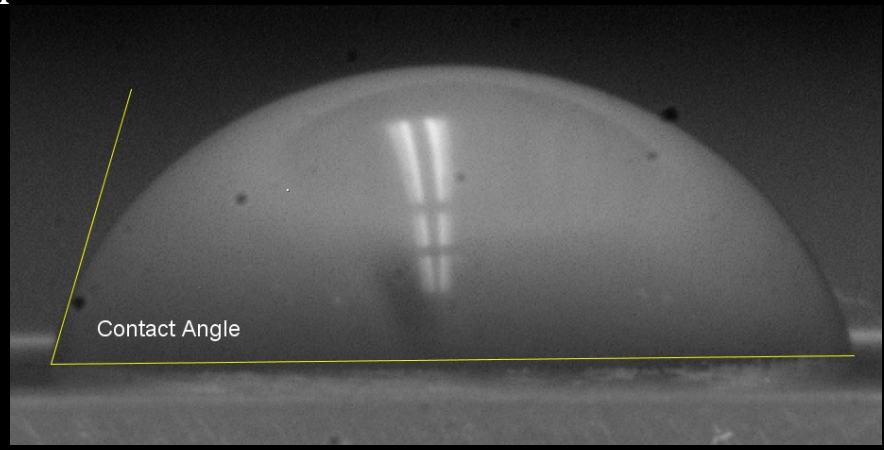
- Redo regime map with cleaner water and more diligent glass cleaning (algae growth and small smudges)
- Test more acrylic obstructions of different shapes
- Formulate a non-dimensional number to help predict which regime a configuration belongs to
- Test in the annular flow facility with refrigerant (very low contact angle with glass <1°)



RO Water



White Resin
$\theta_s \approx 64°$



Gray Pro Resin
$\theta_s \approx 80°$