Spray Characterization at Industrially Relevant Conditions

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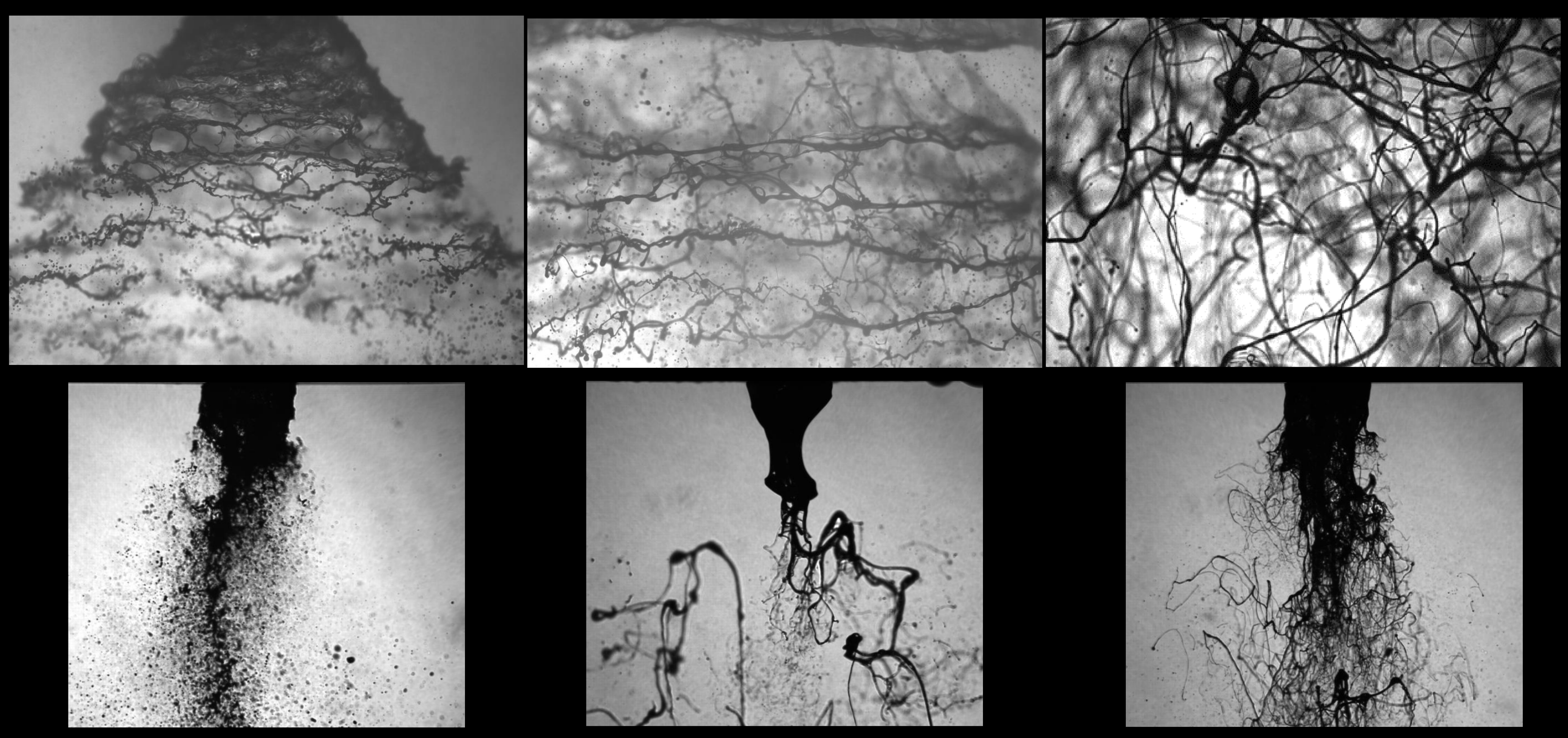
1. Background and Introduction

- We have modelled atomization of inviscid and Newtonian fluid in twin fluid and swirl nozzles in previous term.
- Ligaments of highly viscous, polymeric fluid stretch and become thinner before they break up into droplets
- We need to study the stretching and breakup mechanism of ligaments for these complex fluid to modify our models.

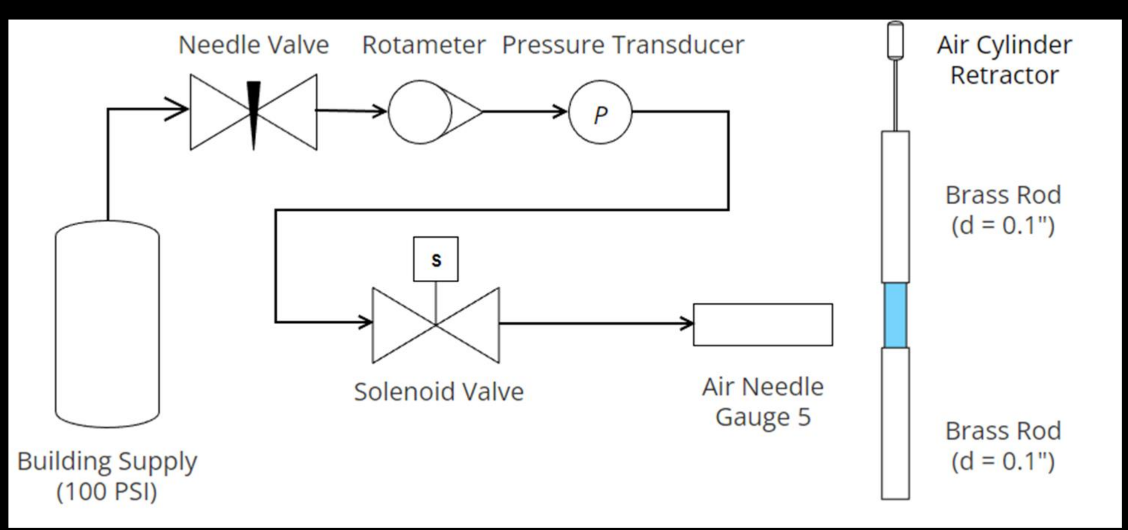
	Water	Glycerin	CMC
Pressure Swirl			
Twin-fluid			



2. Objectives

1. Breakup of ligaments of fluids in cross flows.
2. Spray droplet size measurement of polymeric fluids and slurries.
3. Models for the atomization of high viscosity/polymeric fluids and slurries in swirl and twin fluid nozzles based on ligament dynamics.

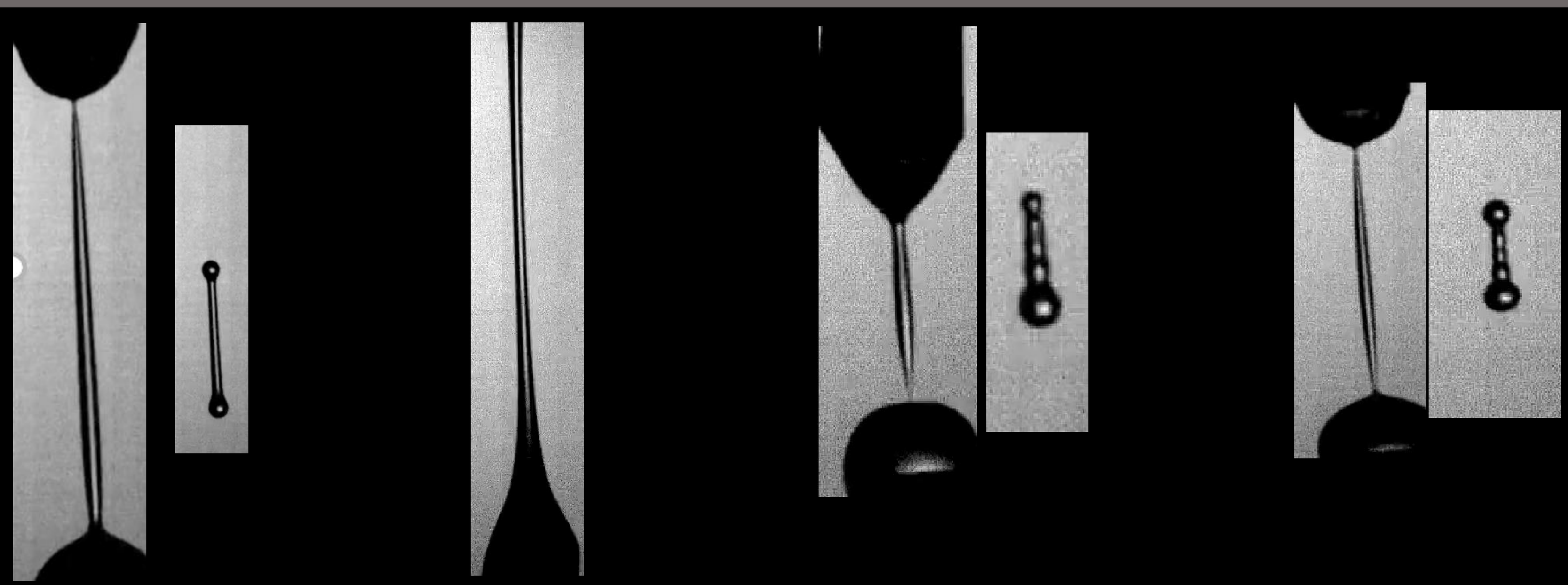
3. Experiment setup



Retractor speed: $0.4m/s$ **Air velocity**: 30-70 m/s

Fluid :			
	High Viscous Newtonian fluid	80 % Glycerin	99.7% Glycerin
	Polymeric fluid	0.25% CMC	0.5% CMC
	Solvent and slurry	Neodol	Slurry with Neodol

4. Pulling without air cross flow



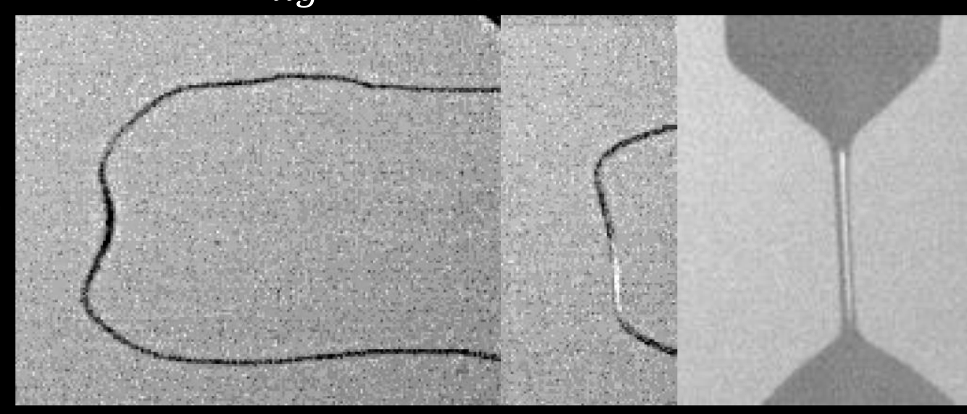
80% Glycerin (60 cps) | 99.7% Glycerin (1410 cps) | 0.25% CMC (1.5 cps) | 0.5% CMC (2.9 cps)

5. Pulling with air crossflow

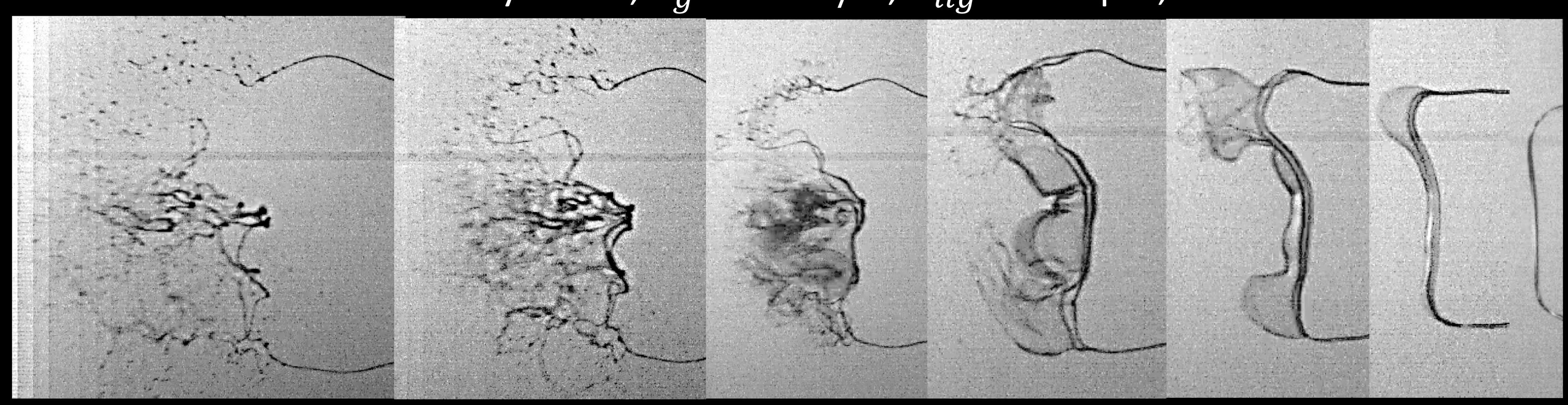
The cylindrical ligament is initially deformed due to air stream.

Then depending on the Weber number $We = \frac{\rho_g U_g^2 d_{lig,0}}{\sigma}$, the ligament will either experience stretching or bag breakup and $We_c = 11$.

80% Gly-water, $u_g = 50m/s$, $d_{lig} = 210\mu m$, $We = 10$

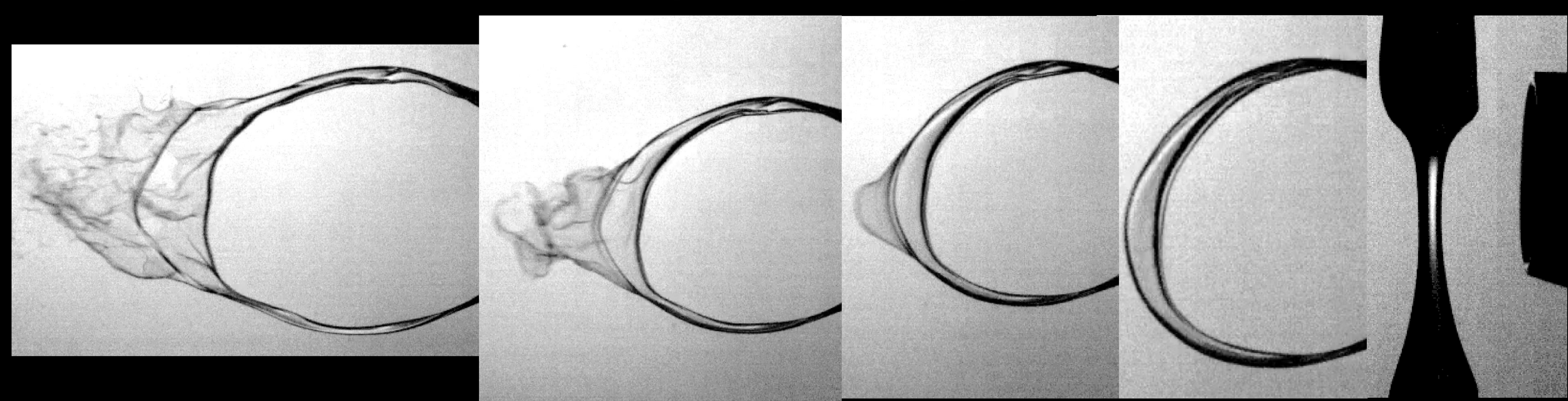


80% Gly-water, $u_g = 72m/s$, $d_{lig} = 300\mu m$, $We = 28$



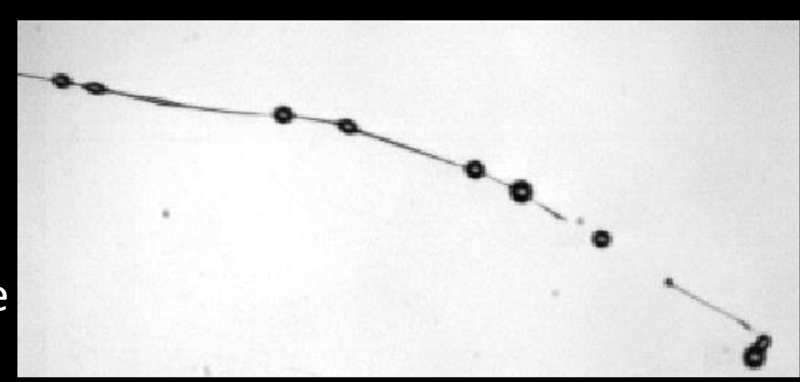
80% Gly-water, $u_g = 72m/s$, $d_{lig} = 480\mu m$, $We = 46$

99.7% Glycerin, $u_g = 72m/s$, $d_{lig} = 570\mu m$, $We = 54$

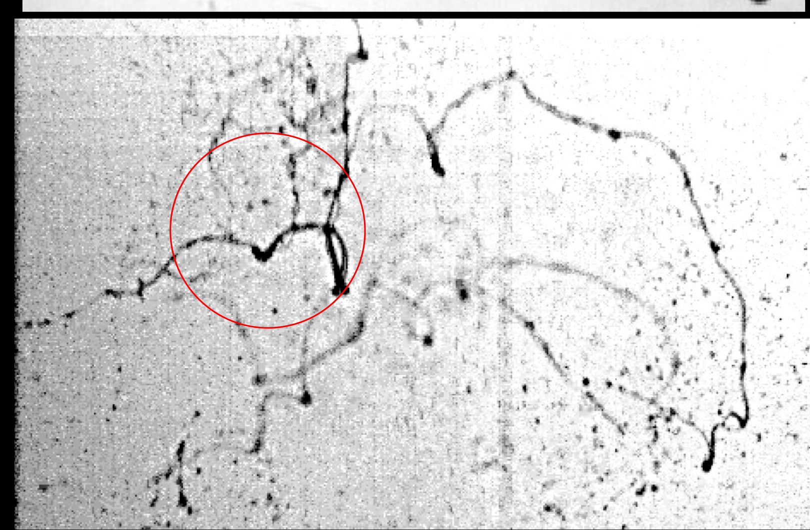


There are two mechanism of bead formation.

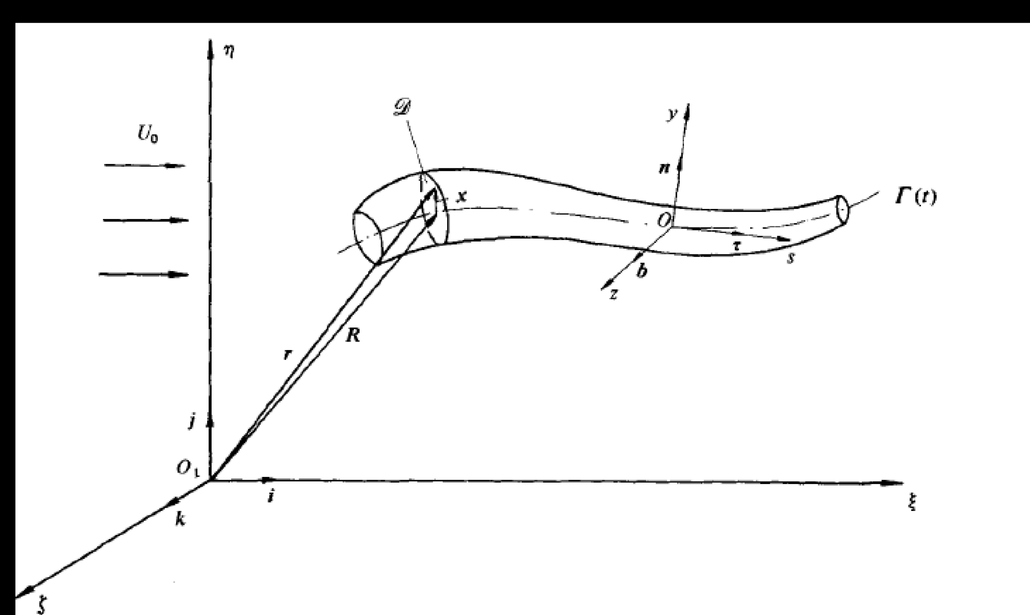
1- Classical Rayleigh-Plateau Instability – In this mechanism, small disturbances on a cylindrical liquid ligament grow, causing the breakup of the ligament.
The bead formation appear when the thinning rate of the ligament is smaller than the growth rate of the instability.



2- Undulations formed by a flapping ligament. Ligaments form bead as they go through large sinusoidal oscillation.



- We modified a model by proposed by Yarin A.L. (1993), which provides a set of equations for
  - the movement of ligament central axis $\Gamma(r)$
  - the movement of a fluid particle in the cross section centered at some point $r = R$



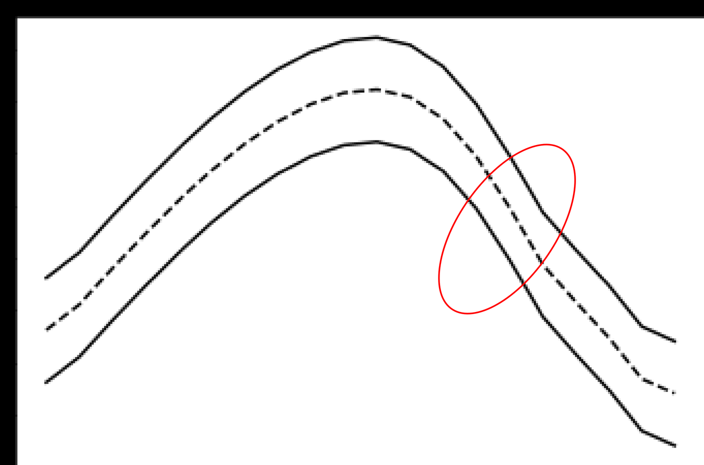
$$\frac{\partial \lambda a^2}{\partial t} + \frac{\partial W a^2}{\partial s} = 0 \quad \text{(mass conservation)}$$

$$\frac{\partial \lambda a^2 V_n}{\partial t} + V_\tau \frac{a^2}{\lambda}\frac{\partial V_n \lambda}{\partial s} + \frac{\partial W V_n a^2}{\partial s} + a^2 W V_\tau \lambda k = \frac{1}{Re}\left(\frac{\partial Q_n}{\partial s} + \lambda P k\right) - J\frac{k a^2}{\lambda} \quad \text{(momentum)}$$

$$v = V + \Omega \times x + \delta x + v' \quad \text{(affine transformation in cross section)}$$

Compared to classical Rayleigh-Plateau instability, this model describes the ligament dynamics based on

- deforming coordinate system fixed on the ligament central axis, and
- changing ligament cross section.



6. Summary

- Designed an experiment to study the breakup of liquid ligaments in cross flows.
- Initial experiments show
  - ligament stretching and thinning, followed by bead and then droplet formation or
  - bag formation, followed by bag breakup and ligament formation by the rims of the bag, followed by ligaments stretching and breakup.
  - Droplet sizes appear smaller in the bag-ligament-drop breakup mechanism.
- Modified a model to describe the flapping process

7. Future work

- More detailed ligament breakup experiments and measurement of droplet sizes after breakup, for polymeric, and slurry ligaments.
- Identify effect of elongational viscosity on breakup mechanism and droplet size.