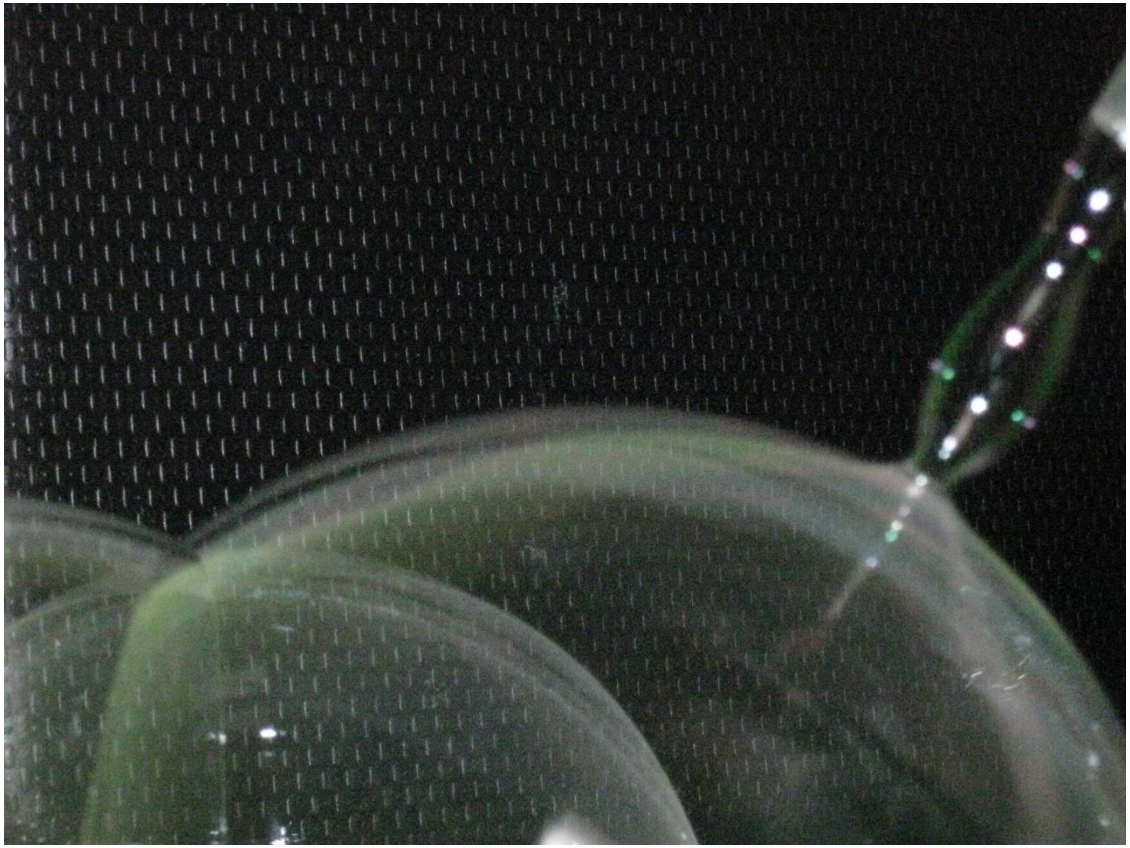
BUBBLES!

Lucas Morton, Alex Strange, Max Strange,
Luke Mayer, Bai Yang Wang (alumnus)

New bubble structure observed

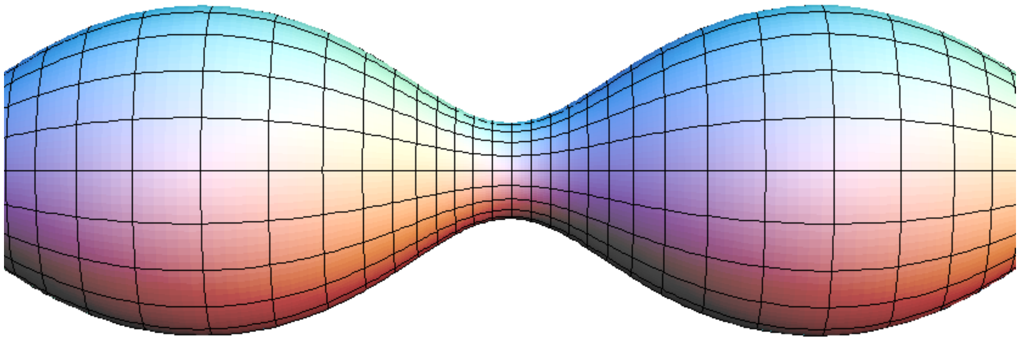
- Requires constant airflow to exist
- Interplay of surface tension, pressure & flow



Bubble tubes may have constant pressure along their length

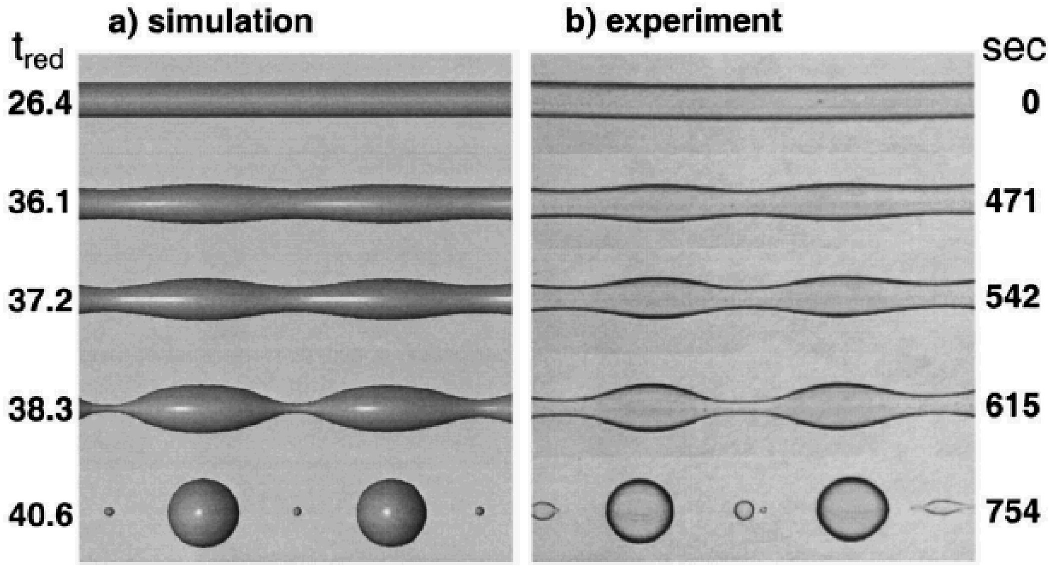
- An unduloid is a surface with constant mean curvature
  - Cylinders & periodic spheres are special cases
- Mean curvature = pressure difference across surface
  - Young-Laplace equation:

$$\begin{aligned}\Delta p &= -\gamma \nabla \cdot \hat{n} \\ &= 2\gamma H \\ &= \gamma \left(\frac{1}{R_1} + \frac{1}{R_2}\right)\end{aligned}$$



Long cylindrical bubble tube should be unstable

- Rayleigh-Plateau instability explains break-up of falling water column into droplets
  - Surface tension increases as diameter decreases
  - Positive feedback loop → instability
  - Most unstable wavelength: $\lambda_c \approx 4.5$ diameter

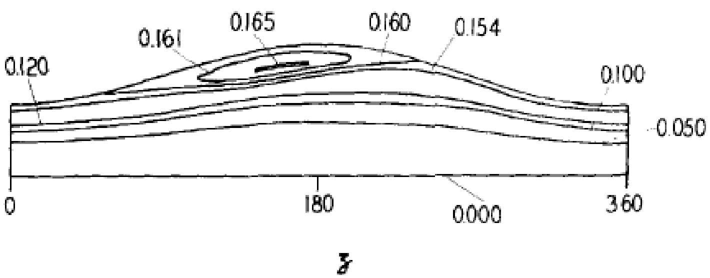


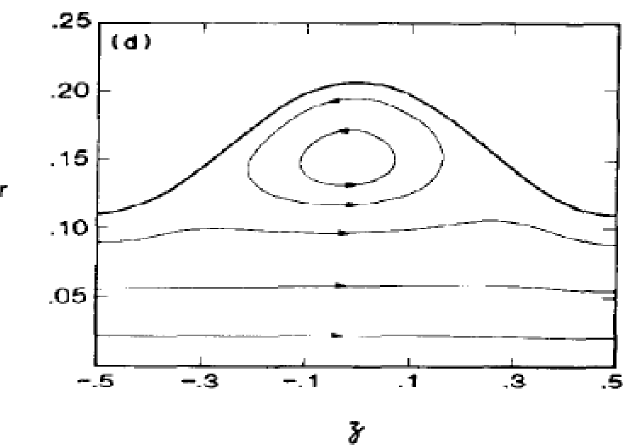
Basic theory says airflow should make things worse, not better

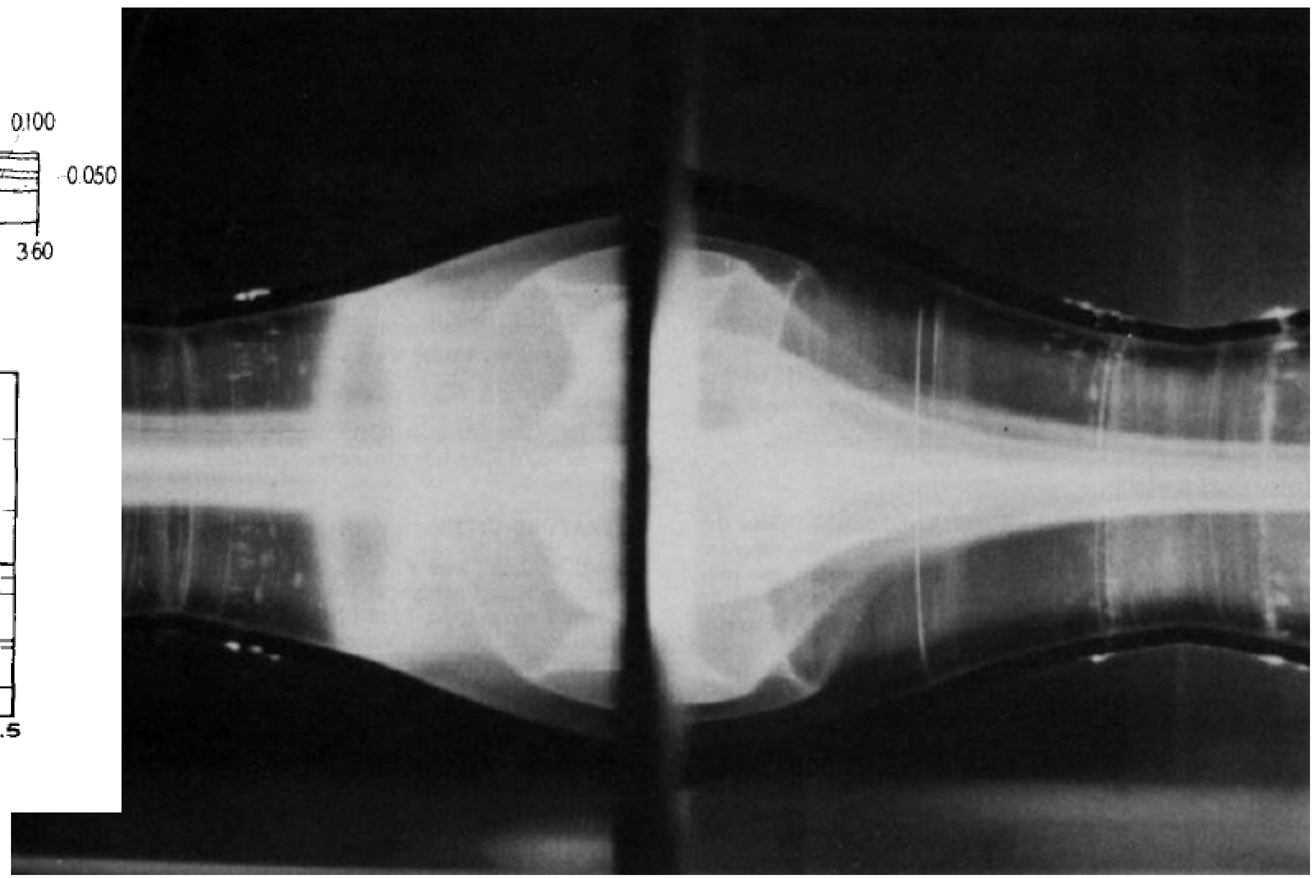
- Get Kelvin-Helmholtz instability
  - Occurs with velocity shear
  - Responsible for ocean waves, most fluid turbulence
  - In ocean, surface tension & gravity stabilize waves
  - Here, no gravity, surface tension adds to wave!

Maybe vortices will save the day?

- Bubble nodes look as though they might house vortices
- Could change the picture

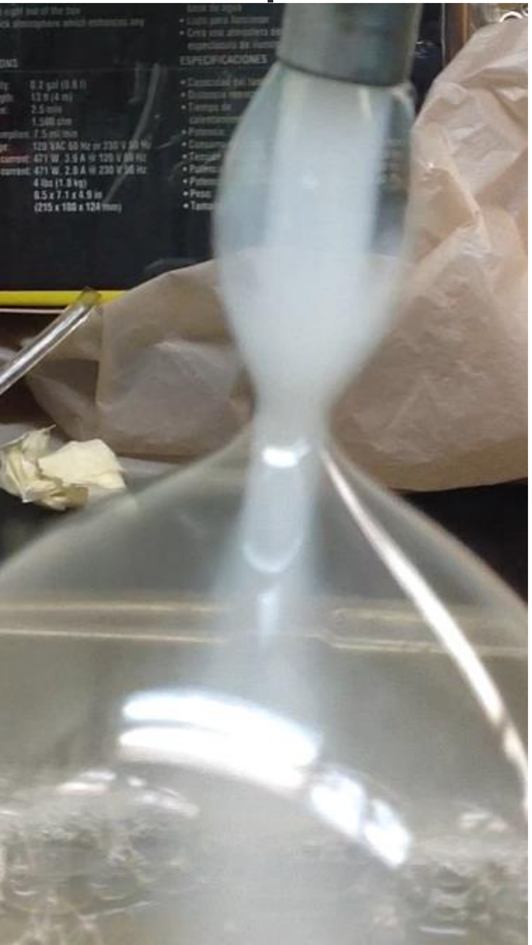


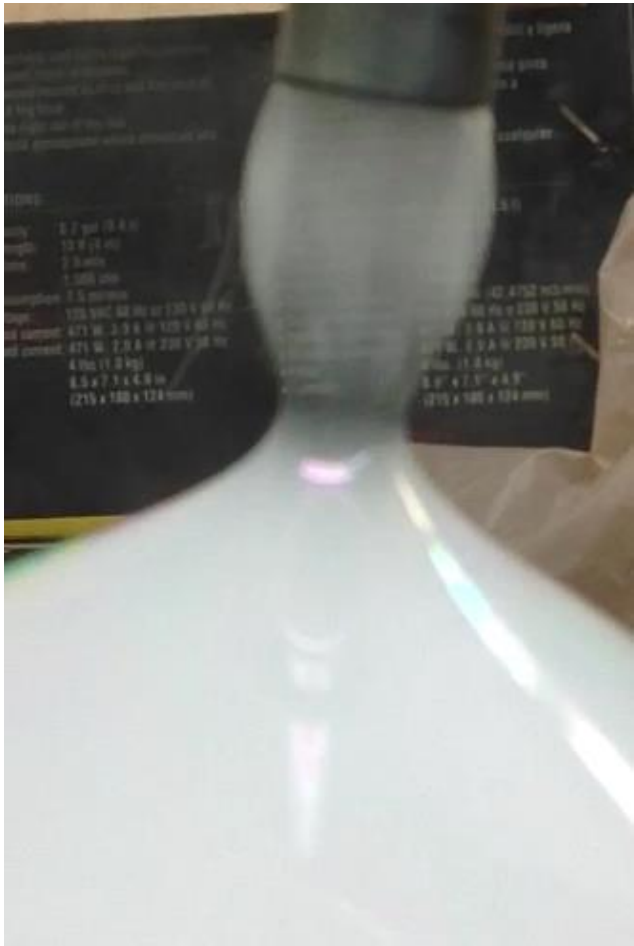




We have vortices!

- Things are now more interesting
- Simple flow model not enough





Next steps

- Experiment:
  - Measure mean curvature from images
  - Map flow using fog
  - Test effect of tube diameter vs flow rate on bubble structure
  - Estimate Reynolds number
  - Test different boundary conditions
- Theory:
  - Understand why basic theory fails for long bubble tube
    - Boundary conditions may be important
  - Find self-consistent solution for flow, pressure, and surface
    - Simulations may be necessary
  - Make predictions we can test