



# Dynamics of Antibubbles

Nick Brewer, Thomas Nevins and Dr. Thomas Lockhart

Department of Physics and Astronomy, University of Wisconsin - Eau Claire

brewernr@uwec.edu, nevinstd@uwec.edu, lockthom@uwec.edu

## Abstract

When a jet of canola oil is incident on a bath of the same oil at an appropriate range of angles and speeds, it is possible to form antibubbles below the surface of the bath. Preliminary discussion will include what an antibubble is and how it is formed. A high speed camera was used to obtain data about the air film thickness and the dynamics of antibubble formation. Analysis was carried out using Excel and the image processing program ImageJ.

## Apparatus

The setup used to create antibubbles is shown in figure 2. A pump pushes the canola oil from the bath up to a buret attached to the nozzle to keep a steady liquid jet hitting the bath. To create an antibubble the jet simply needs to be disrupted. The antibubble is then filmed using a Casio EX-F1 high speed camera operating at 600 frames per second. To establish the scale of the images, a ruler is placed into the bath in the same plane as the liquid jet. The camera is then focused on the ruler and a short video is taken. Using ImageJ, features of the video can be measured in pixels. The measurements in pixels can be converted to SI units by using the video of the in-focus ruler. <sup>(4)</sup>

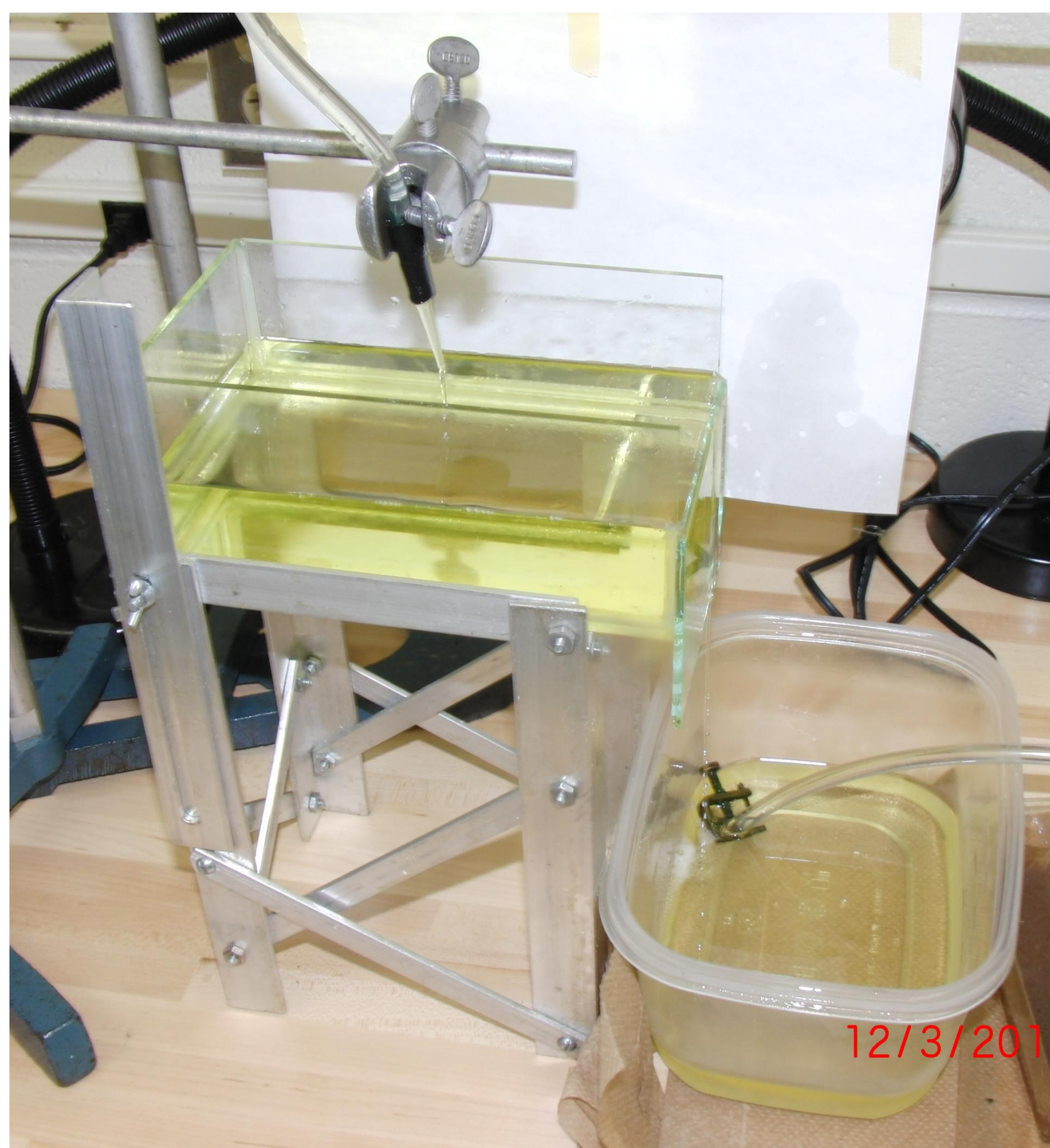


Fig. 2. Experimental Set Up

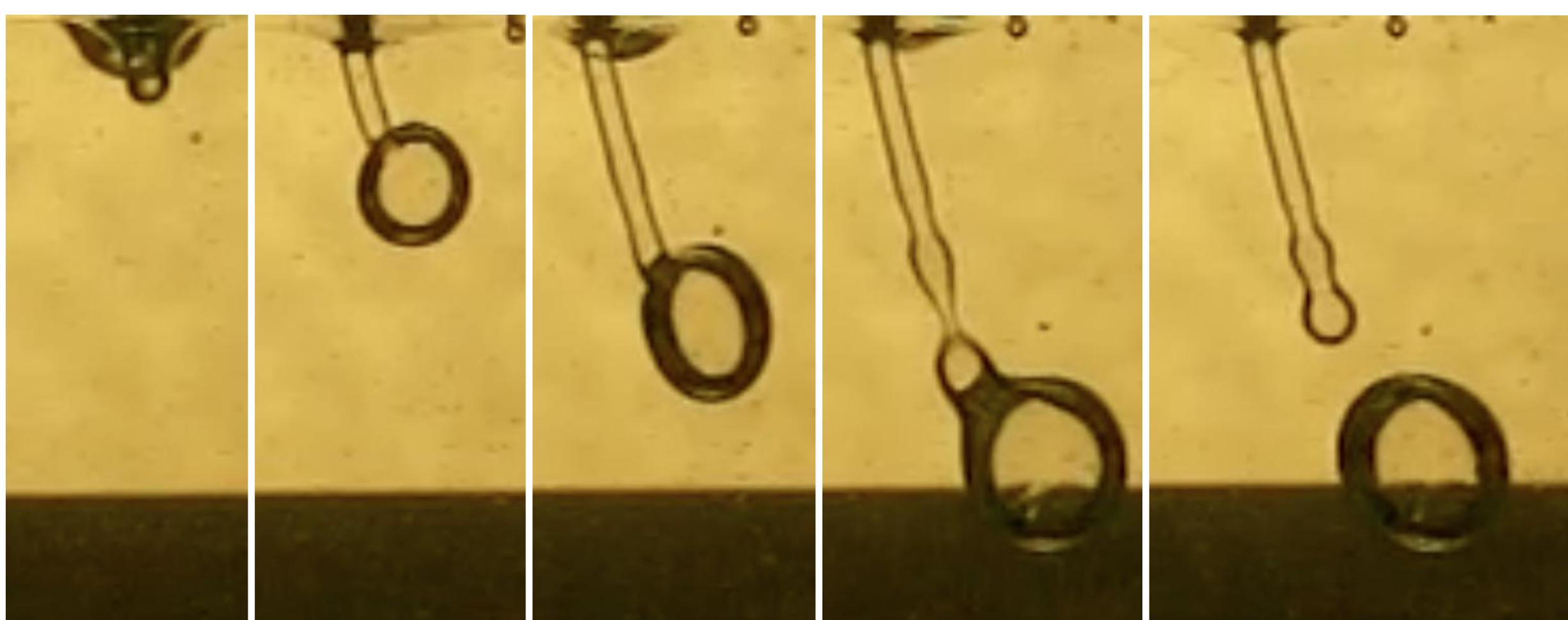


Fig 3. Antibubble formation.

## Antibubble Formation

When the incoming jet is disrupted as it plunges into the bath, a small globule is formed where the disruption occurs. When this globule falls and encounters the oil bath, a thin layer of air is captured between the bath and the globule. At certain jet angles and velocities the noncoalescing drop is pushed underneath the surface with the air film still intact.

As the globule is dragged downward it increases in diameter. The jet eventually pinches off due to the Rayleigh-Plateau instability and the antibubble is formed. A sequence of a typical video is shown in figure 3.

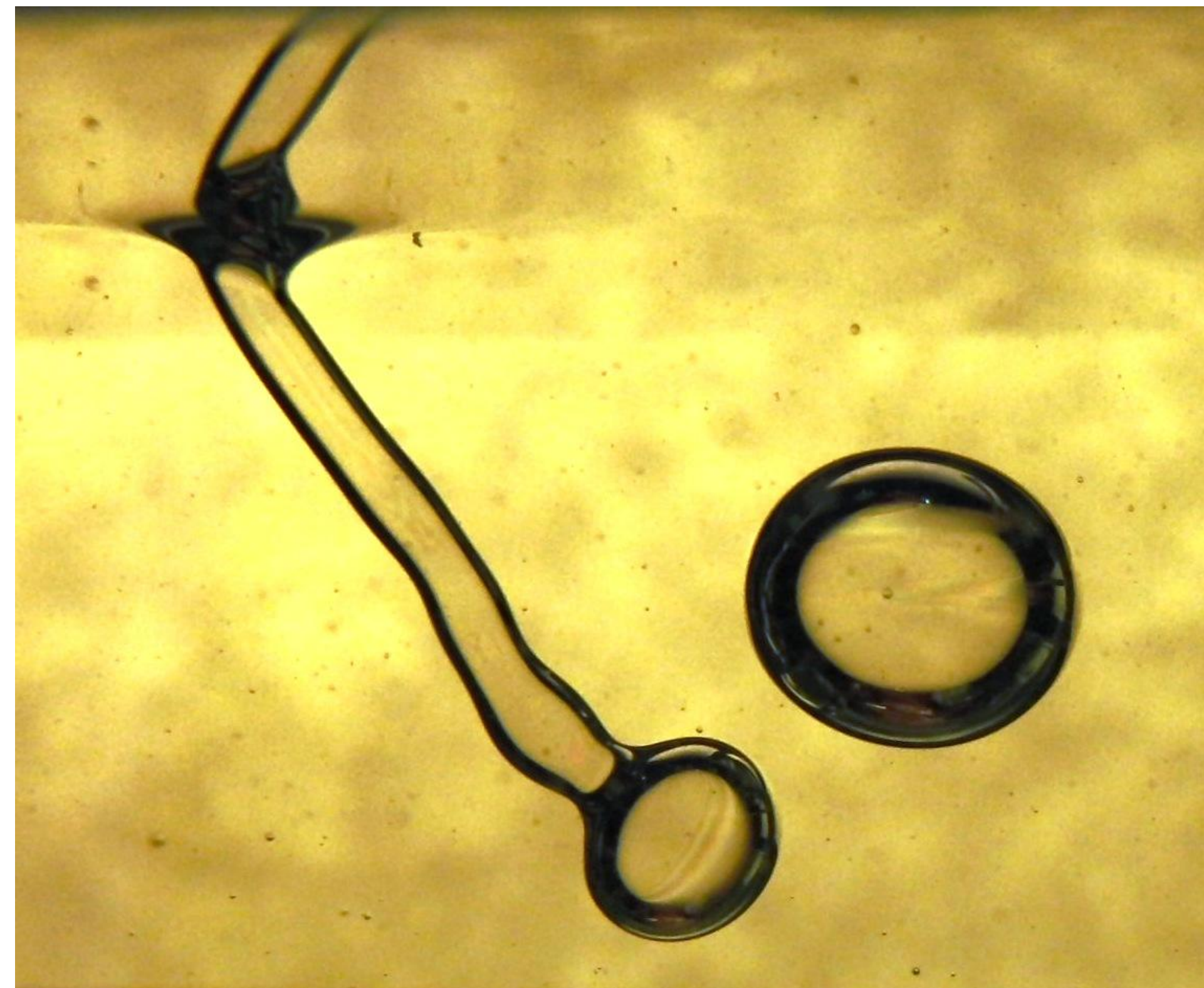


Fig. 1. An antibubble is formed when a liquid jet strikes the bath at the correct speeds and angles.

## Objectives

- To explain what an antibubble is and how it is formed.
- To determine the thickness of the antibubble using data gathered by a high speed camera.
- To examine other fluid dynamics involved in the formation of the antibubble.

## Air Film Thickness

The thickness of the antibubble air film cannot be measured directly due to the optical illusion of the air film being a thick black band. This can be seen in Figure 1. The reason for this is something we're calling the opposite coke bottle effect and is illustrated in figure 4.

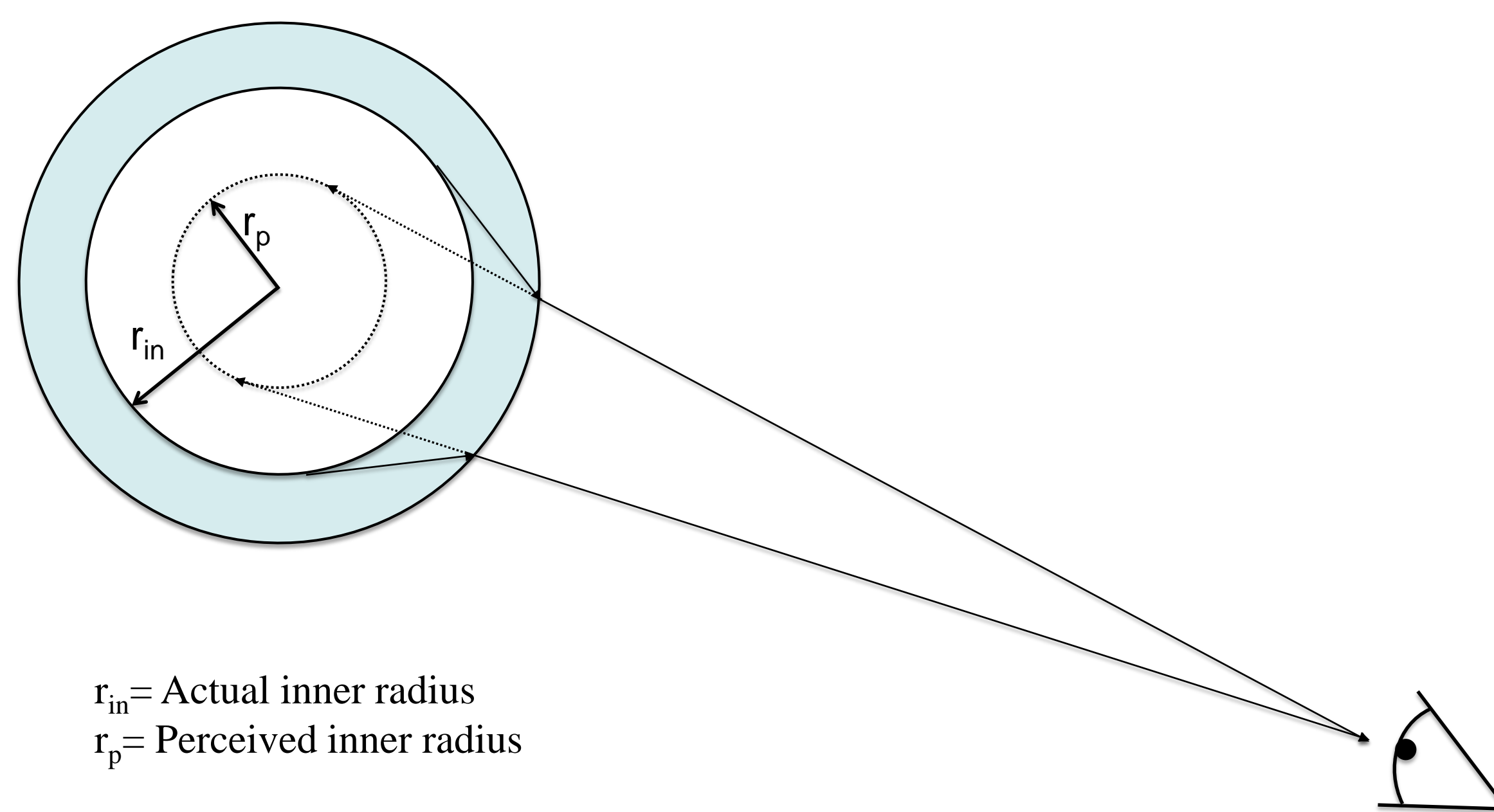


Fig 4. Opposite Coke Bottle Effect. The air film's thickness in proportion to the diameter of the bubble has been exaggerated to help show the effect.

## Calculations

To measure the thickness of the air film, a high speed camera was used to record an antibubble popping and collapsing into only one bubble. ImageJ was used to measure the diameter of the antibubble and the resulting air bubble. Using the following calculations the air film thickness was determined.

$$V_{Film} = 4\pi R_{out}^2 dr \quad V_{Air} = \frac{4}{3}\pi r_{air}^3$$

$$4\pi R_{out}^2 dr = \frac{4}{3}\pi r_{air}^3 \Rightarrow dr = t = \frac{r_{air}^3}{3R_{out}^2}$$

## Results

The antibubble air film was measured to be on the order of six micrometers. A sample of the data with calculated error is shown in a table below. The graph is illustrating the relationship between the outer radius of the antibubble and the thickness of the air film. Other research groups, using soapy water instead of canola oil, have estimated the air film thickness to be  $3\mu m^{(3)}$  and  $.6\mu m^{(2)}$ .

$r_{out}$ (mm)	$t$ ( $\mu m$ )	$\Delta t$ ( $\mu m$ )	$\Delta t/t$
3.22	5.6	2.6	0.46
4.04	7.3	2.6	0.36
3.42	6.3	2.7	0.43
3.16	5.3	2.5	0.47
4.62	8.5	2.5	0.29
5.03	10.2	2.7	0.26
5.09	8.6	2.4	0.28
5.57	9.2	2.3	0.25
5.27	9.4	2.4	0.26
5.35	10.4	2.5	0.24

Fig 5. A sample of air film thicknesses with absolute and relative error

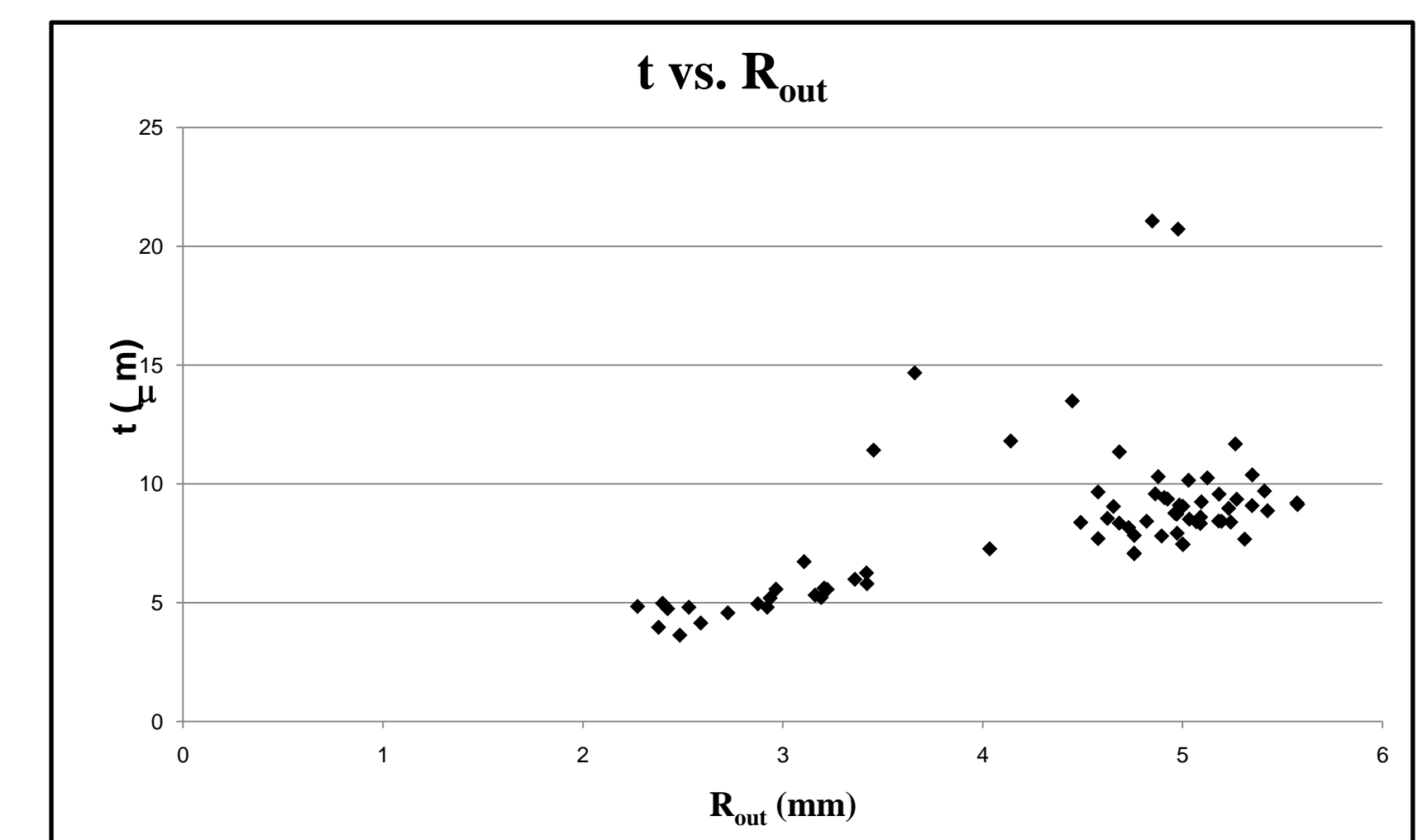


Fig 6. Air film thickness data as a function of the outer radius of the antibubble.

## Pinch-off Rate

As the Rayleigh Plateau instability amplifies to the point of pinching the antibubble off from the jet, it has been predicted that  $r \approx (t_p - t)^\alpha$ , where  $r$  is the narrowest radius of the jet during pinch off,  $t$  is time,  $t_p$  is the time of pinch-off, and  $\alpha$  is estimated to be  $2/3$  <sup>(1)</sup>. Figure 8 shows calculated values of the exponent,  $\alpha$ . The large error bars are most likely a result of the low resolution of the high speed camera when set at a higher frame rate.

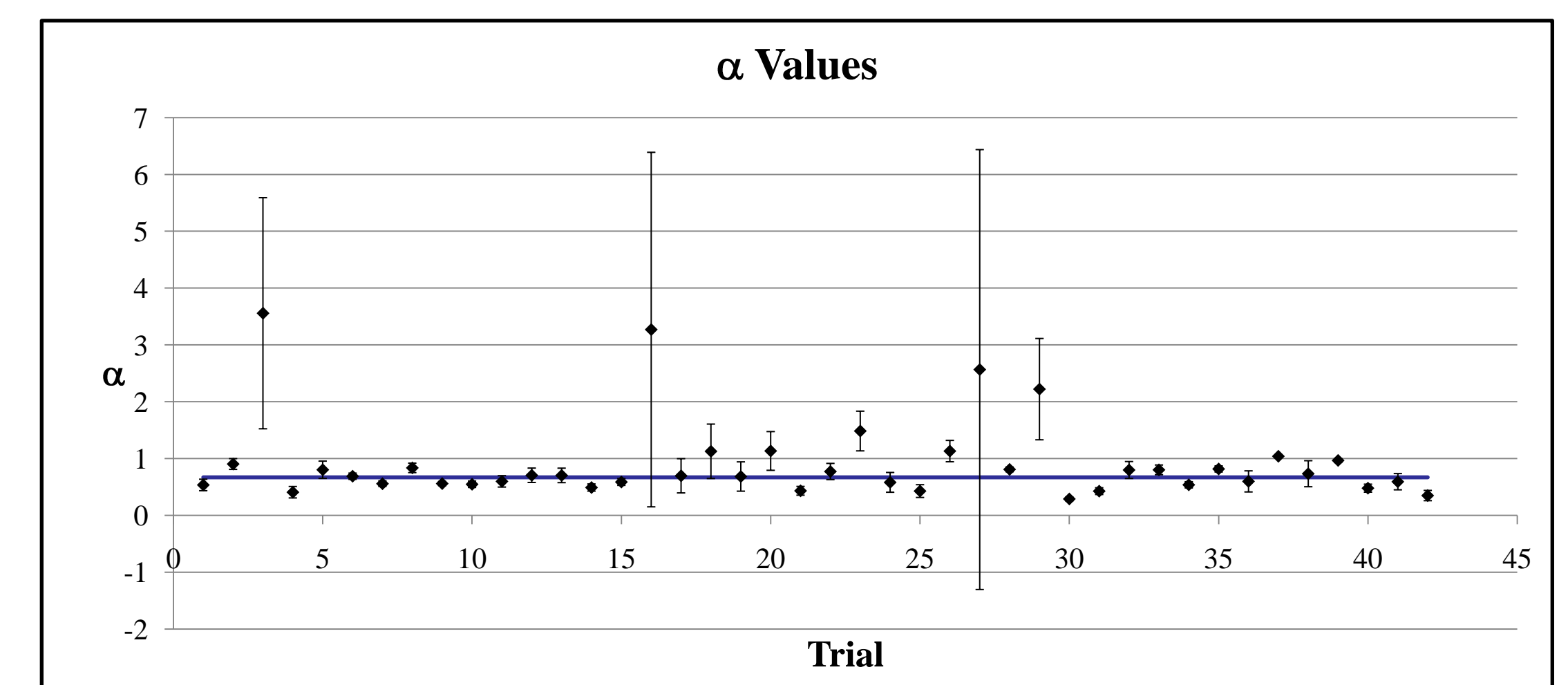


Fig 7. Approximate values of  $\alpha$  using an online least squares curve-fitter <sup>(5)</sup>.

## References

- (1) Kim, P.G. & Stone, A. Dynamics of the formation of antibubbles. EPL Journal. (2008).
- (2) Kim, P.G., & Vogel, J. Antibubbles: factors that affect their stability. *Colloids and Surfaces*. (2006).
- (3) S. Dorbolo, N. Vandewalle, con-mat/0305126 (2003).
- (4) All image processing was done using ImageJ, a public domain Java image processing program available from <http://rsb.info.nih.gov/ij/download.html>.
- (5) Curve fitting was done using the online curve-fitting application from <http://statpages.org/nonlin.html>.

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