Understanding the Dynamics of Soap Bubble Pinch-off
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Background
In topology any change producing additional sides or a break in the surface is usually associated with a singularity. We seek to better understand the topological changes that occur when a soap bubble is pinched-off the main film body.

While on the molecular scale these types of events are not true singularities, the changes during bubble pinch-off indicate two singularity-like events occurring when:

- The internal walls of the soap film meet to form a solid column of soap solution (see fig. 1b).
- The column of solution physically separates from the main film body (see fig. 1c).

We developed an apparatus to consistently produce similarly sized bubbles in an enclosed space. Using high-speed camera video footage, we documented the full process from bubble formation to separation from the main film body. Using edge-tracing in Matlab we determined the geometry associated with various stages of the process.

Fig. 1. a. The bubble is a 2-sided surface with a neck forming as the bubble approaches the time of internal wall collapse. b. The bubble is now a 3-sided surface after internal collapse and a column of soap solution exists at the neck. c. Two separate bubbles now exist. The column of soap solution has completely separated from the main film body and pinch-off is complete.

Experimental Set-up
- Raising the dipping tray coats the nozzle with a layer of soap solution (60 ml distilled water, 10 ml Dawn dishwashing liquid, 3 ml glycerol).
- The nozzle is connected to a pressurized air source with a length of tubing.
- When the device is externally triggered the camera (MotionScope PC8800 5) begins recording at 2,000 frames per second. An air control system, consisting of a solenoid and (normally closed) solid state relay, is also triggered and delivers a 24.9 millisecond burst of air at 0.5 psi.

Data Analysis
We plotted the natural log of the distance difference versus the time difference for 10 trials of bubble pinch-off.

The straight line we placed in the graph (not fitted to the data) has a slope of 2/3 and indicates that surface tension and kinetic energy may play a critical role in the dynamics of the bubble’s surface.

Sources of Error
Vertical error bars show the uncertainty in the location of the edge of the interior wall during neck collapse due to the edge tracing process. Early in the process of neck collapse this uncertainty does not have a significant impact on the data, however this uncertainty becomes more important very close to the moment of pinch-off.

There is also significant error introduced by the uncertainty in the precise time of pinch-off. With a frame rate of 2,000 fps half a millisecond passed between each data point. Internal collapse occurs at such a high speed that we were unable to capture the exact moment the inner film walls first touched. If the collapse occurred between two frames, we set t0 equal to halfway between them. If collapse appeared to happen very near to a frame, we selected that frame as t0. This method of t0 selection led us to an uncertainty for t0 of 0.25 milliseconds. The use of a camera with a higher frame rate would significantly reduce this error.

Conclusion
Based on our data it is likely that kinetic energy and surface tension play a role in at least the early stages of pinch-off. Repeating the experiment with a higher speed camera with better resolution would resolve many of the uncertainties in the data.

It is unclear right now if additional forces become more important as the moment of internal collapse nears as is the divergence of the data points from power law indicate on the left side of the graph.

Citations