Cavity collapse near slot geometries

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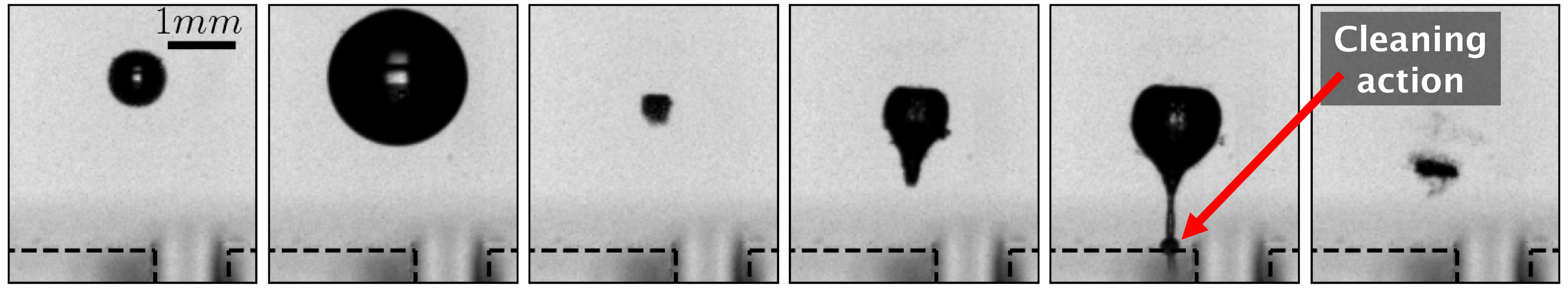
Introduction

Collapsing bubbles can be used as a practical cleaning method[1] for complex geometries that are now more common due to developments of new manufacturing methods such as 3D printing. A collapsing bubble forms a high speed jet that can be used to clean a surface. The frames below show the jet impacting on a solid boundary.

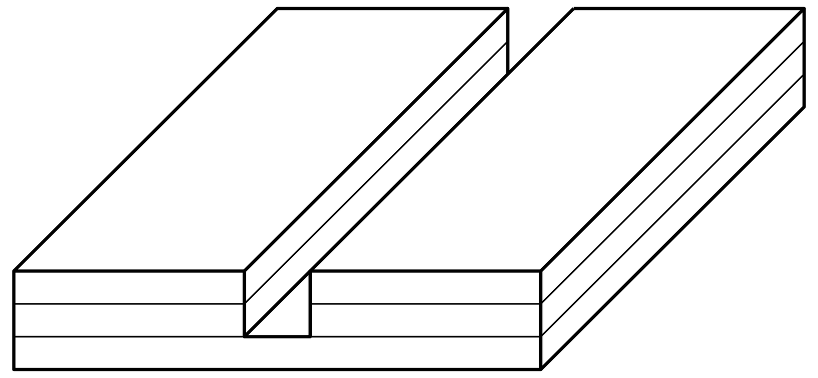


$t = 9\mu s$ $t = 119\mu s$ $t = 239\mu s$ $t = 259\mu s$ $t = 319\mu s$ $t = 489\mu s$

It is well understood how bubbles collapse near flat boundaries and other simple geometries. However, the understanding of how complex geometries affect bubble collapse is still limited. Here we investigate how a slot geometry affects the collapse of a nearby bubble. The jet can be characterised by a strength and direction. We focus on the jet direction as this can be predicted using very simple models[2].

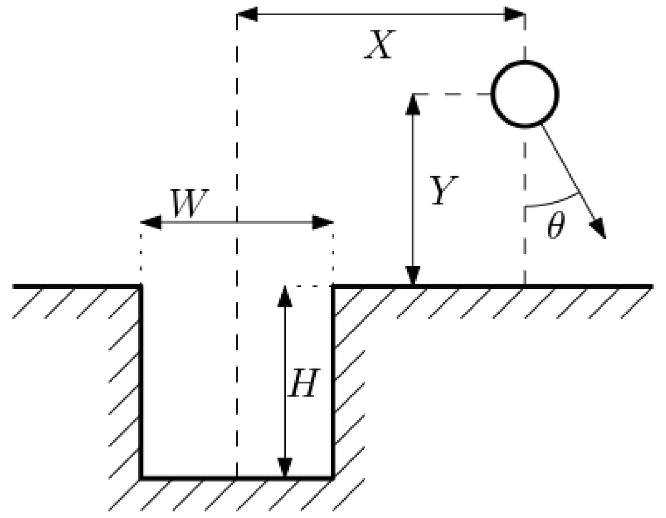
Problem Definition

A slot is a rectangular channel in a surface, shown in the diagram below.



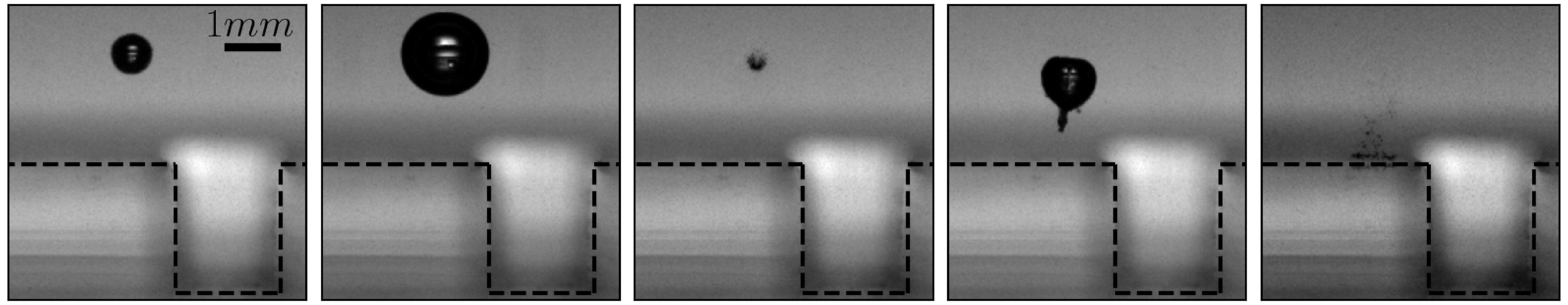
The parameters defining the slot, the bubble position, and the jet angle, θ, are shown in the diagram on the right. The jet angle is positive to the right, and negative to the left.

The jet direction is a function of three non-dimensional variables, we define them as the slot height $h = H/W$, horizontal bubble position $x = 2X/W$, and vertical bubble position $y = Y/W$.



Experiments

We focused a high-powered laser pulse to vaporise a small volume of water, forming a high pressure bubble that expanded and then collapsed, creating a jet. We repeated this for different slots and bubble positions.



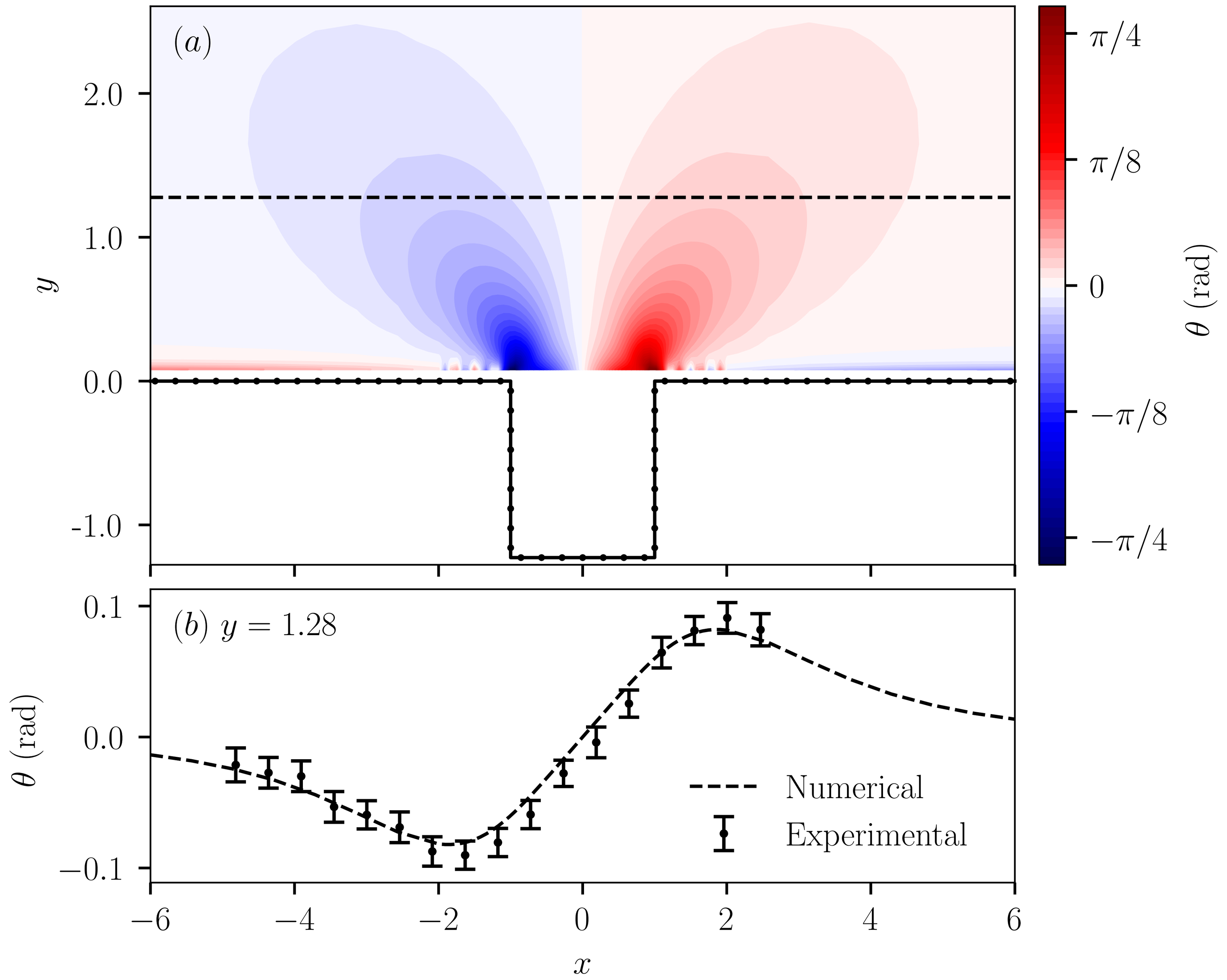
$t = 9\mu s$ $t = 99\mu s$ $t = 179\mu s$ $t = 219\mu s$ $t = 589\mu s$

Experiments were recorded at 100,000 frames per second using a high speed camera. This movie shows a negative jet angle, away from the slot, which is also shown by the blue area in the "Numerical Model" plot.

Numerical Model

We used a simple and fast numerical model to predict the jet direction. This model can quickly predict the jet angle for a range of parameters.

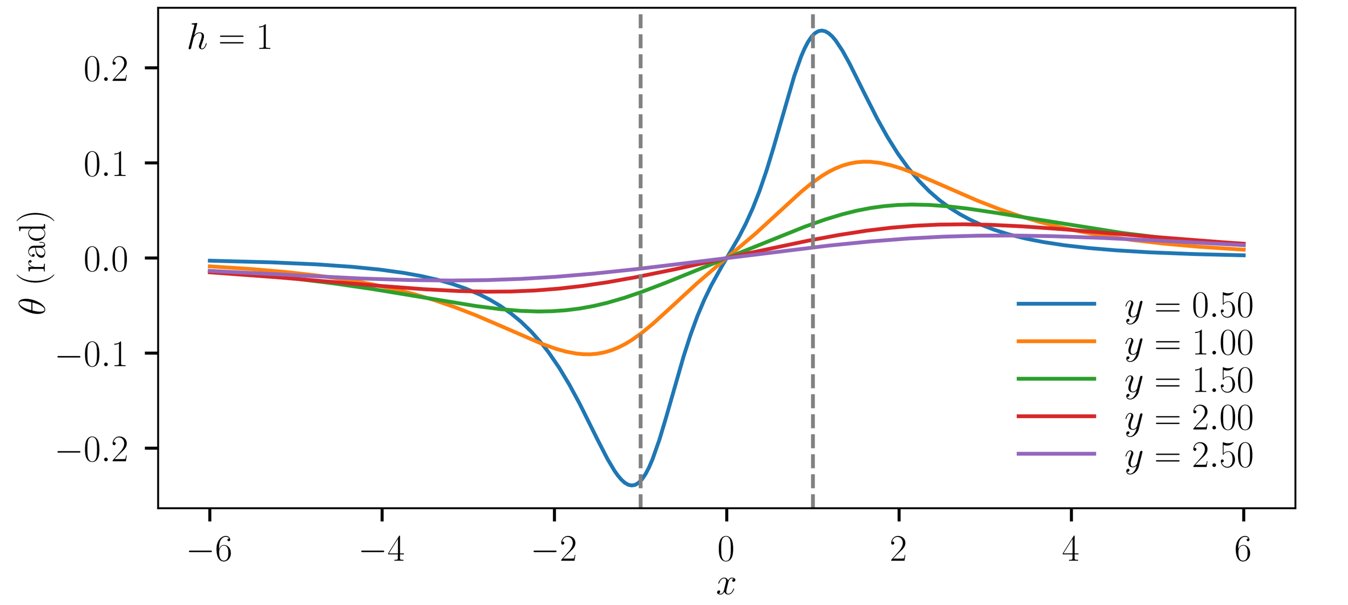
These plots, below, show how the jet angle varies with position. In general the jet is angled away from the slot. One horizontal slice of the contour plot is shown in (*b*) as a θ-x curve. Experimental data is also plotted here and matches the numerical model well.



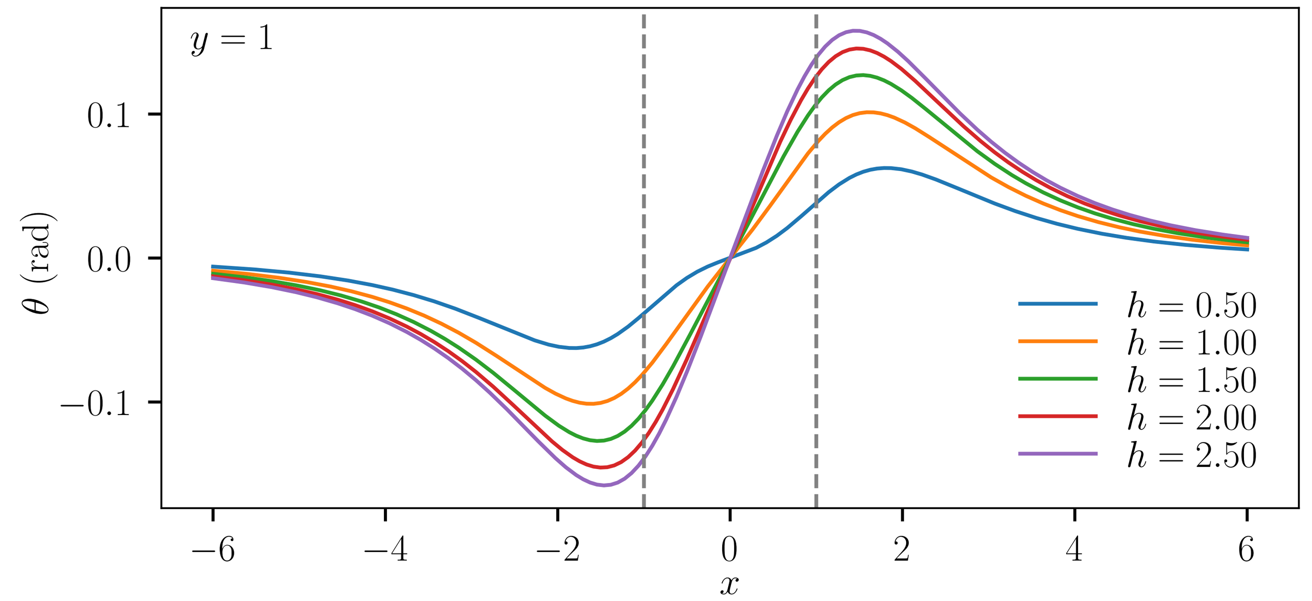
Peak Variation

We used the numerical model to predict how the θ-x curve will vary with the other two parameters: y and h.

When the bubble is closer to the boundary, the peak jet angle increases, and occurs closer to the slot.



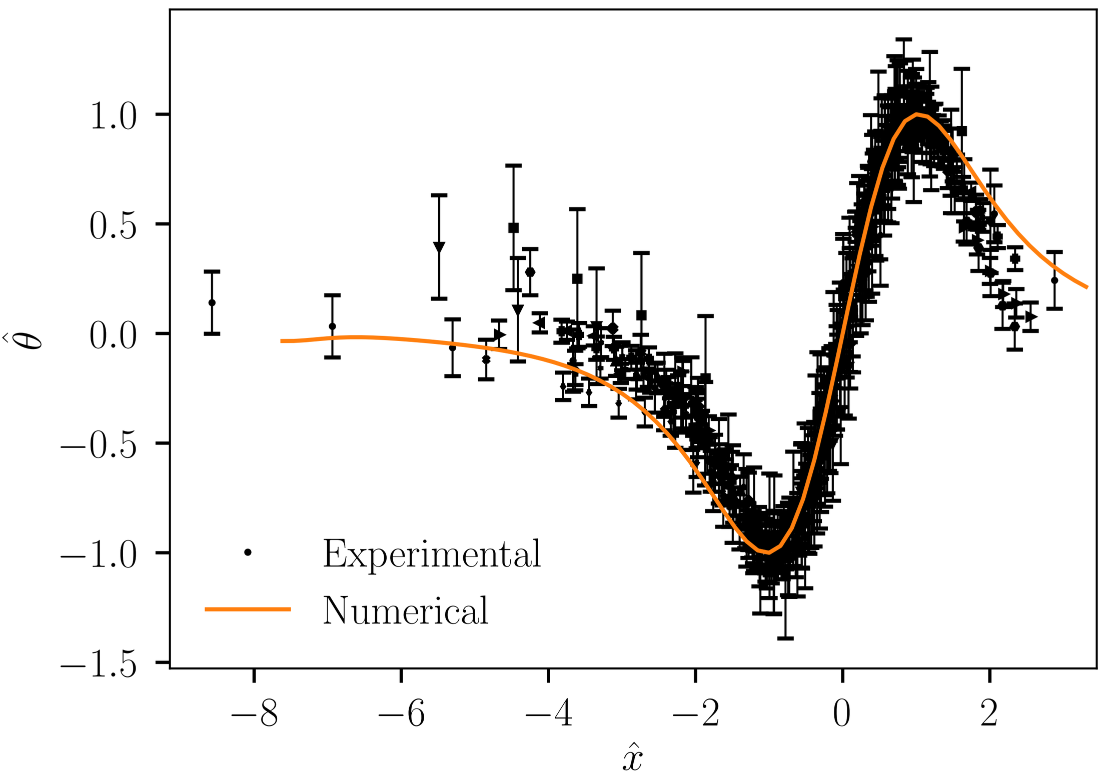
As the slot height, h, increases, the peak jet angle increases towards a limiting value. For very large h the jet angle no longer depends on h and so is only a function of the bubble position.



Curve Collapse

When θ is normalised with the peak value ($\hat{\theta} = \theta/\theta^{\star}$), and x is normalised with the position of the peak ($\hat{x} = x/x^{\star}$), the θ - x curves all collapse down onto one curve as shown by the orange curve in the figure on the right.

This means that the jet angle can be determined using only this curve, scaled using the non-dimensional parameters h and y.



Conclusion

We have shown the tendency of the jet to be directed away from a slot in a flat surface. This suggests that slots may not be cleaned very well due to fewer jets impacting inside the slot. This research has been published in JFM[3].

Further research could focus on quantifying the cleaning effect of the jets, and determining how well the jet angle predicts the final cleaning performance. We show that our numerical model works well for slot geometries, but the same method could also be used in many more complex geometries.

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[1] B. Verhaagen, T. Zanderink, D. Fernandez Rivas, Ultrasonic cleaning of 3D printed objects and Cleaning Challenge Devices. *Applied Acoustics*. **103**, 172–181 (2016).
[2] L. Molefe, I. R. Peters, Jet direction in bubble collapse within rectangular and triangular channels. *Physical Review E*. **100** (2019).
[3] Andrews, E. D., Fernández Rivas, D. & Peters, I. R. Cavity collapse near slot geometries. Journal of Fluid Mechanics **901**, (2020).