On the crown forming instability in the drop splash problem

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The motivation

Figure: the famous milk crown of Edgerton & Killian (1954).

Original question†: “Why there are exactly 24 spikes in the above photo?”
General question: “What is the nature of the crown forming instability?”

Outline

- A bit of history
- Problem set-up
- *Milk* as an experimental material
- Experimental results:
  - Crown formation picture
  - Regularity types of the crown
  - Instability mechanism
  - Bifurcation phenomena
  - Milk vs. water
- Conclusions
A bit of history: existing theories
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- The Rayleigh-Taylor instability (Allen, 1974).

Deceleration of an interface
A bit of history: existing theories

- The Rayleigh-Taylor instability (Allen, 1974).
- The Plateau-Rayleigh instability (Fullana & Zaleski 1999, Roisman et al. 2006).

Disintegration of a retracting rim
A bit of history: existing theories

- The Rayleigh-Taylor instability (Allen, 1974).
- The Plateau-Rayleigh instability (Fullana & Zaleski 1999, Roisman et al. 2006).
- Another Rayleigh-Taylor instability (Thoroddsen & Sakakibara 1998).

Deceleration of the lower drop surface
A bit of history: existing theories

- The Rayleigh-Taylor instability (Allen, 1974).
- The Plateau-Rayleigh instability (Fullana & Zaleski 1999, Roisman et al. 2006).
- Another Rayleigh-Taylor instability (Thoroddsen & Sakakibara 1998).
- The Kelvin-Helmholtz instability (Yoon et al. 2007).
A bit of history: existing theories

- The Rayleigh-Taylor instability (Allen, 1974).
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**Question:** which one is relevant?
Problem set-up

Governing parameters:

\[ We_{\text{drop}} = \frac{\text{inertia}}{\text{surface tension}} \approx (0.6 - 14) \times 10^2 \]

\[ Oh = \frac{\text{viscosity}}{\text{surface tension}} \approx (0.15 - 0.41) \times 10^{-2} \]

\[ \alpha = \frac{\text{drop inertia}}{\text{film inertia}} \approx 0.1 - 10.0 \]

or \[ We_{\text{film}} = \alpha^{-1} We_{\text{drop}} \]

Experimental set-up:

Working fluids: water and milk
Milk as an *experimental* material

Comparison of two milks; release height is 16.51 cm.
Experimental results: crown formation

From ejecta to crown; time interval \( t = 1610 \mu s \).

Three key elements of the drop splash.

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Experimental results: crown regularity

Three modes of a crown formation

Early stages

Late stages
Experimental results: instability type

Kinematics; peak values $a \sim 10^5 \text{m/s}^2$, $v \sim 10 \text{m/s}$

Displacement$^\dagger$

Conclusion: this is the Richtmyer-Meshkov instability

$^\dagger t^* = \sqrt{d^3 \rho/\sigma}$, $v^* = \sqrt{2gH}$. 
Experimental results: bifurcations

Transitions between three regularity types

Intermittency phenomena

Frustration

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Experimental results: milk vs. water

Effects of surfactants (SDS) and viscosity

Milk crown

Water crown

SDS crown

Glycerol crown

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Conclusions

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- There are three major *regularity* types of crowns – axisymmetric, regular (including frustrated), and irregular (possibly chaotic) – and the corresponding *bifurcation* phenomena;

- The crown spike distribution is controlled by the very early stages of ejecta formation through the *Richtmyer-Meshkov* instability mechanism.
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- The reasons which make the milk crown so distinctive are pointed out.