Wetting, spreading & capillary adhesion: putting shape-instability to purpose

Paul Steen
Cornell University
Chemical Engineering
## acknowledgments

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<tr>
<th>PhD Students</th>
<th>Collaborators</th>
<th>Sponsors</th>
</tr>
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<tbody>
<tr>
<td>AL Altieri</td>
<td>Dominik Barz</td>
<td>NASA</td>
</tr>
<tr>
<td>JB Bostwick</td>
<td>Susan Daniel</td>
<td>NSF</td>
</tr>
<tr>
<td>CT Chang</td>
<td>Peter Ehrhard</td>
<td>DARPA</td>
</tr>
<tr>
<td>BL Cox</td>
<td>Amir Hirsa</td>
<td></td>
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<tr>
<td>AM Macner</td>
<td>Monika Nitsche</td>
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<tr>
<td>DM Slater</td>
<td>Kyra Stephanoff</td>
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<tr>
<td>HB van Lengerich</td>
<td>Mike Vogel</td>
<td></td>
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<tr>
<td></td>
<td>XiuMei Xu</td>
<td></td>
</tr>
<tr>
<td><strong>Cornell Fluids</strong></td>
<td><strong>D Anderson</strong></td>
<td></td>
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<tr>
<td><strong>Colleagues</strong></td>
<td><strong>S Grice</strong></td>
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**References:**
- Low-Gravity Fluid Mechanics
- Interfacial Instability
- Capillary Surfaces
- Capillary Flows with Forming Interfaces

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as Mother Nature teaches!


BBC ‘Secret Weapons’
the beetle’s feat


\[ F = \sigma \left\{ 2\pi R \sin(\alpha_0) + \pi R^2 (\kappa_1 + \kappa_2) \right\} \]
favorable scaling

\[ Adhesion \text{ Strength} \propto \frac{1}{\text{Droplet Radius}} \]

Q. a man-made device based on perimeter-packing?
grab/release concept

1.7 mm tube diameter

Aluminum foil

lab demo
capillary coarsening

van Lengerich, Vogel, PHS, PRE
Q. can passive design mitigate coarsening?
dynamical-system

Hagen-Poiseuille viscosity resists

\[ \frac{dV_1}{dt} = c_{21} \Delta p_{21}, \quad V_1(0) = V_{10} \]
\[ \frac{dV_2}{dt} = c_{12} \Delta p_{12} + c_{32} \Delta p_{32}, \quad V_2(0) = V_{20} \]
\[ \frac{dV_3}{dt} = c_{23} \Delta p_{23}, \quad V_3(0) = V_{30}. \]

\[ \sum_{j=1}^{N} V_j = \text{const}. \]
coarsening rates

\[ \dot{V}_L = c \Delta P_L \]

Equation for pressure

\[ P_L \sim 1/r \sim 1/V_L^{1/3} \]

Thus \( \dot{V}_L = cV_L^{-1/3} \)

Total number of large drops

\[ N_L \sim 1/V_L \]

\[ N_L \sim t^{-3/4} \]

\[ N_L \sim t^{-3/7} \]

\[ c \sim 1 \]

\[ c \sim N_L \sim 1/V_L \]
capillary coarsening recap

- neighbors compete, self-similarity
- no ‘signature’ for defective pads
Q. how to make switchable (active)?

A. electro-osmotic pumping

probing the barrier

adhesion device

big-mac device performance

Linoleum: 700 mg
Plywood: 725 mg
Brick: 670 mg
Sandpaper (150 grit): 650 mg
Roof shingle: 675 mg

also tested successfully

shown tested here

Linoleum: 700 mg
Plywood: 725 mg
Brick: 670 mg

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silicon-wafer device

Glass frit pump
(device thickness ~ 5 mm, mass ~ 4 g)

e = 500, 300 (or 150 mm)

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average force measure

A. perimeter-packing achieved!

droplet manipulation

Q. natural frequencies?

literature

Theory
- Strani & Sabetta (84, 88)
- Ganan & Barerro (90)
- Bauer & Chiba (04, 05)
- Lyubimov et al. (04, 06)
- Fayzrakhmanova & Straube (09)

Computation
- Basaran & DePaoli, 94
- DePaoli et al. (95)
- Wilkes & Basaran, 01
- James et al. (03)

Experiment
- Rodot et al. (1979)
- James et al. (03)
- Daniel et al. (04)
- Noblin et al. (04)
- Couder et. al (05)
- Vukasinovic et al. (07)
- Brunet et al. (09)
Rayleigh oscillations

\[ \omega_k^2 = k(k - 1)(k + 1)(k + 2) \frac{\sigma}{\rho r^3} \]

\( k = 0, 1, 2, \ldots \)

surface tension \( \sigma \)

liquid density \( \rho \)

sphere radius \( r \)

\( k \)

*Figure 6.2* Photographs of the shape modes of oscillations for liquid drops suspended in another liquid for modes \( n = 2, 3, \) and \( 4 \), from [71]. Courtesy E. H. Truesd.
spherical-cap base-state w/ ‘Hocking’ spreading

\[ 0 < \alpha_0 < \pi \]

\[ 0 \leq \Lambda < \infty \]

Hocking, JFM 1977
Davis, JFM 1980
classify mode shapes

\[ \eta(s, \varphi, t) = y(s)e^{i\omega t}e^{il\varphi} \]

\(k, l = \text{polar, azimuthal wavenumber}\)

<table>
<thead>
<tr>
<th>Mode</th>
<th>(k, l)</th>
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<tr>
<td>Zonal (l = 0)</td>
<td>(k, l = 4, 0)</td>
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<tr>
<td>Sectoral (l = k)</td>
<td>(k, l = 3, 3)</td>
</tr>
<tr>
<td>Tesseral (l \neq k)</td>
<td>(k, l = 6, 4)</td>
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classify mode shapes

\[(a_0, L) = (90^\circ, 0)\]

\[
\begin{array}{cccccccccc}
  & k=1 & k=2 & k=3 & k=4 & k=5 & k=6 & k=7 & k=8 & k=9 \\
 l=0 & & & & & & & & & \\
l=1 & & & & & & & & & \\
l=2 & & & & & & & & & \\
l=3 & & & & & & & & & \\
l=4 & & & & & & & & & \\
l=5 & & & & & & & & & \\
l=6 & & & & & & & & & \\
l=7 & & & & & & & & & \\
l=8 & & & & & & & & & \\
l=9 & & & & & & & & & \\
\end{array}
\]
unfolding of spectra
sessile-drop recap

- spectra split for $(\alpha_0, \Lambda) \neq (90^\circ, 0)$
- damped (effective dissipation) for $\Lambda \neq 0, \ 1/\Lambda \neq 0$

[3,3] mode

side

top
concluding remarks

• beetle lessons
  – perimeter-packing, switchable

• coarsening & coalescence mitigation
  – passive design

• grab-release device w/ eo pump
  – perimeter-packing, switchable adhesion

• sessile-drop oscillations
  – spectral splitting