Dynamics of the central entrapped bubble during drop impact

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西安交通大學
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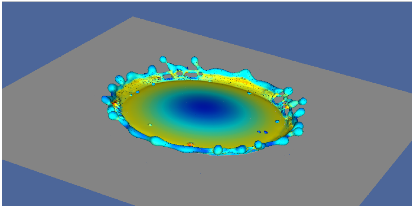
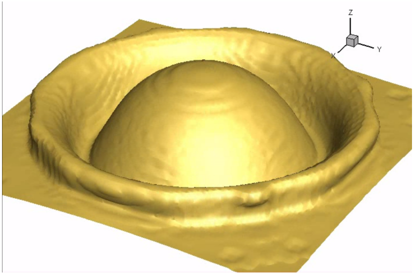
High Speed & Multiphase Flow Laboratory

Drop impact

- Fundamental case to understand complex multiphase dynamics.
- Physical process: liquid drop impacts on target media (solid or liquid).



Impact on solid in 3D by *Gerris*

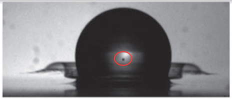


Impact on a pool in 3D by *Basilisk*

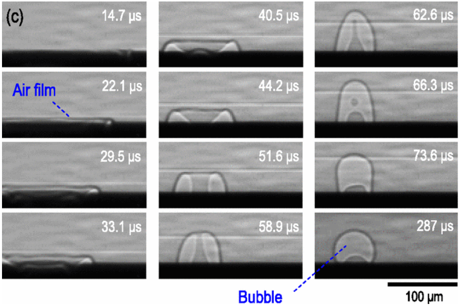
Central entrapped bubble

Central entrapped bubble: widely observed in experiments

Solid

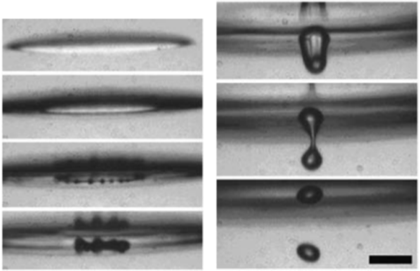


Thoroddsen *et al.* (2008)



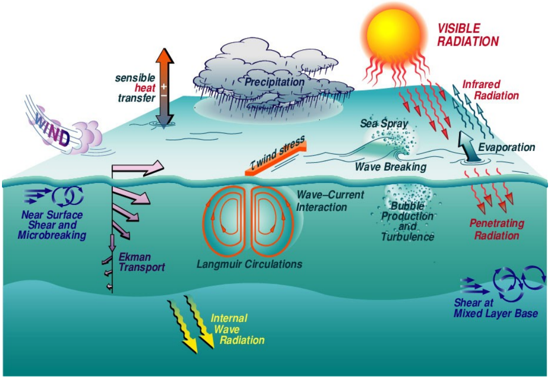
Lee *et al.* (2012)

Liquid

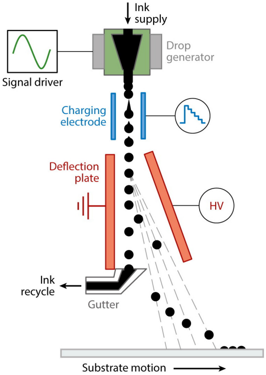


Thoroddsen *et al.* (2003)

Applications



Edson *et al.* (2007)



Basaran *et al.* (2013)

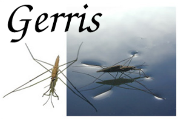
Natural phenomena
Global CO_2 equilibrium
Favorable

Industrial applications
Ink-jet printing
3D printing
Harmful

Basilisk

- Open source, free software program (*basilisk.fr*)
- Created by Stéphane Popinet
- Supported by Institute Jean Le Rond ∂'Alembert

- Diphasic fluid flow solver (NS, SWE,...)
- FVM, Adaptive mesh refinement (AMR)- Quadtree/octree, Cartesian
- VOF, Continuum-Surface-Force (CSF), Height-Function (HF)
- Parallel computations via MPI library



- Successor of *Gerris* (*gfs.sf.net*)
- **References: Popinet (2003, 2009) JCP**

Configuration

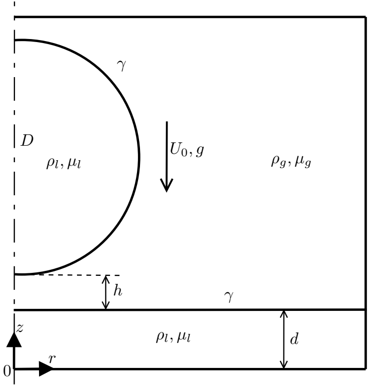
2D, Axisymmetric

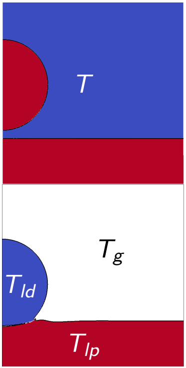
Navier-Stokes, incompressible

Semi-circular droplet:
initial U_0, with g

VOF tracer: T
Passive tracer: T_p droplet

$\mathcal{F}(T, T_p)$: T_g gas, T_{ld} droplet, T_{lp} pool

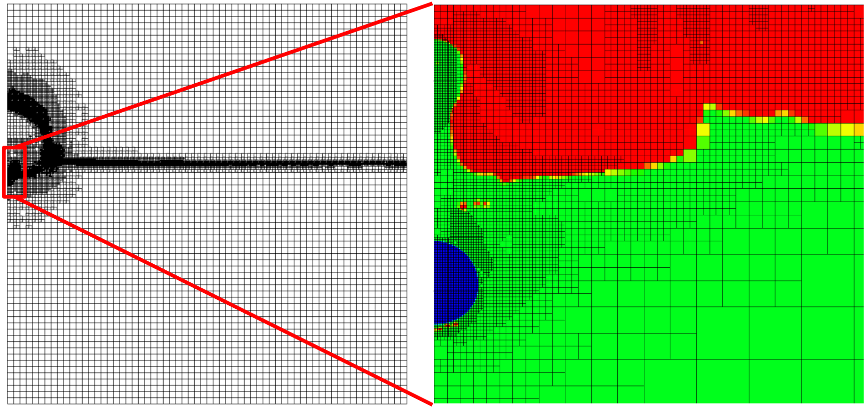




Adaptive mesh refinement

Refinement criteria

- Gradient of VOF tracer T tracking the L/S interface
- Variation of the u, v component of the velocity



Parameters

- Highest refinement level 13 $\Rightarrow$ Cell number per diameter $n_D = 1637$
- Set $t = 0$ at the moment when drop arrives at the initial position of the pool with absence of gas
  Simulation starts at $t = \frac{h}{U_0} = -0.05$

ρ_l^*	ρ_g^*	μ_l^*	μ_g^*	γ^*
1	0.0015	$\frac{\rho_l^* U_0^* D^*}{Re} = 1/Re$	0.00024	$\frac{\rho_l^* {U_0^*}^2 D^*}{We} = 1/We$
g^*	U_0^*	D^*	d^*	h^*
$\frac{1}{Fr} = 1/458.72$	1	1	3	0.05

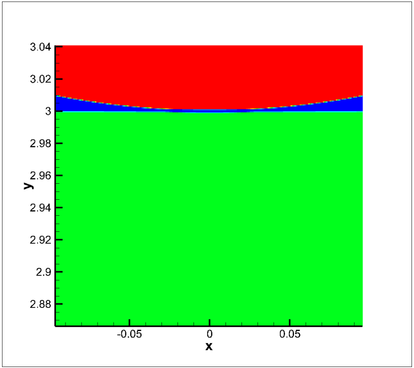
Parameter space

A series of (Re, We) combination calculated

Re	500, 1000, 2000, 3000, 4000, 4500, 5000
We	100, 200, 300, 400, 500, 600, 700, 800

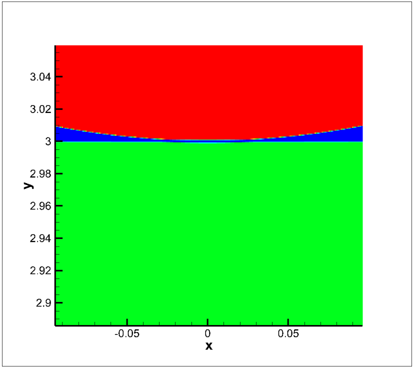
Toroidal bubble

Normal bubble



$Re = 1000, We = 200$

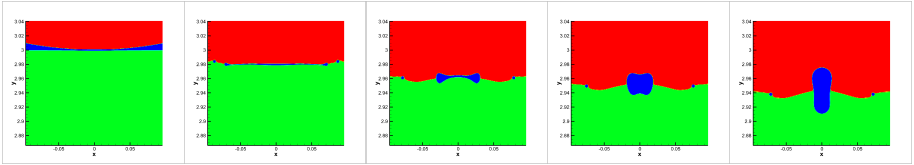
Toroidal bubble



$Re = 3000, We = 200$

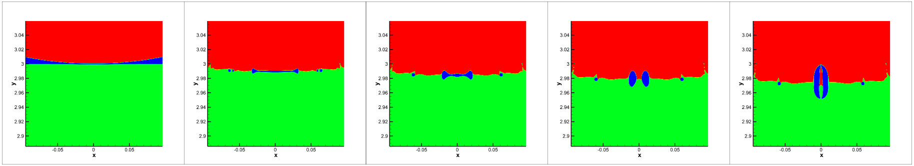
Toroidal bubble - snapshots

$Re = 1000$, $We = 200$



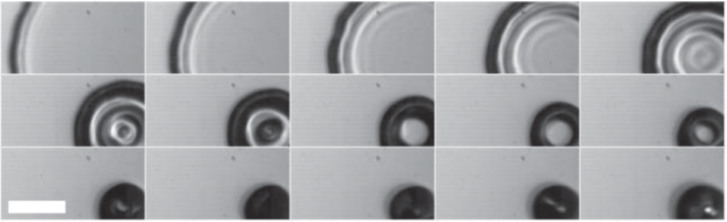
$t = 0$ 0.04 0.08 0.10 0.12

$Re = 3000$, $We = 200$



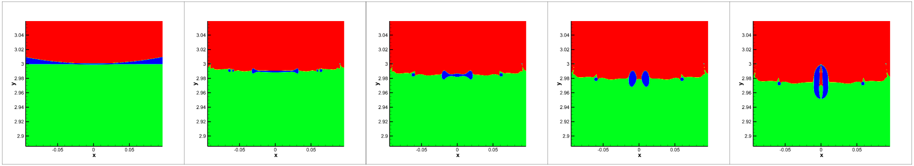
$t = 0$ 0.02 0.03 0.04 0.05

Toroidal bubble - snapshots



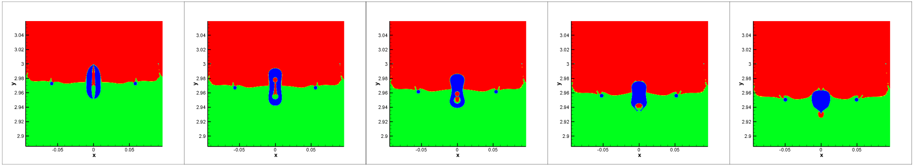
arXiv:1211.3076v1 [physics.flu-dyn]

$Re = 3000$, $We = 200$



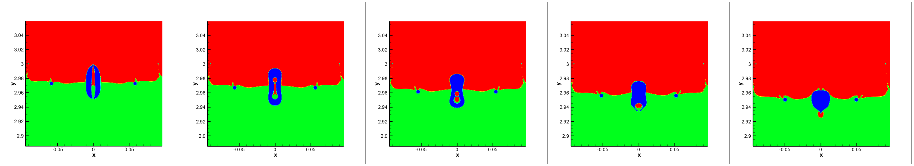
$t = 0$ 0.02 0.03 0.04 0.05

Microdroplet in bubble

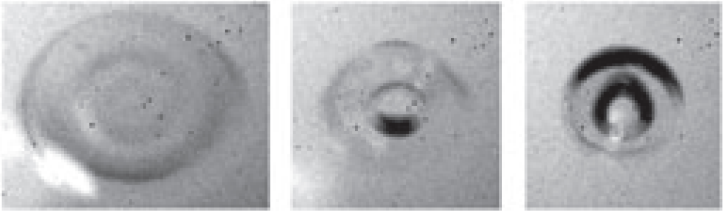


$t = 0.05$ $t = 0.06$ $t = 0.07$ $t = 0.08$ $t = 0.09$

Microdroplet in bubble

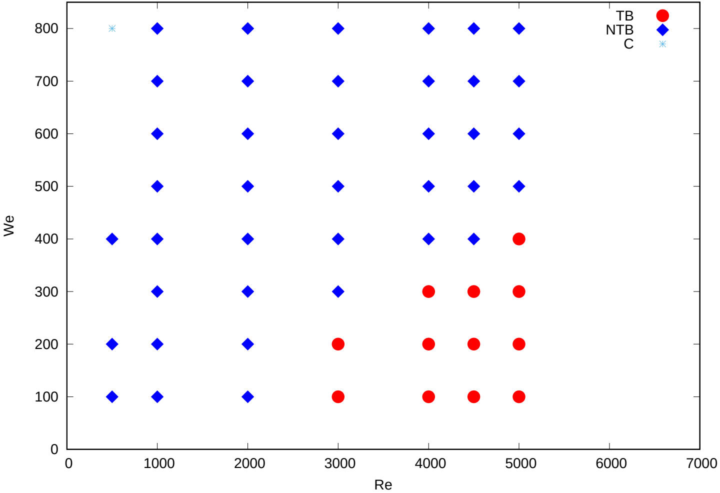


$t = 0.05$ $t = 0.06$ $t = 0.07$ $t = 0.08$ $t = 0.09$



Microdrop caught on the solid surface, inside the entrapped air bubble Thoroddsen *et al.* (2008)

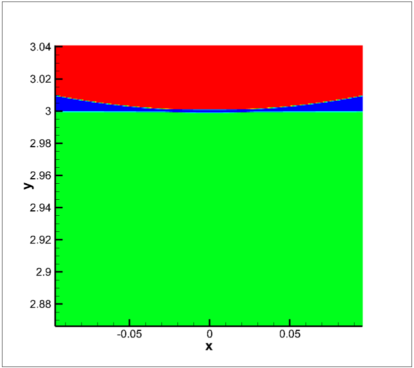
Phase Diagram



TB denotes Toroidal Bubble, NTB No Toroidal Bubble, C Crash

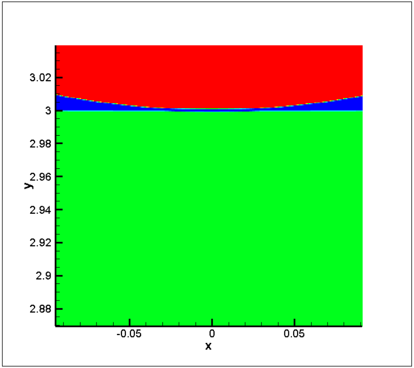
Vertical splitting

Single bubble



$Re = 1000, We = 200$

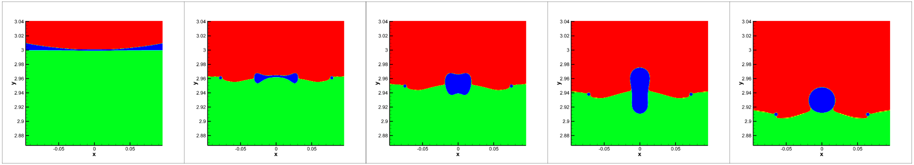
Vertical splitting



$Re = 3000, We = 400$

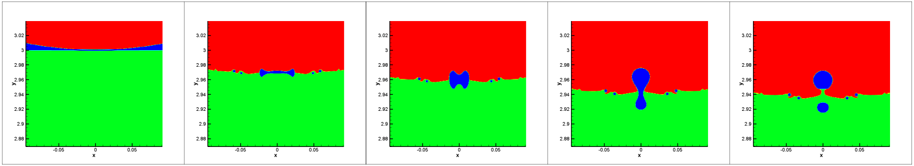
Vertical splitting - snaphots

$Re = 1000, We = 200$



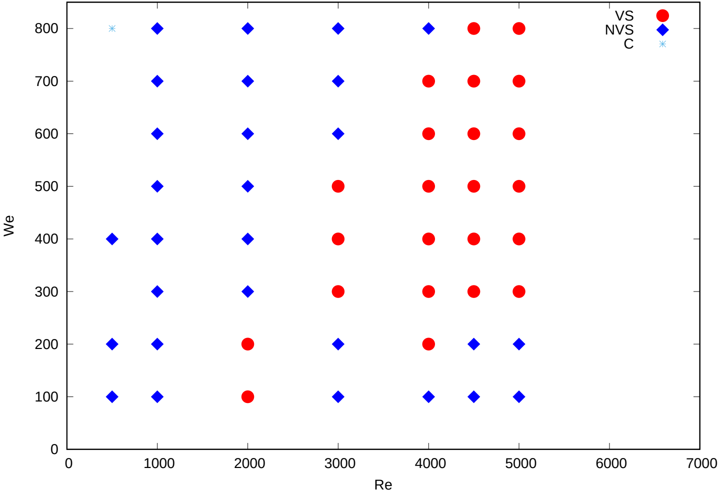
$t = 0$ 0.08 0.10 0.12 0.17

$Re = 3000, We = 400$



$t = 0$ 0.06 0.08 0.11 0.12

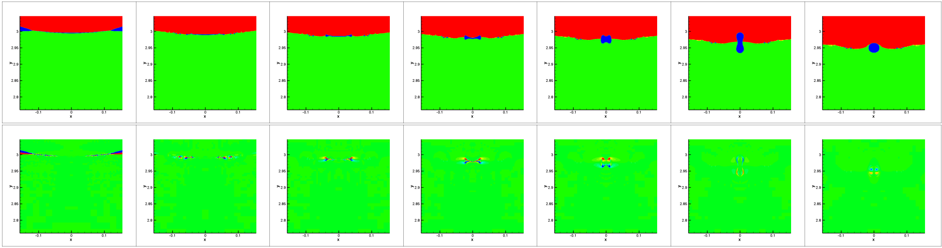
Phase Diagram



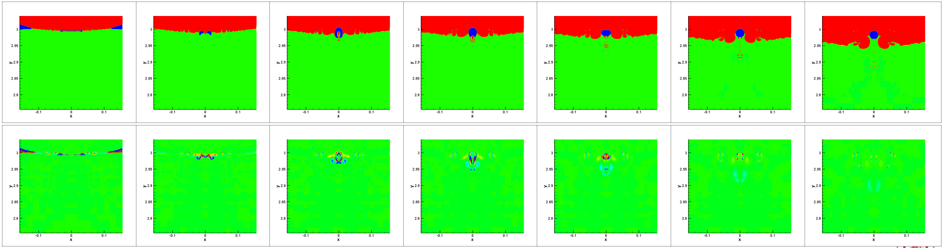
VS denotes Vertical Splitting, NVS No Vertical Splitting, C Crash

Vortex shedding

$Re = 1000$, $We = 100$



$Re = 5000$, $We = 100$



$t = 0.01$ 0.02 0.03 0.04 0.05 0.07 0.10

Summary

- Drop impact on a pool was simulated by *Basilisk* and dynamics of the central entrapped bubble was studied systematically on varying the *Reynolds* and *Weber* Numbers.
- A variety of dynamics such as toroidal bubble, vertical splitting and vortex shedding are observed of the central entrapped bubble

Next

- Higher refinement to increase the n_D
- Comparison between experiments and numerics

Thank you for your attention!

Questions and comments are warmly welcomed!

Basaran, O. A., Gao, H., and Bhat, P. P. (2013). Nonstandard Inkjets. In Davis, SH and Moin, P, editor, *Annual Review of Fluid Mechanics, VOL 45*, volume 45 of *Annual Review of Fluid Mechanics*, pages 85–113. Annual Reviews, 4139 El Camino Way, Po Box 10139, Palo Alto, Ca 94303-0897 Usa.

Edson, J., Crawford, T., Crescenti, J., Farrar, T., Frew, N., Gerbi, G., Plueddemann, A., Trowbridge, J., Weller, R., Williams, A. J., Helmis, C., Hristov, T., Shen, L., Khelif, D., Jessup, A., Jonsson, H., Li, M., Mahrt, L., Skyllingstad, E., Vickers, D., McGillis, W., Zappa, C., Stanton, T., Wang, Q., Sullivan, P., Sun, J., Wang, S., Wilkin, J., and Yue, D. K. P. (2007). The coupled boundary layers and AirSea transfer experiment in low winds. *Bulletin of the American Meteorological Society*, **88**(3), 341–356.

Lee, J. S., Weon, B. M., Je, J. H., and Fezzaa, K. (2012). How does an air film evolve into a bubble during drop impact? *Phys. Rev. Lett.*, **109**, 204501.

Popinet, S. (2003). Gerris: a tree-based adaptive solver for the incompressible euler equations in complex geometries. *Journal of Computational Physics*, **190**(2), 572–600.

Popinet, S. (2009). An accurate adaptive solver for surface-tension-driven interfacial flows. *Journal of Computational Physics*, **228**(16), 58385866.

Thoroddsen, S., Etoh, T., and Takehara, K. (2008). High-speed imaging of drops and bubbles. *Ann. Rev. Fluid Mech.*, **40**, 257–285.

Thoroddsen, S. T., Etoh, T. G., and Takehara, K. (2003). Air entrapment under an impacting drop. *Journal of Fluid Mechanics*, **478**, 125–134.