

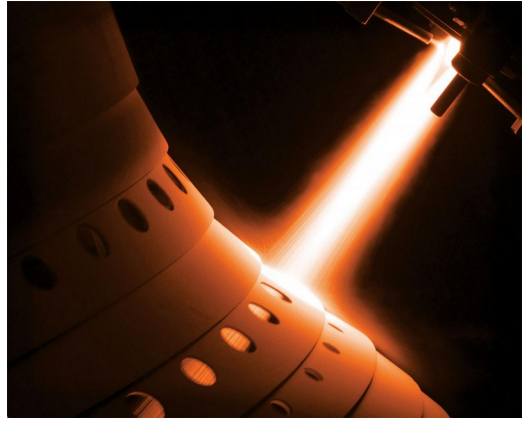
22nd Computational Fluids Conference - CFC2023 CANNES -

Modeling and simulation of single and multiple drop impingement onto liquid surfaces

Syphax FERREKA

26/04/2023

Introduction



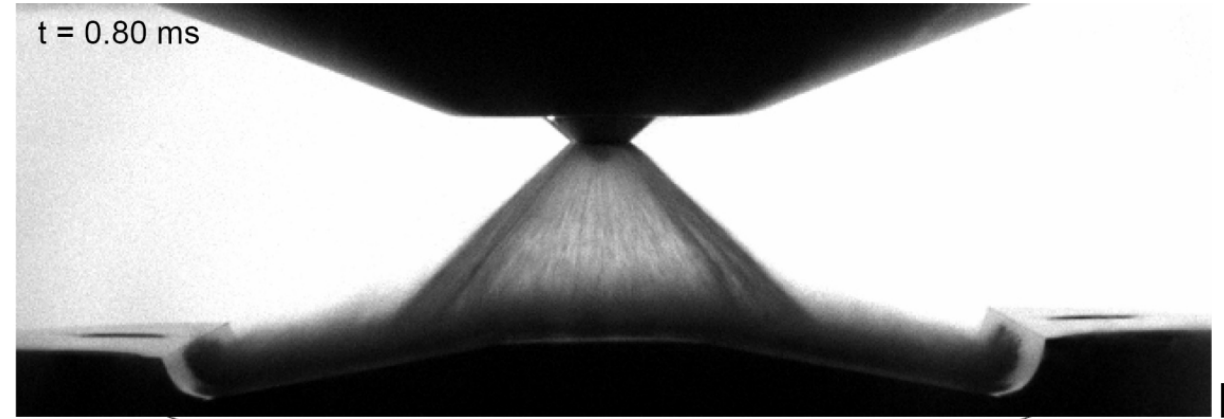
[1]

Coating



[2]

Cooling

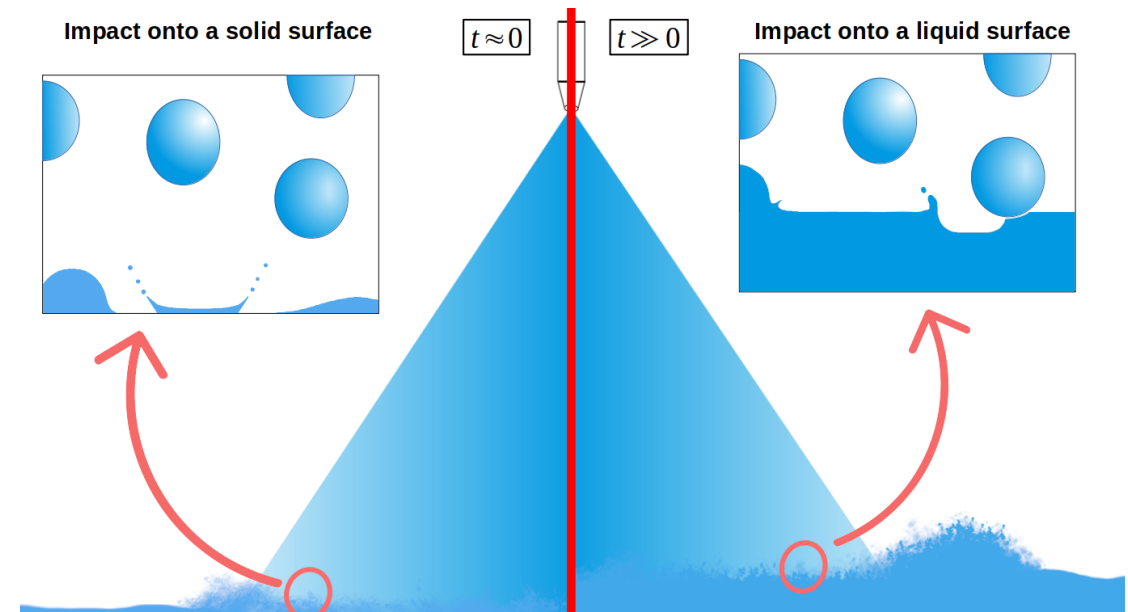


[3]

Combustion

Main objectives

- Modeling and simulation of spray impact onto liquid surfaces
- Quantification of the mass ejection/deposition induced by impacts.

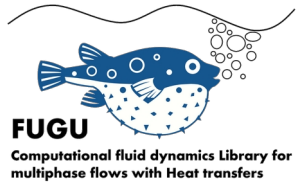


[1]: <https://www.mistjet.in/v-jet-nozzle.htm>

[2]: <https://www.progressivesurface.com/thermalspraying/process.htm>

[3]: Monika Muhlbauer. Modelling wall interactions of a high-pressure hollow cone spray. Phd thesis, Darmstadt university (2009)

Numerical methods



FUGU multiphase solver

- Finite volume discretization
- Cartesian irregular staggered grid
- MPI Parallel solving
- Coupled P-v solving

• 1-fluid formulation Navier-Stokes equations

Coupled Pressure-velocity resolution [Elouafa et al]

$$\begin{cases} \frac{\partial \rho(C)\mathbf{u}}{\partial t} + \nabla \cdot (\rho(C)\mathbf{u} \otimes \mathbf{u}) = -\rho\mathbf{g} - \nabla p + \nabla \cdot [\mu(C)(\nabla\mathbf{u} + \nabla\mathbf{u}^T)] + \sigma\kappa\mathbf{n}\delta_i \\ \nabla \cdot \mathbf{u} = 0 \\ \frac{\partial C}{\partial t} + \mathbf{u} \cdot \nabla C = 0 \end{cases}$$

• Surface tension modeling

- Continuum surface force model [Brackbill et al]

• Interface capturing

- VOF method for interface capturing (1D split [Young], Conservative [Weymouth et al], Unsplit [Owkes & Desjardins]):

• Momentum conserving method [Nangia et al]

$$\frac{\rho^{n+1} - \rho^n}{\Delta t} + \nabla \cdot (\rho^{n+1}\mathbf{u}^{*,n+1}) = 0 \quad (a)$$

- third order upwind schemes,

$$\frac{(\rho\mathbf{u})^{**} - \rho^n\mathbf{u}^n}{\Delta t} + \nabla \cdot ((\rho\mathbf{u})^{*,n+1} \otimes \mathbf{u}^{*,n+1}) \quad (b)$$

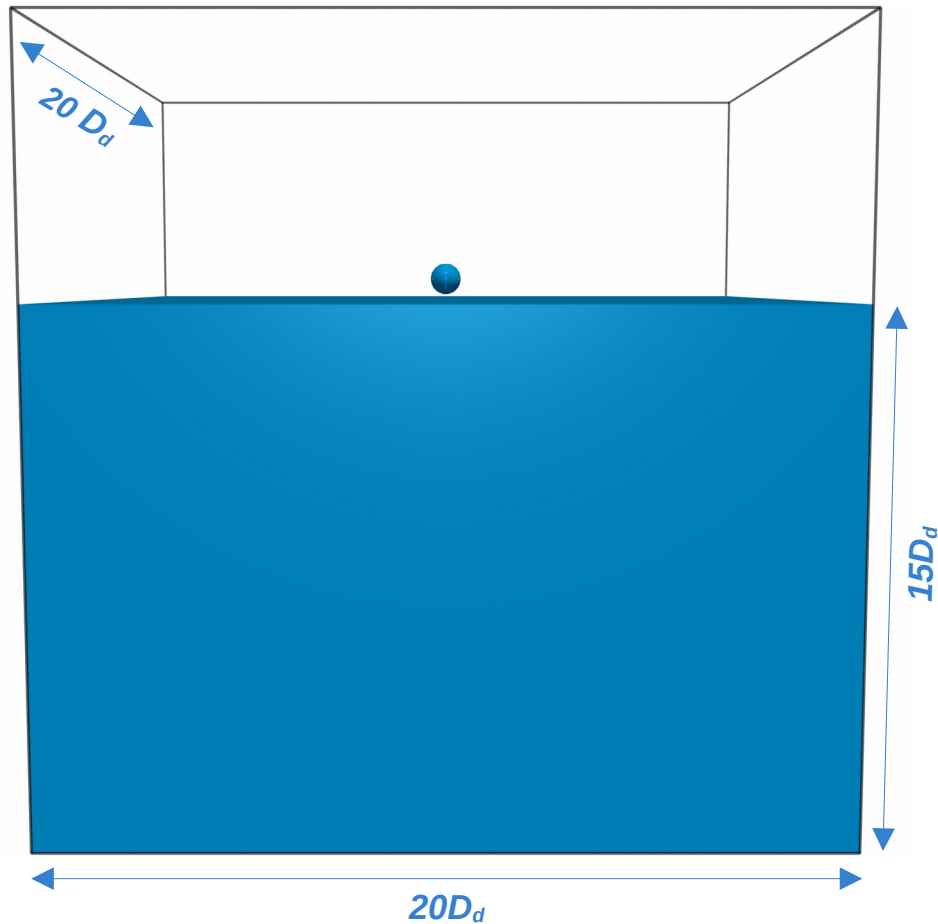
- strong-stability preserving Runge-Kutta 3 (SSP-RK3).

$$\begin{cases} \frac{\rho^{n+1}\mathbf{u}^{n+1} - (\rho\mathbf{u})^{**}}{\Delta t} = -\rho^{n+1}\mathbf{g} - \nabla p^{n+1} + \nabla \cdot [\mu(\nabla\mathbf{u}^{n+1} + (\nabla\mathbf{u}^{n+1})^T)] + \sigma\kappa\mathbf{n}\delta_i \\ \nabla \cdot \mathbf{u}^{n+1} = 0 \end{cases}$$

* : extrapolated quantity
** : intermediate quantity

I. Single drop impacts : simulation of the crater dynamics

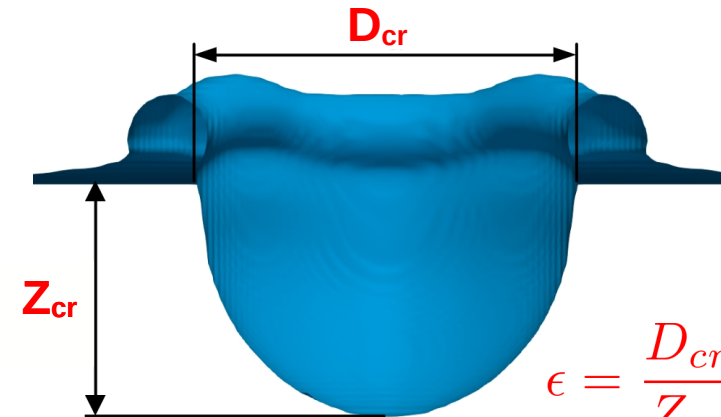
1. Numerical configuration and studied regimes [Bisighini et al]



Domain: $20D_d \times 20D_d \times 15D_d$

Case	V_i (m/s)	D_d (mm)	H^*	We	Re
A	2.4	2.2	15	170	6 391
B	3	1.8	15	226	6 774
C	3.6	2.3	15	406	10 128
D	4.2	2.8	15	683	14 638
E	4.4	2.9	15	2 190	12 687

$$We = \frac{D_d V_i^2 \rho_l}{\sigma}, \quad Re = \frac{D_d V_i \rho_l}{\mu_l}$$



$$\epsilon = \frac{D_{cr}}{Z_{cr}} : \text{shape factor}$$

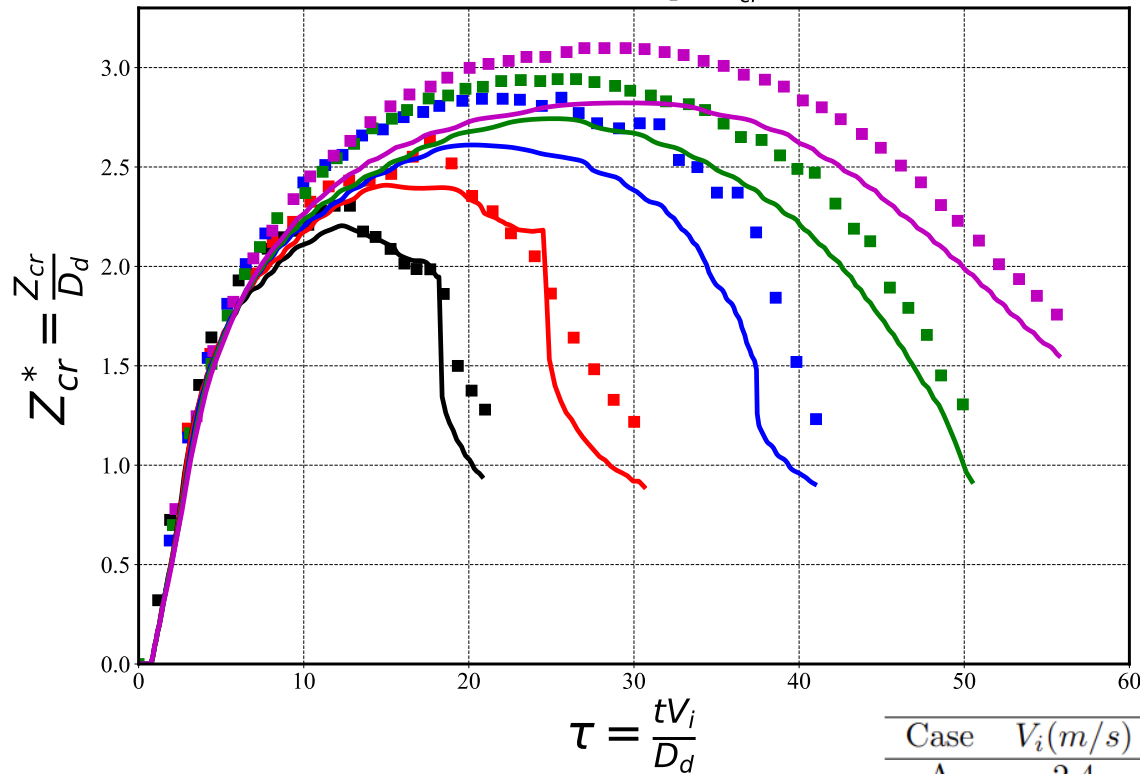
Crater dimensions

I. Single drop impacts : simulation of the crater dynamics

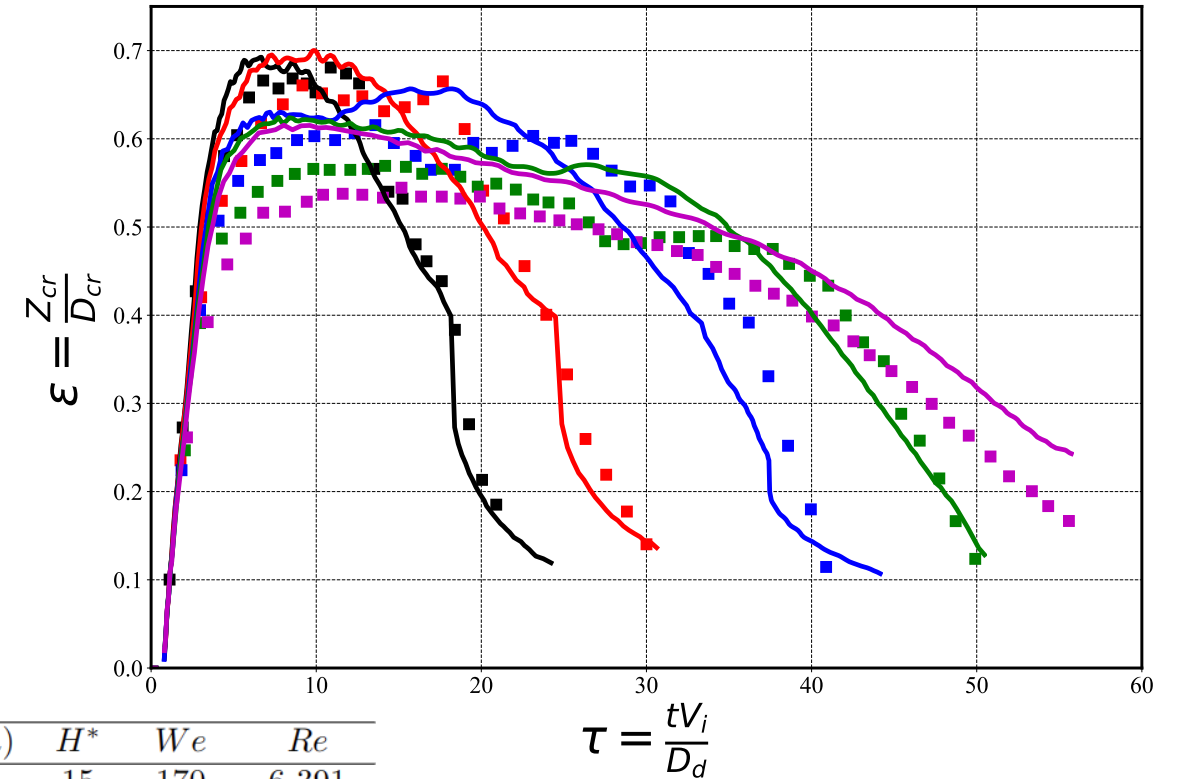
Crater depth and diameter evolutions over time for the different regimes : for a resolution $\Delta = 14$ cells per drop diameter

- EXP case A [Bisighini et al]
- EXP case C
- EXP case E
- EXP case B
- EXP case D
- FUGU 14 cells per diameter

Evolution of the dimensionless crater depth Z_{cr}^* over time for the five cases



Evolution of the crater shape factor ϵ over time for the five cases

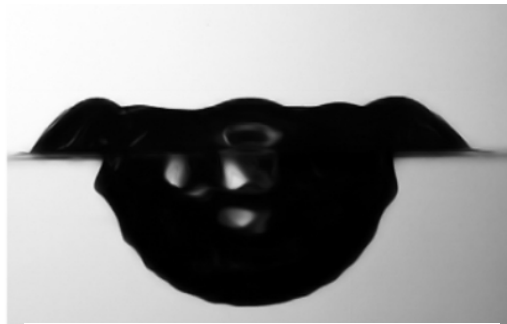
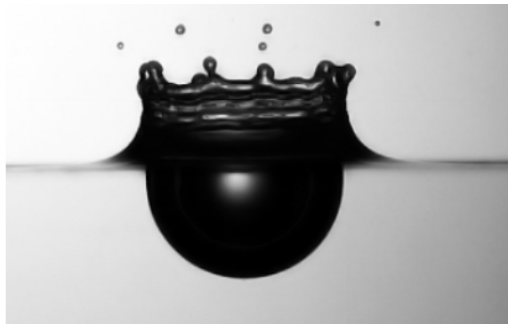


Case	V_i (m/s)	D_d (mm)	H^*	We	Re
A	2.4	2.2	15	170	6 391
B	3	1.8	15	226	6 774
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I. Single drop impacts : simulation of the crater dynamics

Evolution of crater shape over time: using resolution $\Delta = 28$ cells per drop diameter

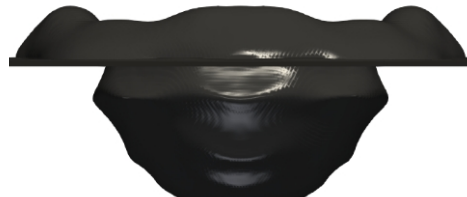
Case	$V_i(m/s)$	$D_d(mm)$	H^*	We	Re
A	2.4	2.2	15	170	6 391
B	3	1.8	15	226	6 774
C	3.6	2.3	15	406	10 128
D	4.2	2.8	15	683	14 638
E	4.4	2.9	15	2 190	12 687



Experiment
[Bisighini et al]



4.3 ms



22.6 ms

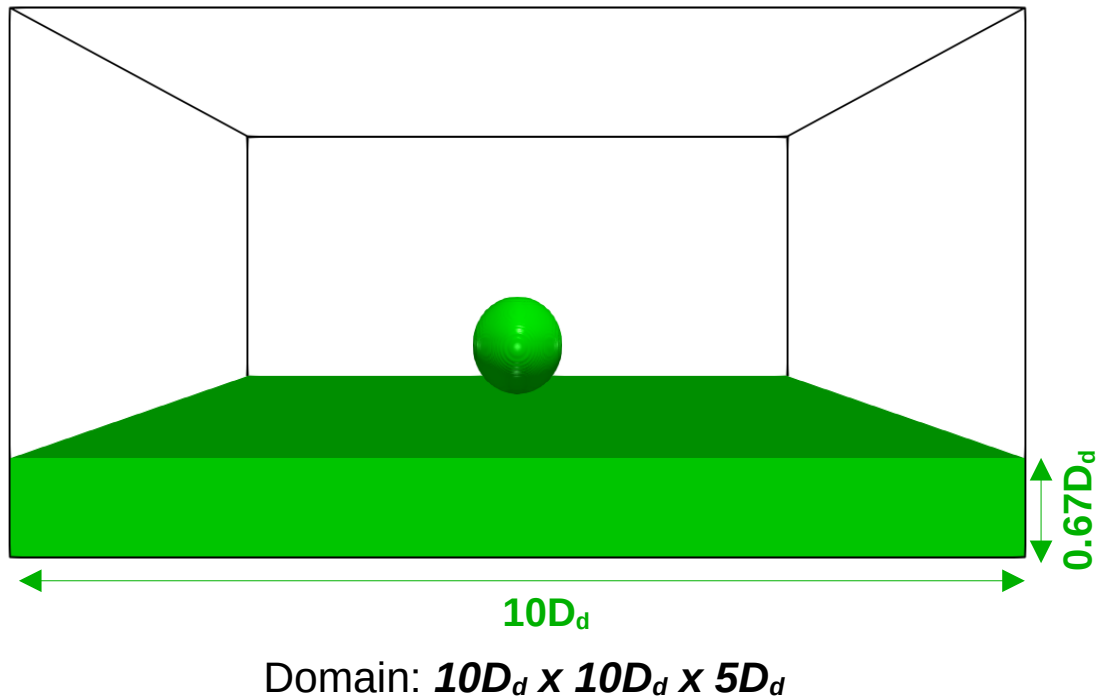


28.7 ms

Simulation

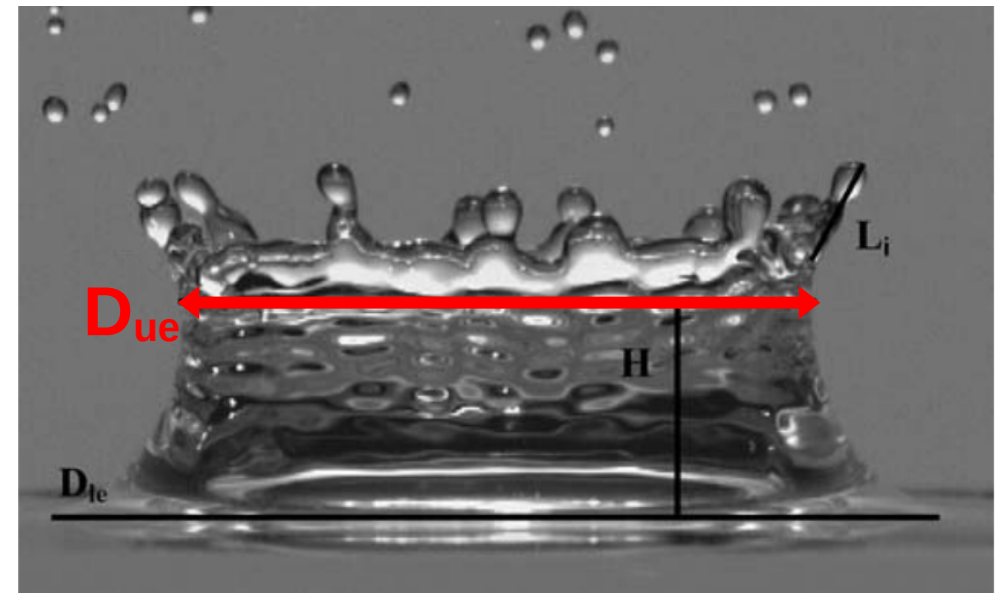
II. Single drop impacts : simulation of the crown dynamics

Numerical configuration and studied regimes [Cossali et al]



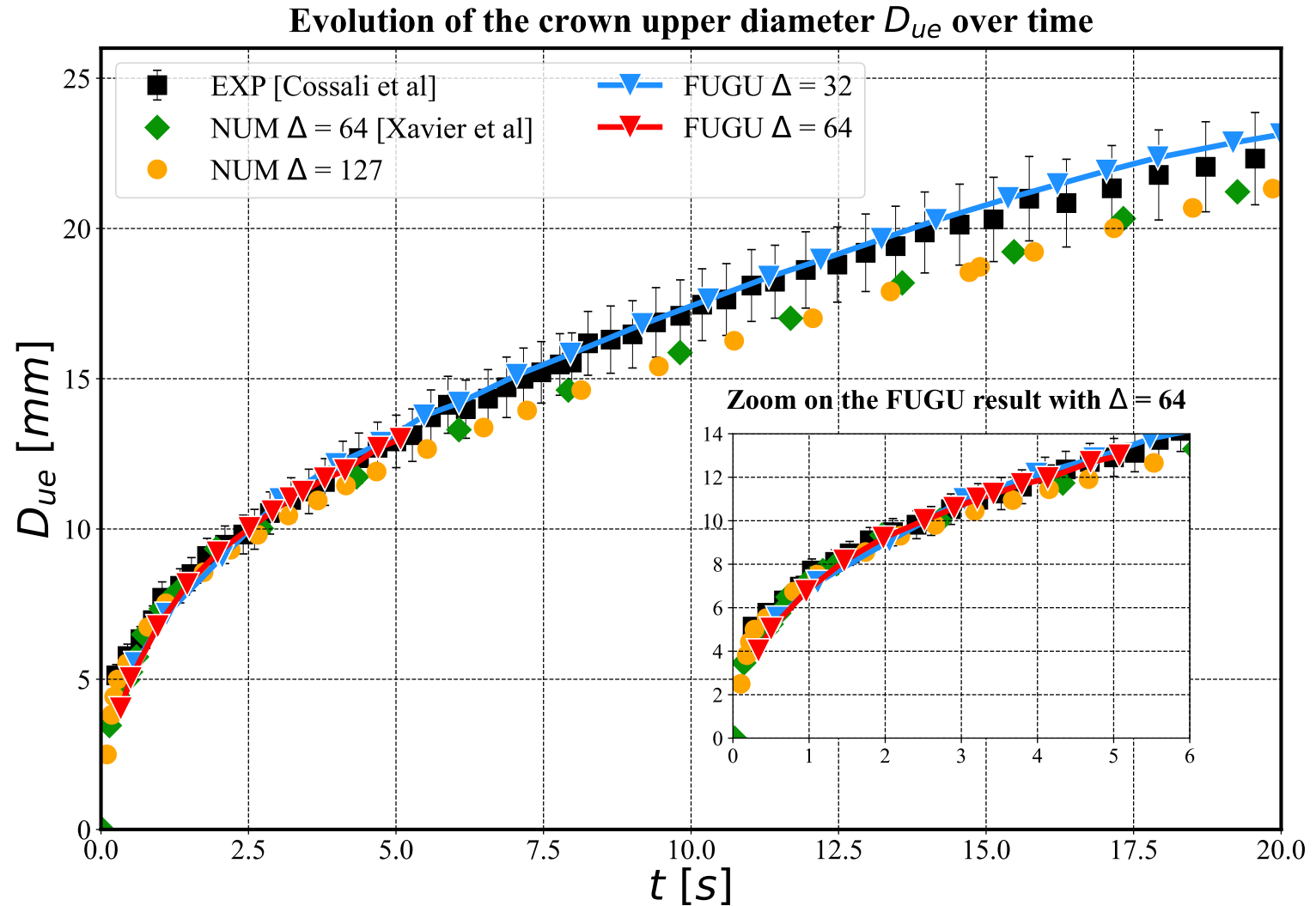
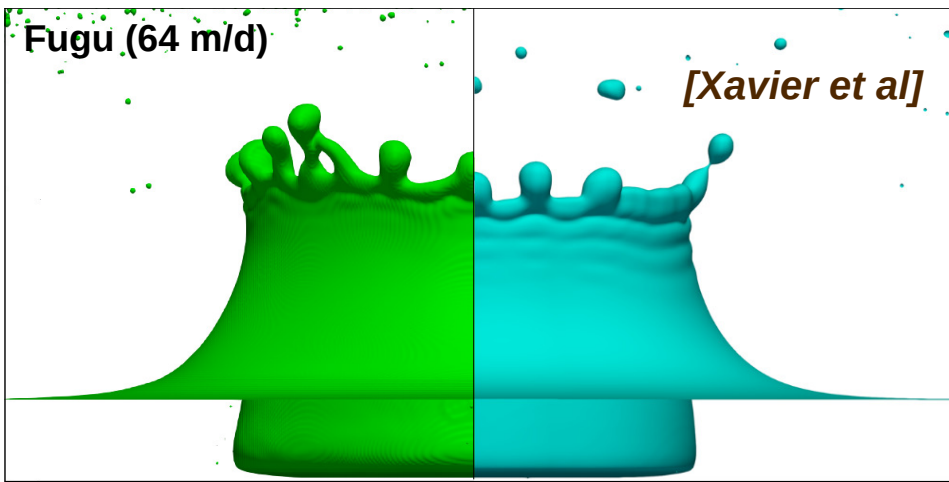
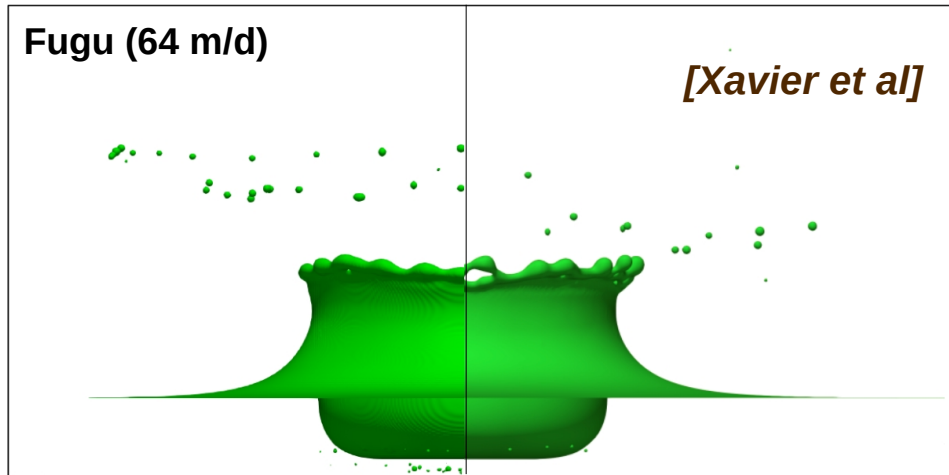
V_i (m/s)	D_d (mm)	H^*	We	Re	K	K_l
3.94	3.82	0.67	842	15 366	10 350	5 403

$$We = \frac{D_d V_i^2 \rho_l}{\sigma}, \quad Re = \frac{D_d V_i \rho_l}{\mu_l}, \quad K = We^{0.8} Re^{0.4}, \quad K_l = 2100 + 5880 \delta^{1.44}$$



II. Single drop impacts : simulation of the crown dynamics

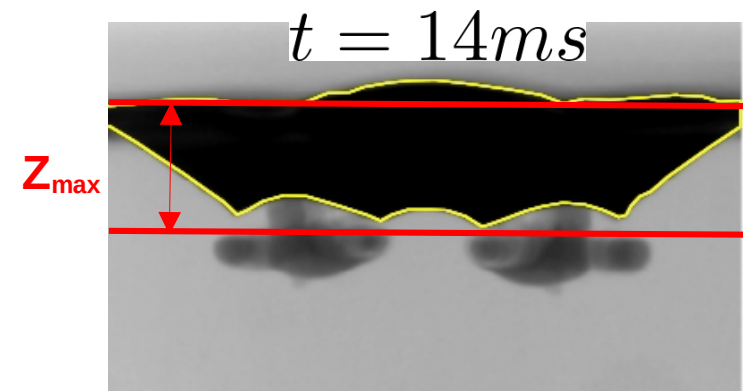
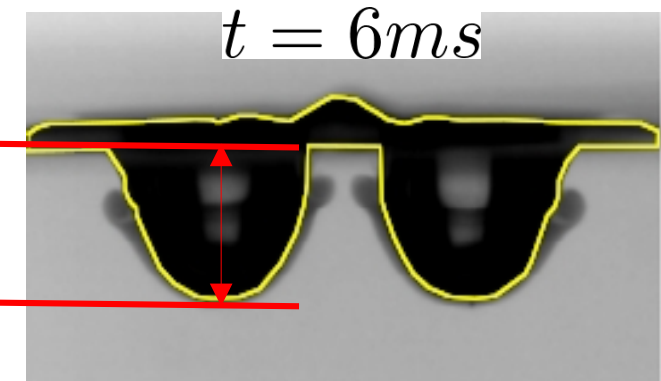
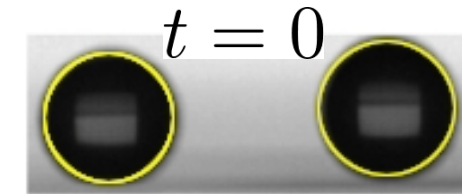
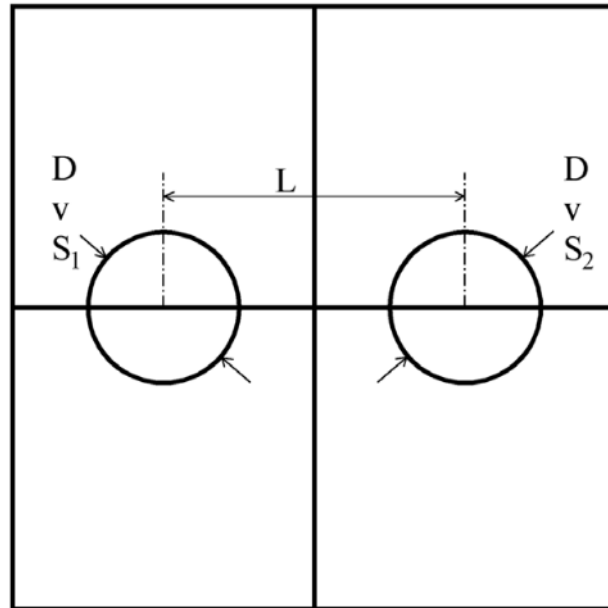
Crown diameter evolution over time : for a resolution of 32 and 64 cells per diameter



III. multi drop impacts : simulation of crater interactions

Numerical configuration and studied regimes [Santini et al]

Case	D_d	V_i	L^*	H^*	We	Fr
A	2.29	1.4	2.0	10	$62.7 \pm 3.1 \%$	$87.2 \pm 4.2 \%$
B	2.32	2.0	2.2	10	$129.5 \pm 2.4 \%$	$175.8 \pm 4.2 \%$

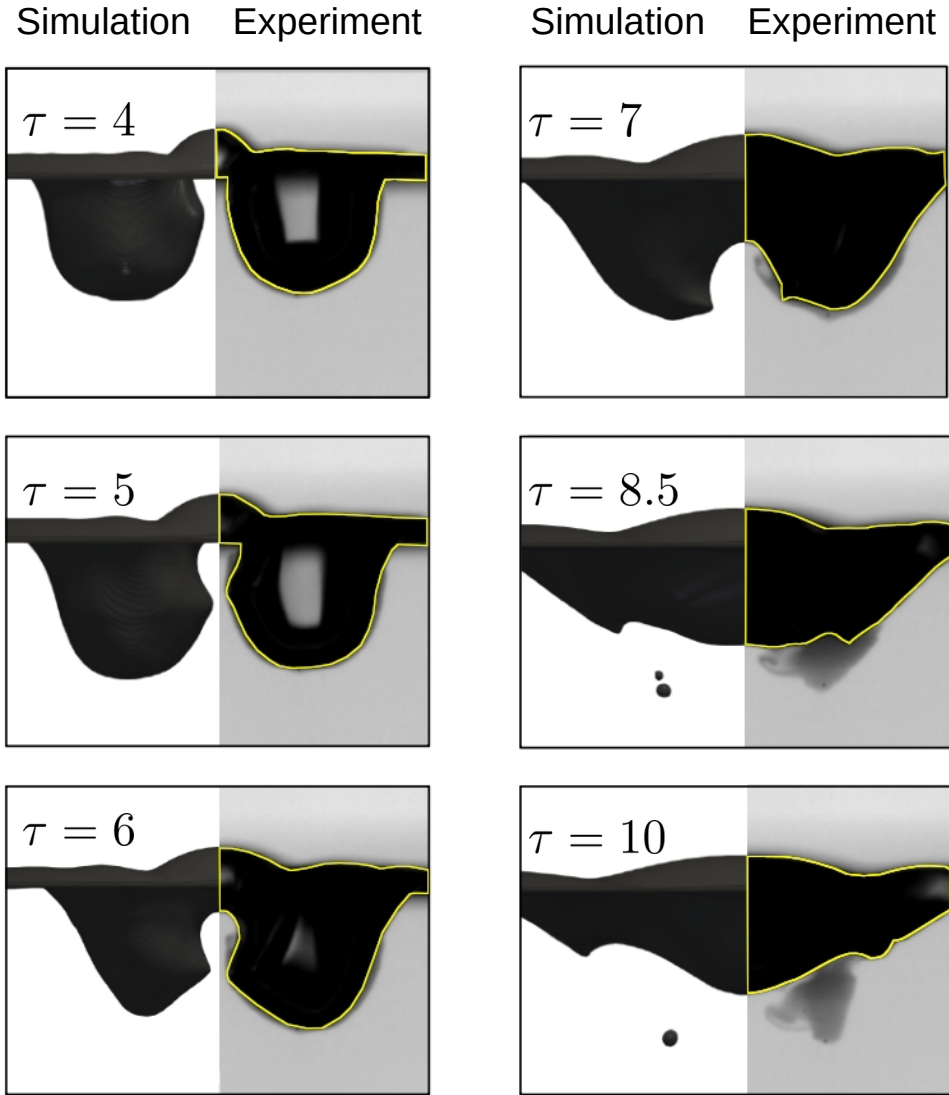


Z_{\max} : is the lowest point of the crater interface under the deep pool surface.

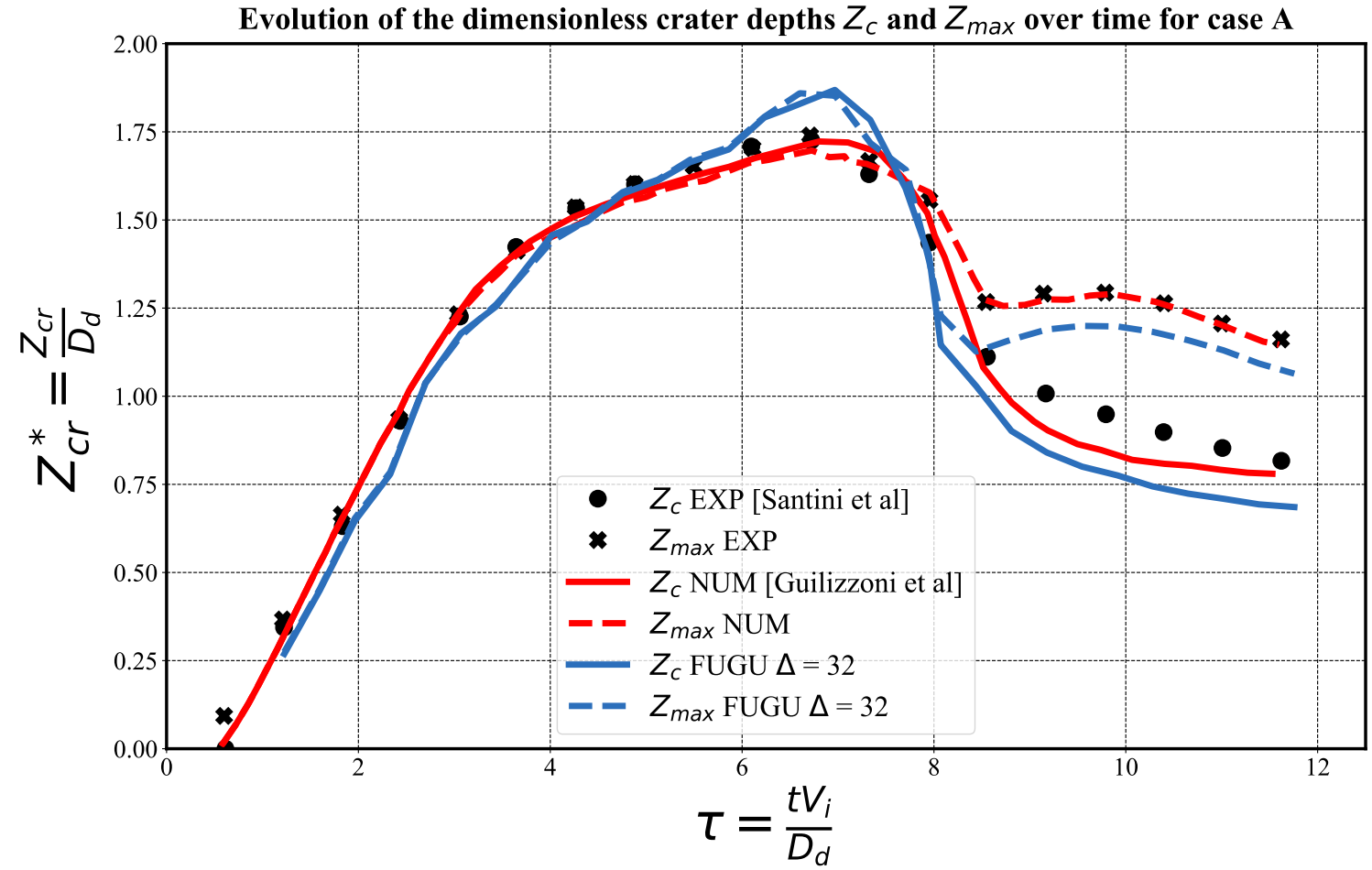
Z_c : is the depth of the crater interface in the transversal plane including the impact point.

III. multi drop impacts : simulation of crater interactions

Merging of the two craters of the CASE A : for a resolution of 32 cells per drop diameter [Santini et al]

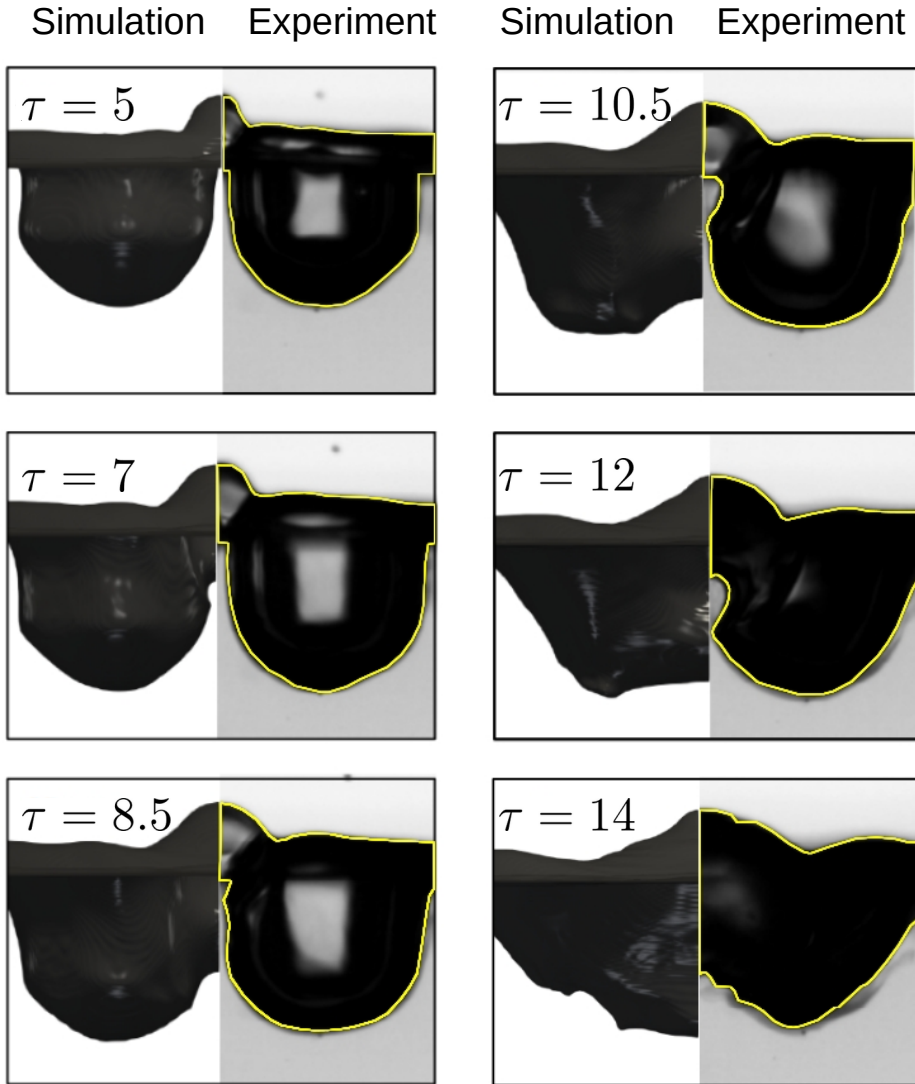


Case	D_d	V_i	L^*	H^*	We	Fr
A	2.29	1.4	2.0	10	$62.7 \pm 3.1 \%$	$87.2 \pm 4.2 \%$
B	2.32	2.0	2.2	10	$129.5 \pm 2.4 \%$	$175.8 \pm 4.2 \%$

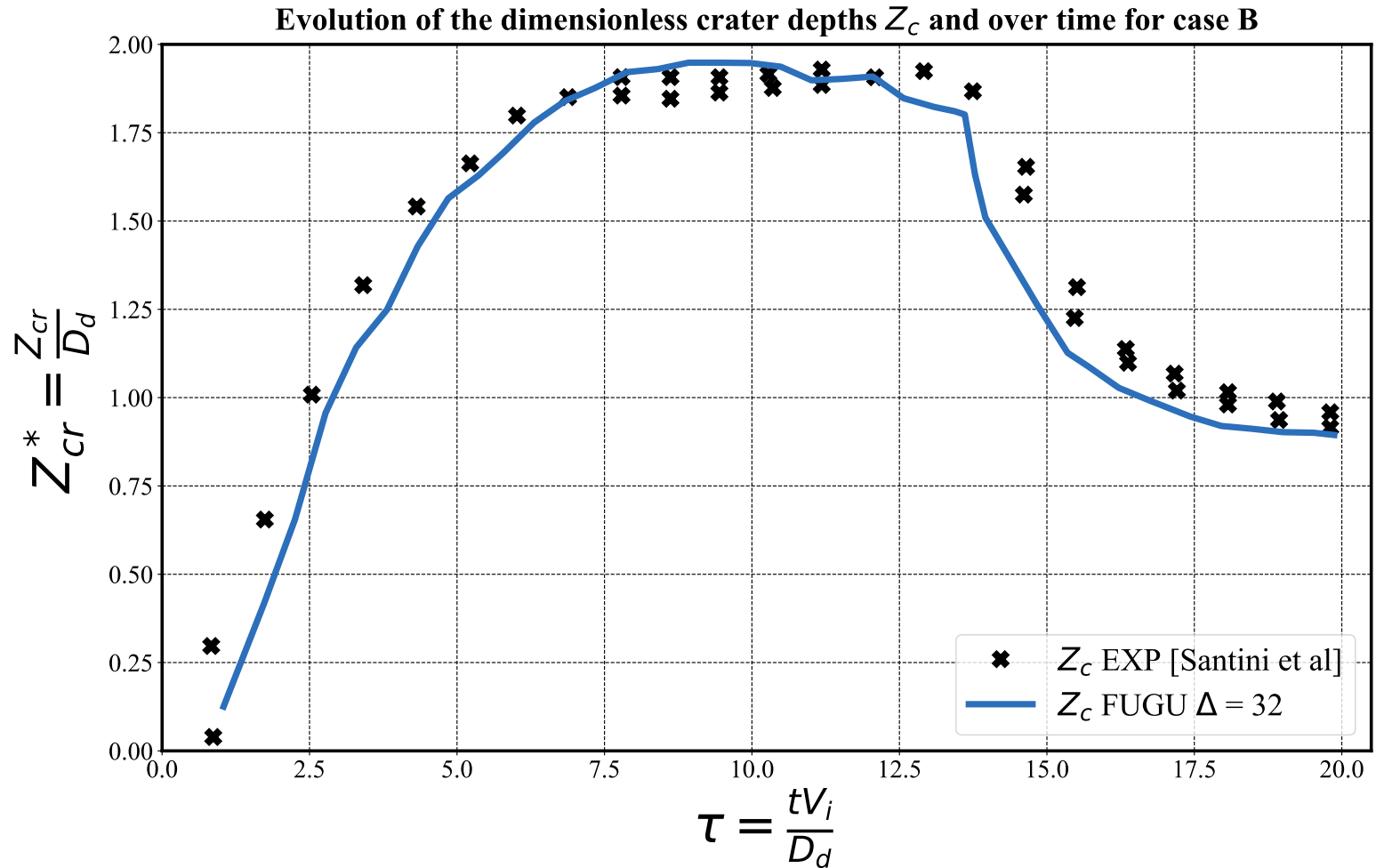


III. multi drop impacts : simulation of crater interactions

Merging of the two craters of the CASE B : for a resolution of 32 cells per drop diameter [Santini et al]



Case	D_d	V_i	L^*	H^*	We	Fr
A	2.29	1.4	2.0	10	$62.7 \pm 3.1 \%$	$87.2 \pm 4.2 \%$
B	2.32	2.0	2.2	10	$129.5 \pm 2.4 \%$	$175.8 \pm 4.2 \%$

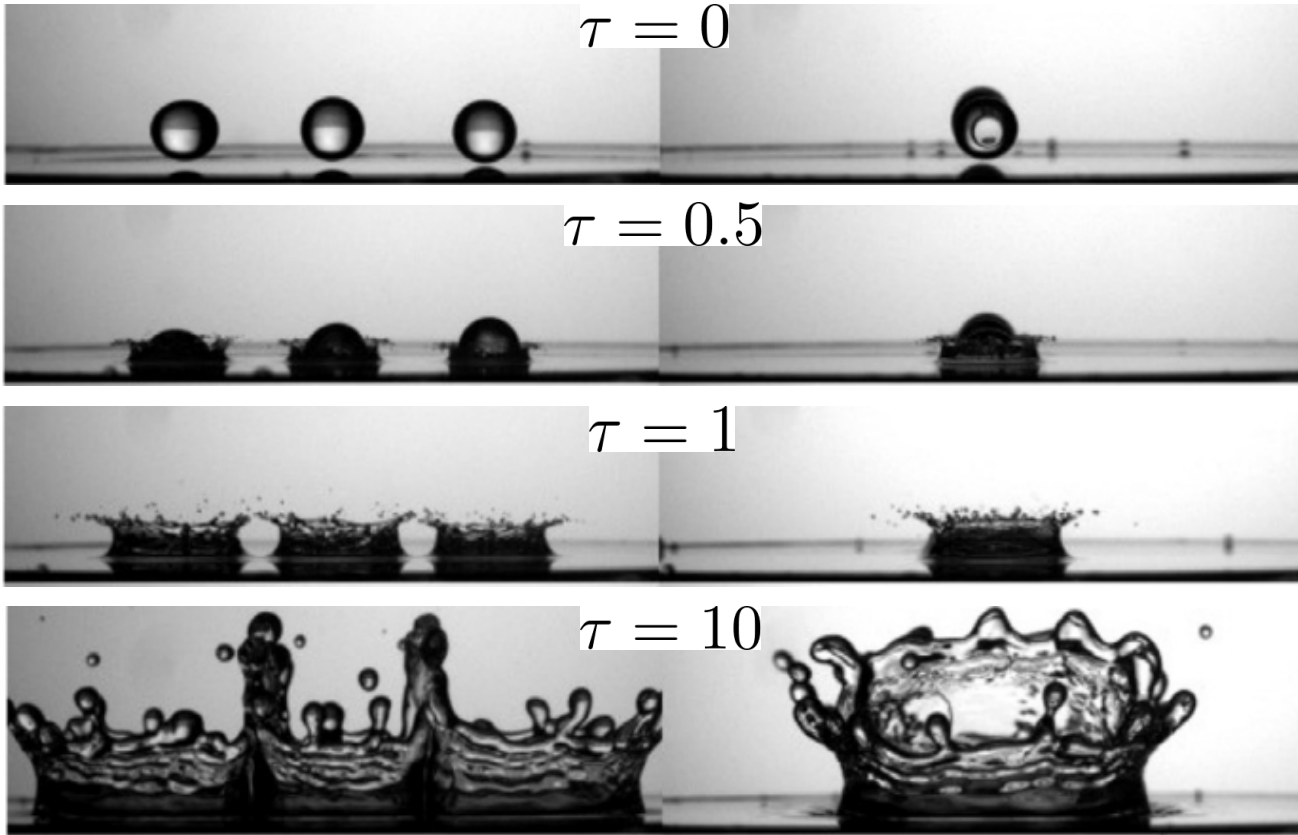


III. multi drop impacts : simulation of crown interactions

Numerical configuration and studied regimes [Cossali et al]

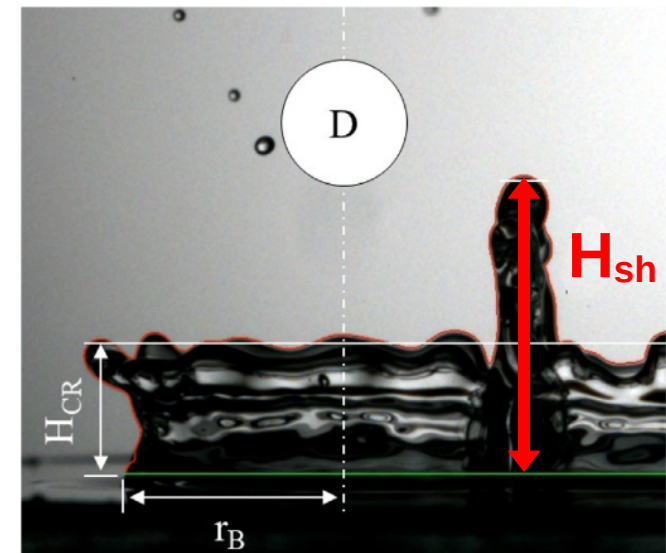
Front view

lateral view



$V_i(m/s)$	$D_d(mm)$	H^*	We	Re	K
3.0	3.1	0.197	382	9 262	4 493

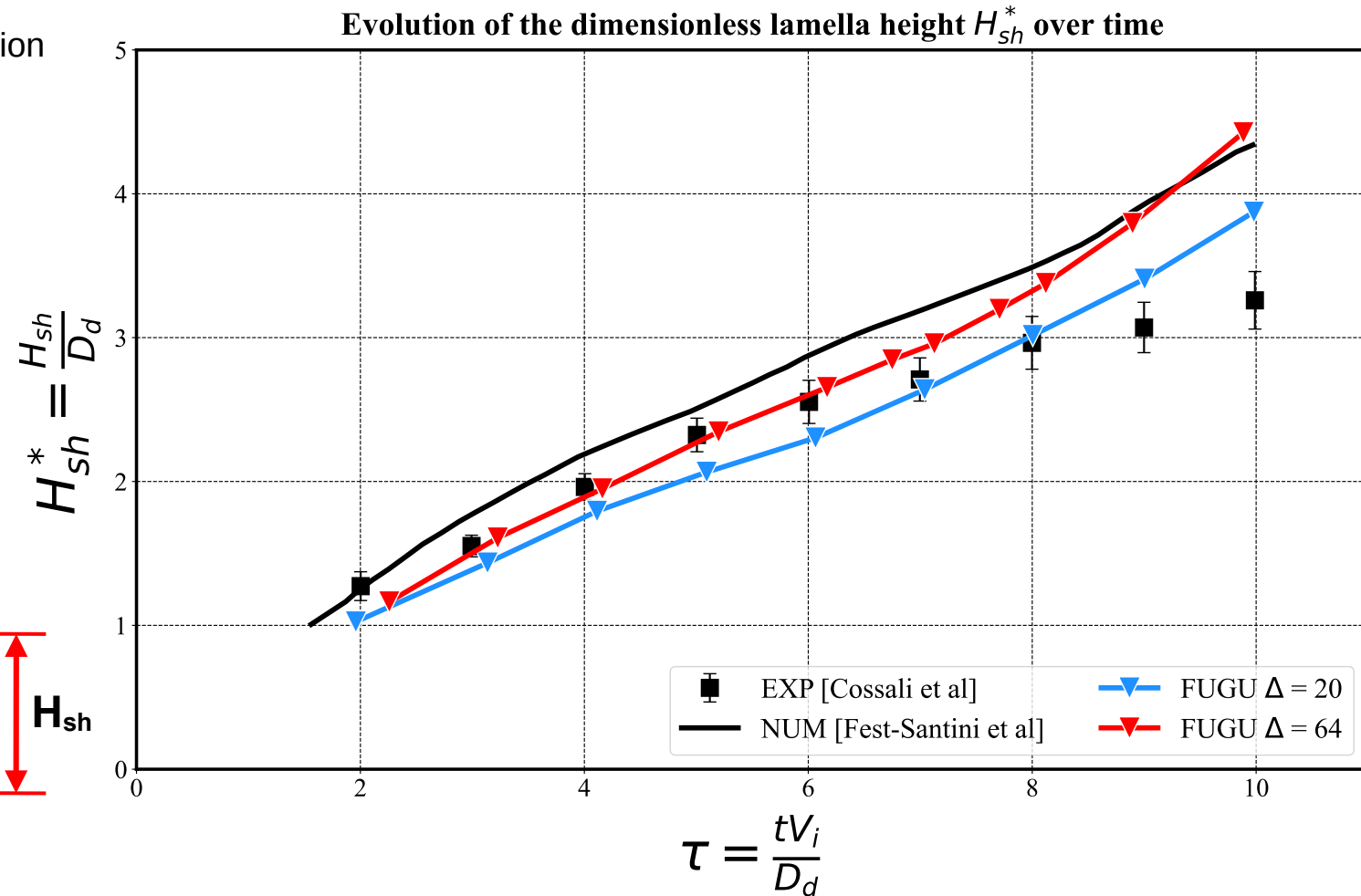
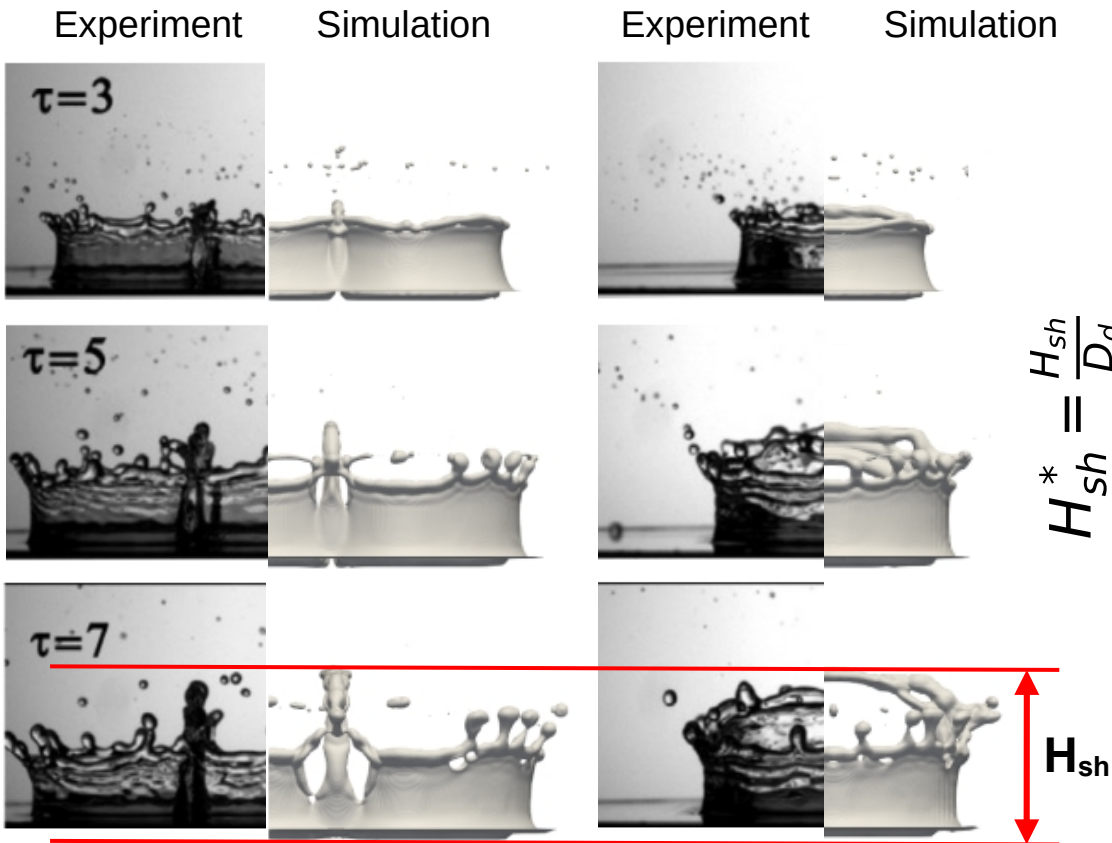
H_{sh} : is the height of the rising lamella induced by the interaction of two crowns



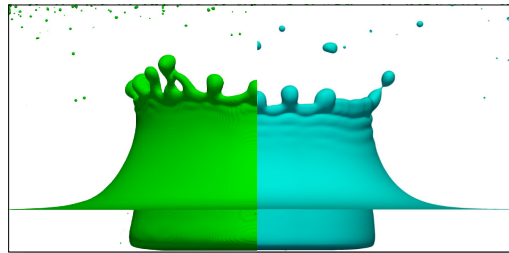
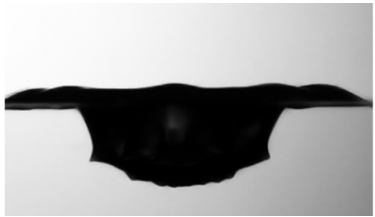
III. multi drop impacts : simulation of crown interactions

Collision of two crowns : formation and growing of a liquid lamella for a resolution of 64 cells per diameter

Case	$V_i(m/s)$	$D_d(mm)$	H^*	We	Fr	Re	Oh	K
A	3.0	3.1	0.197	382	421	9 262	0.0021	4 493

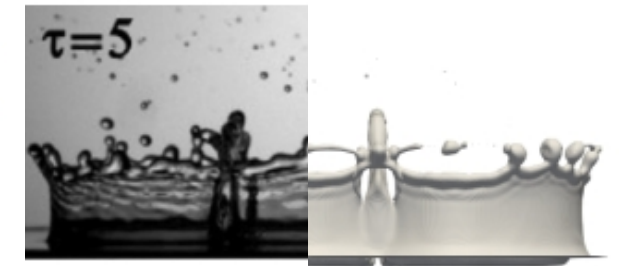
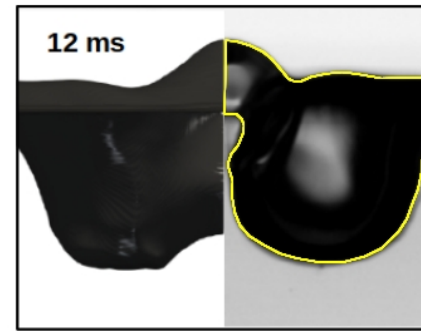


Working cases



- Study bubble entrapment under the crater
- Study crown instabilities (influence the crown ejections)

Cases that require numerical improvement



- Try different numerical methods for surface tension and interface capturing
- Use mesh refinement approaches for the smallest scales (dual grids)

Questions ?

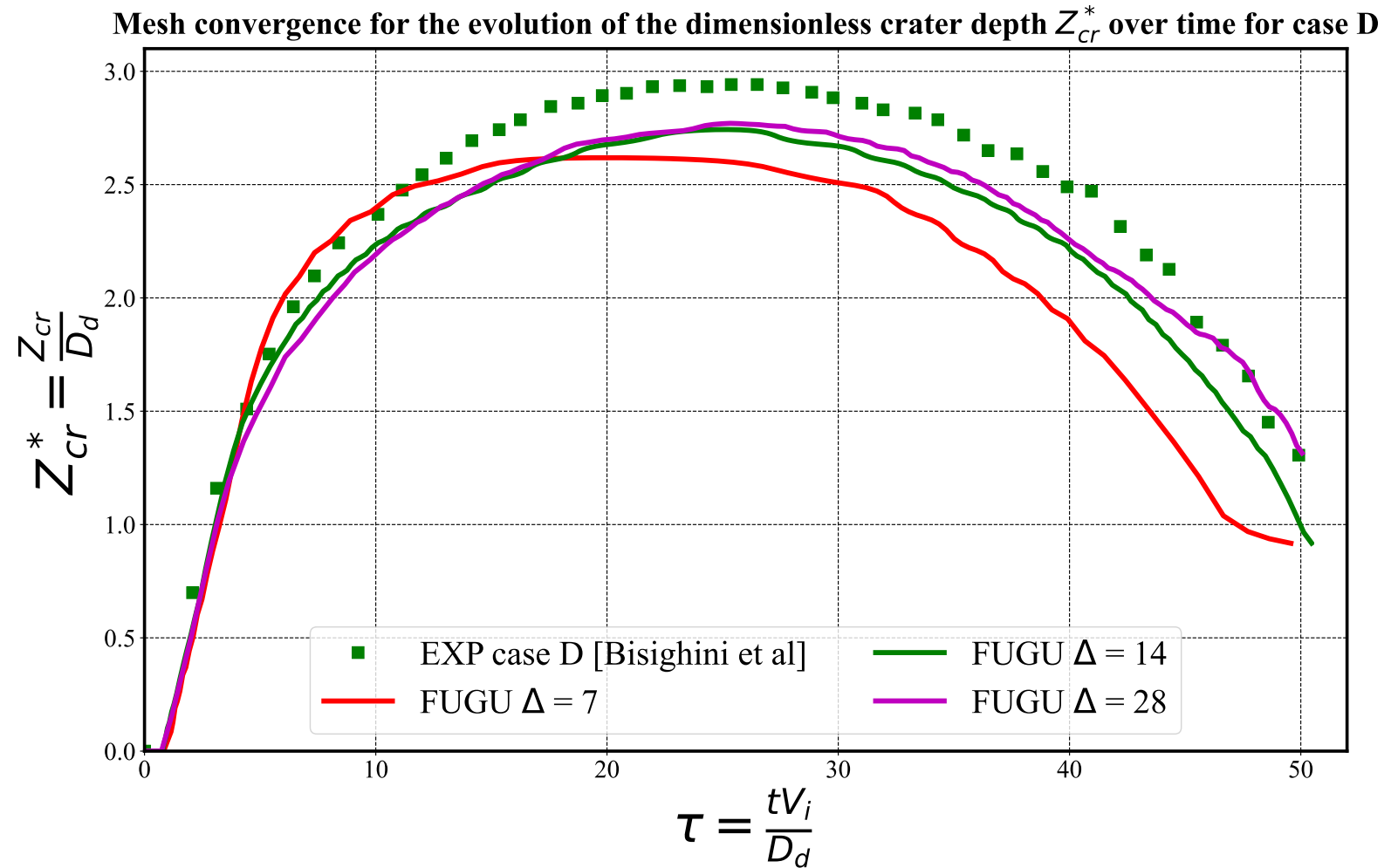
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I. Single drop impacts : simulation of the crater dynamics

Mesh convergence for case D : using a resolution Δ of 7, 14 and 28 cells per drop diameter D_d

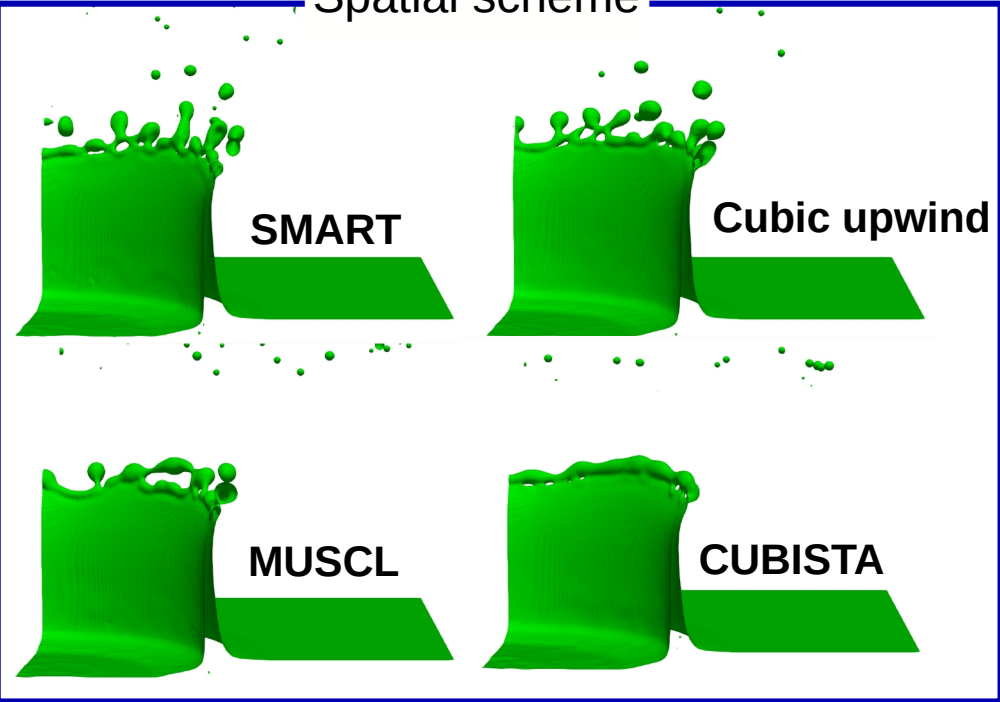
Case	$V_i(m/s)$	$D_d(mm)$	H^*	We	Re
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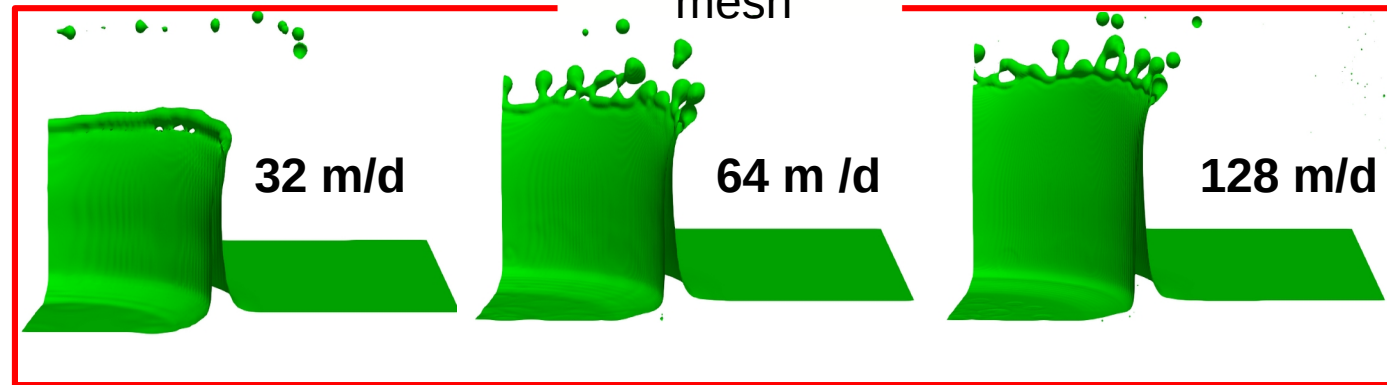
Parametric study of the crown ejection

$We = 699$, $Oh = 0,01039$, $D = 3,03$ mm, $h = 0,198 D$. $V = 3$ m/s

Spatial scheme

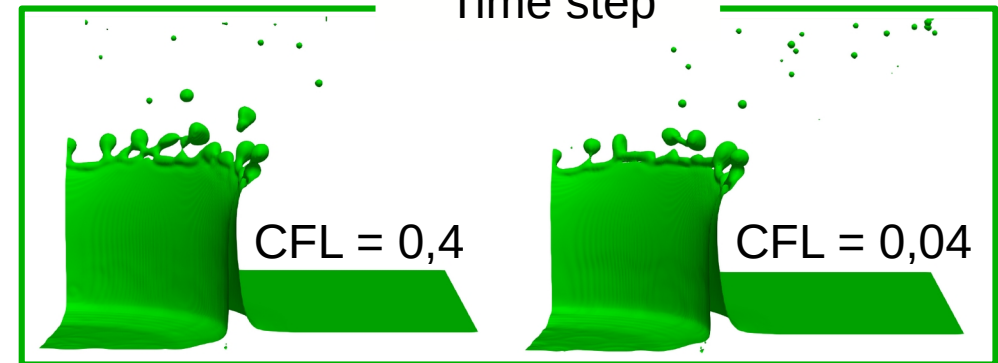


mesh



$t = 2,8$ ms
Resolution : 64 m/d

Time step



Surface tension

