11 février 2021 - Séminaire CALISTO

Corolles d'impact sur fluide visqueux

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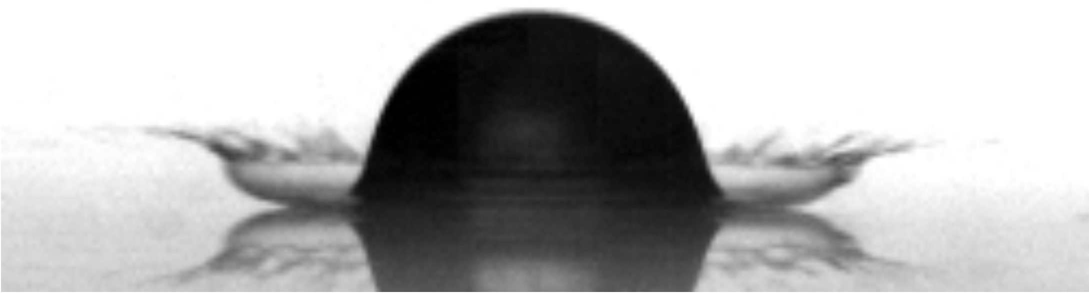
et Christophe Josserand (LadHyx, Ecole Polytechnique, Palaiseau)

Splashes & corolles d'impact

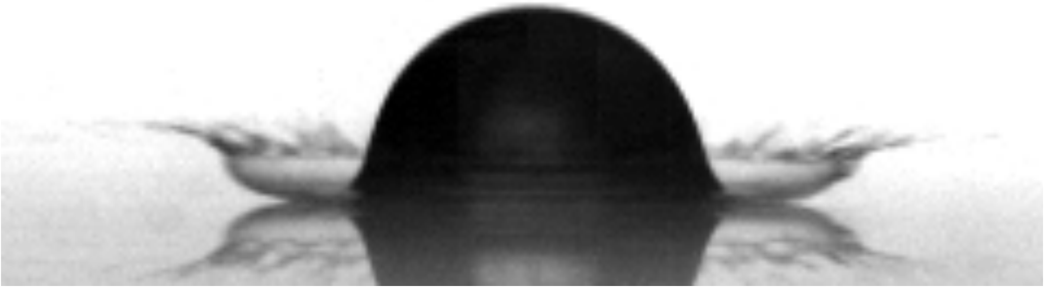


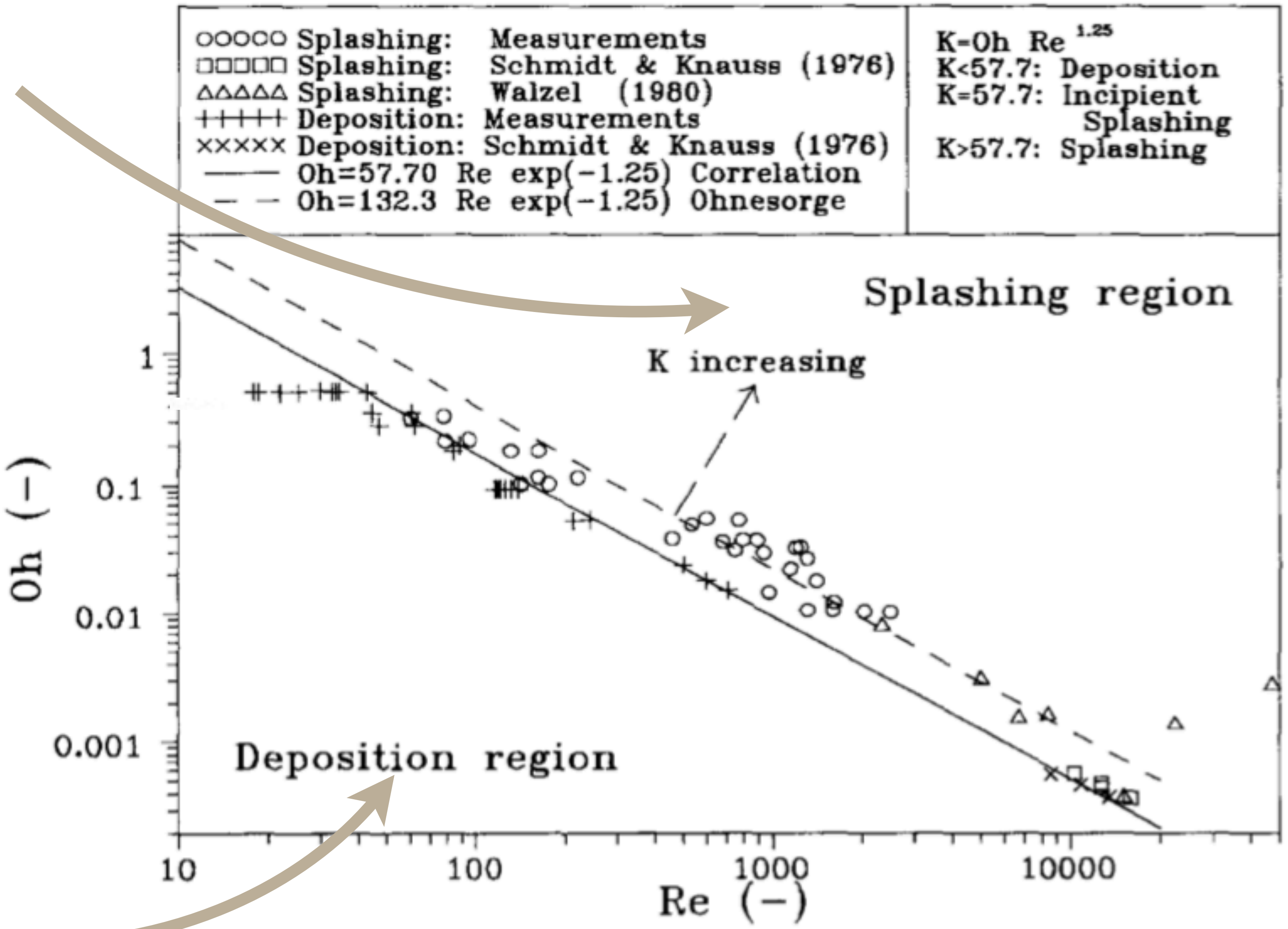
$$We = \frac{\rho U^2 L}{\gamma} \qquad Re = \frac{\rho U L}{\mu}$$

(applications en combustion, hydromorphologie, imprimerie, agronomie, santé...)

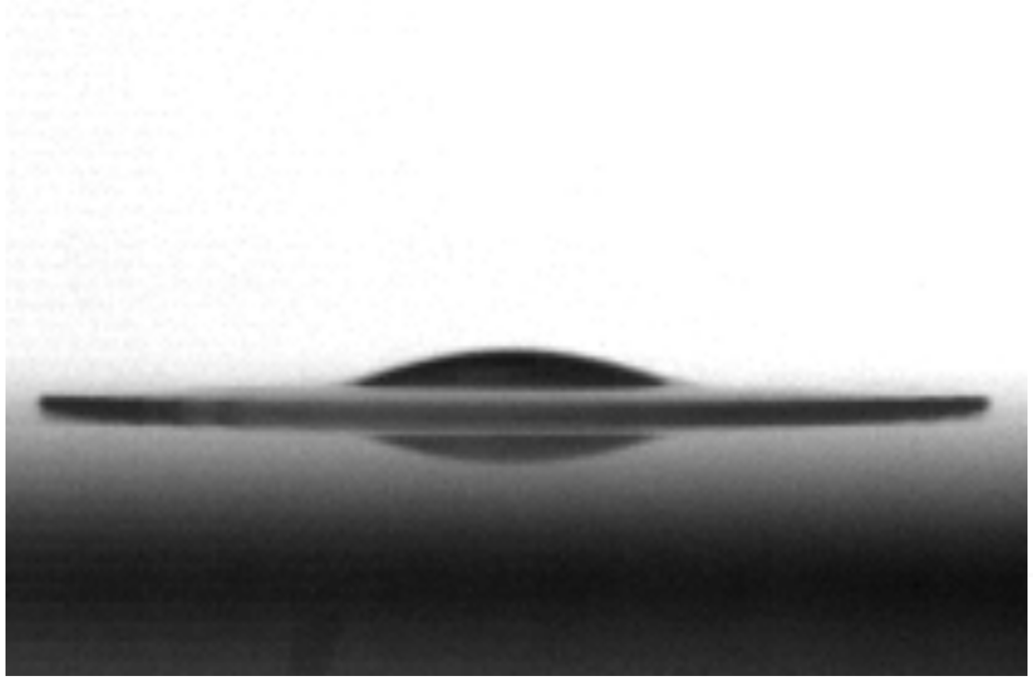
Splashes & corolles d'impact

$$We = \frac{\rho U^2 L}{\gamma} \qquad Re = \frac{\rho U L}{\mu}$$





Mundo, Sommerfeld, Tropea (1995)

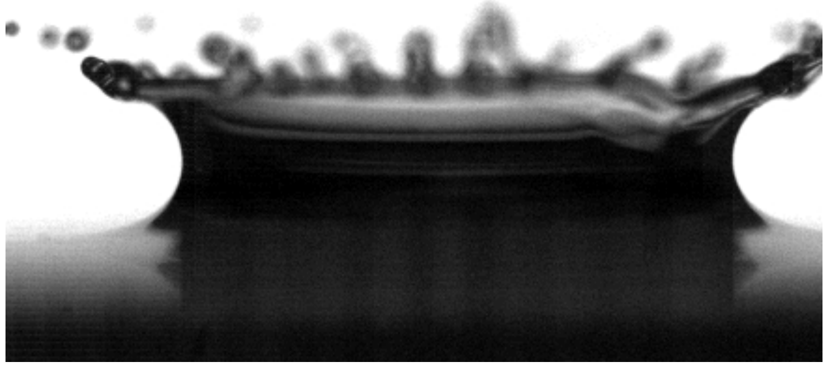


'splashing number' : $K = We^{1/2} Re^{1/4} > K_c$

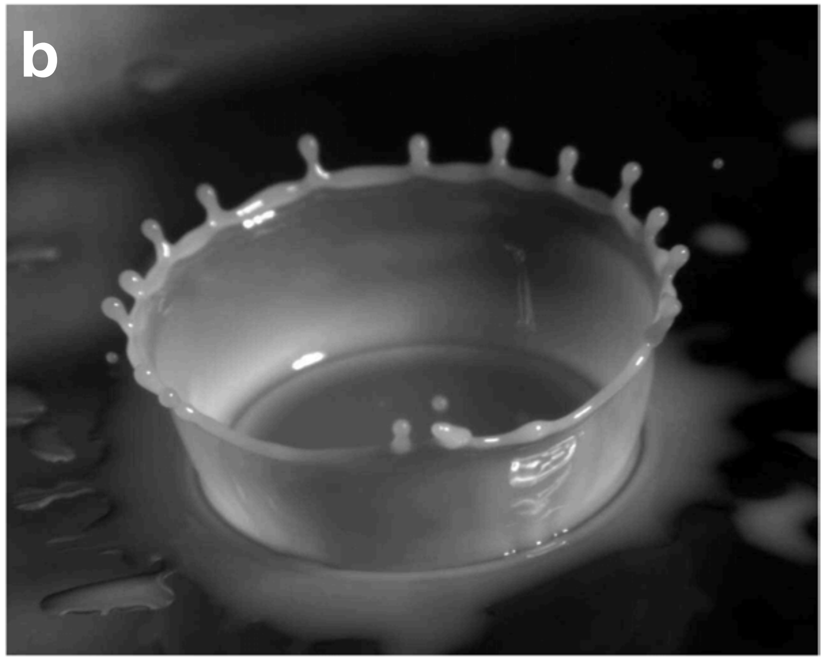
(applications en combustion, hydromorphologie, imprimerie, agronomie, santé…)

Splashes & corolles d'impact

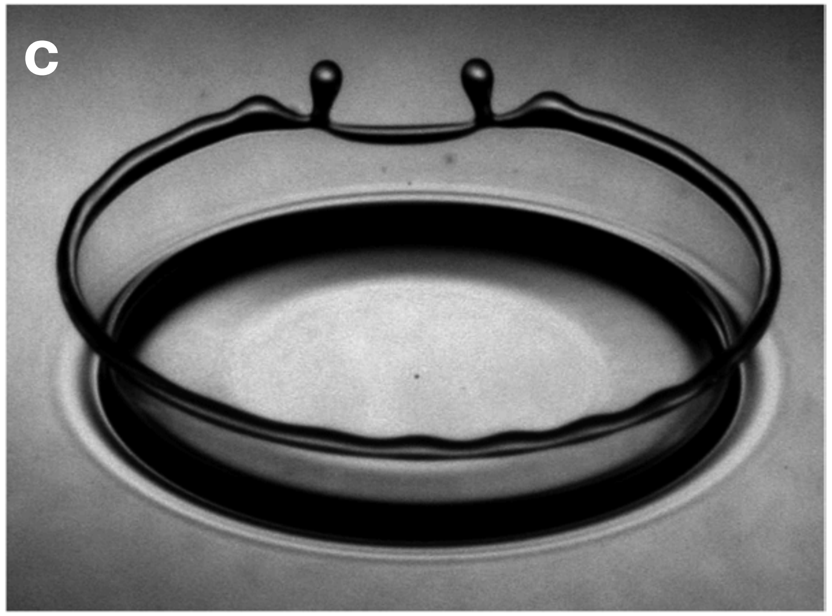
a



b



c



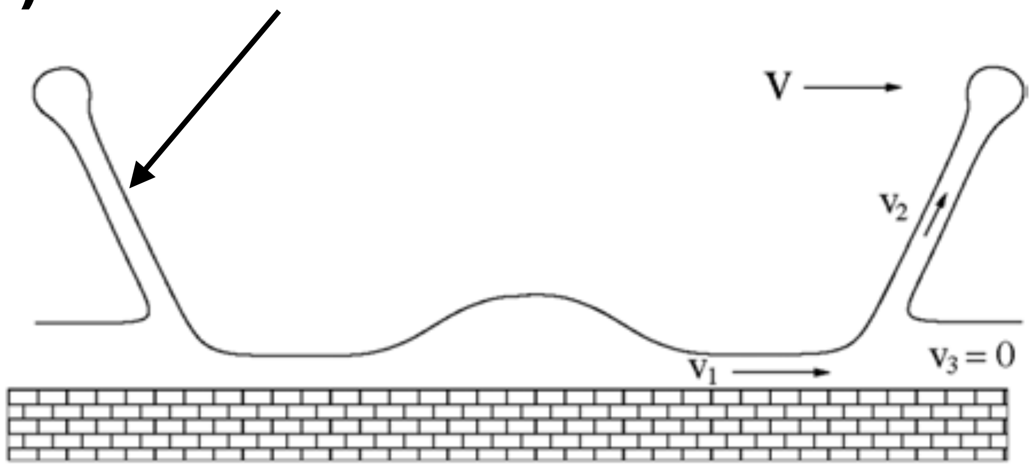
'crown' ou **'corona'** splash

digitation + pincement (pinch-off)

(instabilités de Rayleigh-Taylor/Plateau-Rayleigh-Savart)

nappe de Peregrine

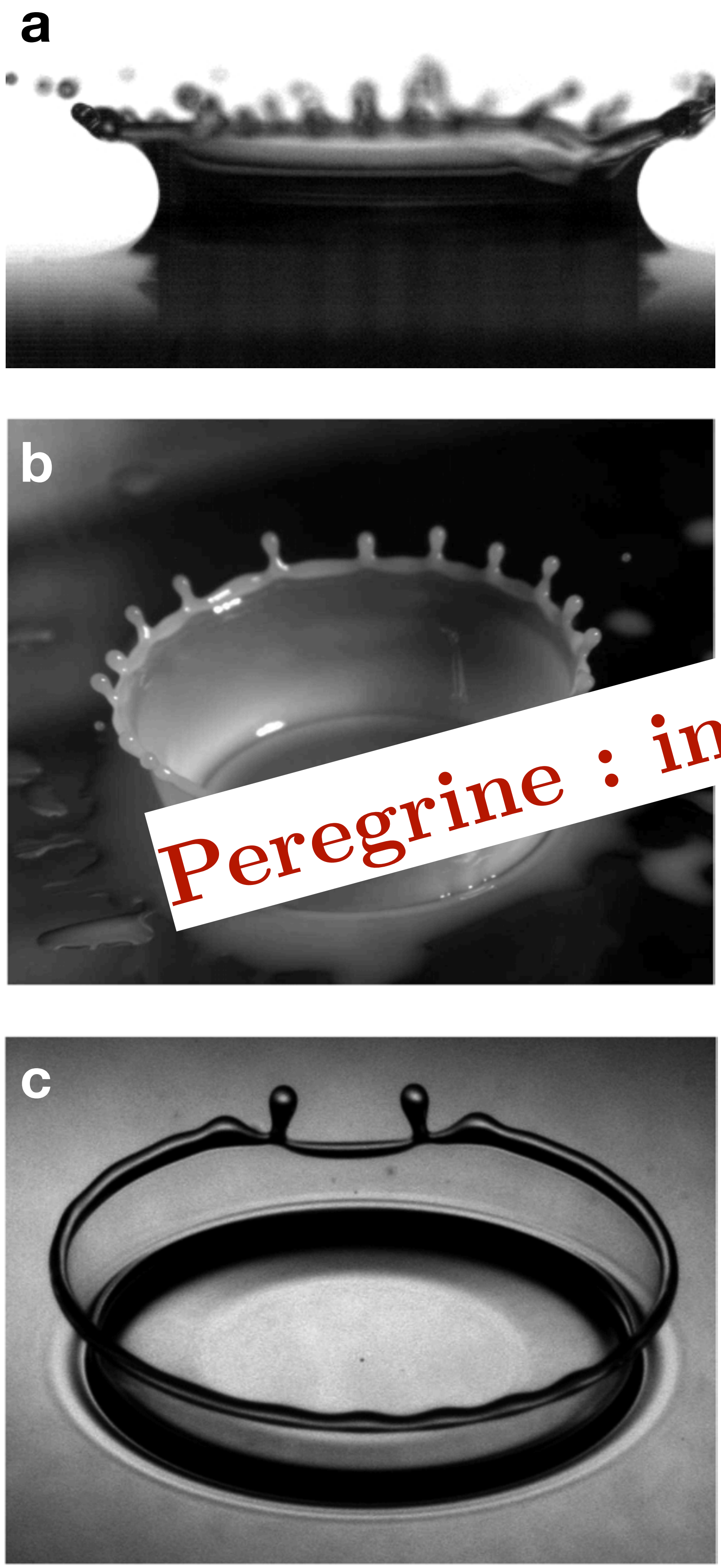
d)



Peregrine (1981)

(b) (c) (d) : Deegan, Brunet & Eggers (2008)

Splashes & corolles d'impact



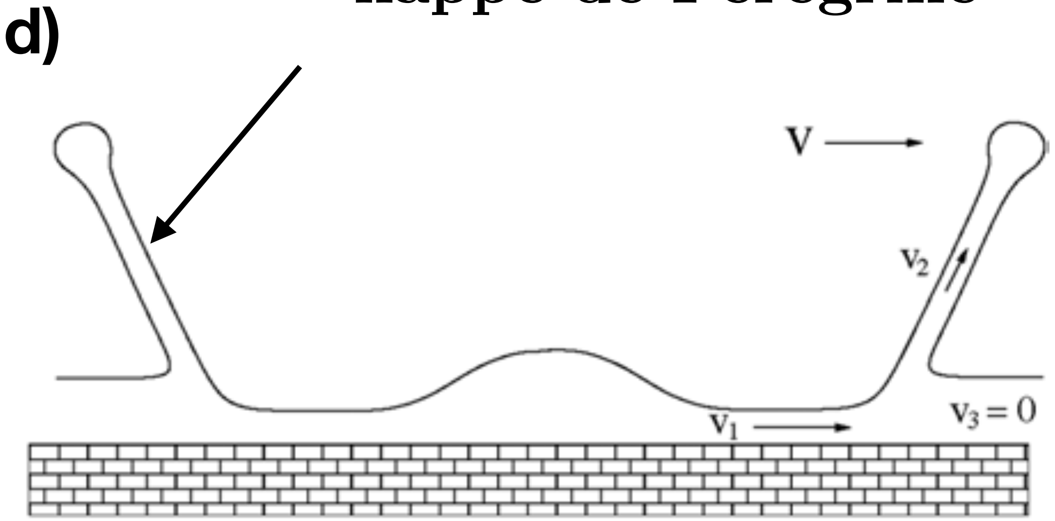
'crown' ou **'corona'** splash

digitation + pincement

(instabilités de Ray … au-Rayleigh-Savart)

Peregrine : impacts sur liquide uniquement !

nappe de Peregrine

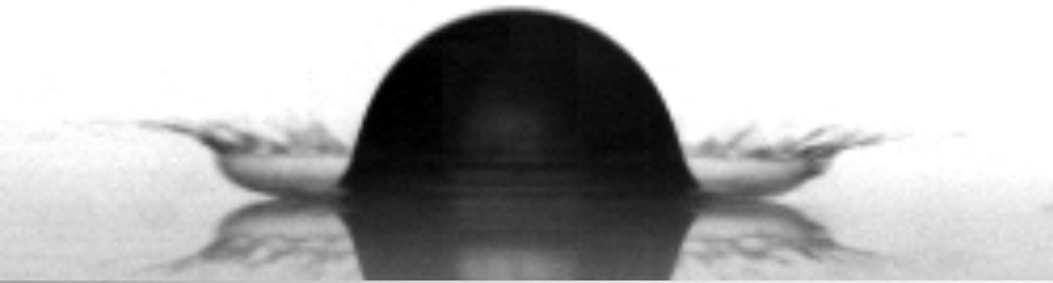


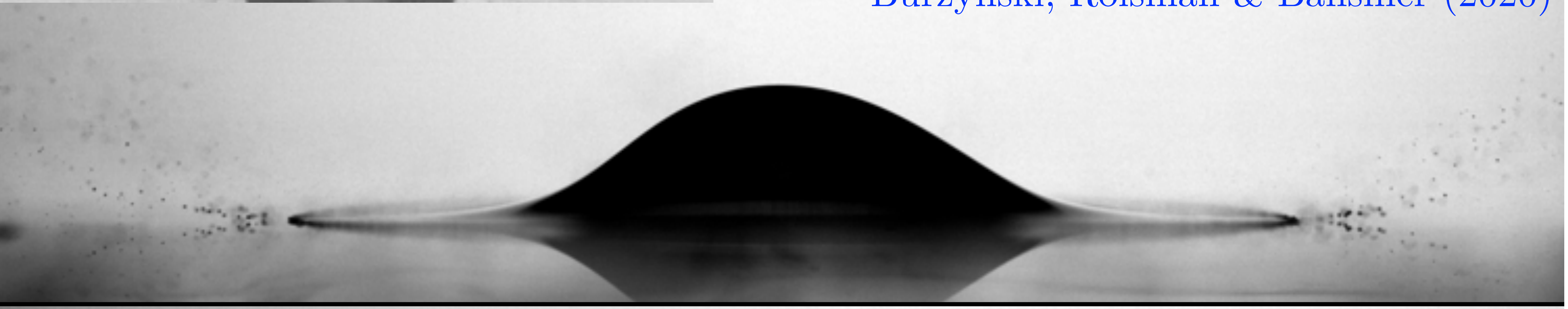
Peregrine (1981)

(b) (c) (d) : Deegan, Brunet & Eggers (2008)

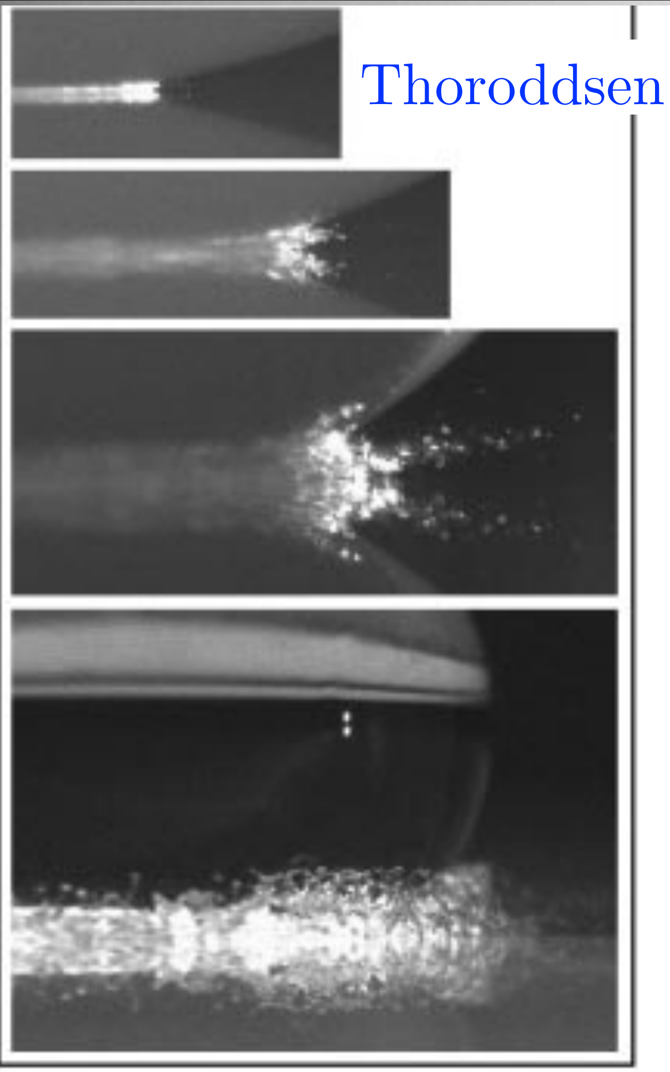
Splashes & corolles d'impact

'ejecta' sheet / **'prompt'** splash

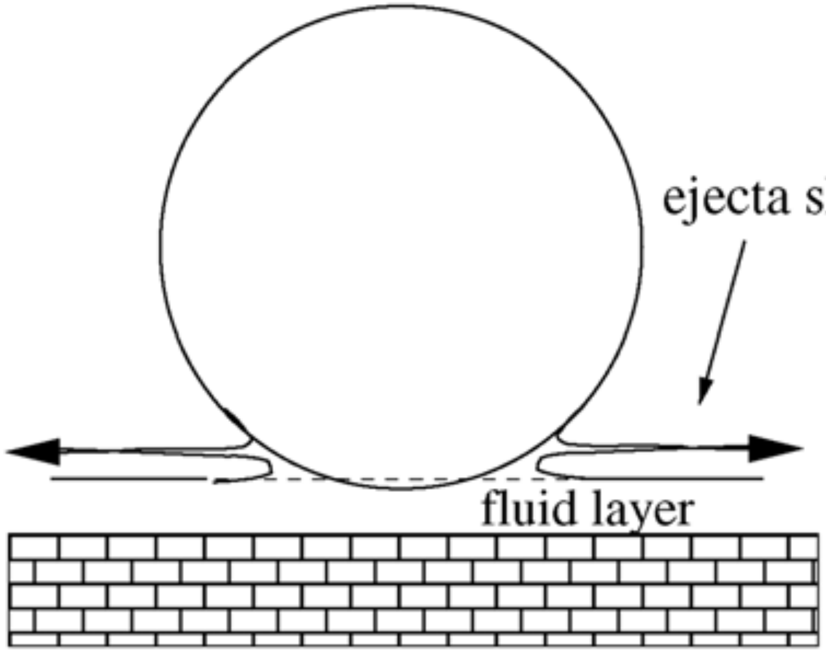




Burzynski, Roisman & Bansmer (2020)



Thoroddsen (2002)



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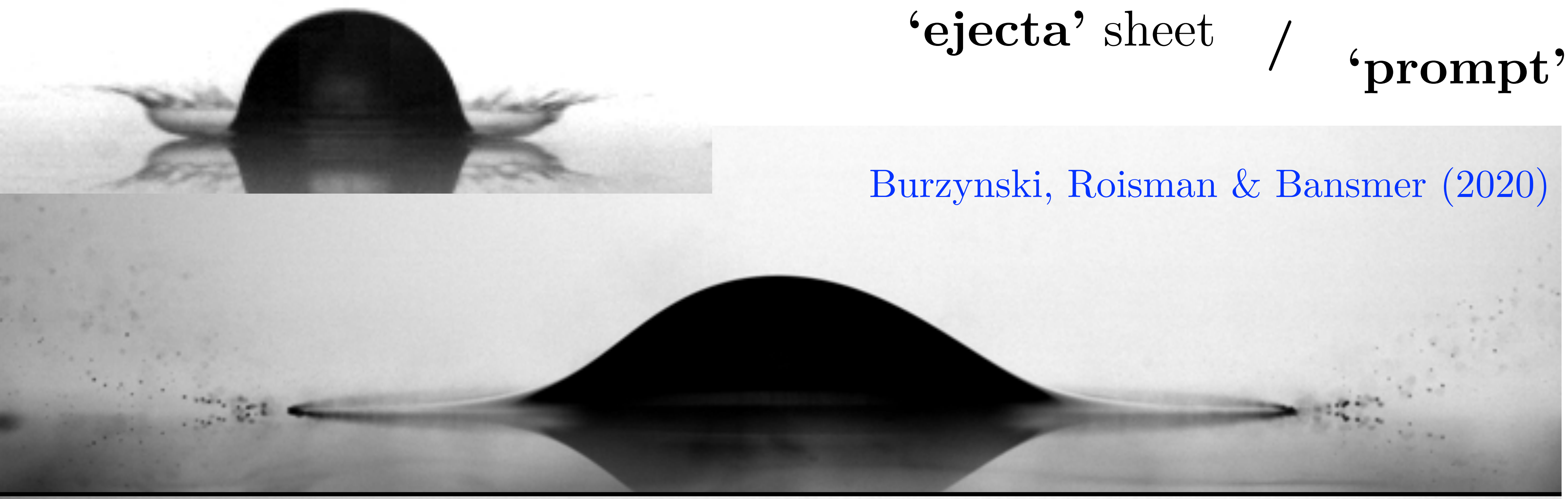
Splashes & corolles d’impact

‘ejecta’ sheet / **‘prompt’** splash



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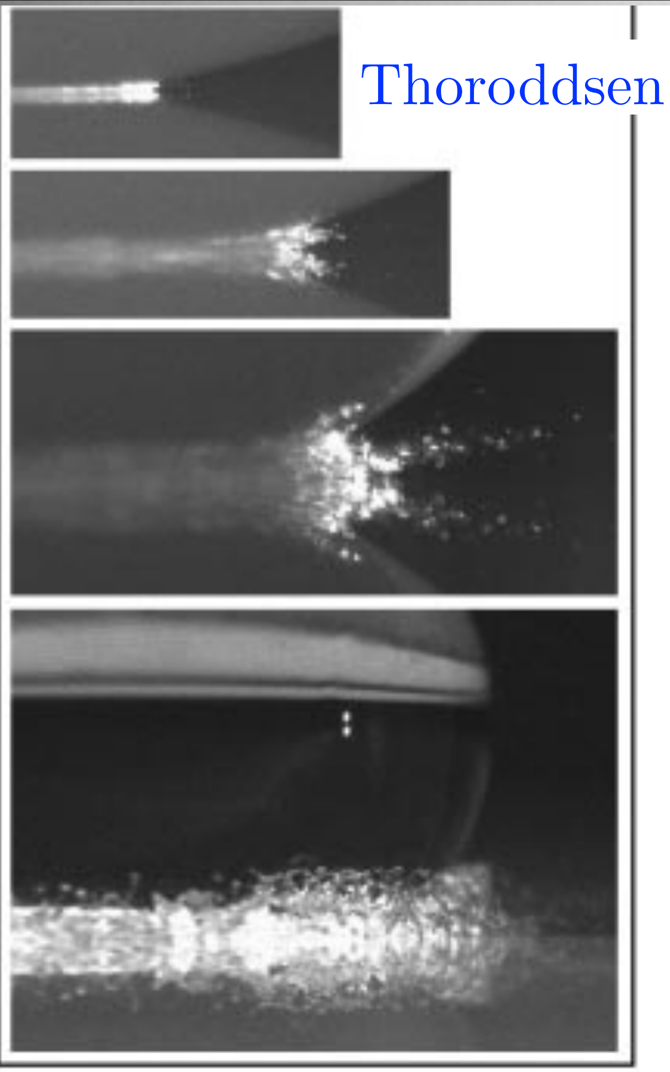

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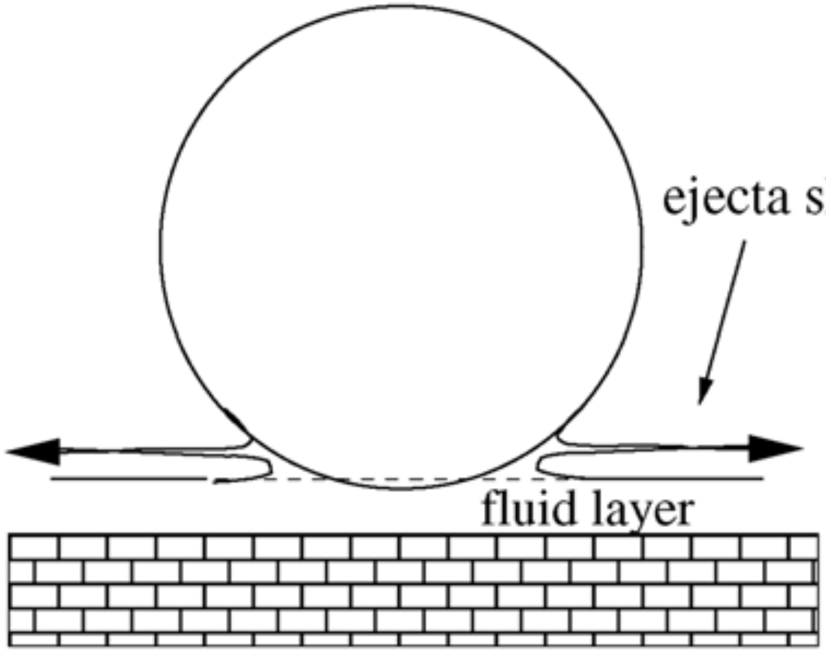


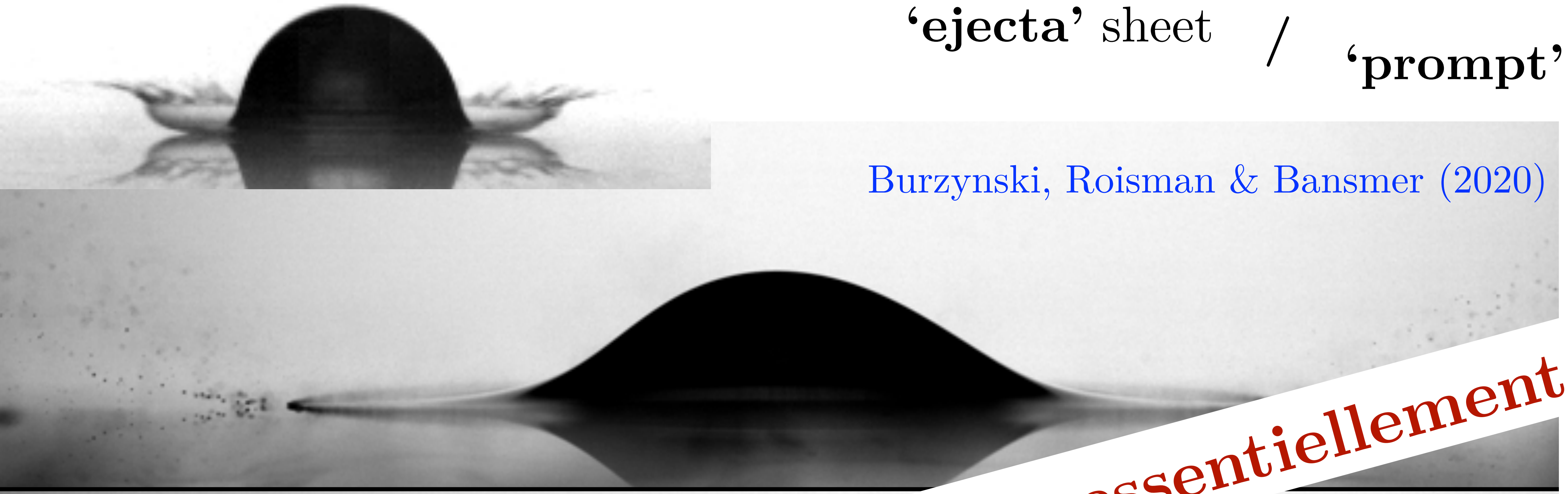
Deegan, Brunet & Eggers (2008)

Corolle d’ejecta sensible à la pression de l’air !

Xu, Zhang & Nagel (2005)

Splashes & corolles d'impact

'ejecta' sheet / **'prompt'** splash



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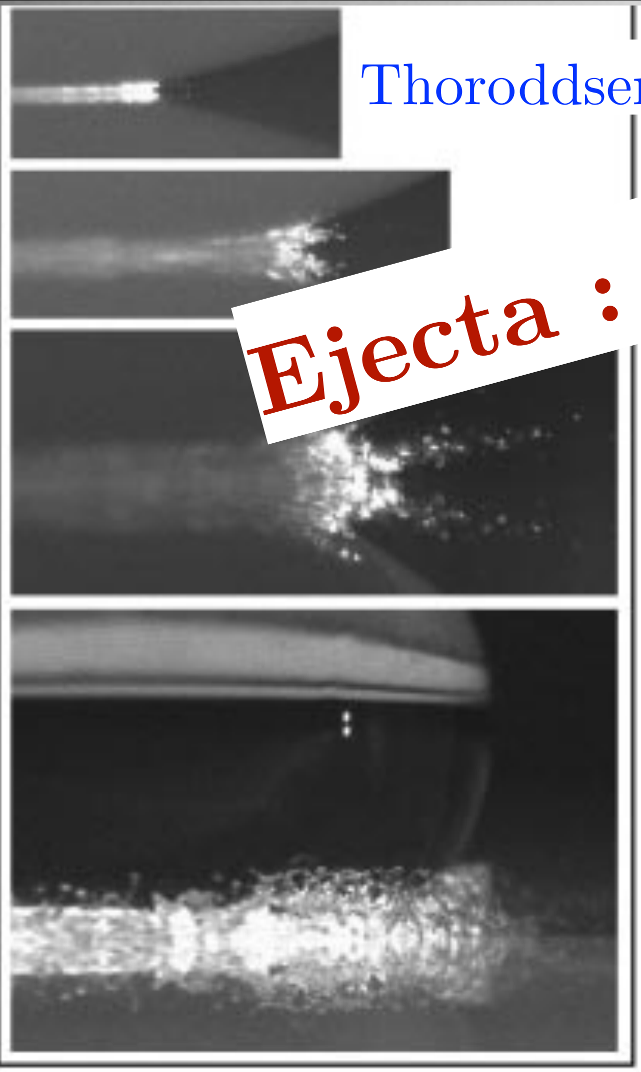
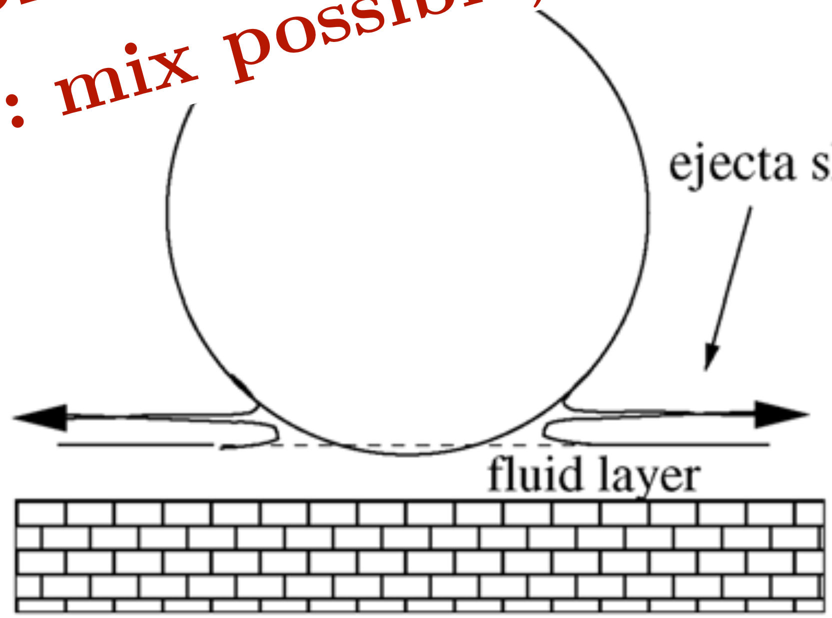


Thoroddsen (2002)

Ejecta : impacts sur solides essentiellement !

(films minces : mix possible)



Deegan, Brunet & Eggers (2008)

Corolle d'ejecta sensible à la pression de l'air !

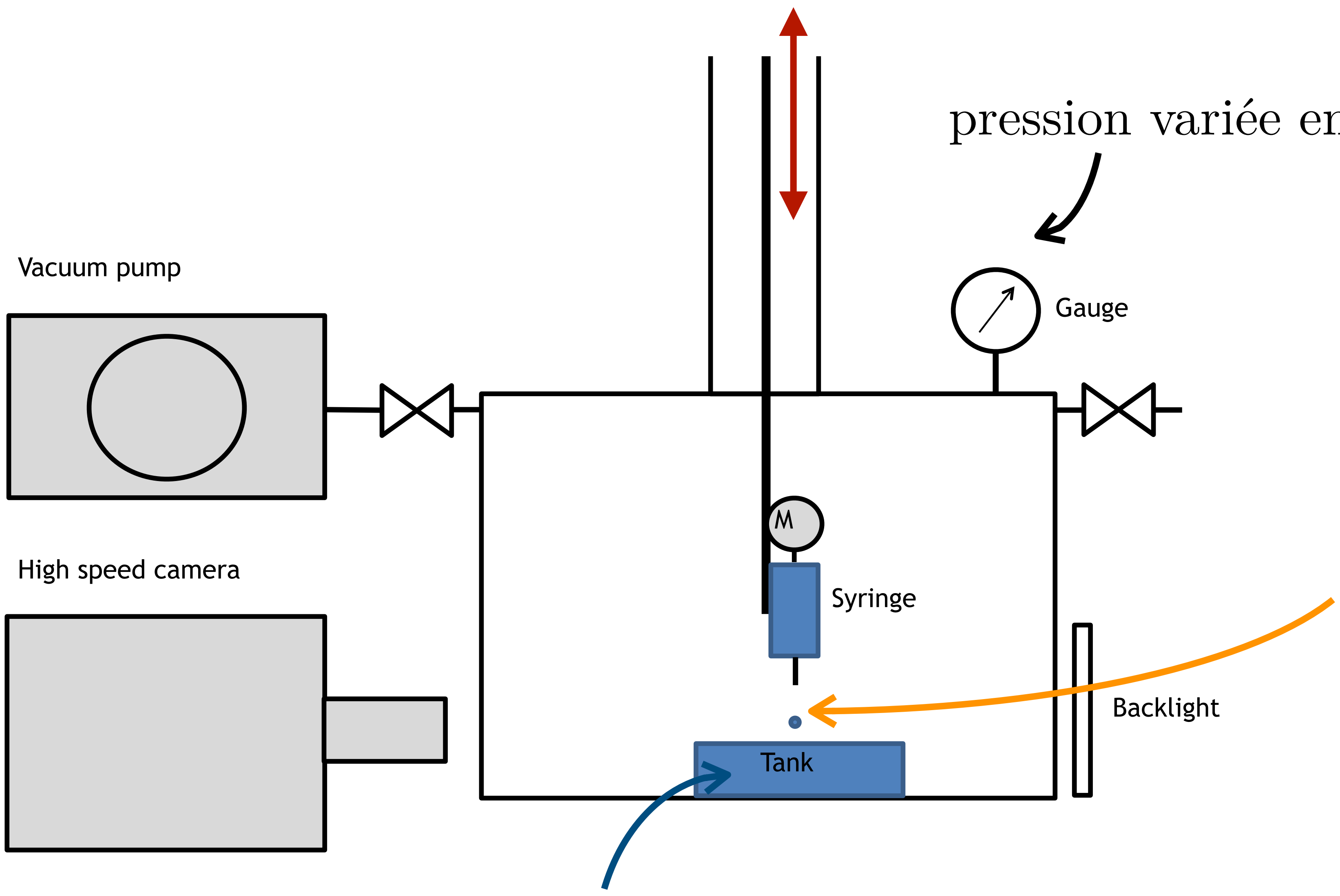
Xu, Zhang & Nagel (2005)

Splashes & corolles d'impact

D'où vient le fluide éjecté ? Substrat ou projectile ?

Credit image : Wim van Hoeve, Université de Twente.

Montage



pression variée entre Patm et 0.25 Patm

goutte d'éthanol, (D, U_0)

viscosité μ_e

densité ρ_e

tension de surface γ_e

solution eau + glycérol

viscosité μ_p : $\mu_w \leq \mu_p \leq \mu_o$

$$Re = \frac{\rho_e U_0 D}{\mu_e} = 5840$$

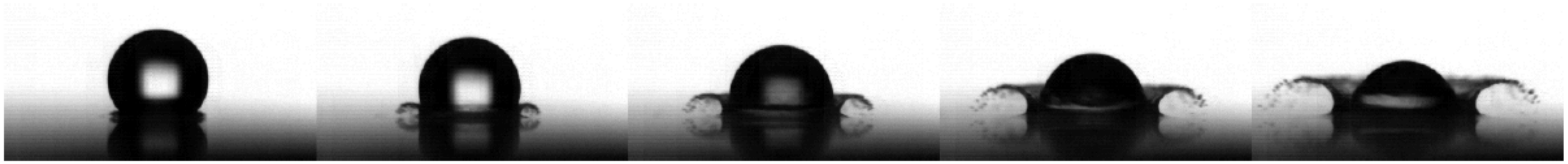
$$We = \frac{\rho_e U_0^2 D}{\gamma_e} = 1080$$

$$0.83 \leq \boxed{\beta = \mu_p/\mu_e} \leq 1000$$

Résultats expérimentaux

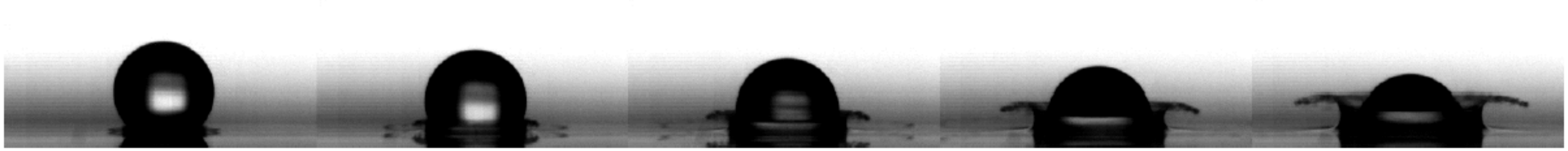
$$\boxed{\beta = 0.95}$$

Viscosité =1.14 mPa.s – Pression atmosphérique (p atm)



Ti + 3/50000 s Ti + 6/50000 s Ti + 9/50000 s Ti + 12/50000 s Ti + 15/50000 s

Viscosité = 1.14 mPa.s – Pression = p atm – 753 mbar



Ti + 3/50000 s Ti + 6/50000 s Ti + 9/50000 s Ti + 12/50000 s Ti + 15/50000 s

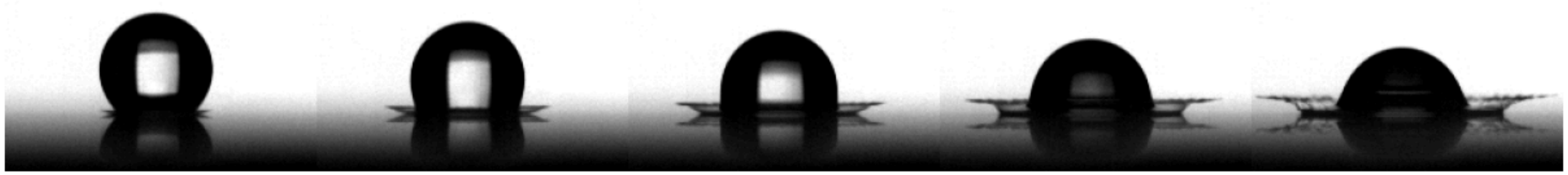
↔

60 microsecondes

Résultats expérimentaux

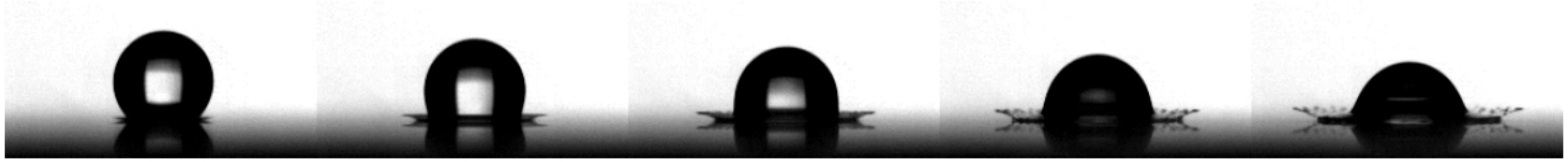
$$\boxed{\beta = 812}$$

Viscosité = 545 mPa.s – Pression atmosphérique (p atm)



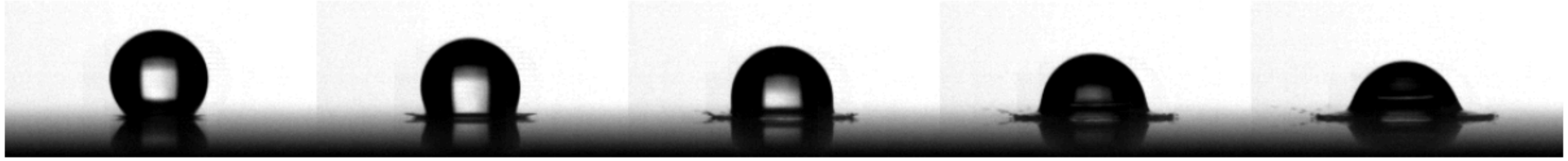
Ti + 3/50000 s
Ti + 6/50000 s
Ti + 9/50000 s
Ti + 12/50000 s
Ti + 15/50000 s

Viscosité = 545 mPa.s – Pression = p atm – 456 mbar



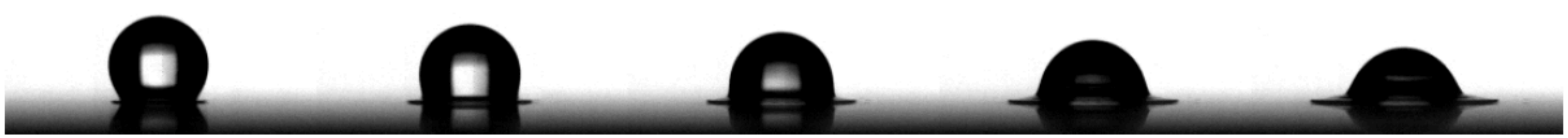
Ti + 3/50000 s
Ti + 6/50000 s
Ti + 9/50000 s
Ti + 12/50000 s
Ti + 15/50000 s

Viscosité = 545 mPa.s – Pression = p atm – 602 mbar



Ti + 3/50000 s
Ti + 6/50000 s
Ti + 9/50000 s
Ti + 12/50000 s
Ti + 15/50000 s

Viscosité = 545 mPa.s – Pression = p atm – 752 mbar

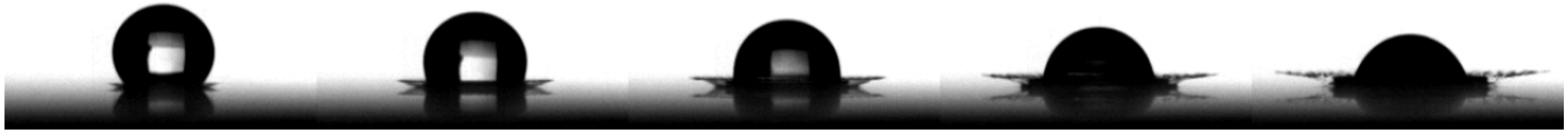


Ti + 3/50000 s
Ti + 6/50000 s
Ti + 9/50000 s
Ti + 12/50000 s
Ti + 15/50000 s

Résultats expérimentaux

$$\boxed{\beta = 94}$$

Viscosité = 112.9 mPa.s – Pression atmosphérique (p atm)

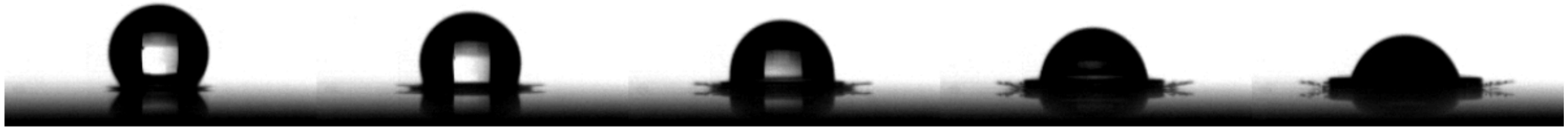


Ti + 3/50000 s Ti + 6/50000 s Ti + 9/50000 s Ti + 12/50000 s Ti + 15/50000 s

Viscosité = 112.9 mPa.s – Pression = p atm – 452 mbar

Ti + 3/50000 s Ti + 6/50000 s Ti + 9/50000 s Ti + 12/50000 s Ti + 15/50000 s

Viscosité = 112.9 mPa.s – Pression = p atm – 602 mbar



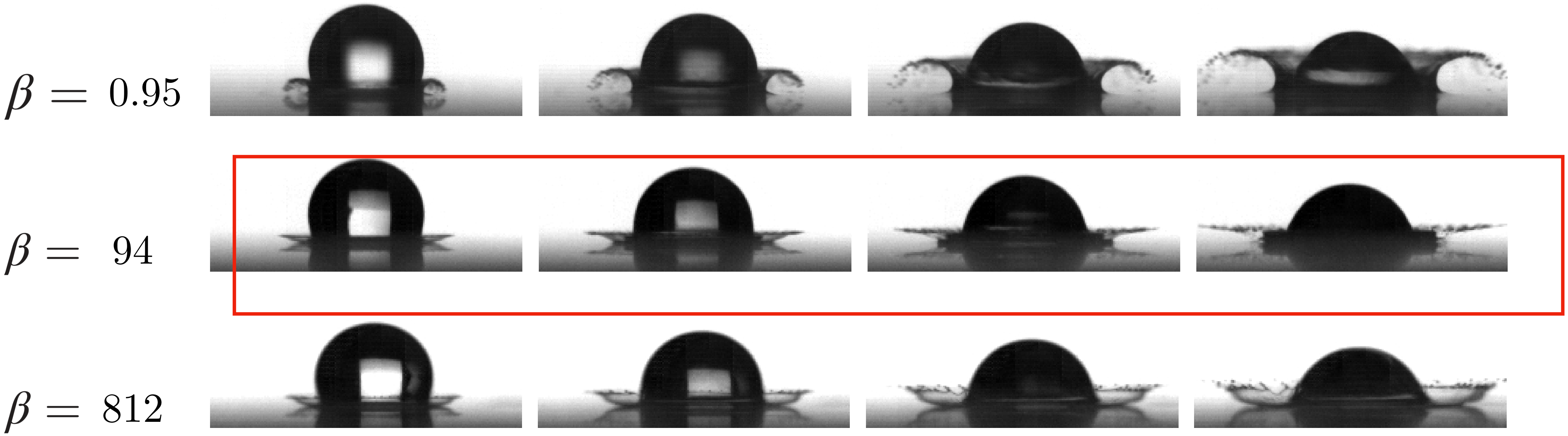
Ti + 3/50000 s Ti + 6/50000 s Ti + 9/50000 s Ti + 12/50000 s Ti + 15/50000 s

Viscosité = 112.9 mPa.s – Pression = p atm – 748 mbar

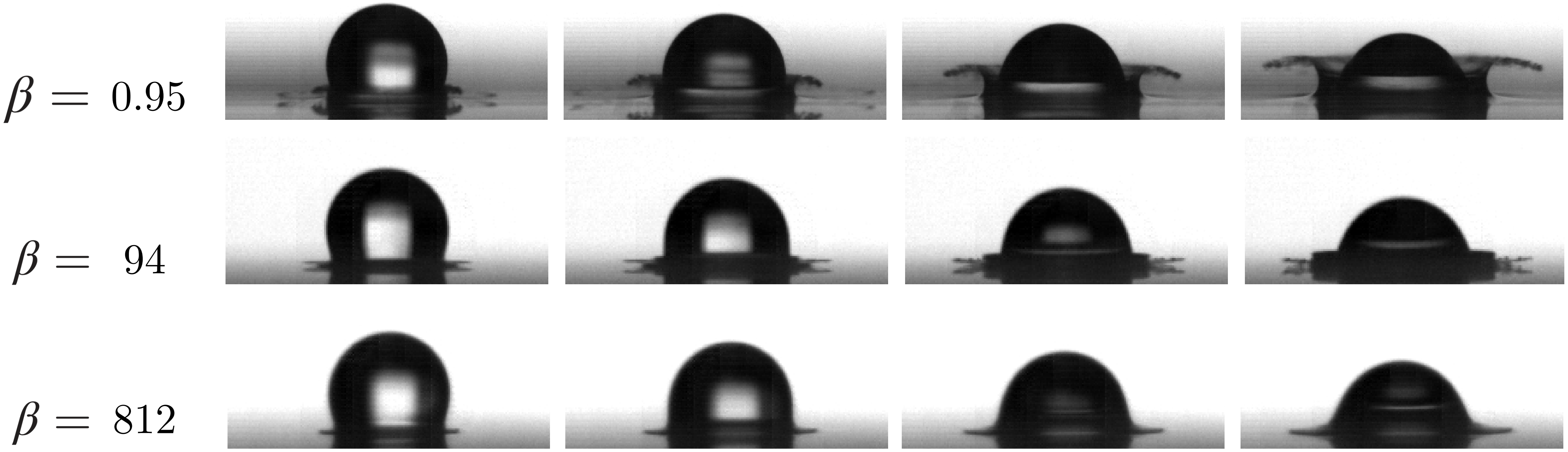
Ti + 3/50000 s Ti + 6/50000 s Ti + 9/50000 s Ti + 12/50000 s Ti + 15/50000 s

Résultats expérimentaux

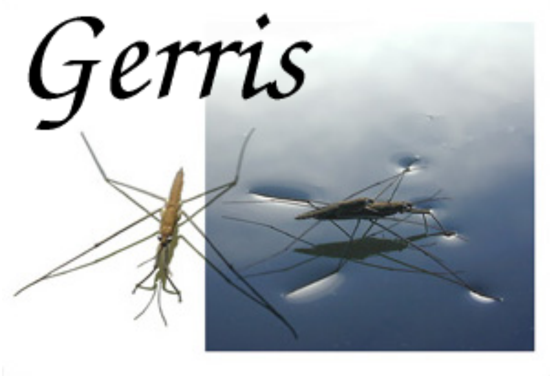
(a) atmospheric pressure



(b) low pressure



Modèle numérique



Popinet JCP (2003, 2009)

http://gfs.sourceforge.net

> discrétisation en volumes finis traitement de l'interface par méthode Volume-of-Fluid

> raffinement adaptatif du maillage en dynamique (structure quadtree/octree)

$$\rho(\partial_t \mathbf{u} + \mathbf{u} \cdot \nabla \mathbf{u}) = -\nabla p + \nabla \cdot (2\mu \mathbf{D}) + \gamma \kappa \delta_s \mathbf{n}$$

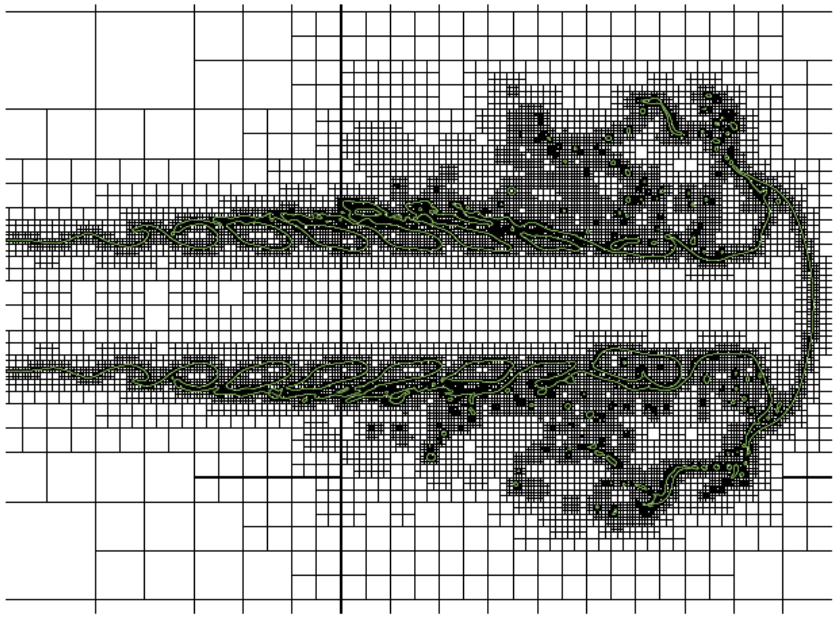
$$\partial_t \chi_i + \nabla \cdot (\chi_i \mathbf{u}) = 0$$

$$\nabla \cdot \mathbf{u} = 0$$

avec :

$$\mathbf{D} = (\nabla \mathbf{u} + \nabla \mathbf{u}^T)/2$$

$$\rho(\mathbf{x}, t) = \rho_p \chi_1 + \rho_g (1 - \chi_1)$$
$$\mu(\mathbf{x}, t) = \rho_p \chi_1 (1 - \chi_2) + \mu_e \chi_1 \chi_2 + \mu_g (1 - \chi_1)$$



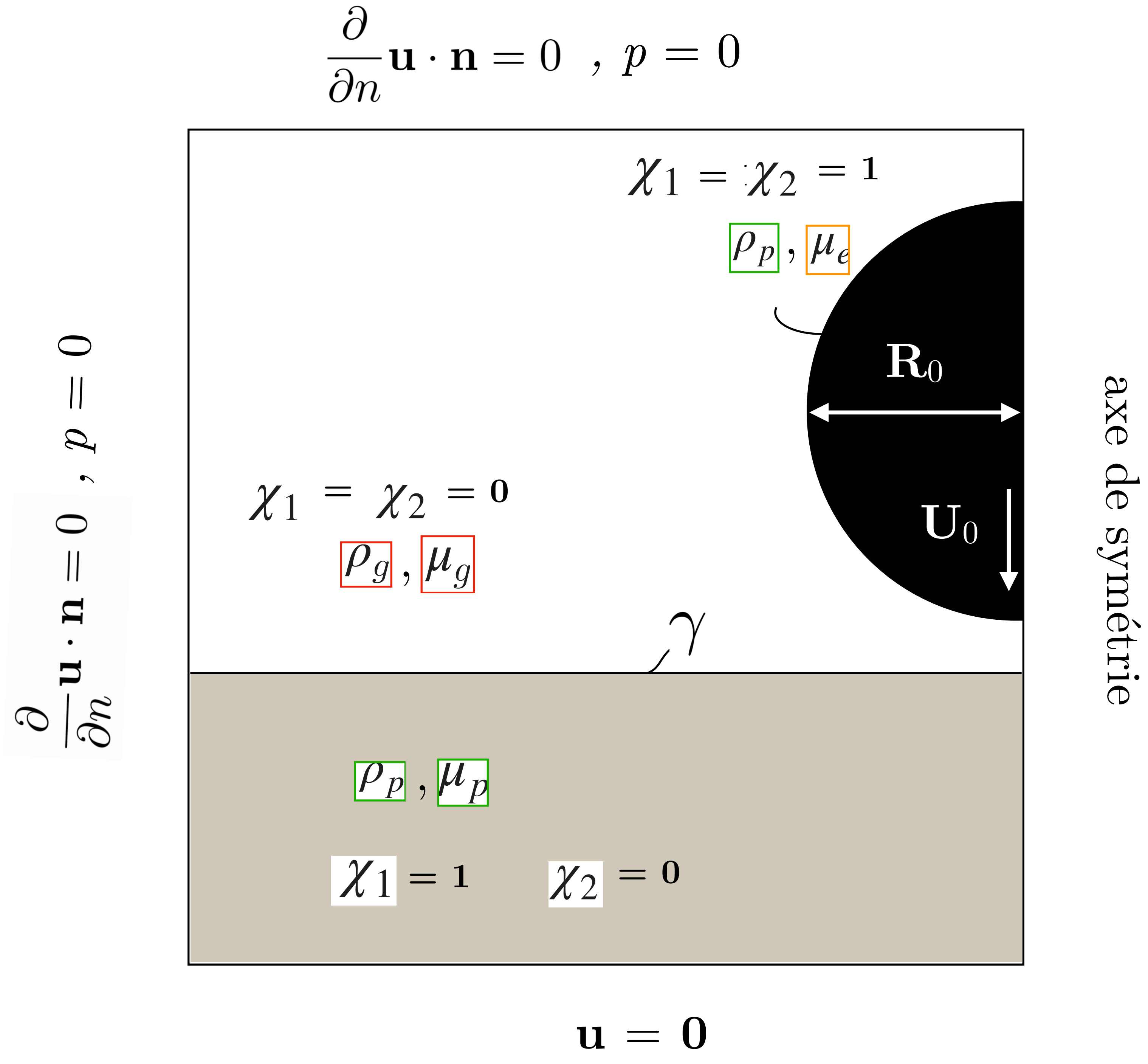
> solveur de Poisson multigrille...

+ Comparaisons DNS (Gerris) et expériences d'impacts : e.g. Thoraval et al. (2012)

Modèle numérique

$$\rho(\mathbf{x},t) = \rho_p \chi_1 + \rho_g (1-\chi_1)$$

$$\mu(\mathbf{x},t) = \rho_p \chi_1 (1-\chi_2) + \mu_e \chi_1 \chi_2 + \mu_g (1-\chi_1)$$



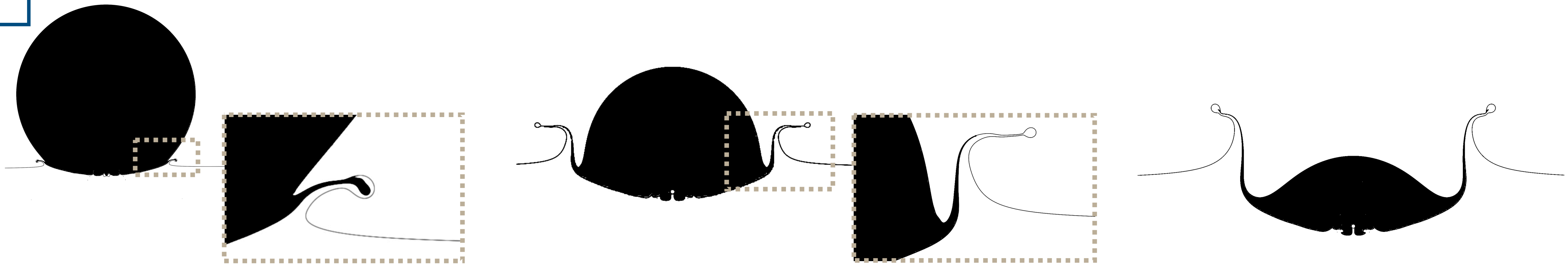
$$We = 440$$
$$Re = 6000$$

(ex: goutte d'eau diam.
1,1mm
impact à 5.3m/s)

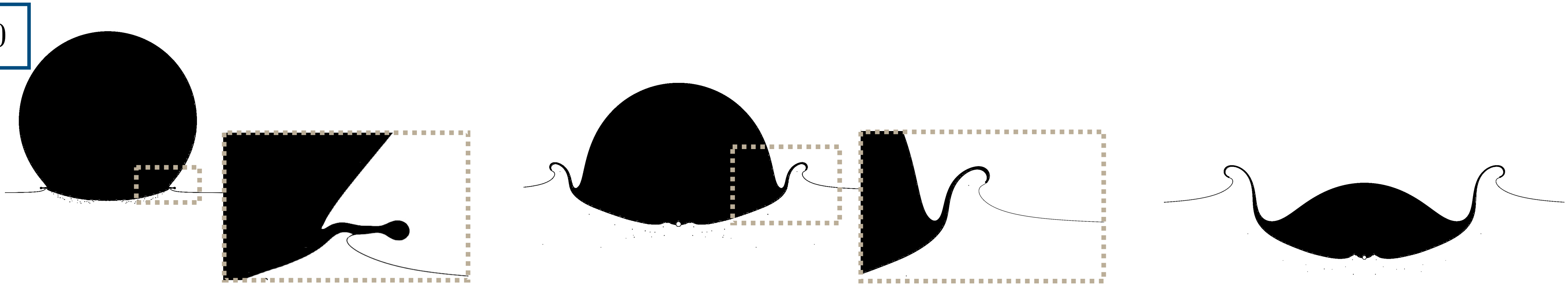
Résultats numériques

Résultats numériques

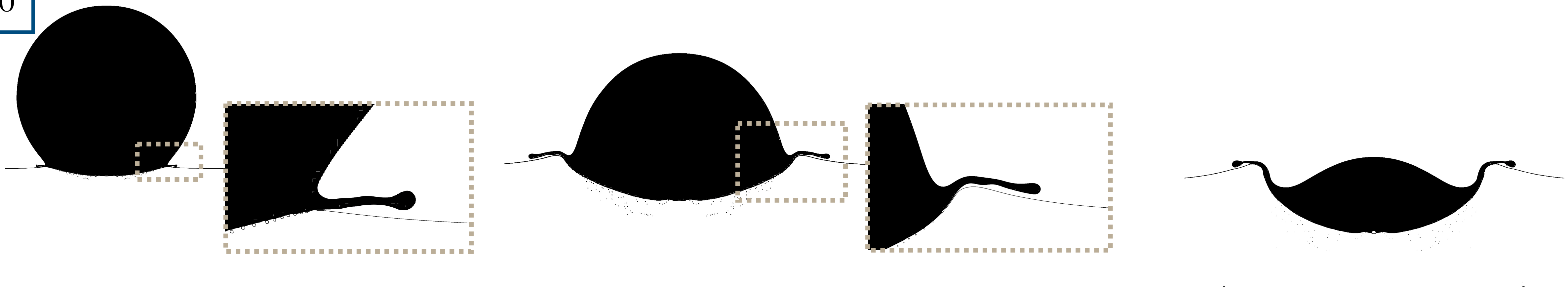
$\beta = 5$



$\beta = 50$

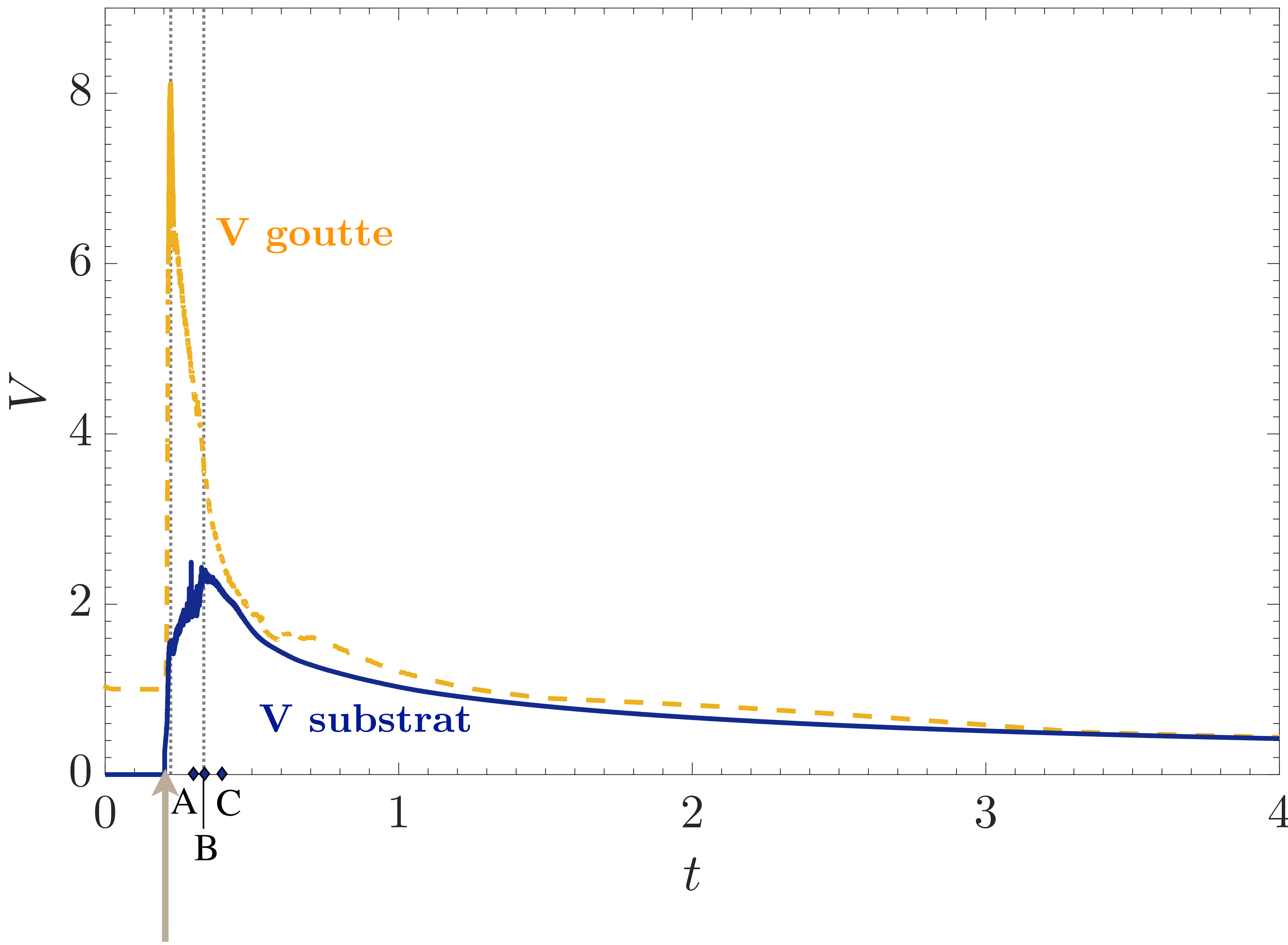


$\beta = 100$



Résultats numériques

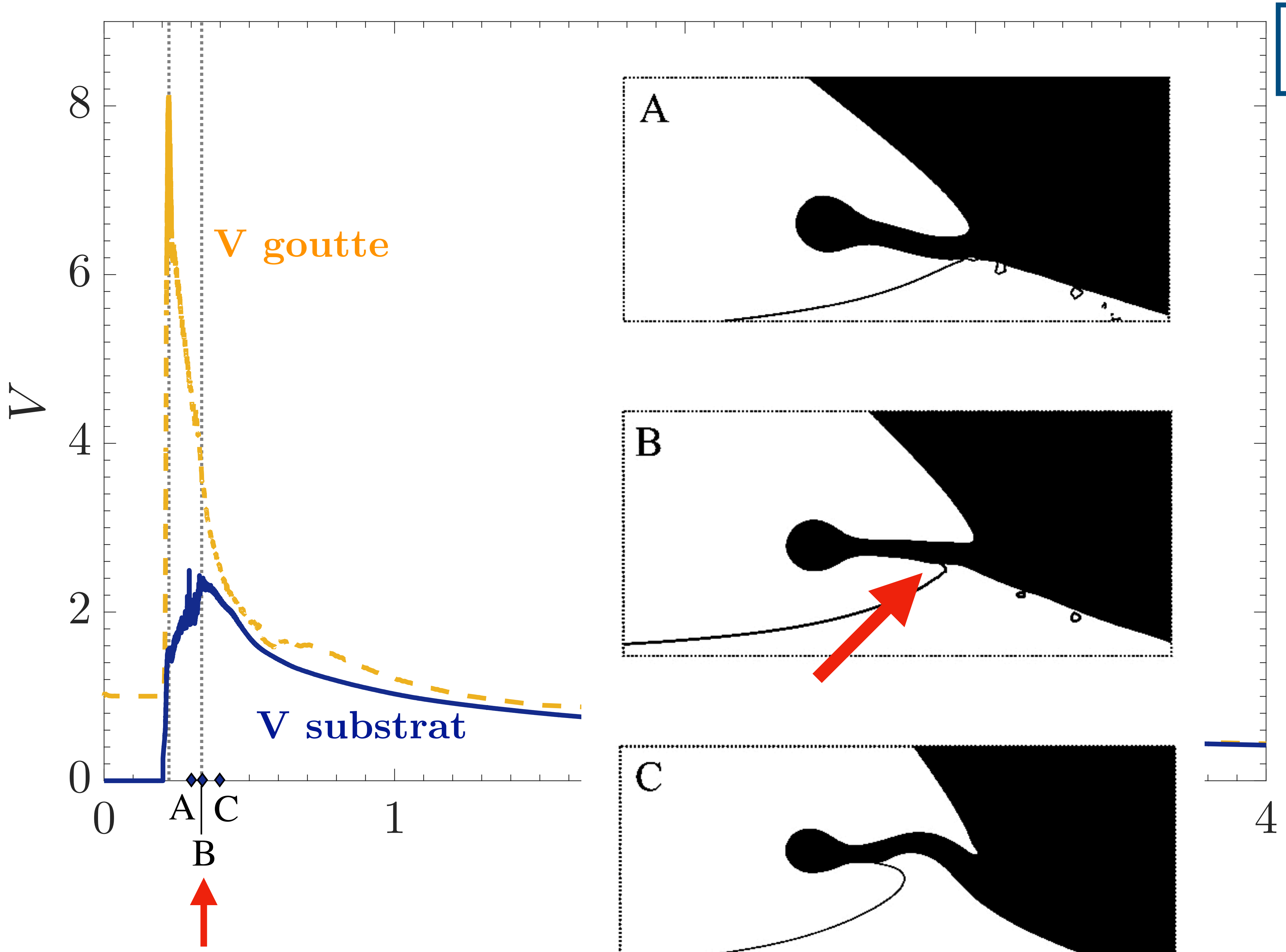
$\beta = 50$



impact à t=0.2

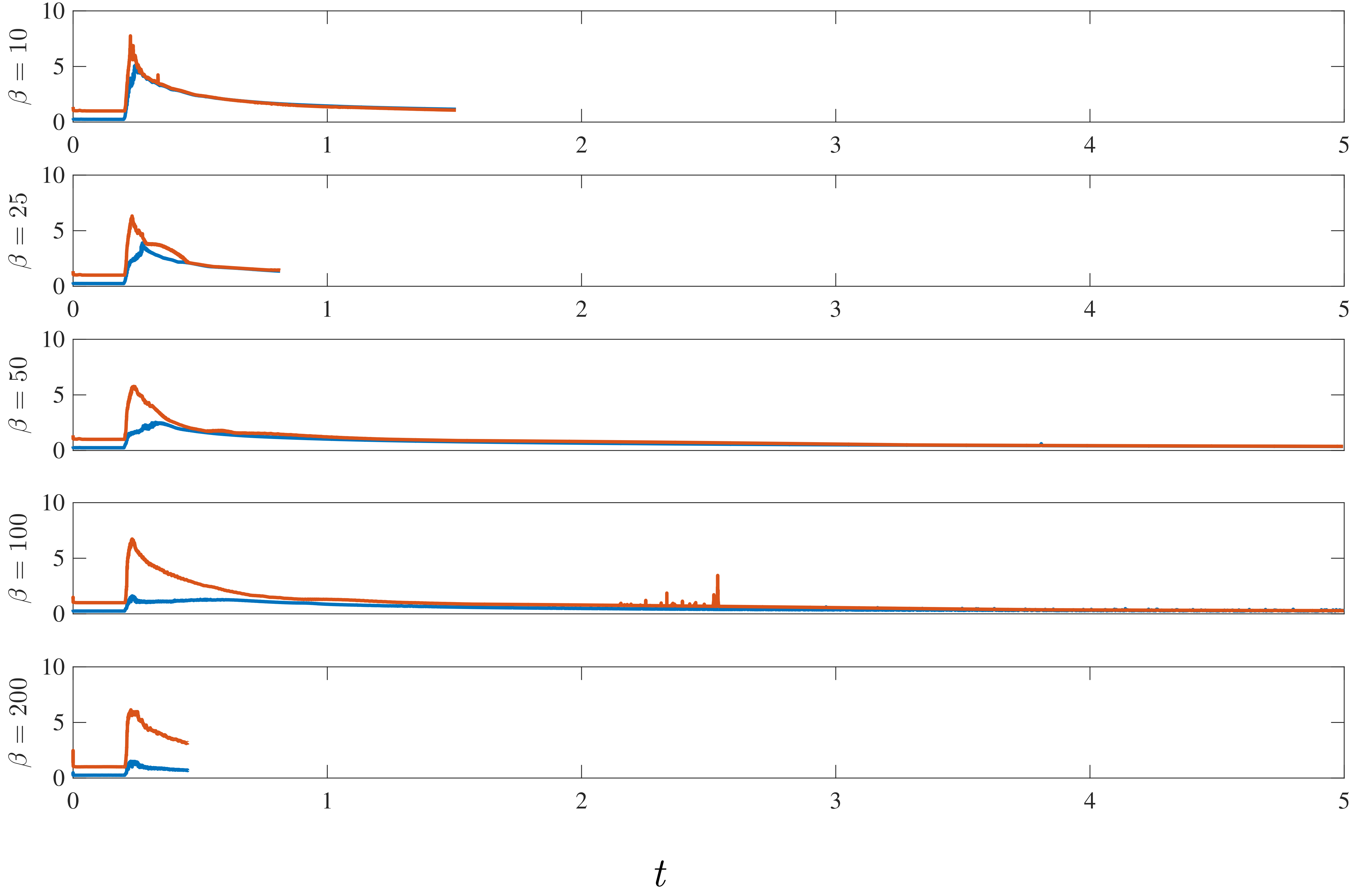
Résultats numériques

$\beta = 50$

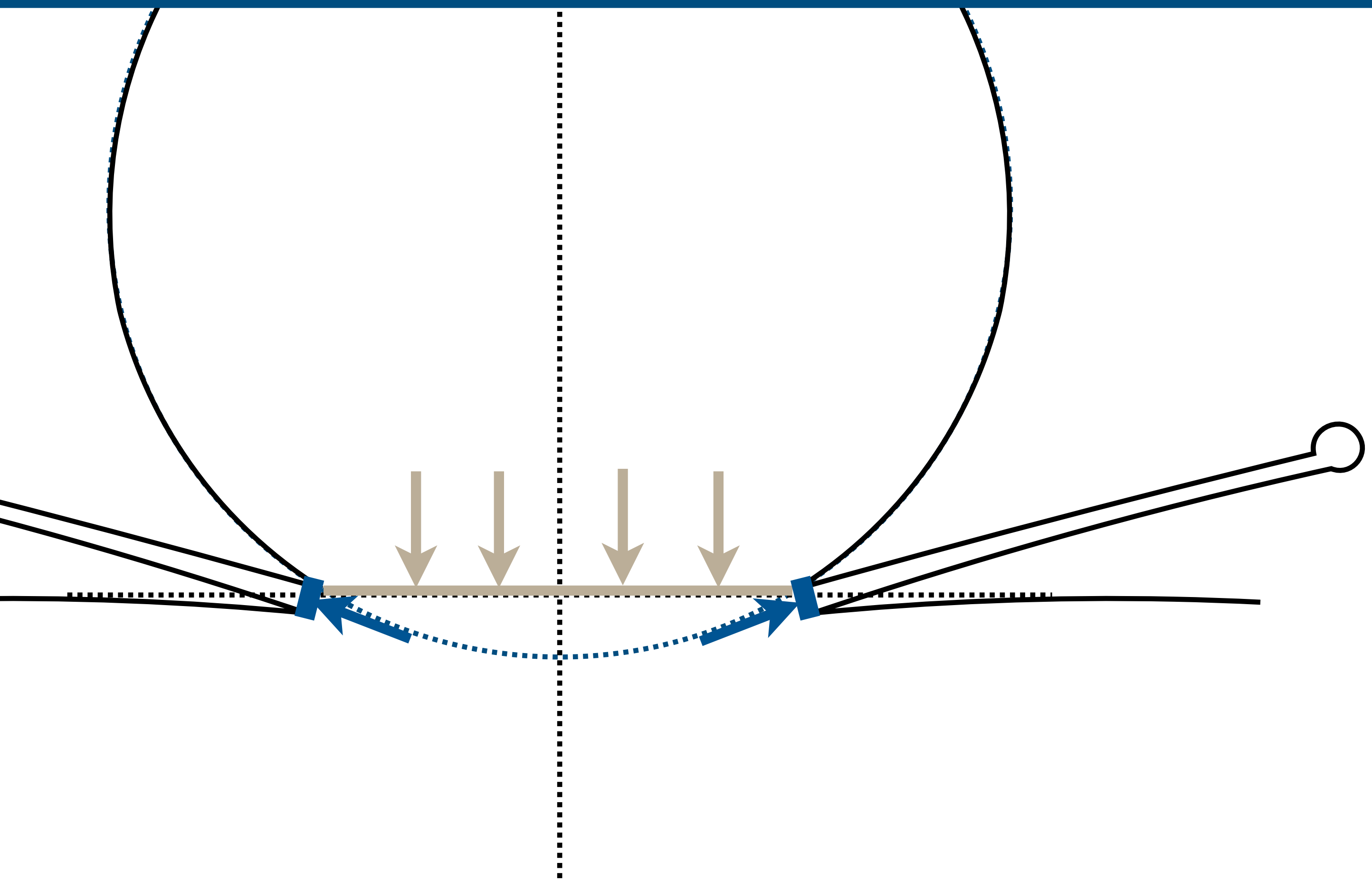


formation du jet secondaire
(substrat)

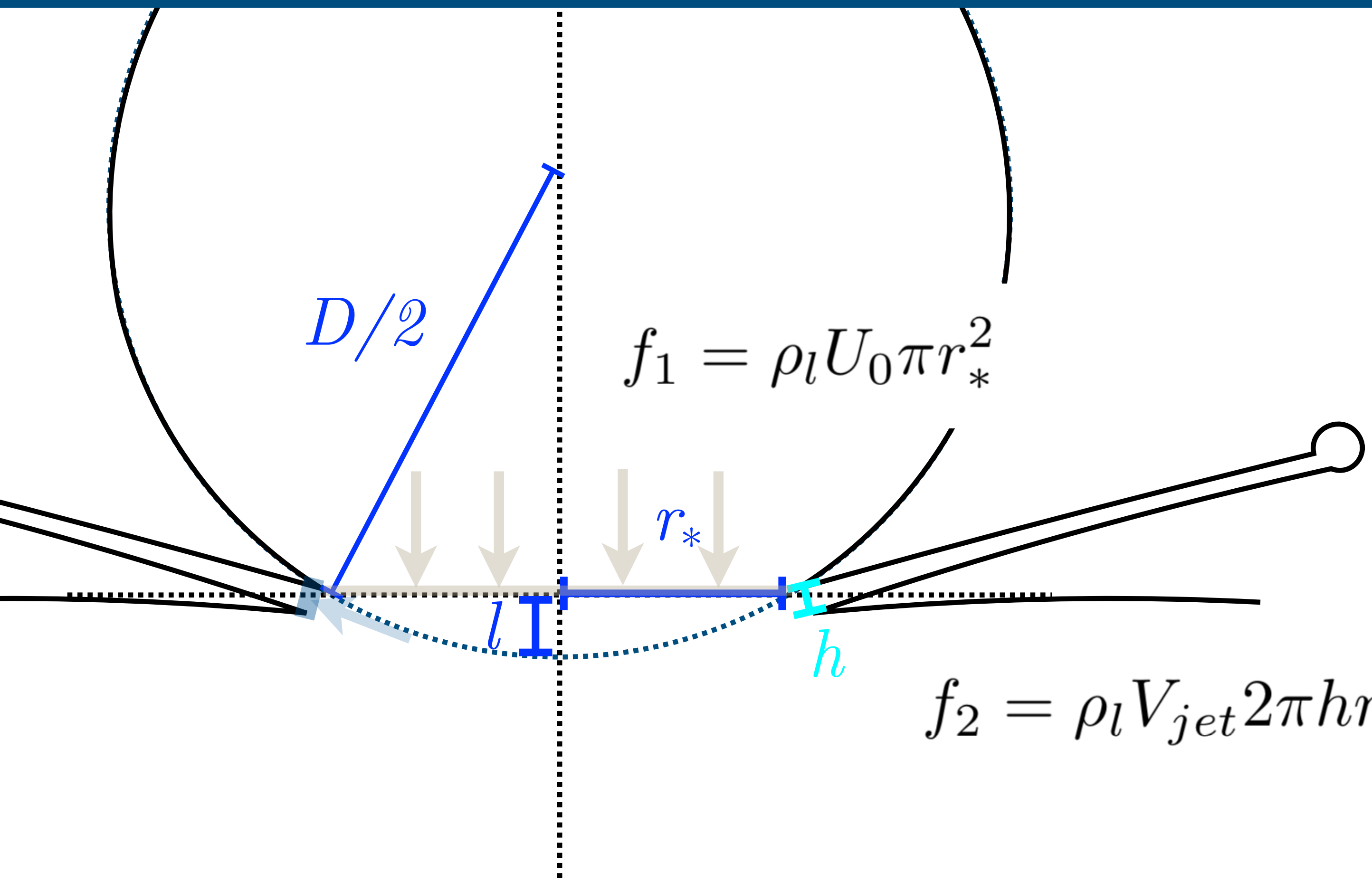
Résultats numériques



Résultats numériques



Résultats numériques



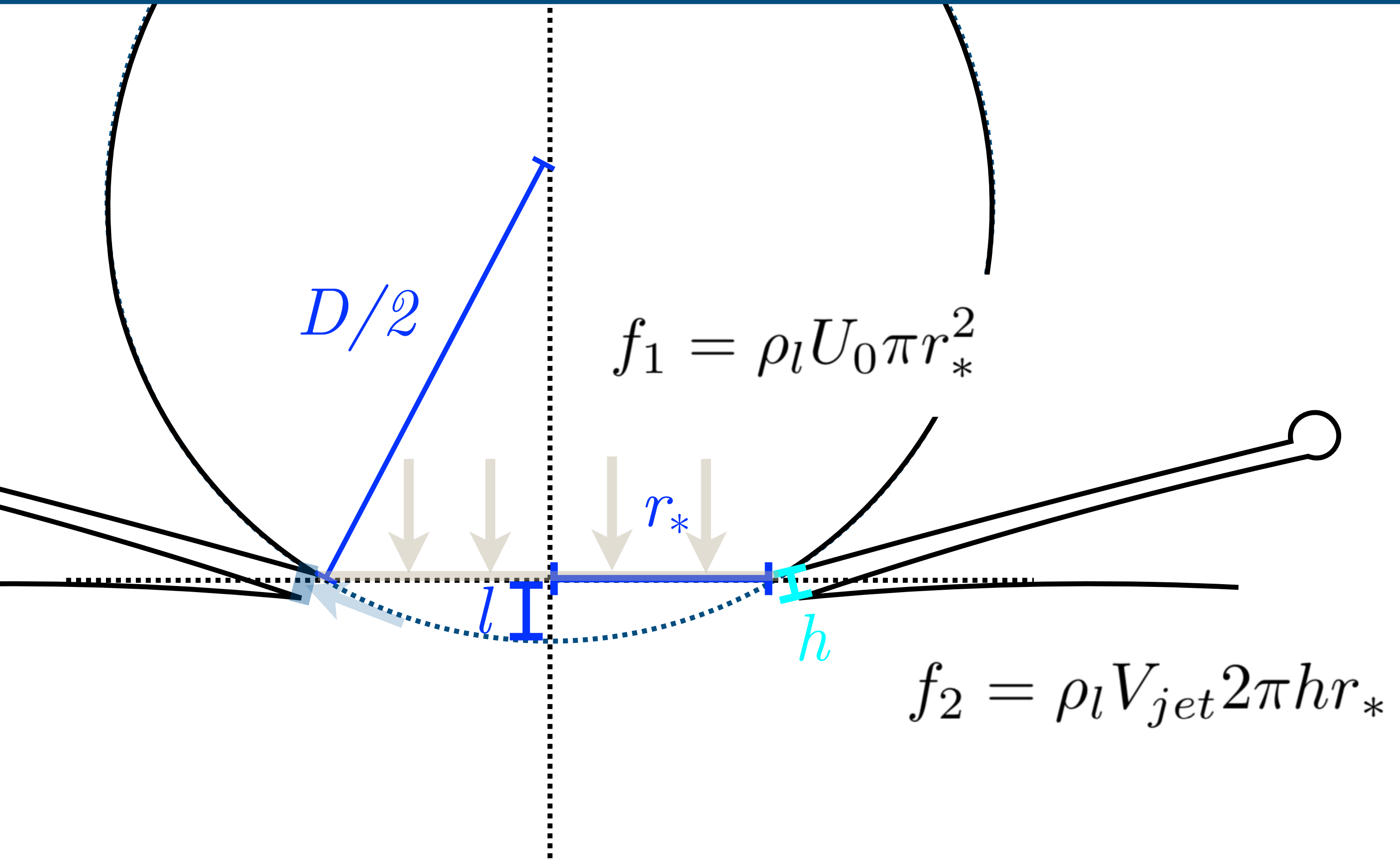
$$f_1 = \rho_l U_0 \pi r_*^2$$

$$f_2 = \rho_l V_{jet} 2\pi h r_*$$

$$l \sim U_0 t$$

$$r_* \sim \sqrt{D U_0 t}$$

Résultats numériques



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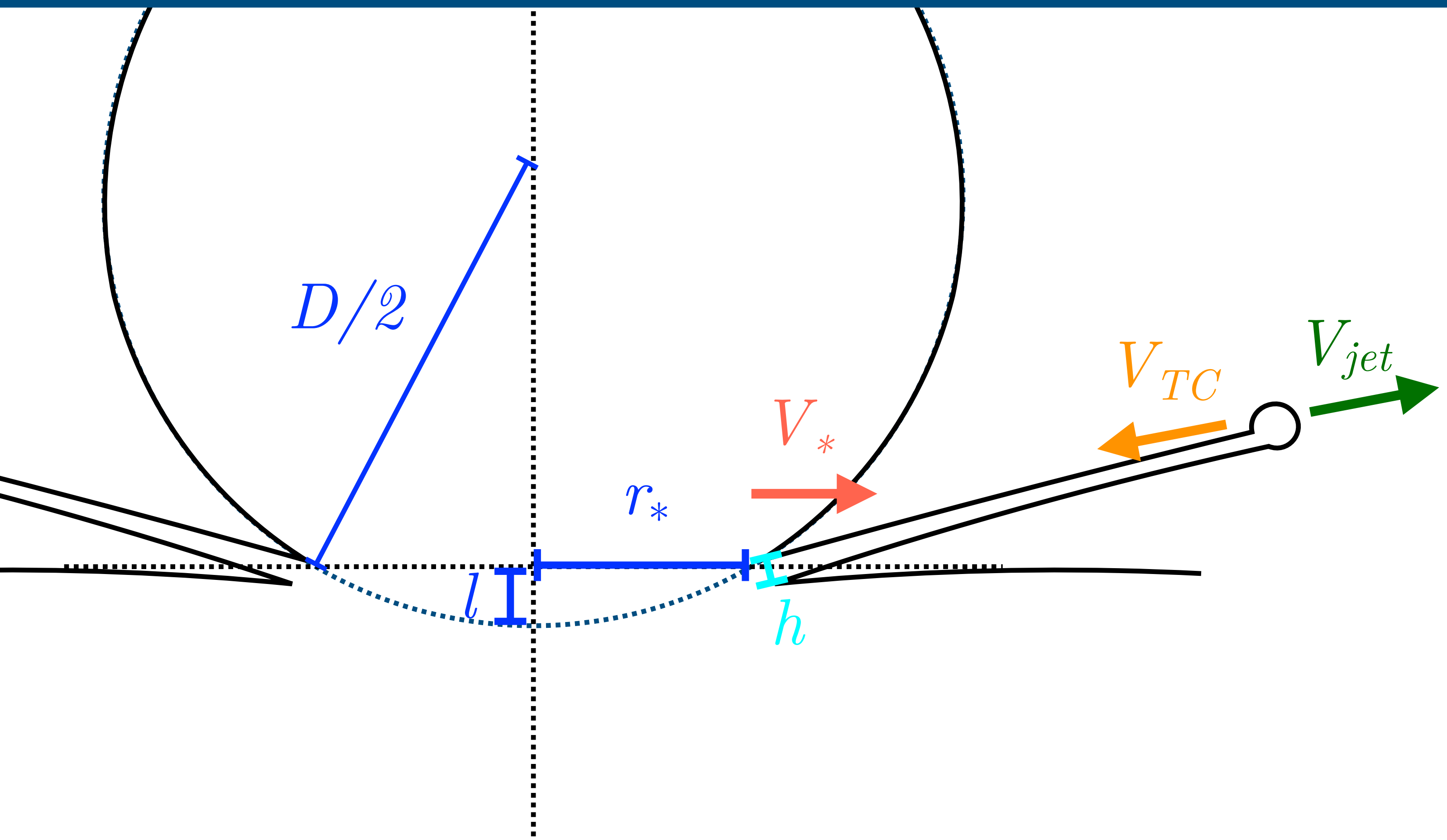
Josserand & Zaleski (2003) : $h \sim \sqrt{\nu t}$ $\longrightarrow$ $\boxed{V_{jet} = U_0 \sqrt{Re}}$

Résultats numériques



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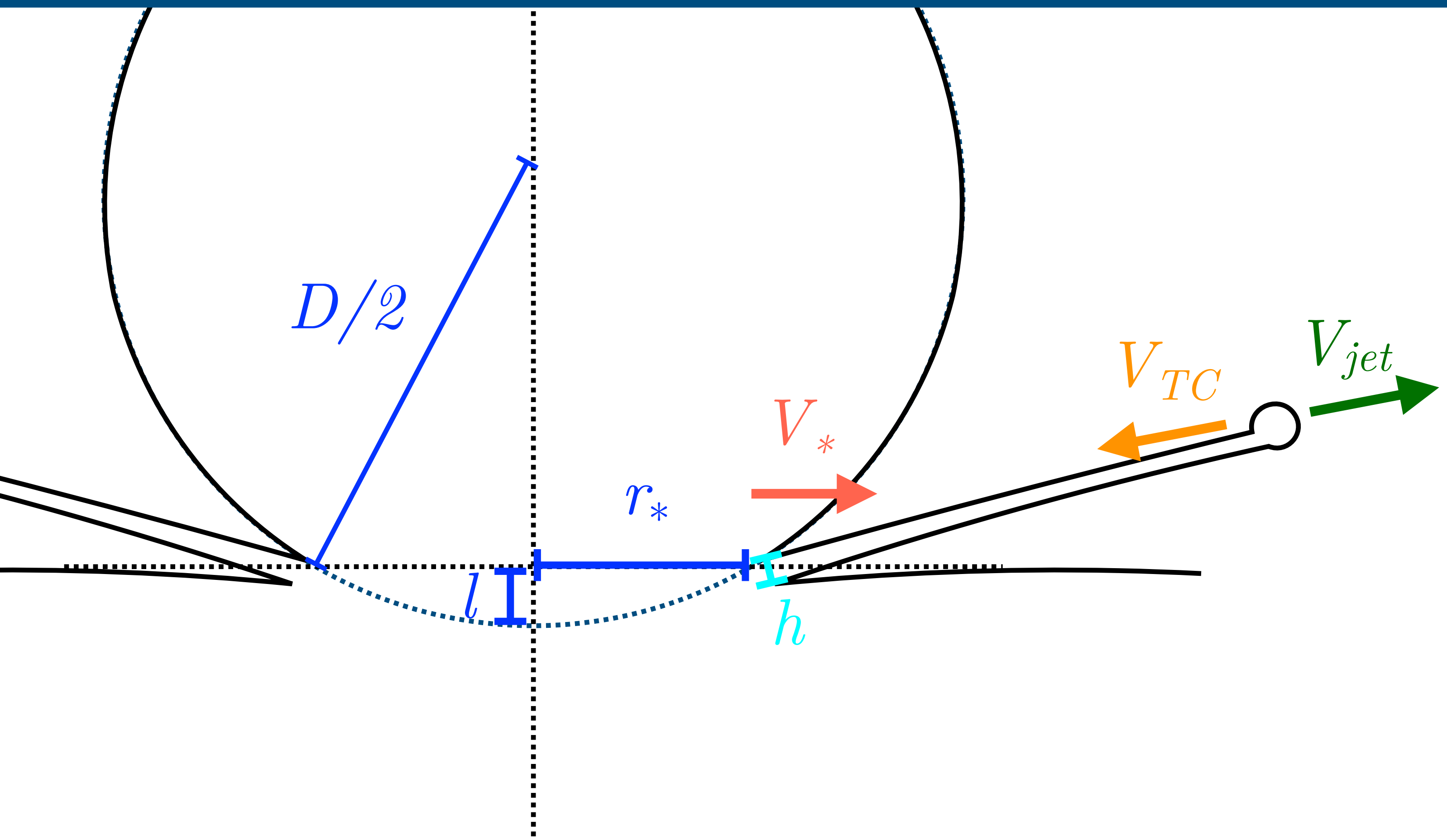
(comparaison avec vitesse de Taylor-Culick : $\boxed{V_{TC} \sim \left(\frac{2\gamma}{\rho_l h}\right)^{1/2}}$

et vitesse d'étalement géométrique : $\boxed{V_* = \frac{dr_*}{dt} = \frac{1}{2}\sqrt{\frac{DU_0}{t}}}$)

—> critère de formation du jet :

$$t > \max(t_{TC}, t_*) = \max\left(\frac{2}{We^2 Re}\frac{D}{U_0}, \frac{1}{Re}\frac{D}{U_0}\right)$$

Résultats numériques



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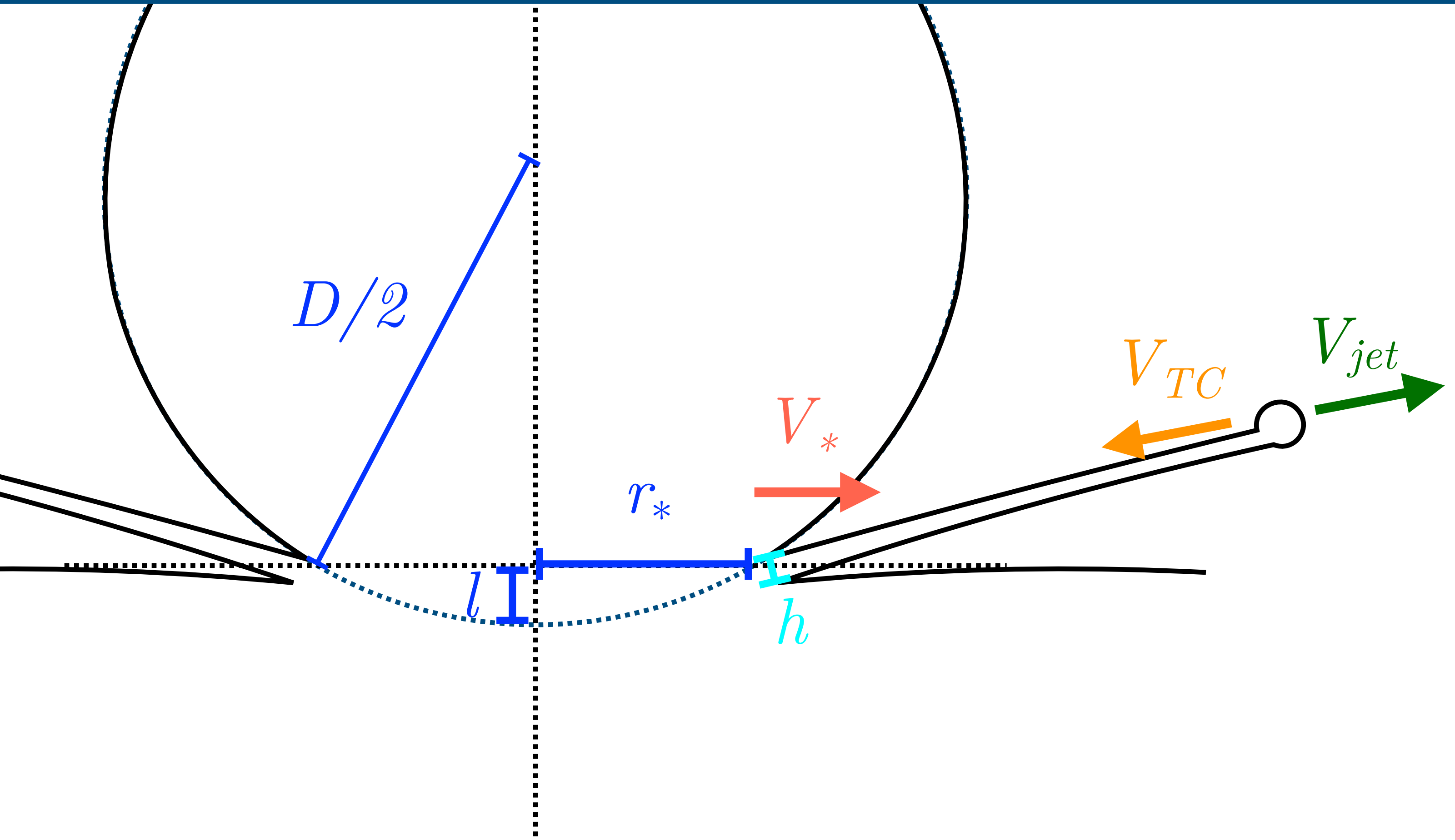
$$t > \max(t_{TC}, t_*) = \max\left(\frac{2}{We^2 Re}\frac{D}{U_0}, \boxed{\frac{1}{Re}\frac{D}{U_0}}\right) \quad (We, Re >> 1)$$

Résultats numériques



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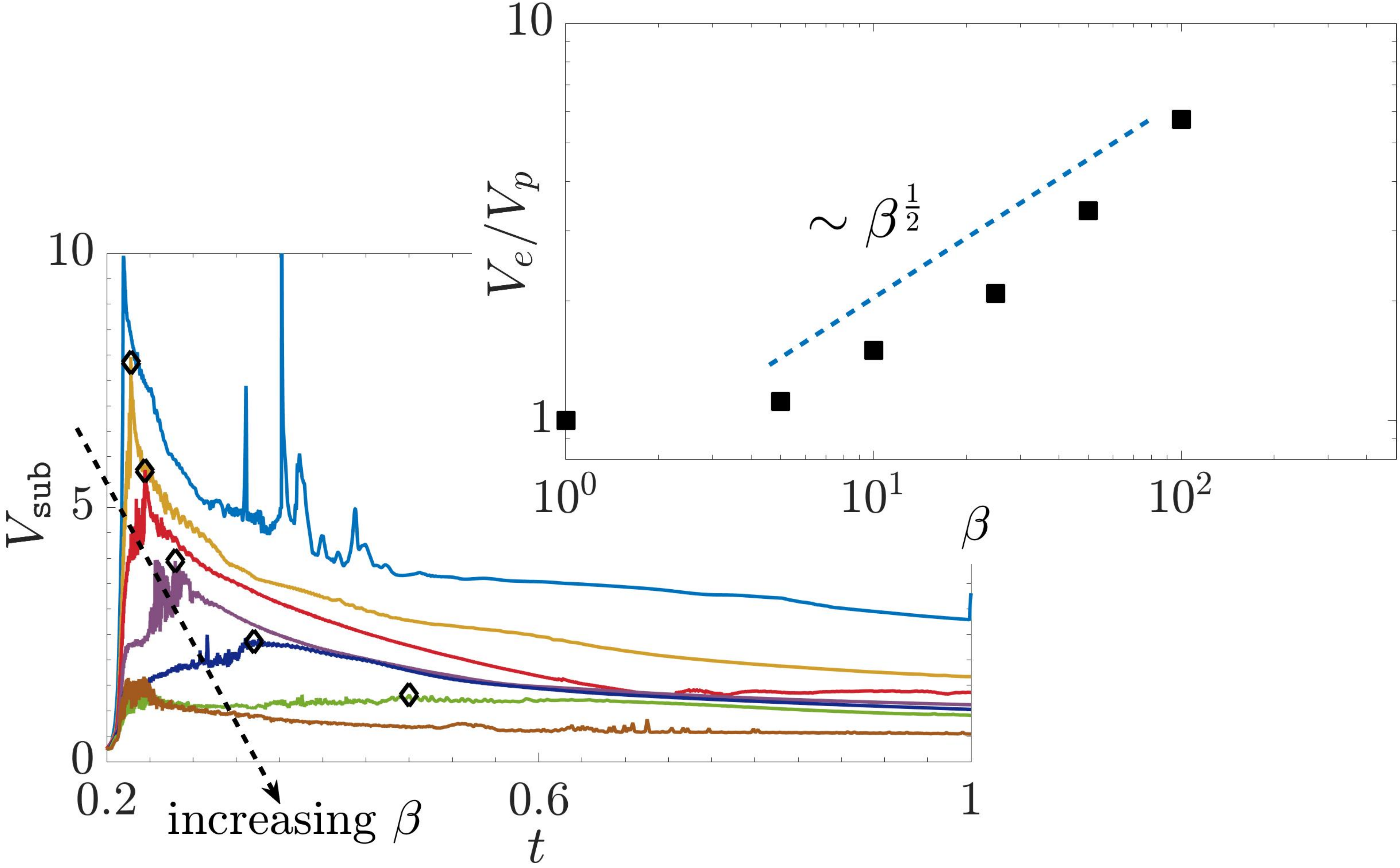
—> critère de formation du jet :

$$t > \max(t_{TC}, t_*) = \max\left(\frac{2}{We^2 Re}\frac{D}{U_0}, \frac{1}{Re}\frac{D}{U_0}\right)$$

Ici 2 jets (goutte/substrat) : $\boxed{V_e/V_p = \sqrt{Re_e/Re_p} = \sqrt{\mu_p/\mu_e} = \sqrt{\beta}}$ **(à temps courts !!)**

Résultats numériques



Conclusion

- Structure double de la corolle d'impact : deux jets/nappes (ejecta et Peregrine ?)

- Transition continue d'un régime de splash-sur-solide à splash-sur-liquide (séparation progressive des échelles de temps)

- Rôle de la pression sur corolles mixtes : déstabilisation à temps court de l'ejecta favorise la déstabilisation du bord d'attaque de la Peregrine ?

- Critères de splash : rôle de la viscosité du substrat ...