Phenomenological study of the interactions between pressure waves and development of jets for simplified liquid impacts

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(d) CENTRALE NANTES

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Outline

- Introduction
- Flat impact of liquid on rigid wall without gas
- Impact of curved liquid domain on rigid wall without gas
- Conclusion

Introduction

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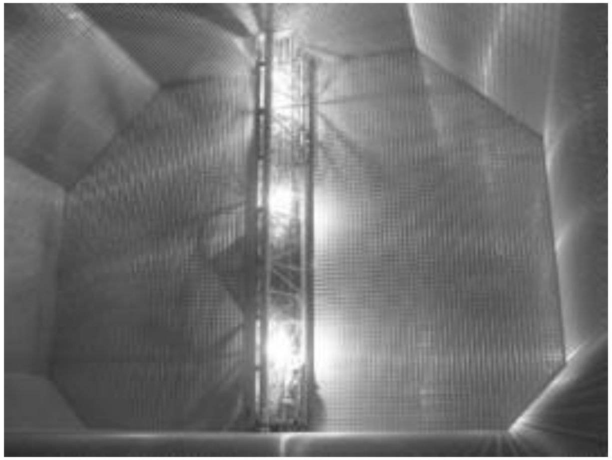
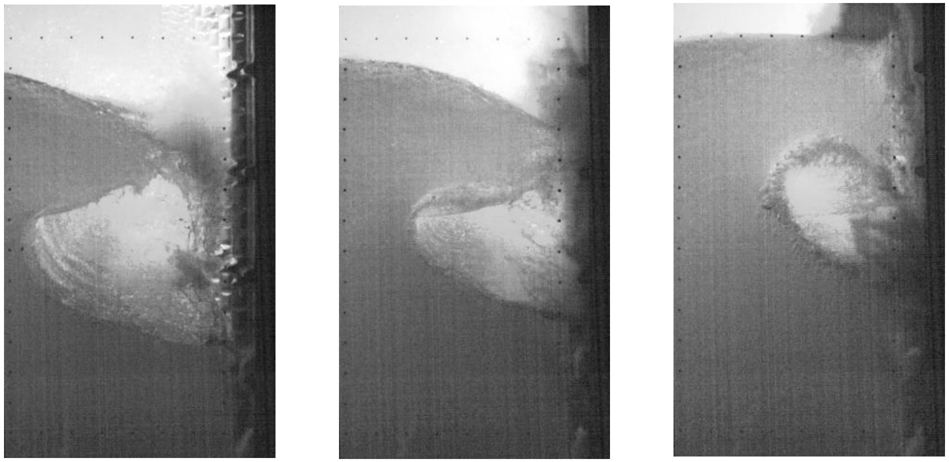
Context

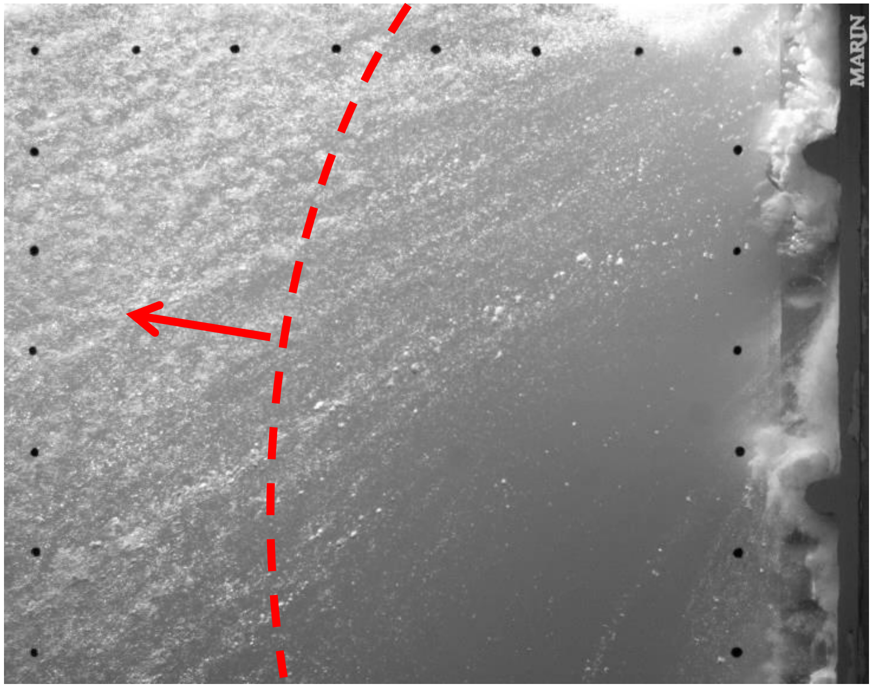


Impact of LNG on insulated walls of tanks due to sloshing



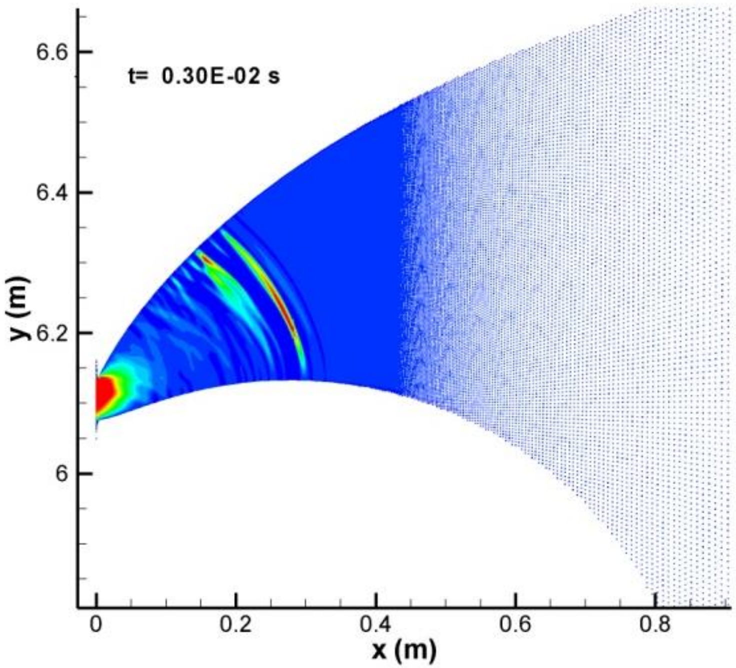
Impact of a plunging wave on corrugations *(Sloshel project)*

Visualization of compressible effects in the liquid



Experimental (*Sloshel project*)

« Flip through » impact



Numerical (*SPH-flow*)

« Large gas pocket » impact

→ High pressure peaks were measured in some cases

Sequence of phenomena

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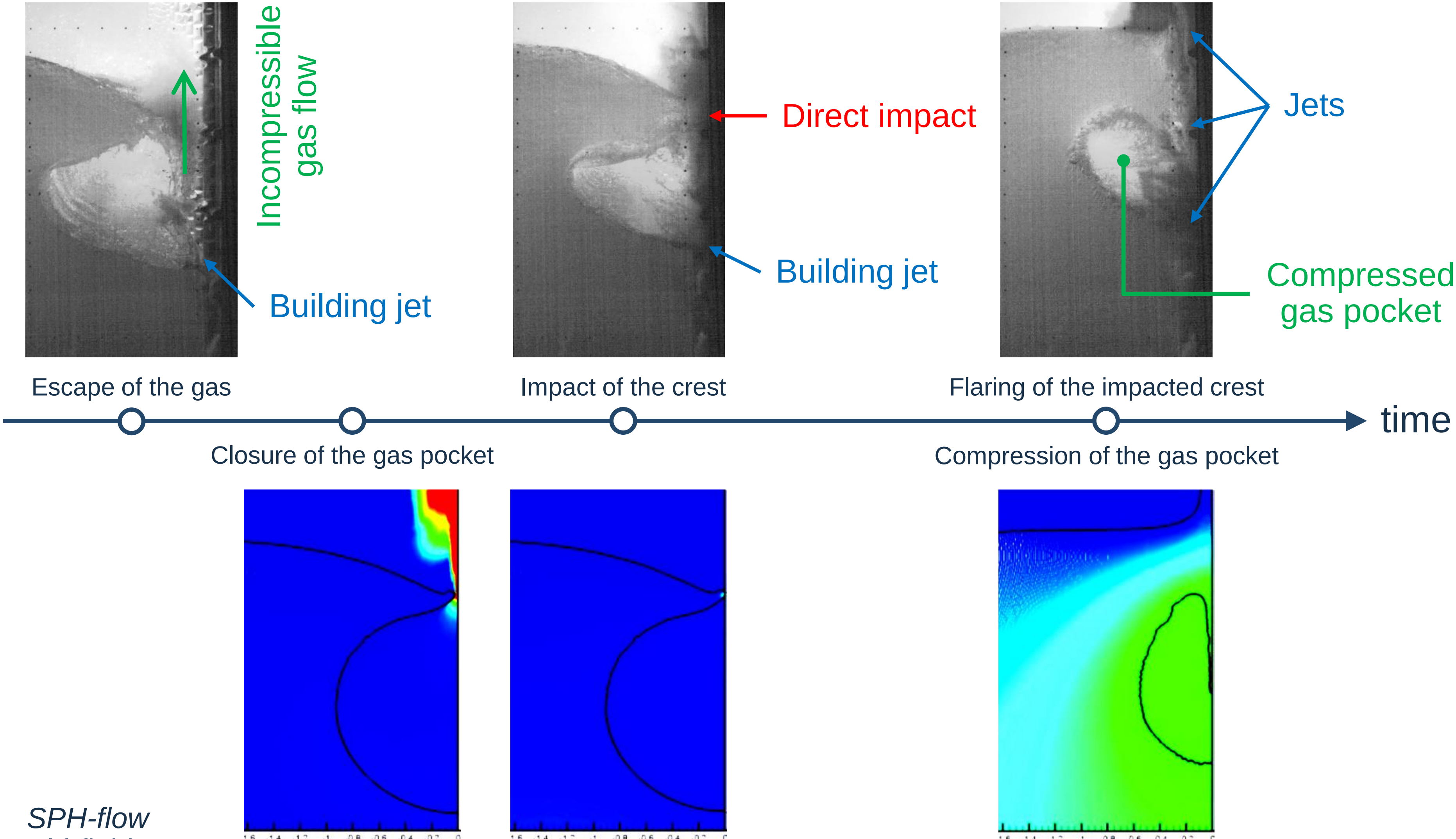
Sloshel project



SPH-flow bi-fluid

Vertical velocity field

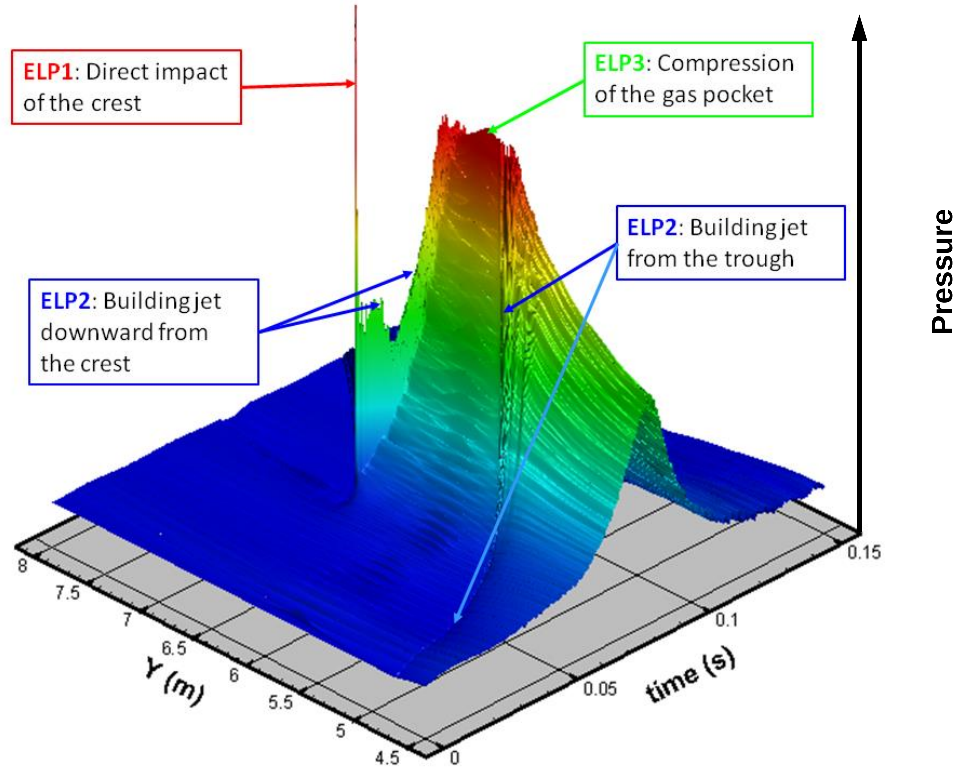
Pressure field

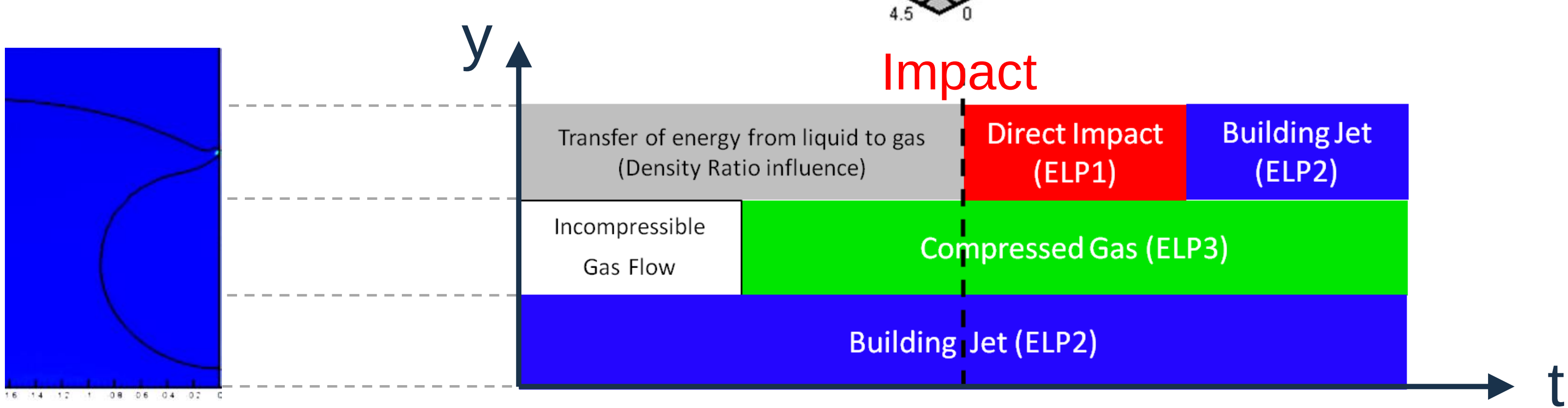
Pressure field

Elementary Loading Processes (ELPs)

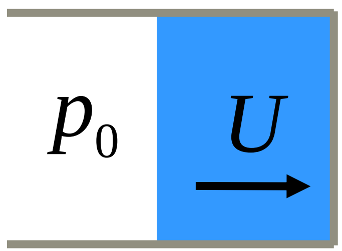
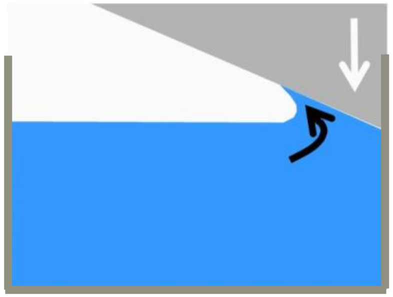
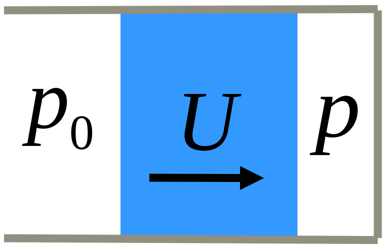
« Pressure surface »:

time-space distribution of pressure on the wall



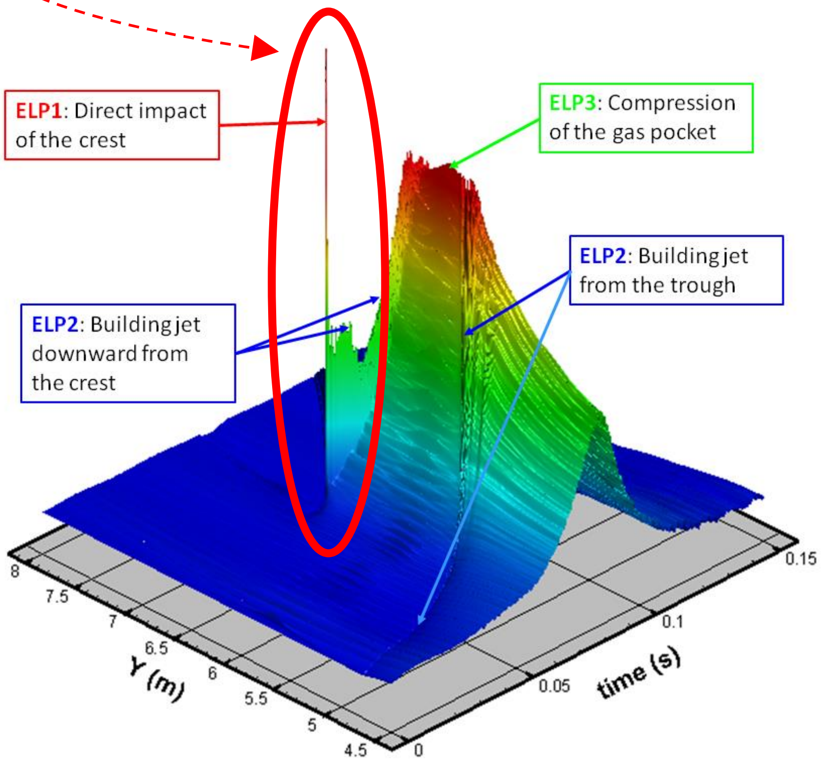


Canonical models of the ELPs

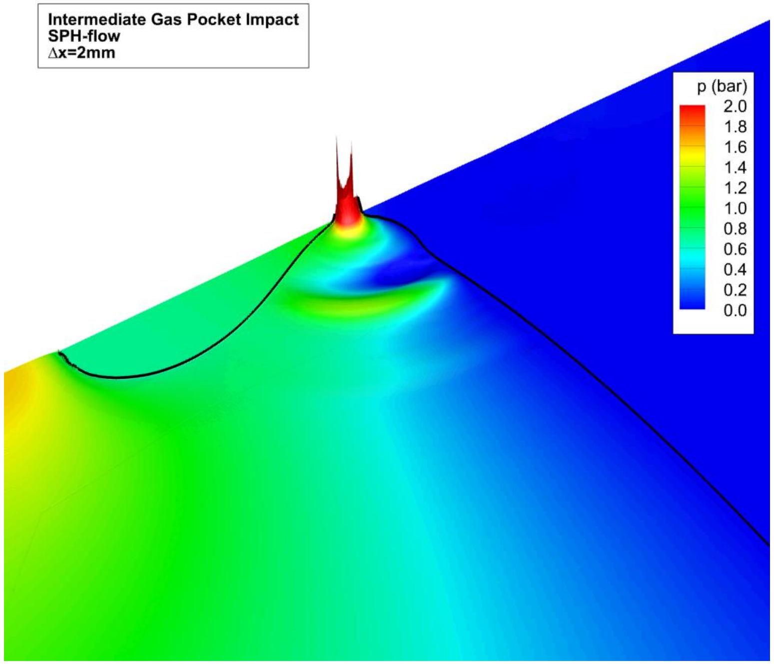
ELP	Liquid compressibility Direct impact (ELP1)	Liquid momentum Building jet (ELP2)	Gas compressibility Compressed gas (ELP3)
Canonical models	 Rankine and Hugoniot	 Wagner	 Bagnold
Scaling laws	Mach (liquid)	Froude	Mach (gas)

Transition between ELP1 and ELP2

- This phase seems to provide high pressures → <u>potentially</u> important for design
- Very small scales of time and space involved → numerical models must be adapted



Pressure field inside the fluids



Purpose of the study

Questions to be answered

- ▶ Pressure levels and duration of initial peaks (with accuracy)?
- ▶ Canonical solution: simply sum 

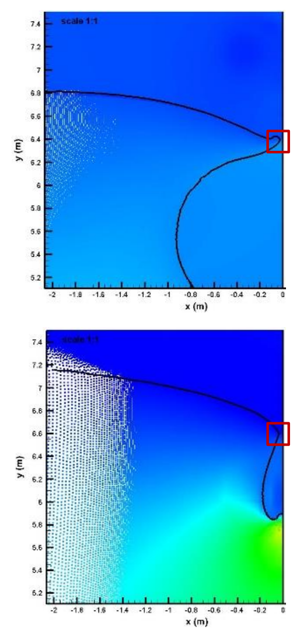
+ 

or coupled brick 

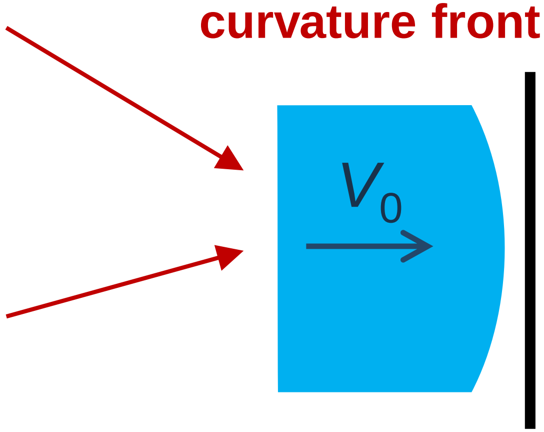
?
- ▶ Consequence on scaling rules?

Scope of work

- ▶ **Means:**
  - Numerical simulation:
    - SPH method (SPH-flow)
    - Eulerian Finite Elements (LS-Dyna)
  - Look at theoretical works
- ▶ **Studied case:**



Idealization of the crest by a **patch with constant curvature front**



No gas

Infinite R

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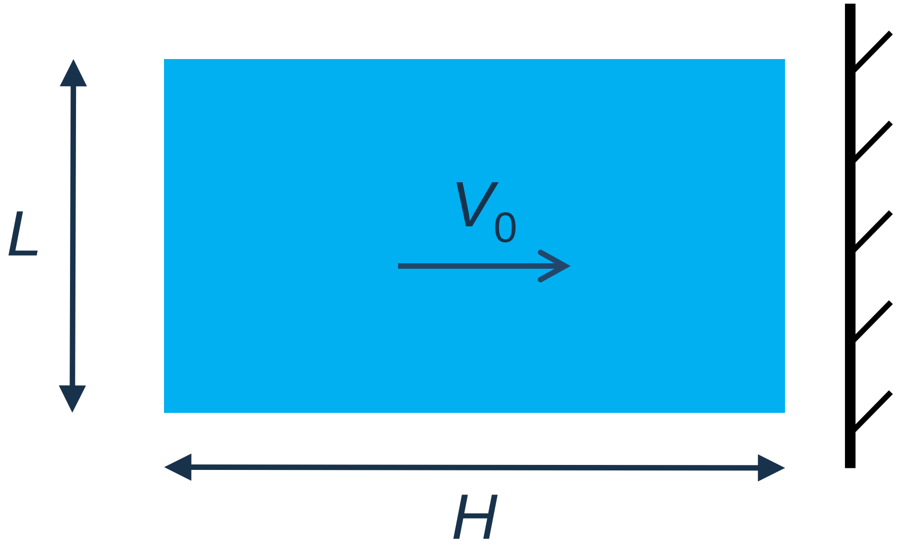
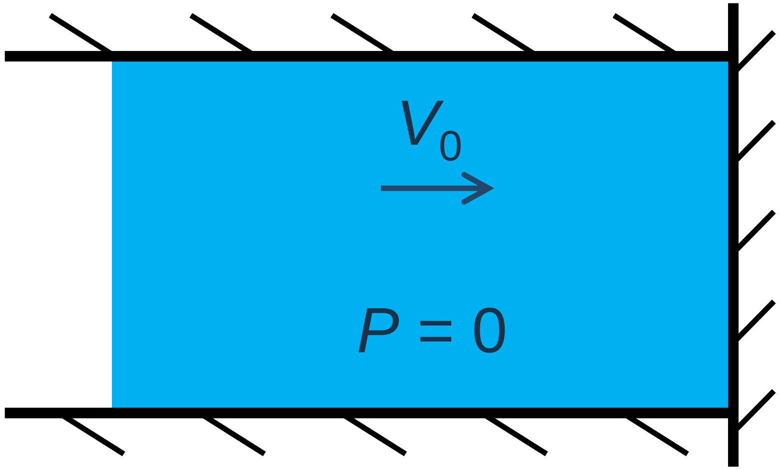
Characteristics of the test



- Aspect ratio: $L/H = 1/8$
- Mass density: $\rho = 455$ kg/m^3
- Celerity of sound: $c = 1300$ m/s
- Impact velocity: $V_0 = 6.26$ m/s (corresponds to a drop of 2 m)
- Acoustic pressure: $\rho c V_0 = 37$ bar

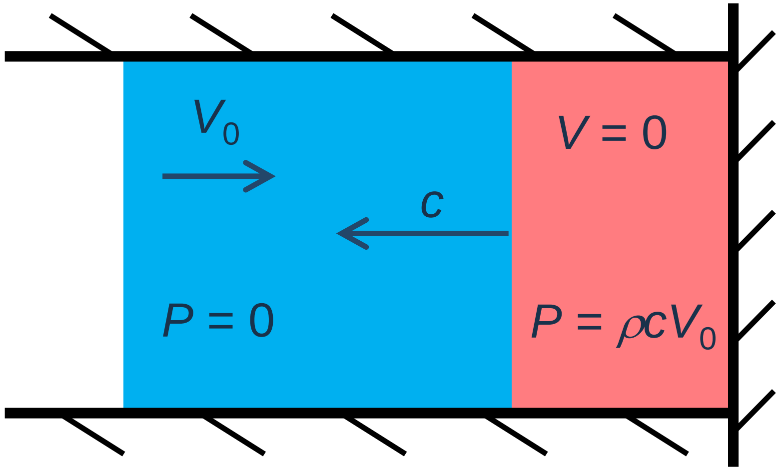
Reminder of the results in 1D

$\underline{t = 0}$



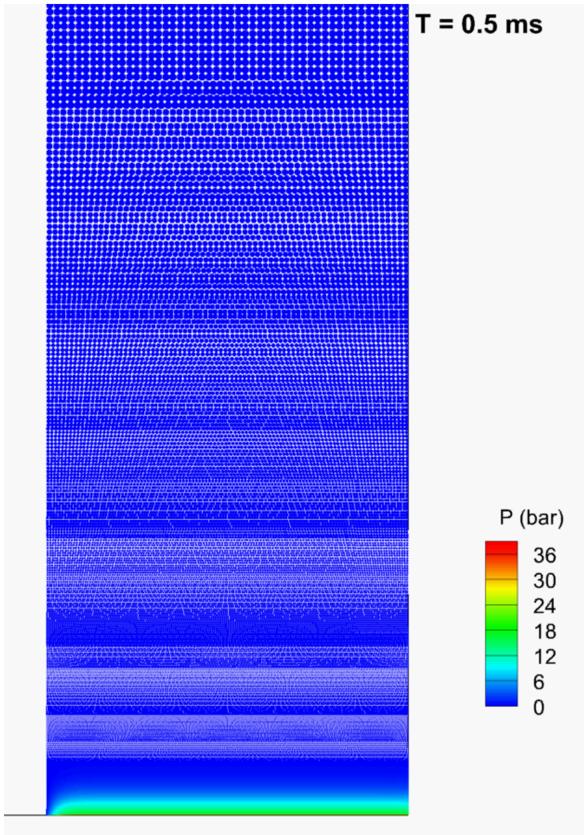
$\underline{t > 0}$

Propagation of a compression shock wave at the celerity of sound

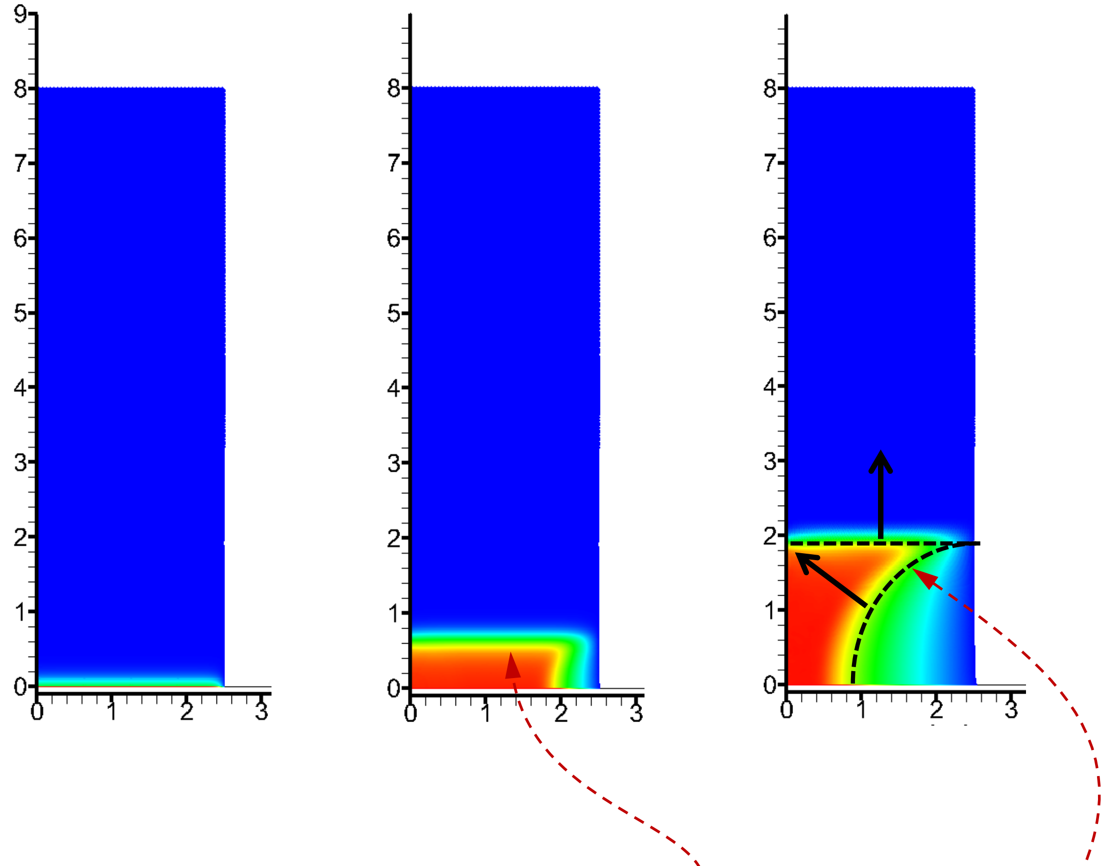


Pressure field in the liquid

SPH-flow computation
Half model



Acoustic pressure:
$\rho c V_0$ = 37 bar



The compression shock wave with flat front
combines with
a relaxation shock wave with circular front
arising from the corners

Pressure field in the liquid (later time)

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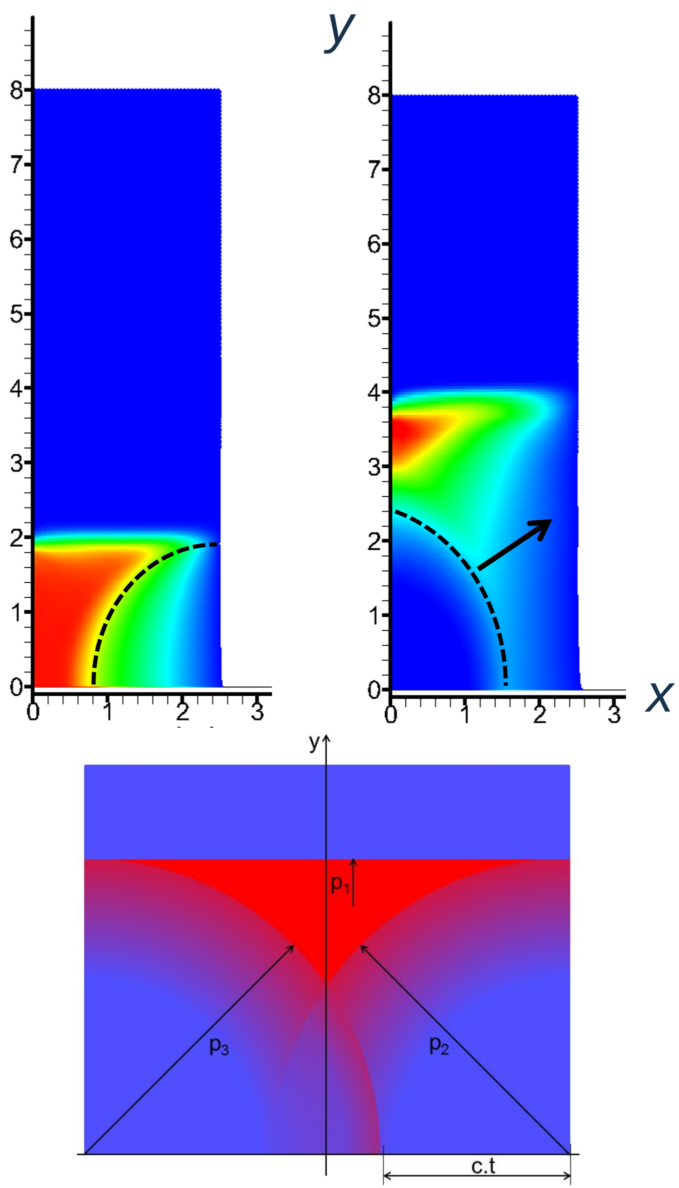


- Flat compression wave P1

$$p_1(x,y,t) = \begin{cases} 0 & for\ t < y/c \\ p_a & for\ \frac{y}{c} \leq t \leq \frac{2H-y}{c} \\ 0 & for\ t > \frac{2H-y}{c} \end{cases}$$

- Circular relaxation wave P2

$$p_2(x,y,t) = \begin{cases} 0 & for\ t < \frac{\sqrt{(L-x)^2+y^2}}{c} \\ -\alpha(t).p_a & for\ t \geq \frac{\sqrt{(L-x)^2+y^2}}{c} \end{cases}$$

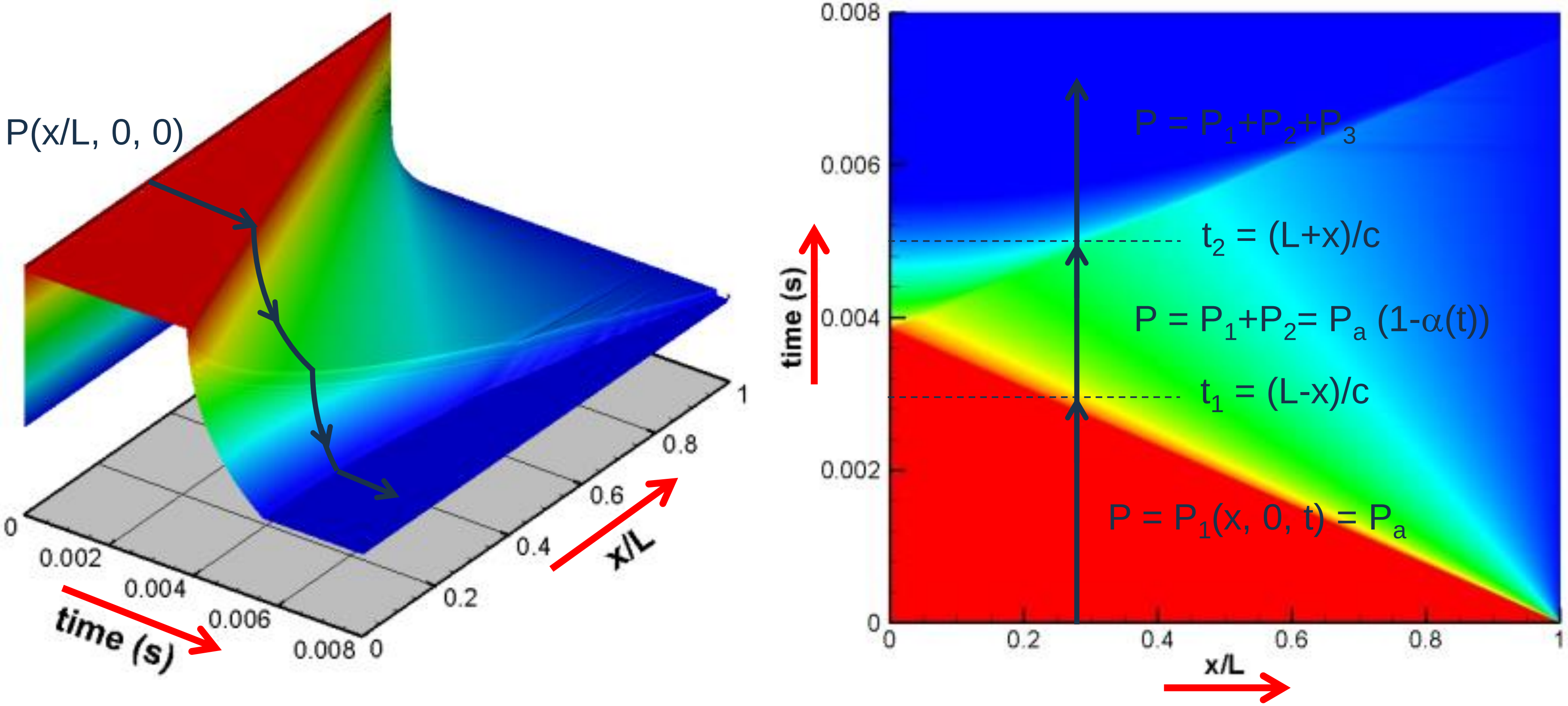
- Circular relaxation wave P3

$$p_3(x,y,t) = \begin{cases} 0 & for\ t < \frac{\sqrt{(L+x)^2+y^2}}{c} \\ -\alpha(t).p_a & for\ t \geq \frac{\sqrt{(L+x)^2+y^2}}{c} \end{cases}$$

Time-space pressure distribution on the wall: $p(x/L, 0, t)$

▶ Perspective

▶ Top view



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Finite R

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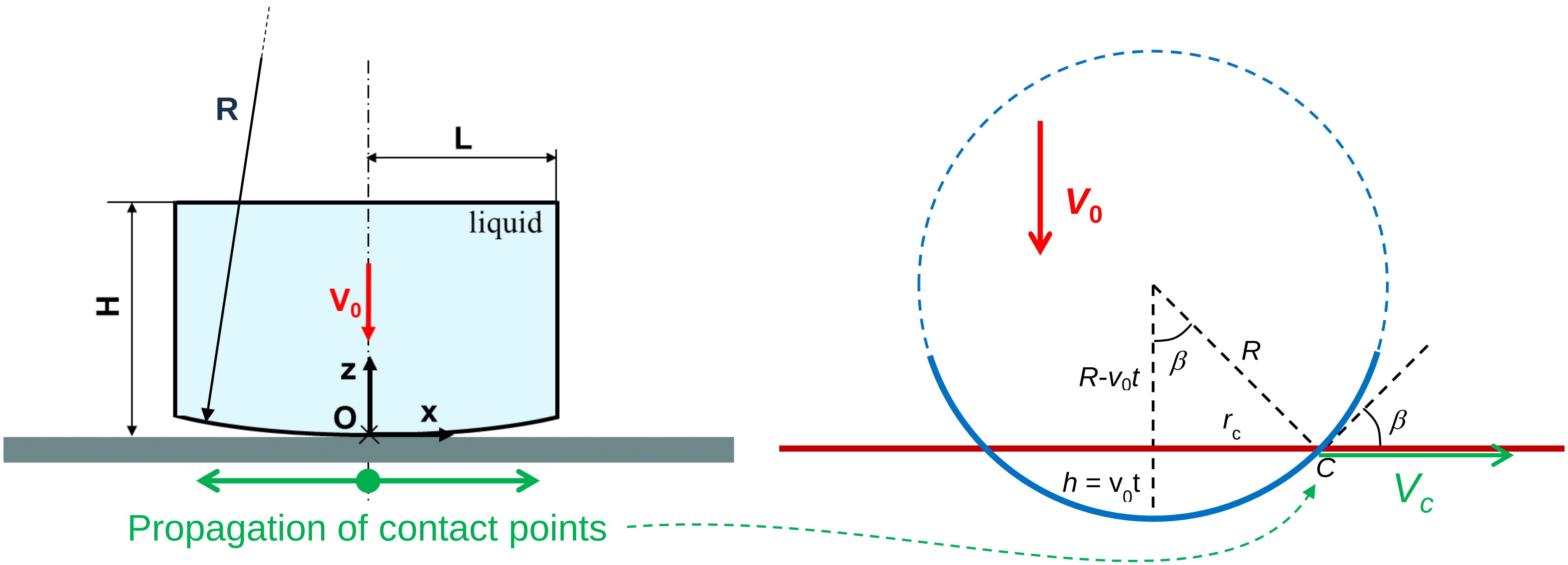
Displacement of the geometrical contact point



- Displacement of the geometrical contact point assuming $V_0 t \ll R$ (small vertical displacement w.r.t. *R*):

$$r_c(t) \approx \sqrt{2RV_0 t}$$

- Speed of the geometrical contact point:

$$V_c(t) \approx \sqrt{\frac{RV_0}{2t}} \Rightarrow \text{Firstly, } V_C \gg c$$

- Existence of a **critical time** $t_{cr} \approx \frac{Rv_0}{2c^2}$ after which $V_c < c$

Pressure field in the liquid column

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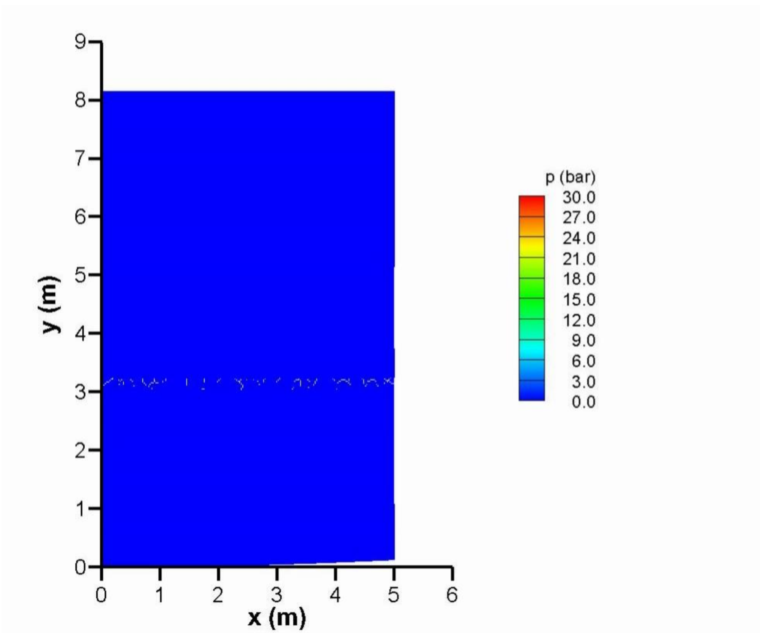
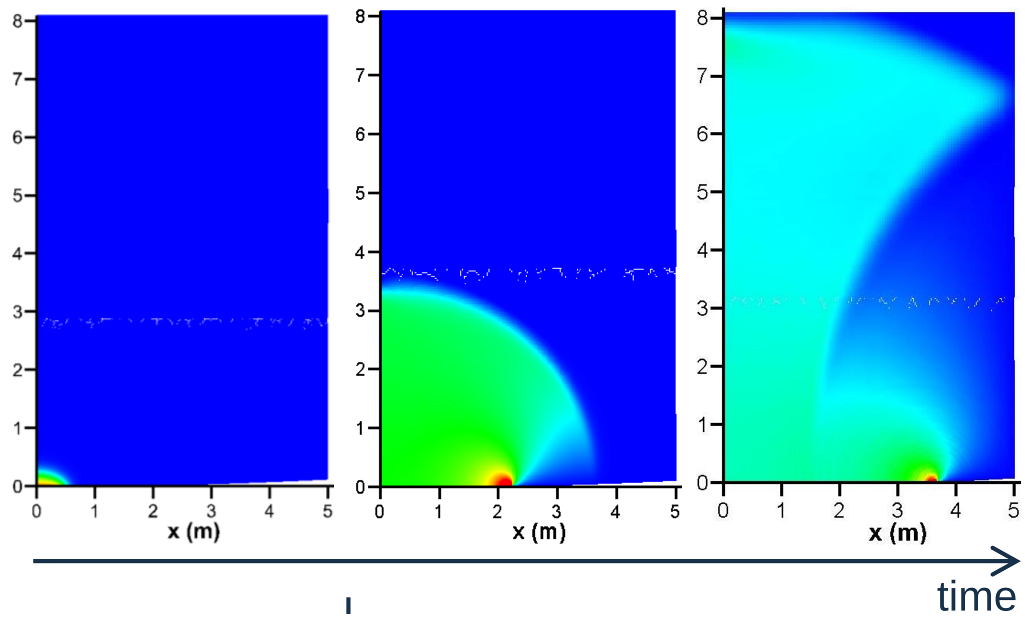
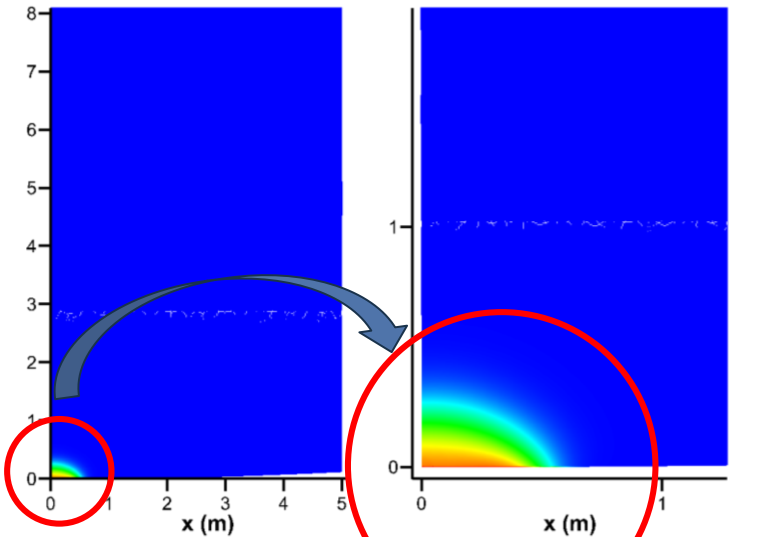


SPH-flow computation



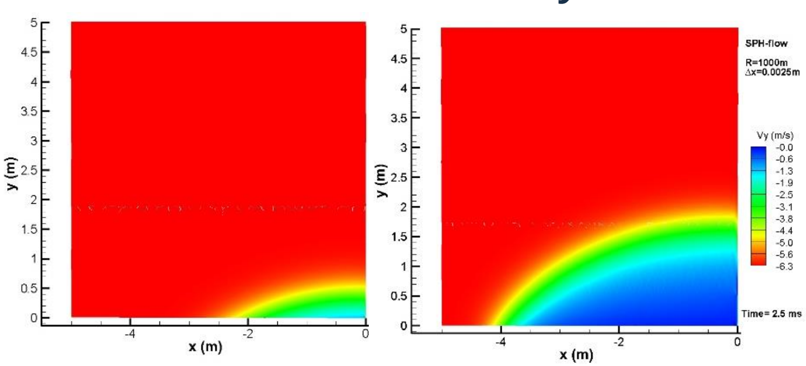
Acoustic phase (compressible, ELP1)

Pressure



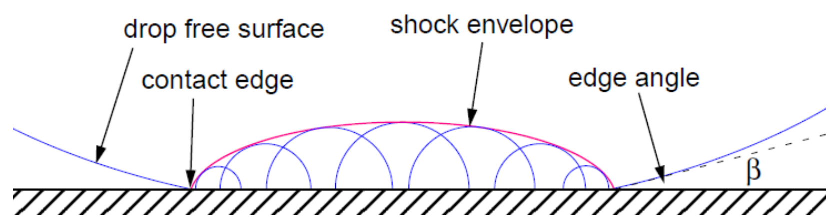
time

Vertical velocity



2 instants

- As long as $V_c > c$:
  - Purely acoustic phase
  - The jet cannot start
  - Succession of impacts at the contact point:

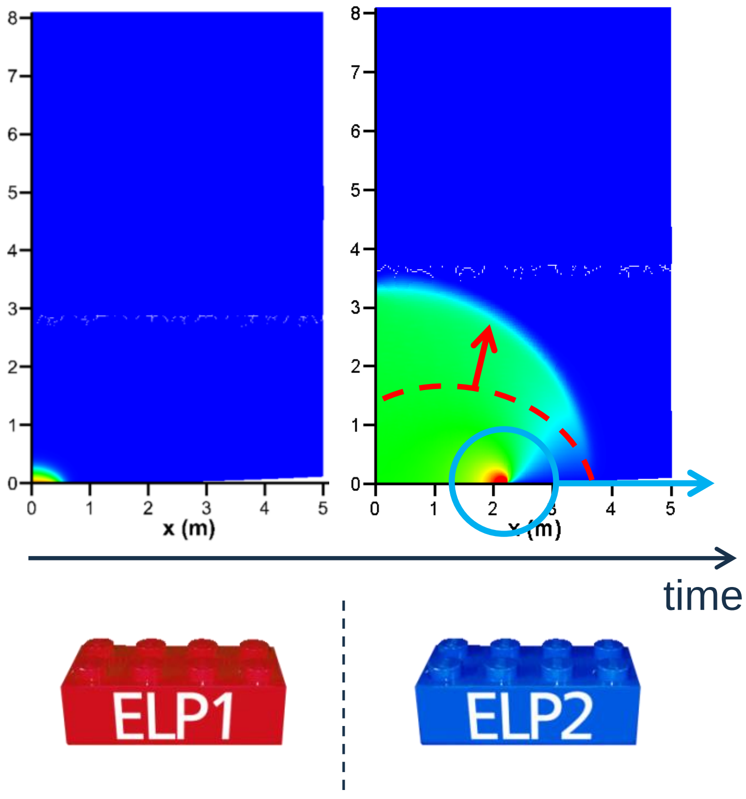


Shock front as envelope of superposed circular waves [(1)]

[(1)] Knežević K. H. (1972). *High-velocity impact of a liquid droplet on a rigid surface: the effect of liquid compressibility*. Dissertation submitted to the Swiss Federal Institute of Technology Zurich for the degree of Doctor of Technical Sciences.

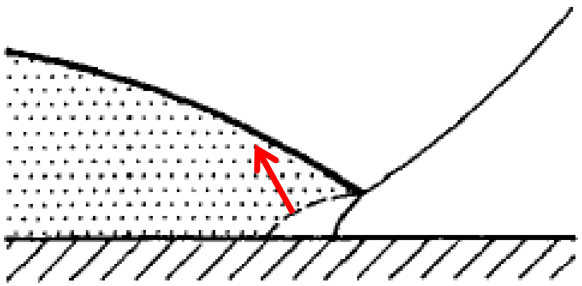
Jet phase (incompressible?, Wagner, ELP2)

Pressure

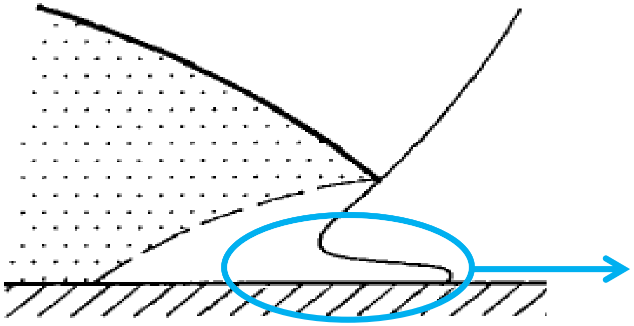


► From $t > t_{cr}$ ($V_c < C$):

- Relaxation wave from critical point



- The jet can build up



Rein M. (1993). *Phenomena of liquid drop impact on solid and liquid surfaces*. Fluid Dynamics Research, vol. 12, pp 61-93.

Birth of the jet (numerical…)

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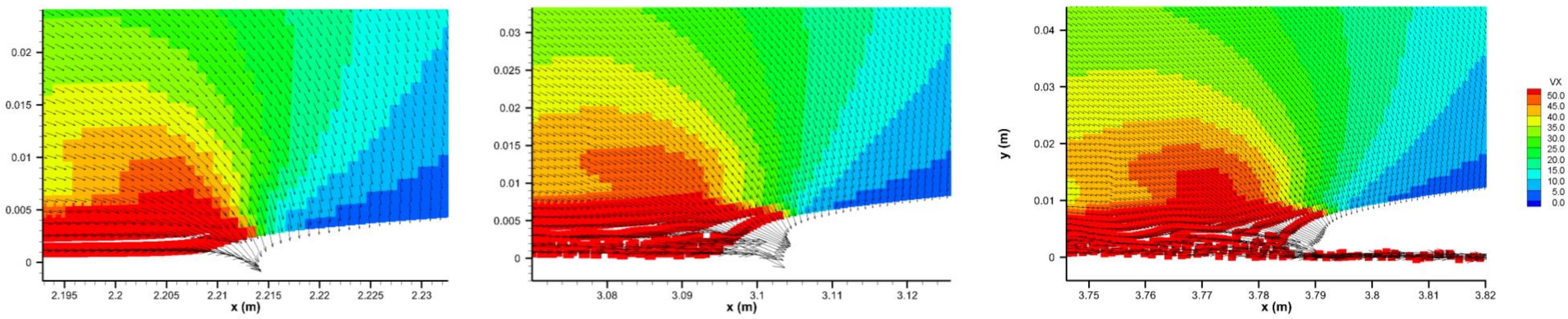
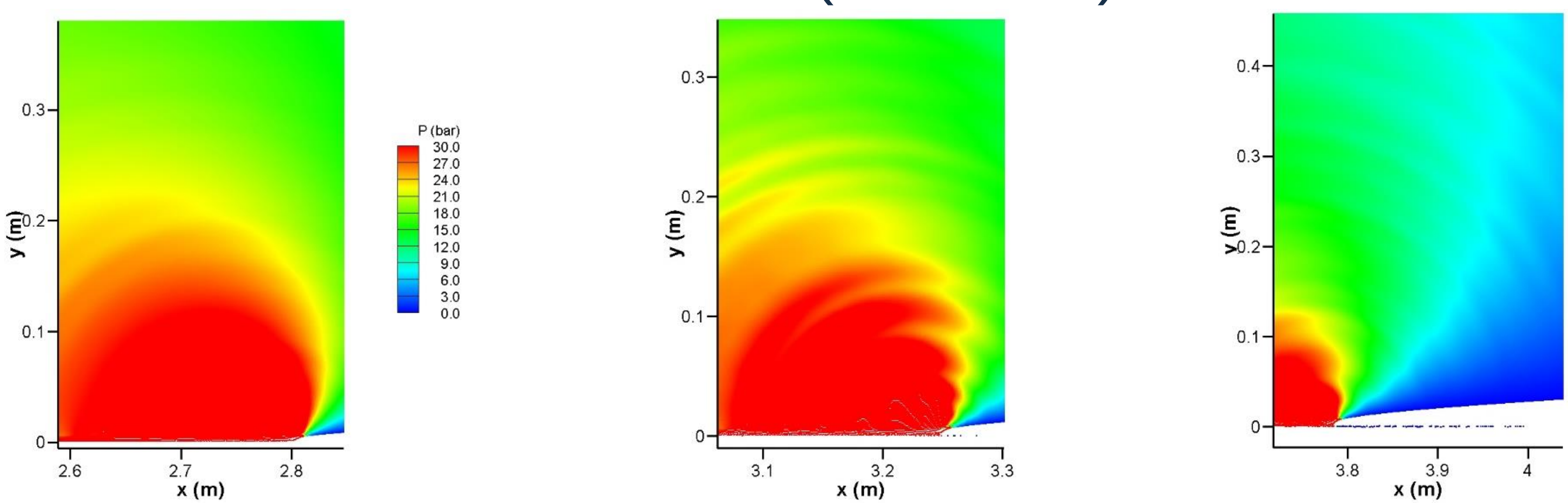
Horizontal velocity field (SPH-flow)



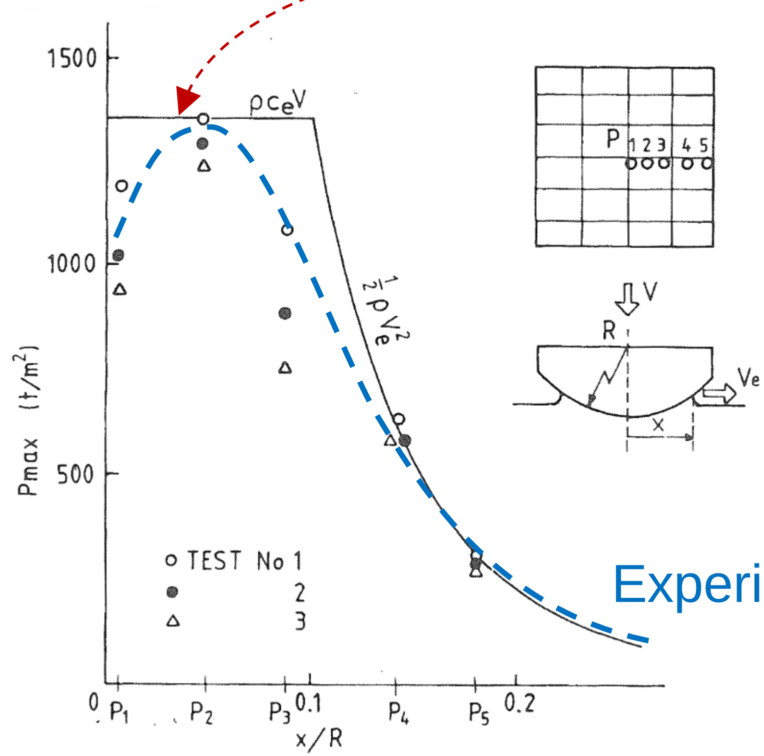
time

Pressure (SPH-flow)



What we had in mind!

Max. pressure = acoustic pressure



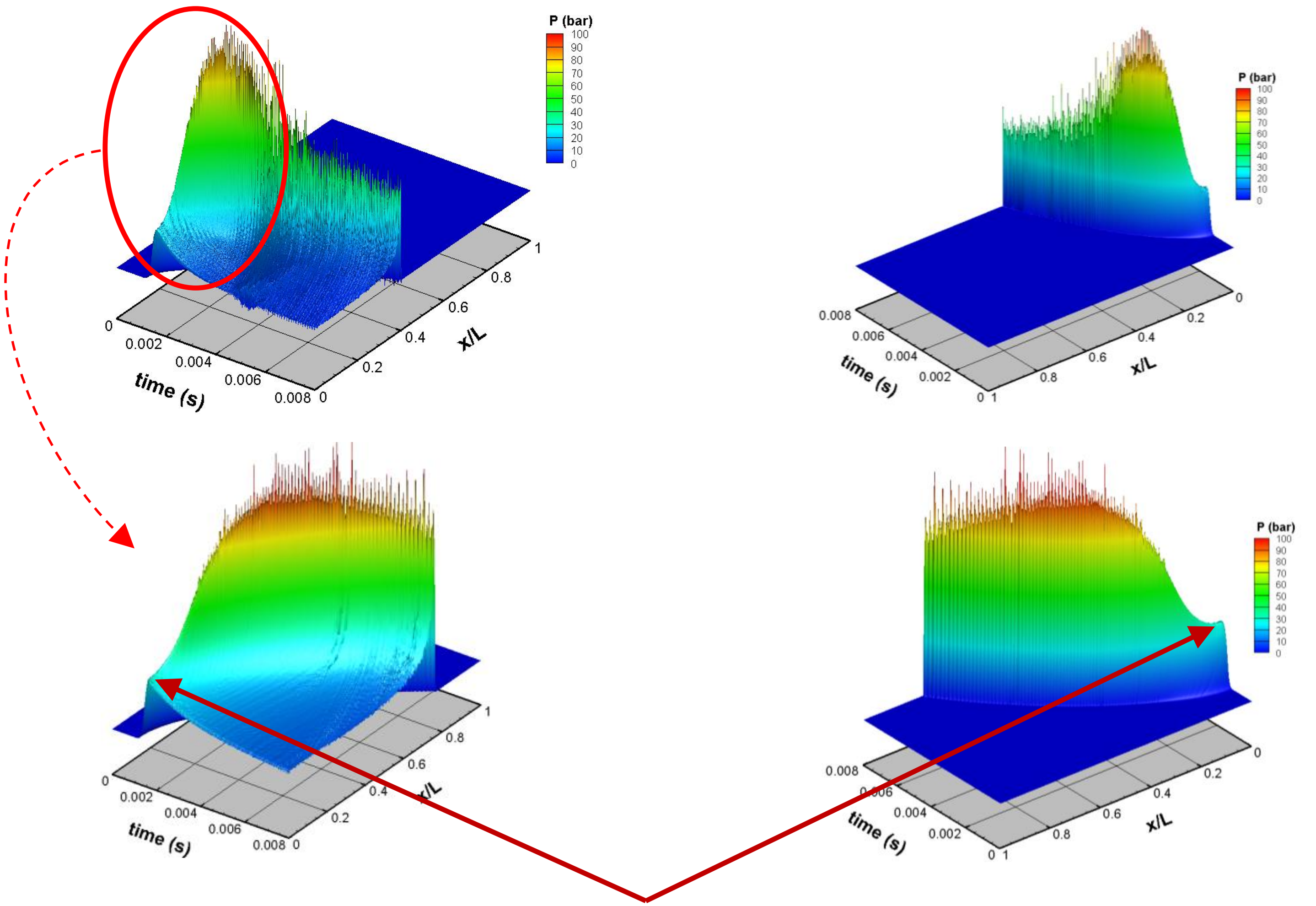
Experiment

Pressure field measured in experimental impact of a cylinder [1]

[1] Faltinsen O. M. (1990). *Sea loads on ships and offshore structures*. Cambridge University Press.

Time-space pressure distribution on the wall

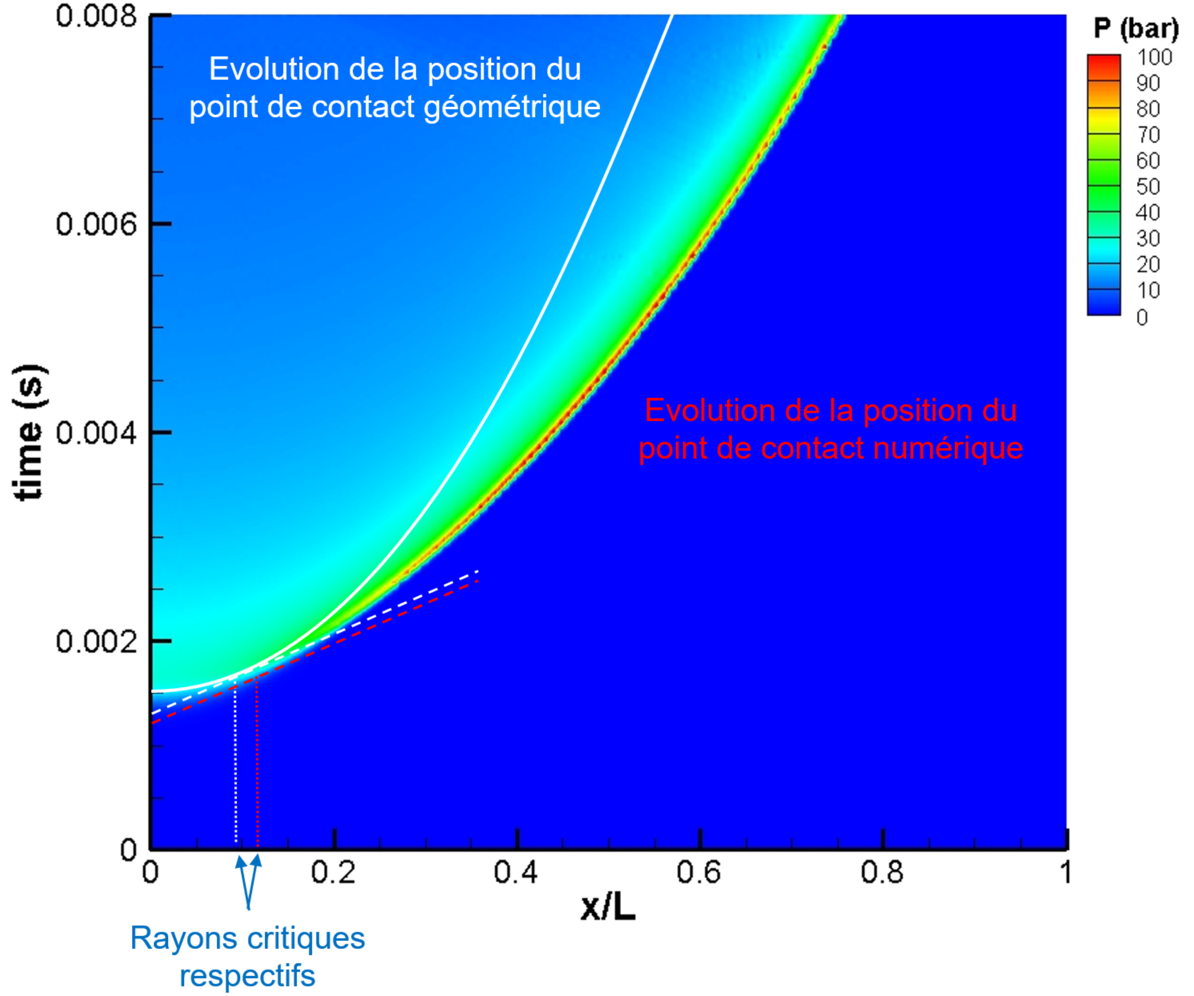
Zoom:



► The acoustic pressure is here

► And it is exceeded!

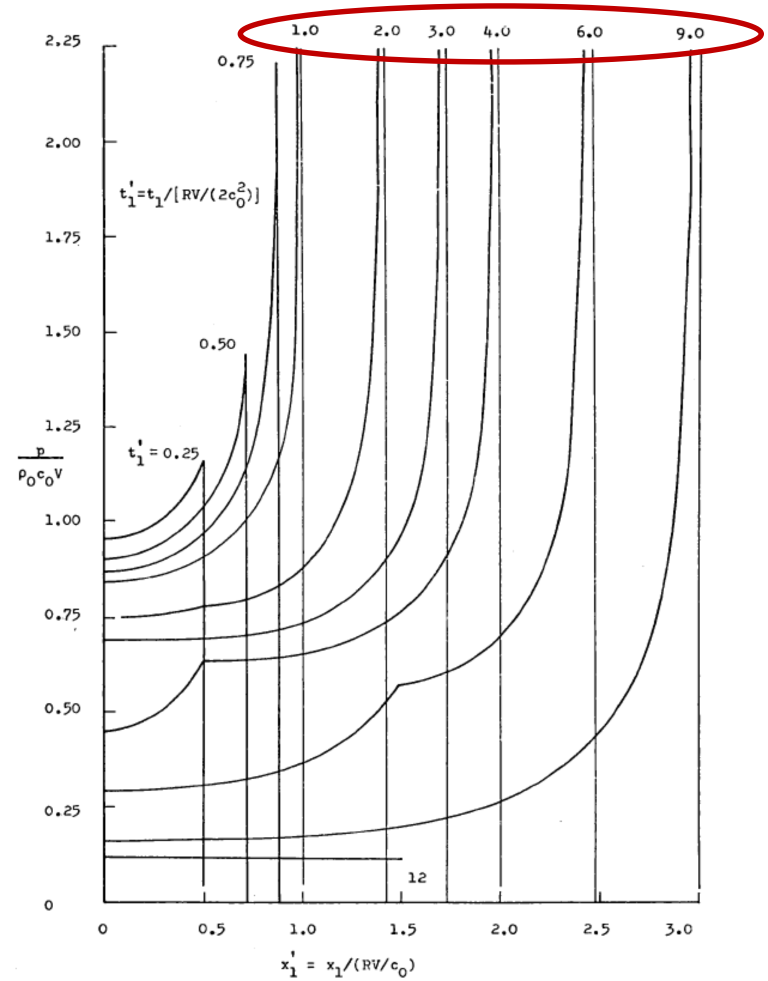
Top view



Geometrical / numerical positions of the contact point

Existing works

- Some references in the litterature about the impact of droplets
- But lack of formulation describing the whole ELP1+ELP2 phenomenon
- ELP2 may be compressible before getting incompressible



Pressure field at the wall at different time instants [(1)]

[(1)] Rochester M. C. (1977). *The impact of a solid drop with a solid surface*. University of Cambridge.

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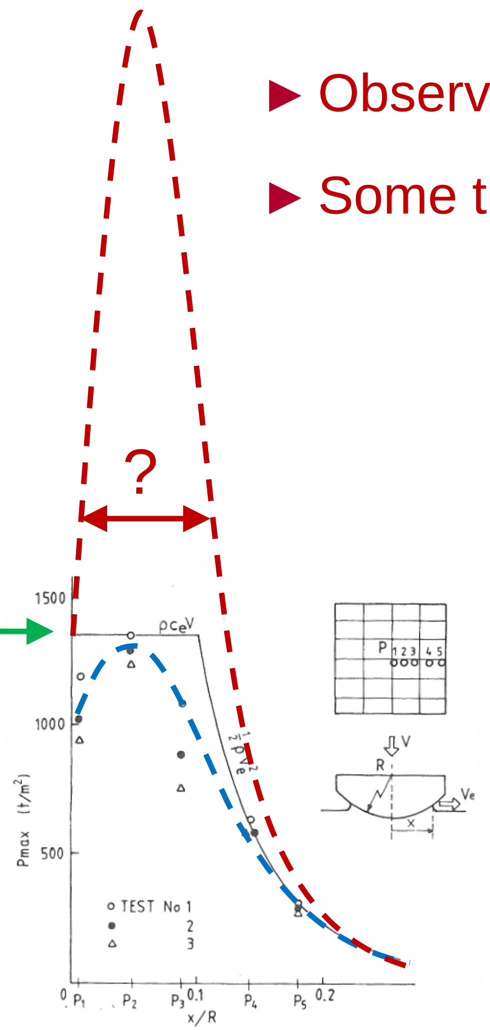
Conclusion

How the pressure field on the wall might look like

- ► Observed with two codes in the study
- ► Some theoretical works in the literature

Acoustic pressure



Experiment:

- ► Was it able to measure high pressure peaks?
- ► Influence of the air?

Pressure field measured in experiment of impact of a rigid cylinder [1]

[1] Faltinsen O. M. (1990). *Sea loads on ships and offshore structures*. Cambridge University Press.

Conclusion

- Pressure on the wall exceeds $\rho c V_0$! :
  - Rather unexpected
  - Be careful: potentially very short in time and concentrated in space
- References found in the litterature (impact of droplets, Koropkin, etc.)
- Phenomenology to complete
- Now we have to go deeper in the formulations:
  - ELP1: analytical model possible
  - ELP2: « compressible Wagner theory »?
- Aim unchanged:
  - Canonical model to represent this phase by locally approaching the crest free surface by a constant curvature
  - Scale rules
- Perspectives :
  - Addition of model of local small gas pocket in the crest

Thank you for your attention

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