Fluid-Structure Interaction: simulating the cavitation phenomenon

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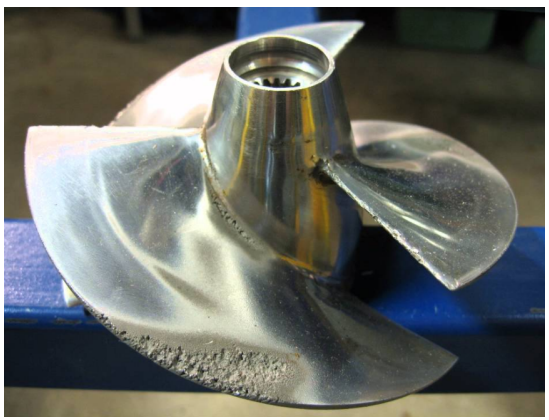
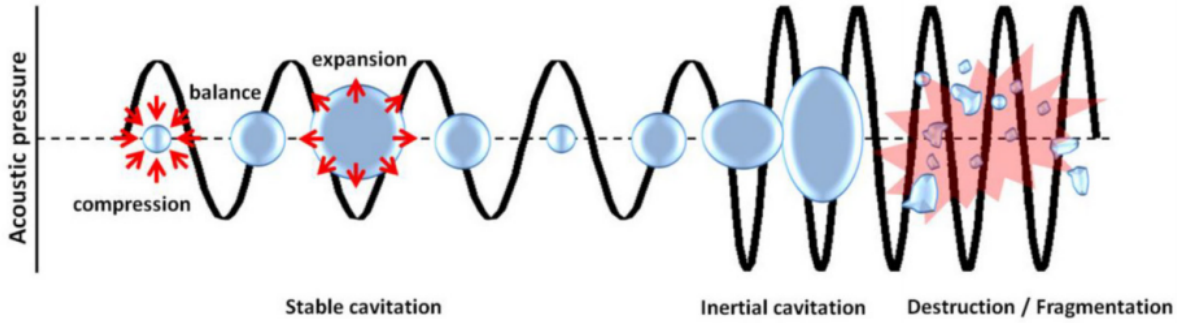
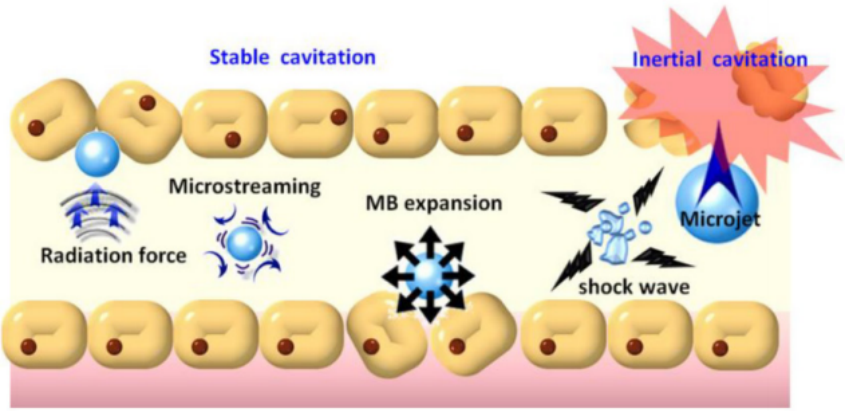
Cavitation effects

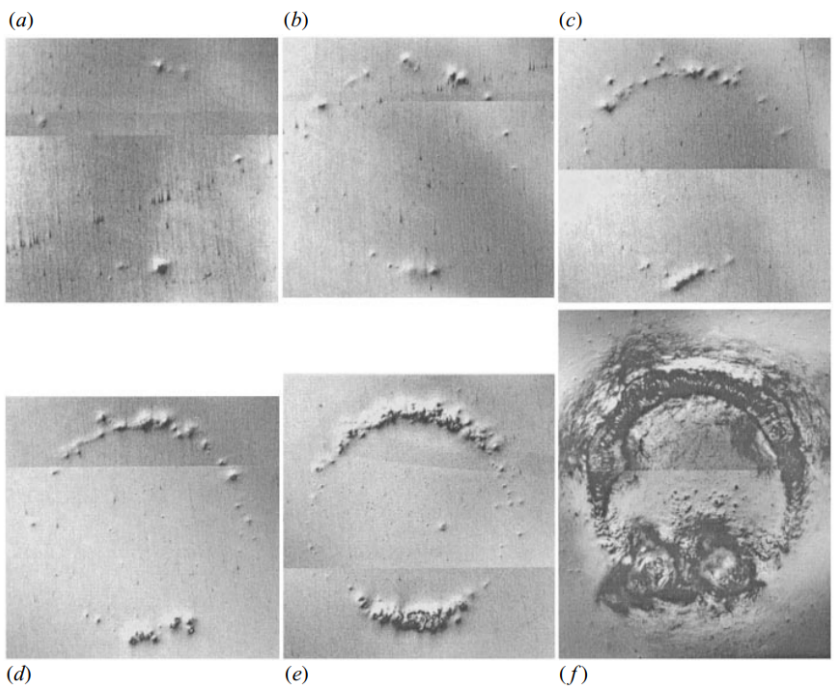


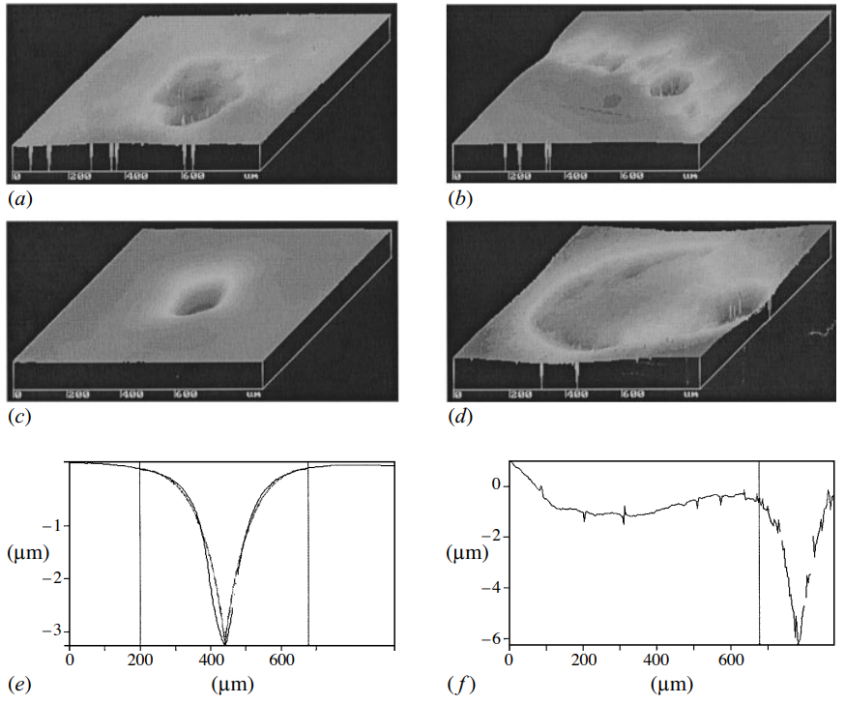
Cavitation effects





Cavitation damage





Philipp, A., & Lauterborn, W. (1998). Journal of Fluid Mechanics.

Diffuse Interface Model: Thermodynamics

Van der Waals gradient approximation of the Helmholtz free energy functional:

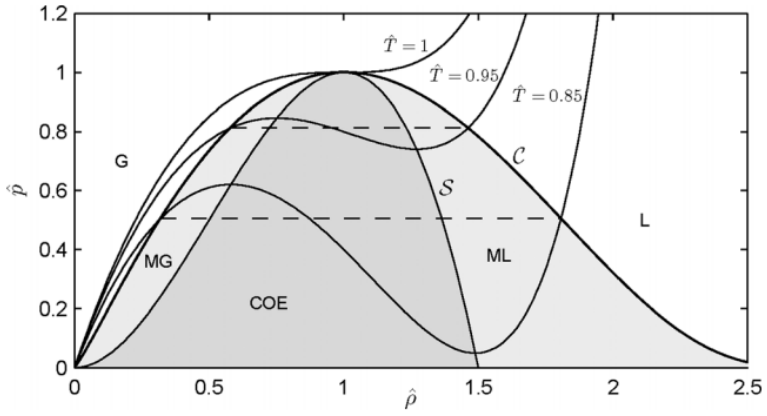
$$F = U - \theta S$$

$$F(\rho, \nabla\rho, \theta) = \int_{\mathcal{B}} \left[f_0(\rho, \theta) + \frac{\lambda}{2} |\nabla\rho|^2 \right]$$

- $f_0(\rho, \theta)$ is the classical bulk free energy density;
- The gradient term $\frac{\lambda}{2} |\nabla\rho|^2$ energetically penalizes sharp interfaces.

- Equation of state $P(\rho, \theta)$

Van der Waals, IAPWS, etc.



$$p_0 = R\frac{\rho\theta}{1 - b\rho} - a\rho^2$$

Diffuse Interface Model: Field Equations

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0$$

$$\frac{\partial \rho \mathbf{u}}{\partial t} + \nabla \cdot (\rho \mathbf{u} \otimes \mathbf{u}) = \nabla \cdot T$$

$$\frac{\partial E}{\partial t} + \nabla \cdot (E\mathbf{u}) = \nabla \cdot (T \cdot \mathbf{u} - \mathbf{q}_e)$$

$$T = \left(-p_0 + \frac{\lambda}{2} |\nabla \rho|^2 + \rho \nabla \cdot (\lambda \nabla \rho) \right) I + - \lambda \nabla \rho \otimes \nabla \rho + \mu(\nabla \mathbf{u} + (\nabla \mathbf{u})^T) - \frac{2}{3} \mu (\nabla \cdot \mathbf{u}) I$$

$$\mathbf{q}_e = -k \nabla \theta + \lambda \rho \nabla \rho \nabla \cdot \mathbf{u}$$

$$\rho \frac{\mathrm{D}\hat{s}}{\mathrm{D}t} = \nabla \cdot \left(\frac{\lambda \rho \nabla \rho \nabla \cdot \mathbf{u} - \mathbf{q}_e}{\theta} \right) + \frac{\lambda \rho \nabla \rho \nabla \cdot \mathbf{u} - \mathbf{q}_e}{\theta^2} \cdot \nabla \theta + \frac{1}{\theta} \left[T + \left(p_0 - \frac{\lambda}{2} |\nabla \rho|^2 - \rho \nabla \cdot (\lambda \nabla \rho) \right) I + \lambda \nabla \rho \otimes \nabla \rho \right] : \nabla \mathbf{u}$$

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- The model handles liquid and vapor phases at the same time
- All physical quantities and behaviors are naturally embedded (e.g. surface tension, latent heat, phase changes, ...)

Artificial thickening of the interface

- Less computational efforts
- Mantaining the macroscopic physical quantities unchanged (e.g. surface tension, latent heat)

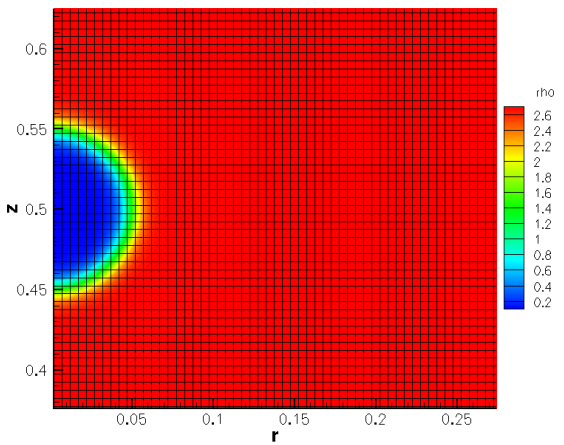
$$(\mu^{mod} - \mu^{eq})\big|_{\rho_l,\rho_v} = 0$$

$$\int_{\rho_v}^{\rho_l} (\mu^{mod} - \mu^{eq})\,\mathrm{d}\rho = 0$$

$$\left.\frac{\mathrm{d}\mu}{\mathrm{d}\rho}\right|_{\rho_l,\rho_v} = \frac{1}{\rho}\left.\frac{\mathrm{d}P}{\mathrm{d}\rho}\right|_{\rho_l,\rho_v}$$

$$\sigma = \lambda \int_{\rho_v}^{\rho_l} \rho'(x)\,\mathrm{d}\rho$$

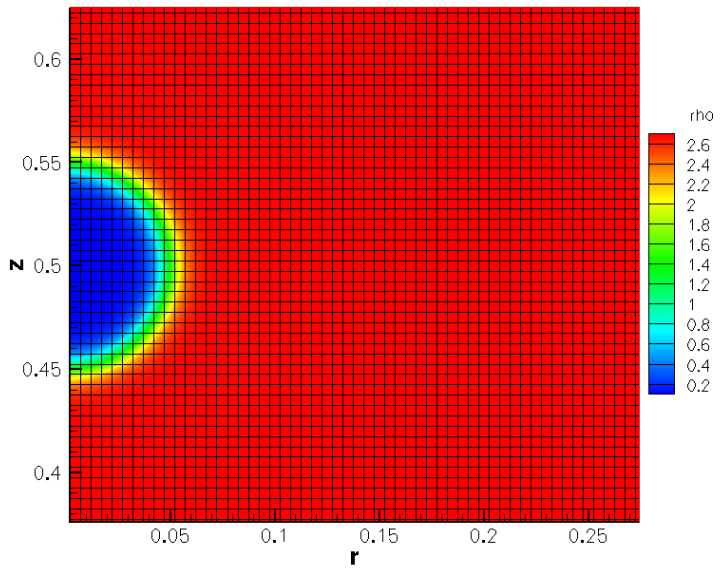
$$h = \frac{\rho_l - \rho_v}{\max|\rho'(x)|}$$



Jamet, D., Lebaigue, O., Coutris, N., & Delhaye, J. M. (2001). Nuclear engineering and design.

How can deal.II help

- Ability to refine the mesh to obtain a better space resolution in the desired zone
- Possibility of studying the phenomenon in non-trivial domains
- Full coupling between fluid and structural part



Future perspectives

Main objectives

- Have a working code to simulate the fluid behavior.
- Find a feasible description for real materials, to be used for simulating the material behavior (plasticity, viscoplasticity, crystal plasticity).
- Simulate the fluid-structure interaction.

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THANK YOU FOR YOUR ATTENTION