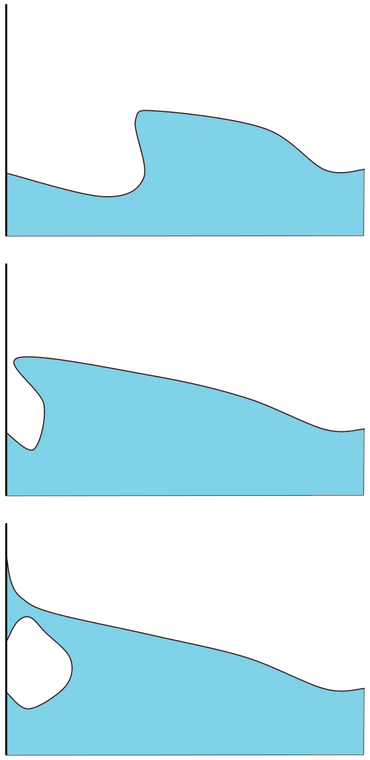
High-Fidelity Finite Elements Simulations of Two-Phase Flows for Fast and Accurate Estimation of Wave Impact Pressure

Yohann Vautrin, Dominique Pelletier and Stéphane Etienne

Dept. of Mechanical Engineering - Polytechnique Montréal, C.P. 6079, succ. Centre-Ville, Montréal, Québec, H3C 3A7, Canada

SLAMMING PHENOMENON

- **Violent wave impacts on rigid structures** (slamming) can cause **severe structural damage**
- **Multiple engineering fields concerned**: maritime transport (oil tankers, LNG carriers), spacecraft propulsion (LO_2 and LH_2 tanks), ...
- Multitude of **complex, localized, small-scale and high-frequency** phenomena happening at the interface between fluids (e.g.: K-H and R-T instabilities)
- Conditions are **hard to replicate experimentally**
- Accurate numerical simulations require **state-of-the-art modelling of physics and numerical methods**

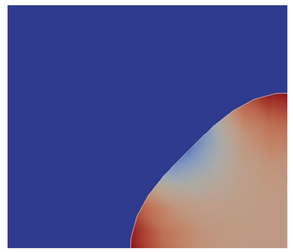


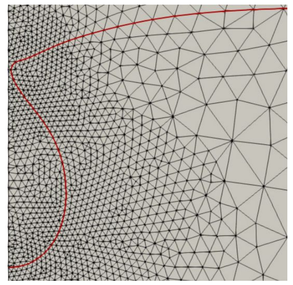
OBJECTIVES

This project aims at developing a **fast and accurate** finite-element solver for **separated two-phase flows** problems using an **interface-tracking method**, **advanced numerical algorithms and physical models,** in order to be able to better **estimate wave impact pressure on rigid structures**.

METHODOLOGY

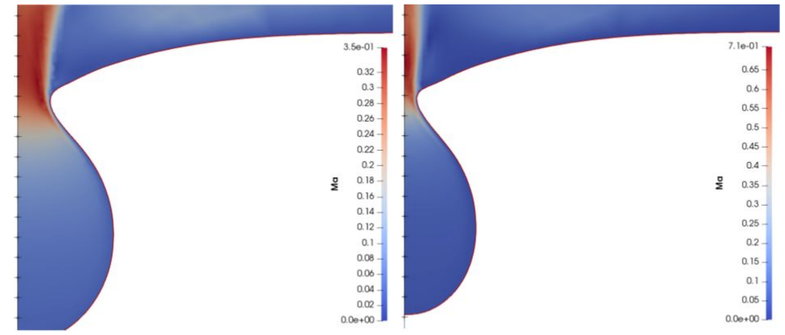
1. **Implement state-of-the-art models** for surface tension forces and contact line dynamics
2. **Develop and implement an efficient and robust algorithm** to handle changes in interface topology
3. **Ensure the correctness of the implement and validate the results** against analytical and theoretical data
4. **Demonstrate the capabilities of the software** on large scale industrial cases



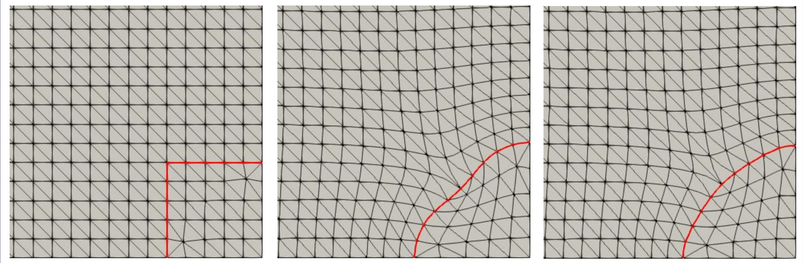


PRELIMINARY RESULTS

Simulation of a slamming wave with compressibility effects

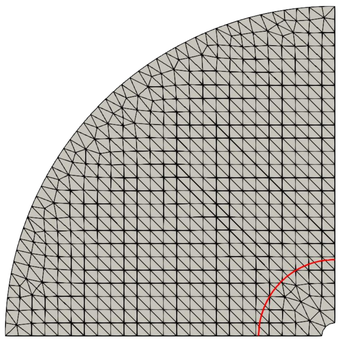


Simulation of an arbitrary volume of fluid changing shape because of surface tension forces (including contact angle)



INTERFACE REPRESENTATION

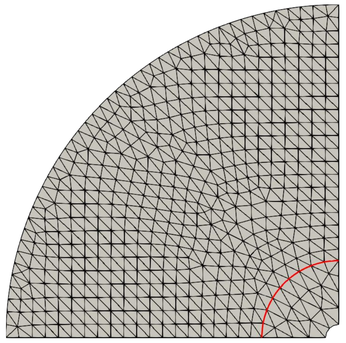
Interface capture



Interface representation with a scalar function (level set, VoF, ...)

- \+ Easy to handle topological changes
- \+ Fluid mesh does not move
- − Low resolution of interfacial structures and low spatial accuracy at the interface
- − Harder to accurately represent interfacial physics

Interface tracking



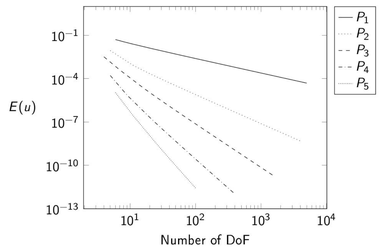
Explicit representation in the mesh (**our approach**)

- \+ Able to represent small structures (local refinement)
- \+ Better representation of interfacial phenomena
- − Handling of topological changes is challenging
- − Mesh must deform (might require remeshing)

VERIFICATION & VALIDATION

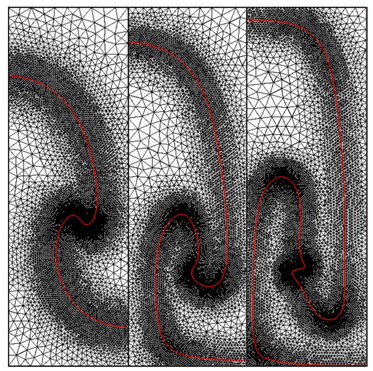
Verification

- Original problem $\mathcal{L}(u) = 0$
- Choose u_m $\mathcal{L}(u_m) = g$
- Modified problem $\mathcal{L}(u) = g$



- Ensures that the models and methods are implemented correctly
- MMS: exact solution chosen and modified problem solved
- Exact numerical error available, order of accuracy compared to theoretical order

Validation



- Ensures that the models and methods give an accurate representation of physics
- Experimental data and analytical models can be used
- Examples: growth rates of R-T and K-H instabilities, rising bubble, ...

CONCLUSIONS & FURTHER WORK

- **Interface tracking method coupled with an adaptive remeshing algorithm** shows **tremendous capabilities** to accurately predict the evolution of separated two-phase flows
- Implementation of a **variational formulation for the surface tension forces** done and in progress of being tested and validated
- **Design and implementation of an algorithm to handle changes in interface topology**, the cornerstone of this work, has yet to be done
- Should lead to **significant advances in the numerical study of interfacial instabilities**, but also in the studies of such fields as **primary atomization, bubbles and droplets**

NOMENCLATURE

- **K-H** Kelvin–Helmholtz instability
- **R-T** Rayleigh–Taylor instability
- **LNG** Liquified Natural Gas
- **VoF** Volume of Fluid Method
- **LO_2** Liquid Oxygen
- **LH_2** Liquid Hydrogen
- **MMS** Method of Manufactured Solutions

ACKNOWLEDGMENTS

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