

## **Travail de Fin d'Etudes : Development of a compressible flow solver for PFEM fluid simulations**

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**Faculté :** Faculté des Sciences appliquées

**Diplôme :** Master en ingénieur civil physicien, à finalité approfondie

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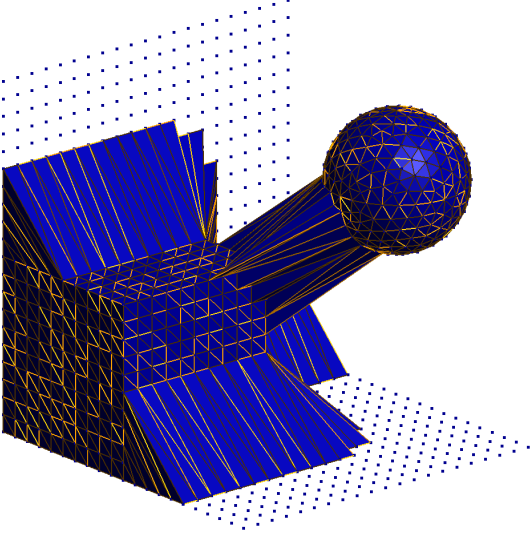
ATFE9007-1 - FINAL THESIS  
(INCLUDED AN INTRODUCTION TO RESEARCH METHODOLOGY)

# Development of a 3D compressible flow solver for PFEM fluid simulations

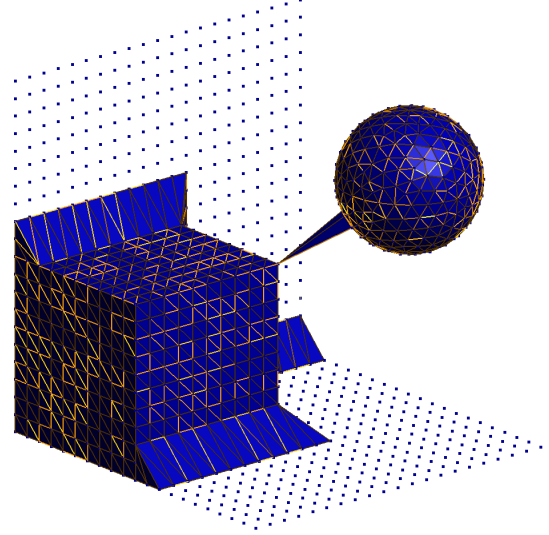
*Master of Science (MSc) in Engineering Physics*

**Supervisors:** Jean-Philippe Ponthot, Romain Boman

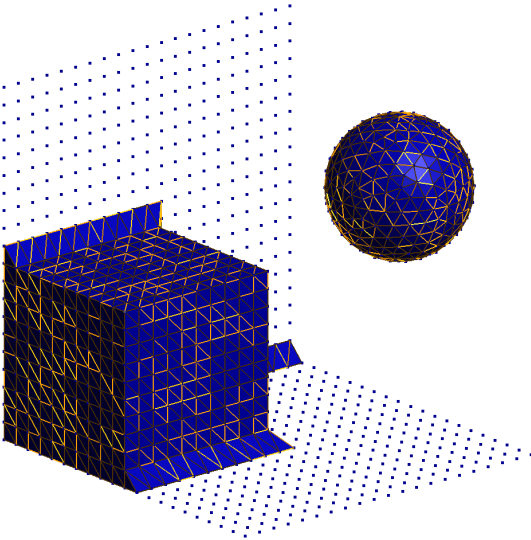
A solver using the Particle Finite Element Method (PFEM) for incompressible and weakly-compressible Navier–Stokes equations is developed in order to simulate quasi incompressible 3D flows. The equations describing these types of flows are recalled in their analytical form. The PFEM method and the discretized version of the equations are described in 3D, using an implicit scheme for the incompressible equations and an explicit scheme for the compressible ones. The problem of 3D triangulation and alpha shape algorithm is solved by using the Computational Geometry Algorithms Library (CGAL). The results are compared to the solver developed during the PhD thesis of M.-L. Cerquaglia as well as analytical results when available. The solver, although able to simulate flows with fluids near incompressibility quite well, seems to have more difficulties simulating fluids which are too compressible.



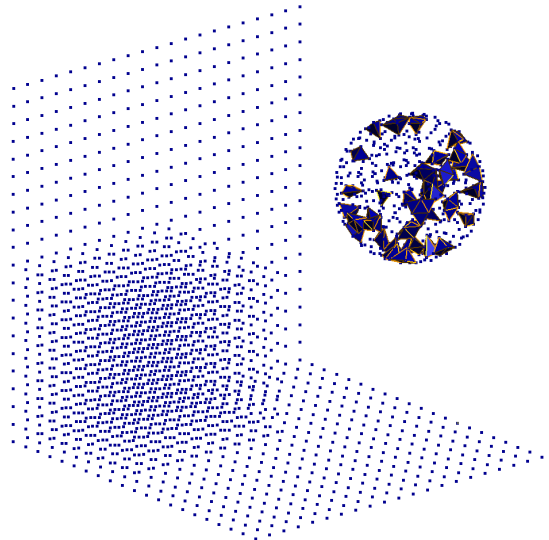
(a)  $\alpha = 5$ .



(b)  $\alpha = 2.5$ .

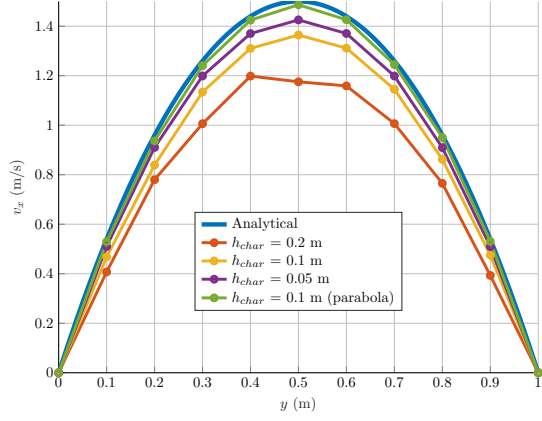


(c)  $\alpha = 1.25$ .

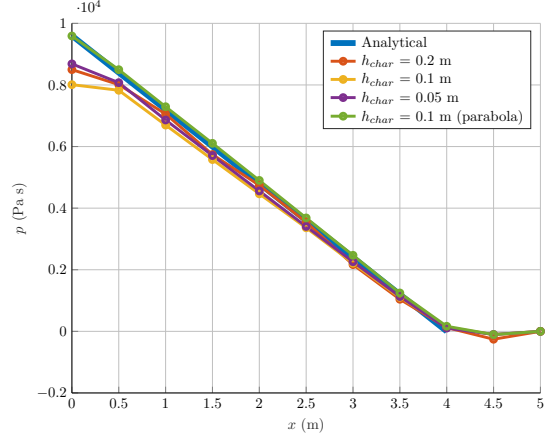


(d)  $\alpha = 0.625$ .

Figure 1: Alpha-shape algorithm results on a Delaunay triangulation for various  $\alpha_{C,M}$  values using CGAL in 3D ( $h_{char} = 1$  unit of length).



(a) Horizontal velocity profile along  $x = 3$  m.



(b) Pressure profile along  $y = 0.5$  m.

Figure 2: Simulation results for a flow between two plates of four metres long separated by 1 metre, with a uniform horizontal velocity flow of 1 m/s at the left entrance of the plates. Results at  $t = 4$  s.

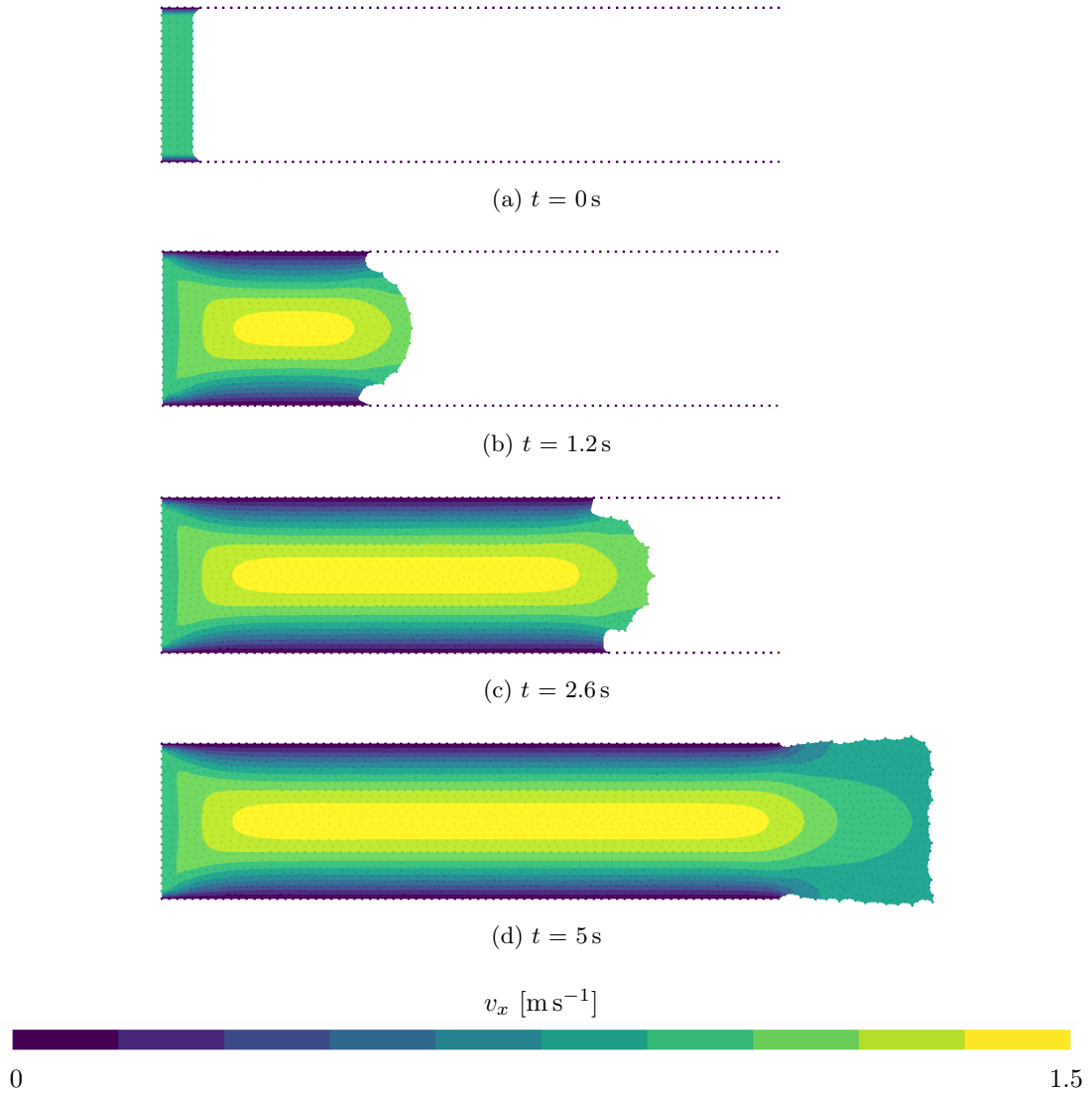
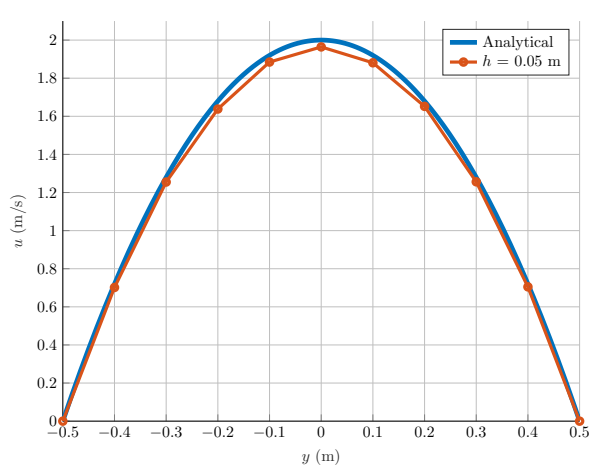
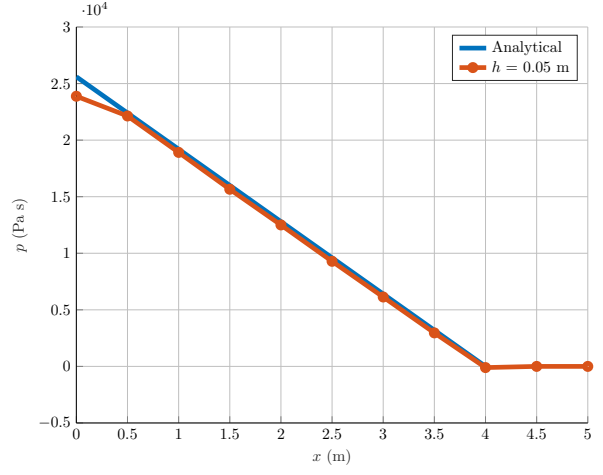


Figure 3: Horizontal component of the velocity at different times for a flow between two plates of four metres long separated by 1 metre, with a uniform horizontal velocity flow of 1 m/s at the left entrance of the plates. Element characteristic size of 0.05 m.

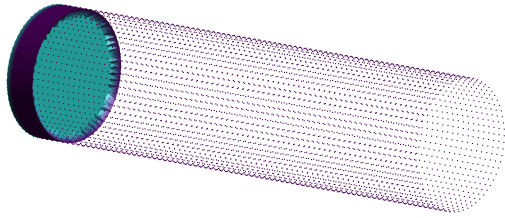


(a) Horizontal component of the velocity as a function of  $y$  at  $x = 3$  m.

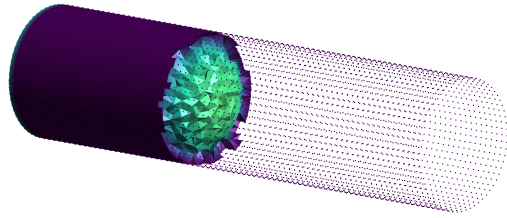


(b) Pressure along the pipe center.

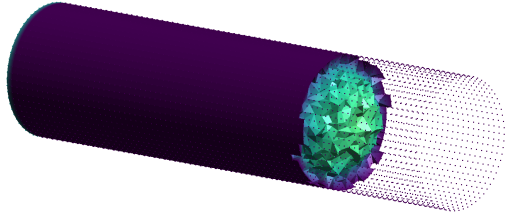
Figure 4: Simulation results for a flow inside of pipe four metres long with a one metre diameter with a uniform entrance velocity of 1m/s. Results at  $t = 2.7$  seconds.



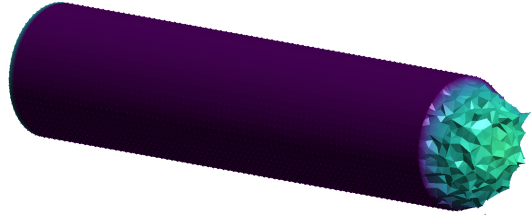
(a)  $t = 0$  s



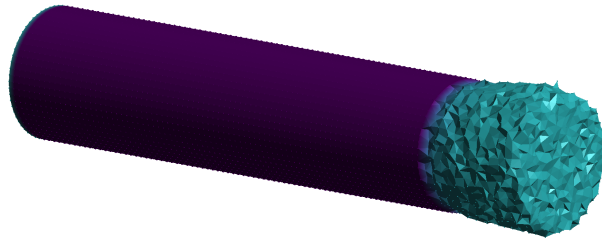
(b)  $t = 1$  s



(c)  $t = 2$  s



(d)  $t = 3$  s



(e)  $t = 4$  s

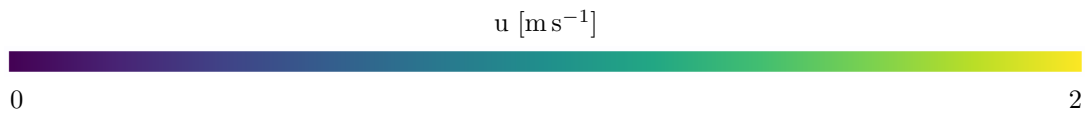
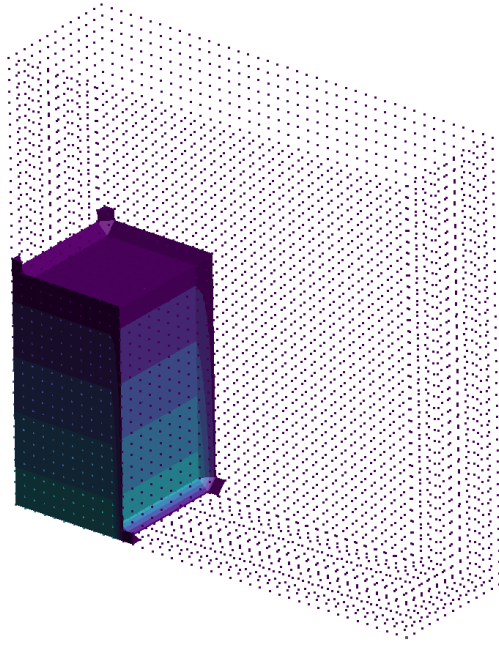
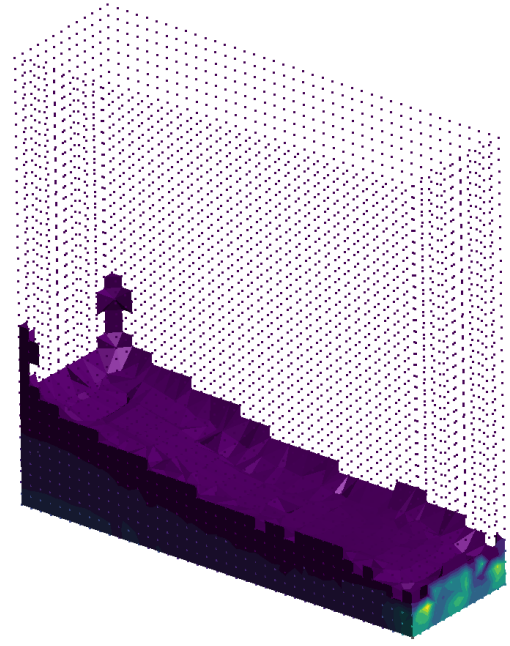


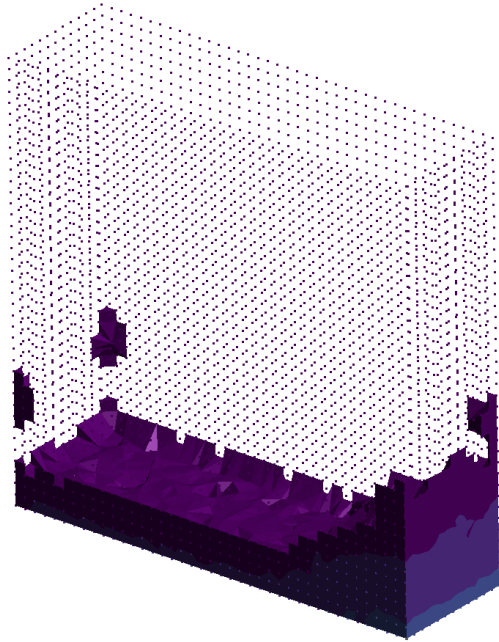
Figure 5: Simulation results for a flow inside of pipe four metres long with a one metre diameter with a uniform entrance velocity of 1m/s. Element characteristic size  $h_{char} = 0.05$  m.



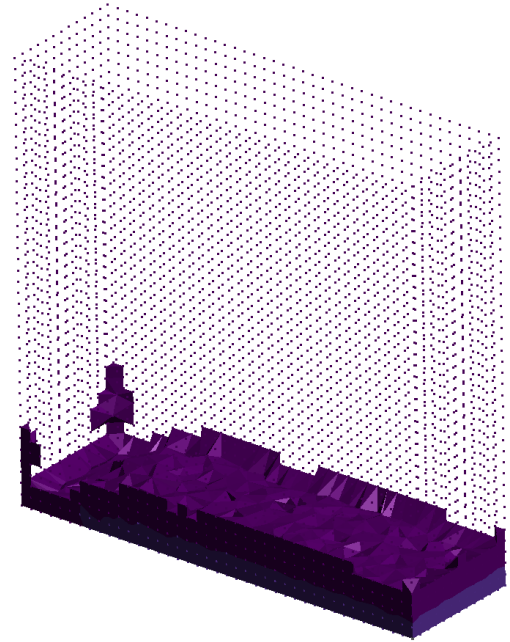
(a)  $t = 0 \text{ s}$



(b)  $t = 0.3 \text{ s}$



(c)  $t = 0.65 \text{ s}$



(d)  $t = 1 \text{ s}$

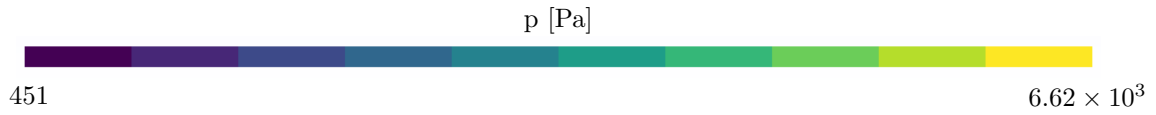


Figure 6: Pressure at multiple time stations for a parallelepiped of fluid of dimension (0.146 m, 0.175 m, 0.292 m) initially at rest, in a box of dimensions (0.584 m, 0.175 m, 0.584 m).