# Méthodes Particle-in-Cell (PIC) en mécanique des fluides

MATH0471 – Spring 2026

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November 13, 2025

This project consists in studying Particle-in-Cell (PIC) methods for solving fluid mechanics problems. PIC methods are numerical techniques that model continuum media—such as plasmas, fluids, or solids—by representing them with computational particles whose motion is tracked in time. Field quantities (e.g., density, velocity, or stress) are computed on a fixed grid, while the particles exchange information with the grid through interpolation and deposition steps, allowing accurate coupling between Lagrangian and Eulerian descriptions.

The project is organized as follows:

1. Students will be divided in 3 groups. Each group will write its own solver.
2. Four intermediate deadlines are given, with a mandatory (but not graded) progress report that should detail the computer implementation and the mathematical, numerical and physical experiments.
3. The final report (about 60 pages) will present the method and numerical results, the computer implementation and a detailed analysis of physical experiments on non-trivial configurations.
4. An oral presentation of the main project results will be organized during the June exam session; individual theoretical and practical questions will be asked to each member of each group.

In the first part of the project, each group will develop a solver implementing the semi-Lagrangian approach (i.e., without particles: cf. [1], ch 3) on a 2D Cartesian grid. Three variants of the PIC method will then be implemented by each group: vanilla PIC ([1], ch 7), Fluid Implicit Particle (FLIP) and Affine APIC (APIC) [2]. Each method will be validated and its performance analyzed on test-cases of increasing complexity: Couette flow and vortex shedding behind a cylindrical obstacle (a "von Karman vortex street") for all methods; dam break and other free surface flow cases for PIC, FLIP and APIC.

In the second part of the project, each group will further develop its solver to tackle one challenging physical, numerical or computational topic. Possible topics include: 3D simulations, more accurate handling of boundaries, GPU acceleration.

Important dates:

1. **Tuesday February 3rd: Intermediate deadline #1 – JSON parameter input and Paraview output for velocities, pressure and particles.** Implementation of C++ functions to read input parameters from a JSON file and output clouds of particles as well as time-series of prescribed velocities and pressures on a Marker-And-Cell (MAC) grid in VTK format.

2. **Wednesday February 25th: Intermediate deadline #2 – Semi-Lagrangian solver.** Implementation of the semi-Lagrangian method in 2D, parallelized with OpenMP.

3. **Wednesday March 25th: Intermediate deadline #3 – Extension to the vanilla PIC method.** Extension of the code to handle the vanilla PIC method, with comparison and validation on selected test-cases.

4. **Wednesday April 15th: Intermediate deadline #4 – Extension to FLIP and APIC.** Modification of the code to handle FLIP and APIC methods, with comparison and validation on selected test-cases.

5. **Friday May 15th: Final deadline – Advanced topic of choice.** Final report and code.

6. **June exam session.** Oral presentation of the projects.

The full source code and report in PDF format should be tagged in the ULiège Gitlab for each deadline. Each group should send an email to r.boman@uliege.be and cgeuzaine@uliege.be for each deadline once the code and report are ready to be reviewed.

# References


[1] Robert Bridson. *Fluid simulation for computer graphics.* AK Peters/CRC Press, 2015.

[2] Chenfanfu Jiang, Craig Schroeder, Andrew Selle, Joseph Teran, and Alexey Stomakhin. The affine particle-in-cell method. *ACM Transactions on Graphics (TOG)*, 34(4):1–10, 2015.