

A ROBUST PFEM-LS/FEM PARTITIONED COUPLING FRAMEWORK FOR 3D FLUID-STRUCTURE INTERACTION

Martin Lacroix^{*1}, Simon Février¹, Eduardo Fernández¹, Dorian Bogucki¹, Romain Boman¹, Luc Papeleux¹ and Jean-Philippe Ponthot¹

¹University of Liège (ULiège)
Aerospace and Mechanical Engineering Department (A&M)
Allée de la Découverte 13, 4000 Liège, Belgium
e-mail: martin.lacroix@uliege.be, web page:
<http://metafor.ltas.ulg.ac.be>

ABSTRACT

Simulating solids subjected to complex, flow-induced loads remains a major challenge in fields such as aerospace, turbomachinery, and biomechanics. These scenarios often involve intricate Fluid-Structure Interactions (FSI) characterized by free surface flows, large deformations, thermo-mechanical interaction, strong coupling effects, solid-solid contact and material rupture, phenomena that conventional simulation approaches struggle to capture with accuracy. In such cases, using simplified boundary conditions to model fluid behavior on the solid surface is inadequate. To address these limitations, we present a robust, fully partitioned coupling framework that integrates a Particle Finite Element Method (PFEM) [1] fluid solver and a non-linear, Finite Element Method (FEM) structural solver. The remeshing procedure of the PFEM is combined to a computationally efficient Level Set (LS) algorithm, which uses a signed distance to the fluid's boundary as an additional filter to constrain the Delaunay tessellation based on the previously known fluid domain [2]. More specifically, the PFEM-LS achieves better mass conservation than standard α -shape remeshing by reducing spurious geometrical changes of the fluid's boundary throughout the simulation.

Strong FSI coupling is enforced via a Dirichlet-Neumann strategy, where equilibrium between fluid and structure is iteratively achieved at each time step using an Interface Quasi-Newton (IQN) method with Multi-Vector Jacobian (MVJ) [3] updates. The IQN-MVJ is combined with a dimensionality reduction technique based on a truncated Singular Value Decomposition (SVD) to decrease computation time on large-scale simulations. Boundary data transfer across non-conformal fluid and solid meshes is handled through radial basis function interpolation, enabling independent and adaptive mesh refinement on both sides of the interface. The framework's robustness is demonstrated through validation against established 2D and 3D benchmarks as well as newly developed test cases. The set of applications presented in this work includes, but is not limited to, the failure of a solid obstacle due to its collision with the fluid flow, an initially cylindrical body compressed by the surrounding fluid as it moves through a hyperelastic ridge, and the simulation of a hanging plate inside a rolling tank.

REFERENCES

- [1] Idelsohn S.R., Oñate E., Del Pin F., *The Particle Finite Element Method: A Powerful Tool to Solve Incompressible Flows with Free-Surfaces and Breaking Waves*, International Journal for Numerical Methods in Engineering, Vol. 61, pp. 964-989, 2004.
- [2] Lacroix M., Fernández E., Février S., Papeleux L., Boman R., Ponthot J.-P., *An Efficient Level Set-Based Mesh Adaptation for the Particle Finite Element Method*, Computer Methods in Applied Mechanics and Engineering, Vol. 450, pp. 118644, 2026.
- [3] Scheufole K., Mehl M., *Robust Multisecant Quasi-Newton Variants for Parallel Fluid-Structure Simulations and Other Multiphysics Applications*, CSIAM Journal on Scientific Computing, Vol. 39, pp. S404-S433, 2017.