Partitioned method for fluid-structure interaction developed based on OpenFOAM & FEM solvers

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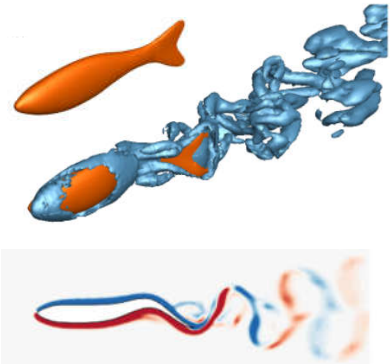
List

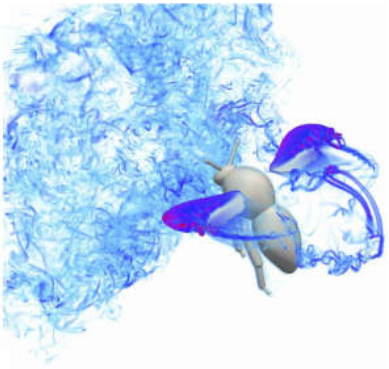
- Introduction to FSI
- Partitioned FSI method
- PreCICE
- Applications

Fluid structure interaction

- Efficient propulsion
- Flight control
- …



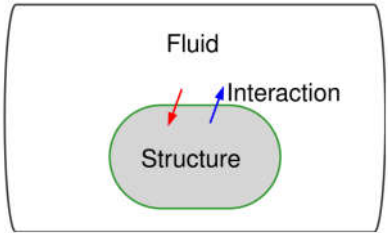
Maertens et al. Journal of Fluid Mechanics, 813:301-345, 2017



Engels et al. Physical Review Fluids 4, 013103, 2019

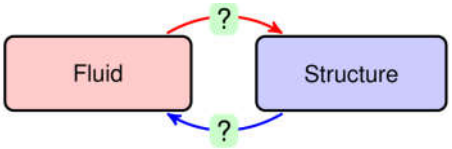
Partitioned method vs monolithic method

- The partitioned method is to separately solve the governing equations of the flow and structure with two independent solvers.
- The monolithic method is to simultaneously solve the governing equations of the flow and structure with a single solver.



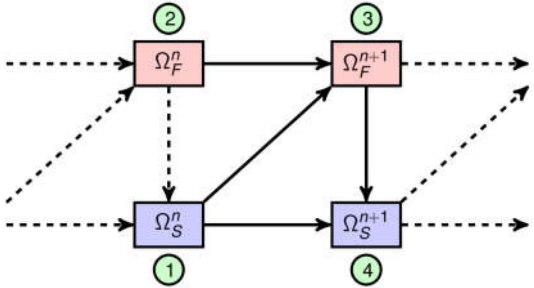
How to couple fluid and structure solvers?

- The FSI solvers of OpenFOAM in present are implemented using the partitioned method.
- There are two techniques coupling the fluid and structure solvers,
  - ✓Explicit coupling.
  - ✓Implicit coupling.



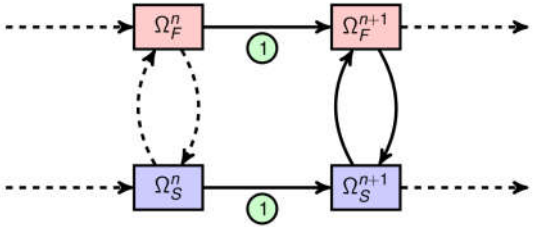
Explicit coupling

- The explicit coupling method applies to the weak interaction.
- OpenFOAM includes a weak-FSI solver.
- The weak coupling method is infeasible for solving scenarios with large structure deformations, which can influence surrounding flows.



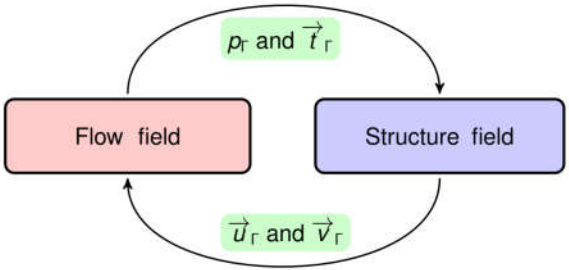
Implicit coupling

- The implicit coupling method is suitable for the strong interaction.
- The focus in this lecture is the FSI of large structural deformations.

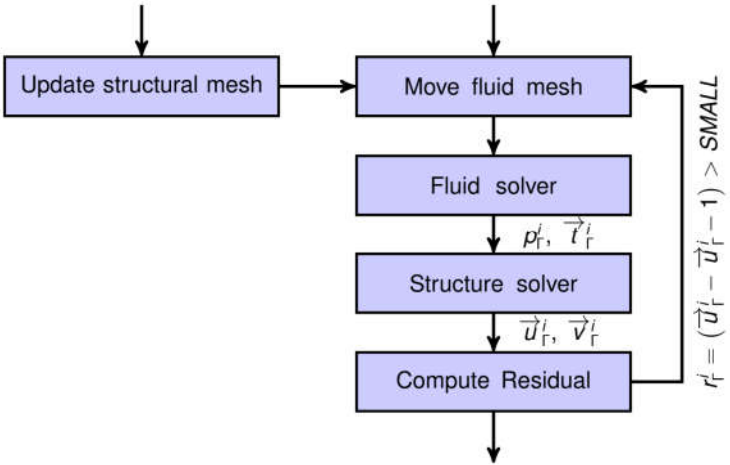


Coupling method for interaction

- The exchanged variables on the interfaces are:
  - ✓ pressure (p_Γ) and viscous force ($\vec{t}_\Gamma$) in the fluid side,
  - ✓ displacement increment ($\vec{u}_\Gamma$) and velocity ($\vec{v}_\Gamma$) in the structure side.



Coupling method for interaction



Aitken relaxation

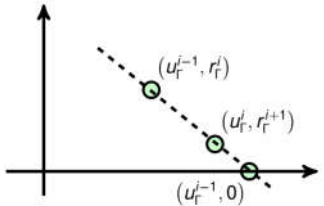
- The Aitken relaxation applies to accelerate the coupling process

$$u_\Gamma^i = \widetilde{S} \circ \widetilde{F}\left(u_\Gamma^{i-1}\right)$$

$$r_\Gamma^i = \widetilde{u}_\Gamma^i - \widetilde{u}_\Gamma^{i-1}$$

$$r_\Gamma^{i+1} = \widetilde{u}_\Gamma^{i+1} - \widetilde{u}_\Gamma^i$$

$$0 = r_\Gamma^{i+1} + \frac{r_\Gamma^{i+1} - r_\Gamma^i}{u_\Gamma^i - u_\Gamma^{i-1}}\left(u_\Gamma^{i+1} - u_\Gamma^i\right)$$

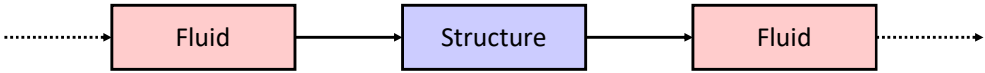


$$u_\Gamma^{i+1} = u_\Gamma^i - r_\Gamma^{i+1}\frac{\widetilde{u}_\Gamma^i - \widetilde{u}_\Gamma^{i-1}}{r_\Gamma^{i+1} - r_\Gamma^i} = u_\Gamma^i + \underbrace{\frac{u_\Gamma^i - u_\Gamma^{i-1}}{u_\Gamma^{i-1} - u_\Gamma^i + \widetilde{u}_\Gamma^{i+1} - \widetilde{u}_\Gamma^i}}_{\omega_{i+1}} \underbrace{\left(\widetilde{u}_\Gamma^{i+1} - u_\Gamma^i\right)}_{r_\Gamma^{i+1}}$$

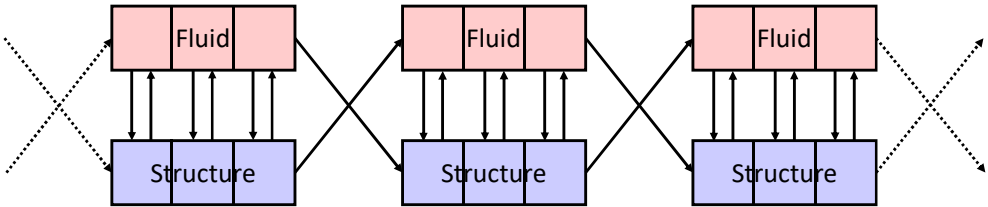
$$u_\Gamma^i := u_\Gamma^{i-1} - \omega_i r_\Gamma^i \qquad \omega_{i+1} = -\omega_i \frac{\left(r_\Gamma^i, r_\Gamma^{i+1} - r_\Gamma^i\right)}{\left\| r_\Gamma^{i+1} - r_\Gamma^i \right\|^2}$$

preCICE (https://www.precice.org/)

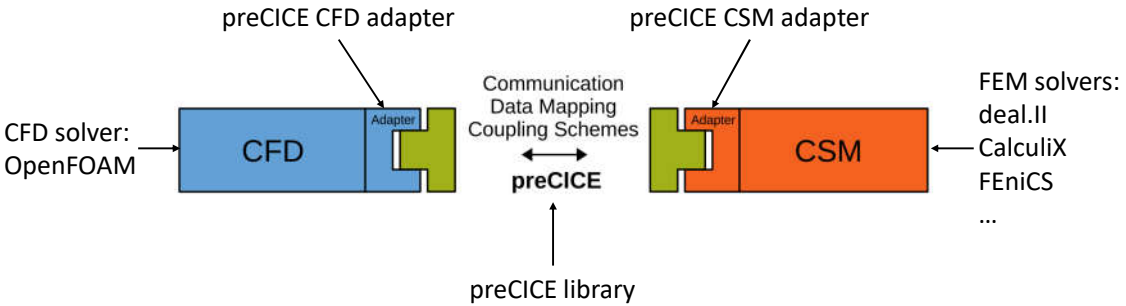
- Partitioned solver embedded in OpenFOAM
- **Serial** processing on the fluid-structure interface



- Partitioned solver using preCICE, which couples OpenFOAM with external FEM solvers
- **Parallel** processing on the fluid-structure interface



How does preCICE work?

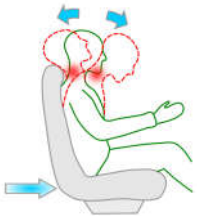


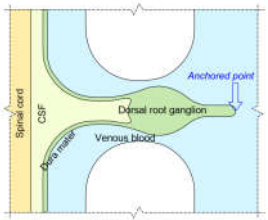
Uekermann et al. Official preCICE adapters for standard open-source solvers. In Proceedings of the 7th GACM Colloquium on Computational Mechanics for Young Scientists from Academia, October 2017.

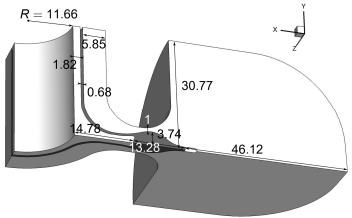
Features of preCICE

- Cross-platform: Linux, Windows and macOS.
- Scalability: up to 10,000 cores.
- Minimally-invasive, high-level API in C, C++, Fortran 90/95, Fortran 2003, and Python
- Parallel or sequential coupling between two or more coupling participants
- Configurable at run-time
- All data mappings either in a consistent or in a conservative variant
- …

Whiplash nerve injury







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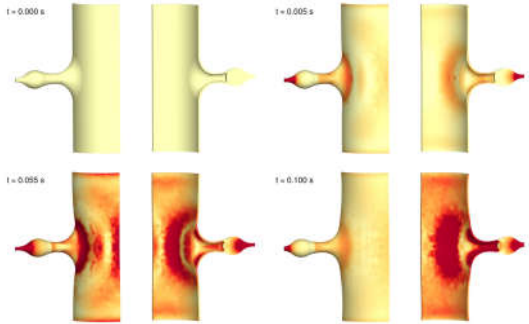
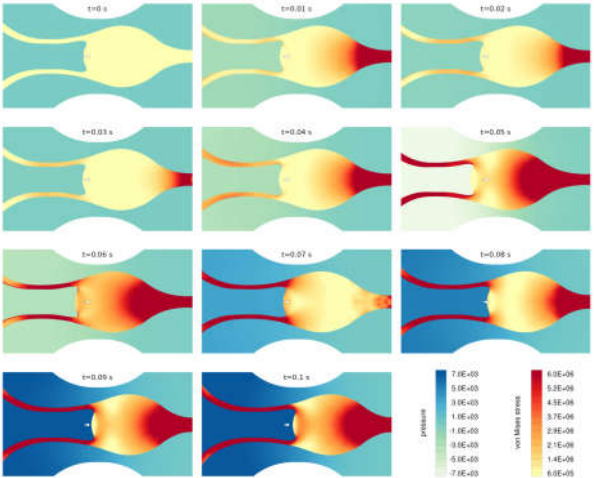
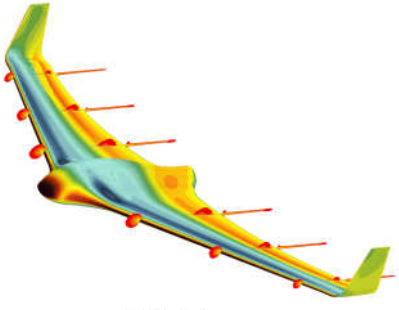
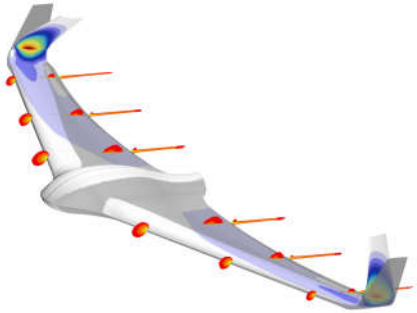




Skywalker X8 (UAV)

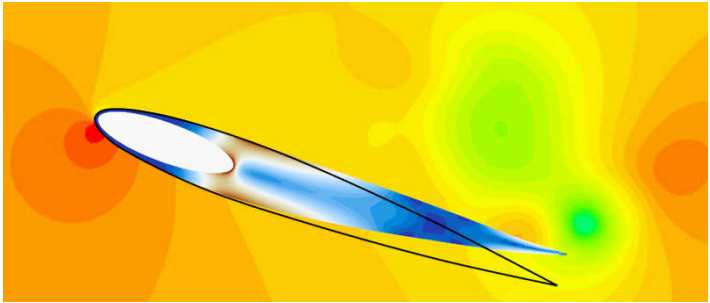


Surface pressure & velocity magnitudes



von Mises stresses & velocity magnitudes

Flexible airfoil NACA0012



Thanks