# Seminar on Partitioned Fluid-Structure Interaction – Topics and Schedule

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Please note: We might move topics between block 1 and 2, and between block 3 and 4.

## 0 First meetings

### 0.1 Preliminary meeting, January 30

- Presentation by CO (course organizers)
- Introduction to partitioned FSI and preCICE
- Overview of all topics
- Rules and timeline
- How to apply

### 0.2 Kick-off session, April 12

- Presentation by CO (course organizers)
- Repetition: Rules and timeline

## 1 First Block – April 23

### 1.1 From partitioned to monolithic FSI

- A rather literature only topic
- Comparison between the partitioned and the monolithic approach
- Overview for FSI in [1] (Section 1.2)
- General overview in [2]
- Further reading e.g. [3, 4, 5], but also refer to other literature cited in [1]

# References


[1] Uekermann, B. Partitioned fluid-structure interaction on massively parallel systems *Ph.D. thesis, Technische Universität München, Inst. für Informatik* (2016).

[2] D. Keyes et al. Multiphysics simulations: Challenges and opportunities *High Performance Computing Applications* (2012) **27**(1):4–83.

[3] Bazilevs, Y., Takizawa, K. and Tezduyar, T. E. *Computational Fluid-Structure Interaction - Methods and Applications.* John Wiley and Sons, Vol. I., (2013).

[4] Gee, M., Küttler, U. and Wall, W. A. Truly monolithic algebraic multigrid for fluid-structure interaction *Int. J. for Numer. Meth. in Eng.* (2011) **85**:987–1016.

[5] Felippa, C., Park, K. and Farhat, C. Partitioned analysis of coupled mechanical systems *Eng. Comp.* (2001) **24**:123–133.


### 1.2 Added-mass effect and explicit/implicit coupling

- Explain theoretical considerations on added-mass effect [1, 2]
- Explain explicit and implicit coupling, e.g. [3] (Section 2.3)
- Implement a simple example (with Python or Matlab) and do a thorough test study (e.g. 1D tube [4] or piston problem)

# References


[1] Causin, P., Gerbeau, J. F. and Nobile, F. Added-mass effect in the design of partitioned algorithms for fluid-structure problems. *Comput. Methods Appl. Mech. Eng.* (2005) **194**:4506–4527.

[2] Van Brummelen, E. H. Added mass effects of compressible and incompressible flows in fluid-structure interaction. *J. Appl. Mech.* (2009) **76**:1–7.

[3] Gatzhammer, B. Efficient and flexible partitioned simulation of fluid-structure interactions *Ph.D. thesis, Technische Universität München, Inst. für Informatik* (2015).

[4] Degroote, J., Bruggeman, P., Haelterman, R. and Vierendeels, J. Stability of a coupling technique for partitioned solvers in FSI applications. *Comput. Struct.* (2008) **86**:2224–2234.

### 1.3 preCICE from user perspective

- Give overview of preCICE ([1] Chapter 2)
- Explain features from user perspective
- Explain API by a simple own example (e.g. coupling between two 2D heat equations)

## References

[1] Uekermann, B. Partitioned fluid-structure interaction on massively parallel systems *Ph.D. thesis, Technische Universität München, Inst. für Informatik* (2016).

## 2 Second Block – April 26

### 2.1 A practial introduction to CFD

- Take a preCICE-coupled community CFD code of your choice (e.g. OpenFOAM or SU2)
- Explain modeling and numerics used in solver (search for respective literature)
- Run and explain examples

### 2.2 A practial introduction to CSM

- Take a preCICE-coupled community CSM code of your choice (e.g. CalculiX or Code_Aster)
- Explain modeling and numerics used in solver (search for respective literature)
- Run and explain examples

### 2.3 Brief overview of remaining topics

- CO give quick overview of remaining topics and explain how they are built on the already seen topics

## 3 Third Block – June 28

### 3.1 Conjugate heat transfer

- Explain modeling of CHT

- Run an example with preCICE and two solvers of your choice
- Use [1] and referred literature
- Do a thorough performance study (e.g. comparison between Dirichlet-Neumann and Robin-Robin coupling)

## References

[1] Cheung, L. Conjugate Heat Transfer with the Multiphysics Coupling Library preCICE. *Master thesis, Technische Universität München, Inst. für Informatik* (2016).

### 3.2 Interface quasi-Newton coupling

- Explain theory of IQN and acceleration techniques [1] (Section 3.1-3.3) and references therein (e.g. [2])
- Implement coupling via IQN for simple example (e.g. into existing Python 1D FSI code)
- Do thorough parameter studies

## References

[1] Uekermann, B. Partitioned fluid-structure interaction on massively parallel systems *Ph.D. thesis, Technische Universität München, Inst. für Informatik* (2016).

[2] Degroote, J., Bathe, K.-J. and Vierendeels, J. Performance of a new partitioned procedure versus a monolithic procedure in fluid-structure interaction *Comput. Struct.* (2009) **87**:793–801.

### 3.3 Data mapping methods

- Explain data mapping methods implemented in preCICE to each other and to alternatives in the literature, e.g. [1, 2]
- Implement own example and do thorough testing (either own Matlab/Python code or with preCICE as in [1], Section 4.2)

## References

[1] Gatzhammer, B. Efficient and flexible partitioned simulation of fluid-structure interactions *Ph.D. thesis, Technische Universität München, Inst. für Informatik* (2015).

[2] de Boer, A., van Zuijlen, A. H. and Bijl, H. Comparison of conservative and consistent approaches for the coupling of non-matching meshes *Comput. Methods Appl. Mech. Engrg.* (2008) **197**:4284–4297.

### 3.4 Time interpolation

- Explain reason for order degradation and loss of stability properties in the partitioned approach [4].
- Use a simplified ODE example (e.g. [1, 2]) to reproduce order degradation.
- Show possible solutions, such as Strang splitting, waveform relaxation [1] or a predictor [3].
- Verify maintained order with your ODE example code.

## References

[1] Bartel, A., Brunk, M., and Schps, S. On the Convergence Rate of Dynamic Iteration for Coupled Problems with Multiple Subsystems *J. Comput. Appl. Math.*, (2014) **262**:14–24.

[2] Prakash, A., Taciroglu, E., and Hjelmstad, K. D. Computationally efficient multi-time-step method for partitioned time integration of highly nonlinear structural dynamics *Computers and Structures*, (2014) **133**:51–63.

[3] Piperno, S. Explicit/implicit fluid/structure staggered procedures with a structural predictor and fluid subcycling for 2D inviscid aeroelastic simulations *International Journal for Numerical Methods in Fluids*, (1997) **25**(10):1207–1226.

[4] Gillebaart, T., Blom, D. S., Zuijlen, A. H. Van, and Bijl, H. Time Consistent Fluid Structure Interaction on Collocated Grids for Incompressible Flow, (2016).

# 4 Fourth Block – July 5

### 4.1 Inter-solver communication

- Explain how inter-solver communication is realized in preCICE [1, 2]
- Do performance testing with preCICE or implement own example (e.g. `PRECICE_ROOT/tools/communication_dummies`)

# References

[1] Shukaev, A. A Fully Parallel Process-to-Process Intercommunication Technique for preCICE. *Master thesis, Technische Universität München, Inst. für Informatik* (2015).

[2] Vollmer, A. Performanzanalyse und Optimierung einer verteilten Multi-Physik Simulationssoftware. *Masterarbeit, Universität Stuttgart, Inst. für Parallele und Verteilte Systeme* (2017).

## 4.2 Moving geometries

- Explain different possibilities to resolve moving geometries in CFD solvers (immersed boundary and ALE, e.g. [1, 2, 3])
- Explain realization of a moving boundary technique in a code of your choice and run examples (e.g. SU2, OpenFOAM) or implement a small demo code yourself (e.g. heat equation with prescribed moving geometry, in Python or Matlab)

# References

[1] Benk, J. Immersed Boundary Methods within a PDE Toolbox on Distributed Memory Systems *PhD thesis, Technische Universität München, Inst. für Informatik* (2012).

[2] Bazilevs, Y., Takizawa, K. and Tezduyar, T. E. *Computational Fluid-Structure Interaction - Methods and Applications.* John Wiley and Sons, Vol. I., (2013).

[3] Wall, W. A. Fluid-Struktur-Interaktion mit stabilisierten Finiten Elementen. *PhD thesis, Universität Stuttgart* (1999).

## 4.3 Turek FSI benchmarks

- Explain, run, and validate the Turek/Hron FSI benchmarks [1]
- Use any two solvers coupled via preCICE (e.g. OpenFOAM and CalculiX)
- Prepare tutorial for preCICE GitHub wiki

# References

[1] S. Turek and J. Hron. Proposal for numerical benchmarking of fluid-structure interaction between an elastic object and laminar incompressible flow. *Fluid Structure Interaction II: Modelling, Simulation, Optimization* (2006).