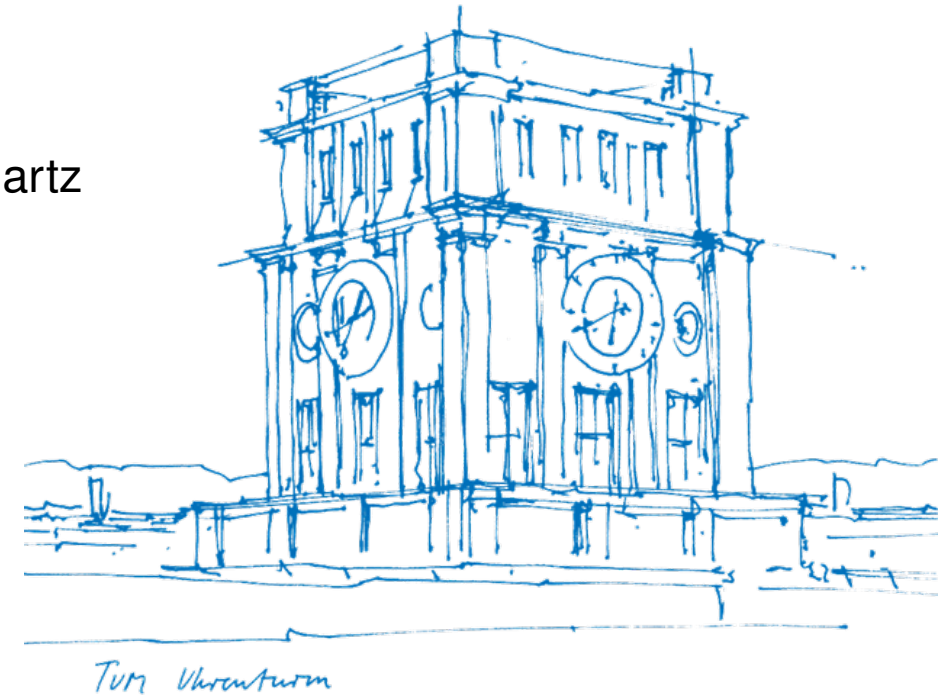
Chair of Scientific Computing
TUM School of Computation, Information and Technology
Technical University of Munich

Time stepping review of open-source solvers

Guided research

Marc Amorós Trepat

Supervisor: Prof. Dr. Hans-Joachim Bungartz
Advisor: M.Sc. Benjamin Rodenberg



Outline

1 Introduction
- Motivation
- Open-Source solvers
- Time stepping schemes

2 OpenFOAM

3 CalculiX

4 FSI simulation

5 Sources of error

6 Conclusions

Motivation

Open-source solvers

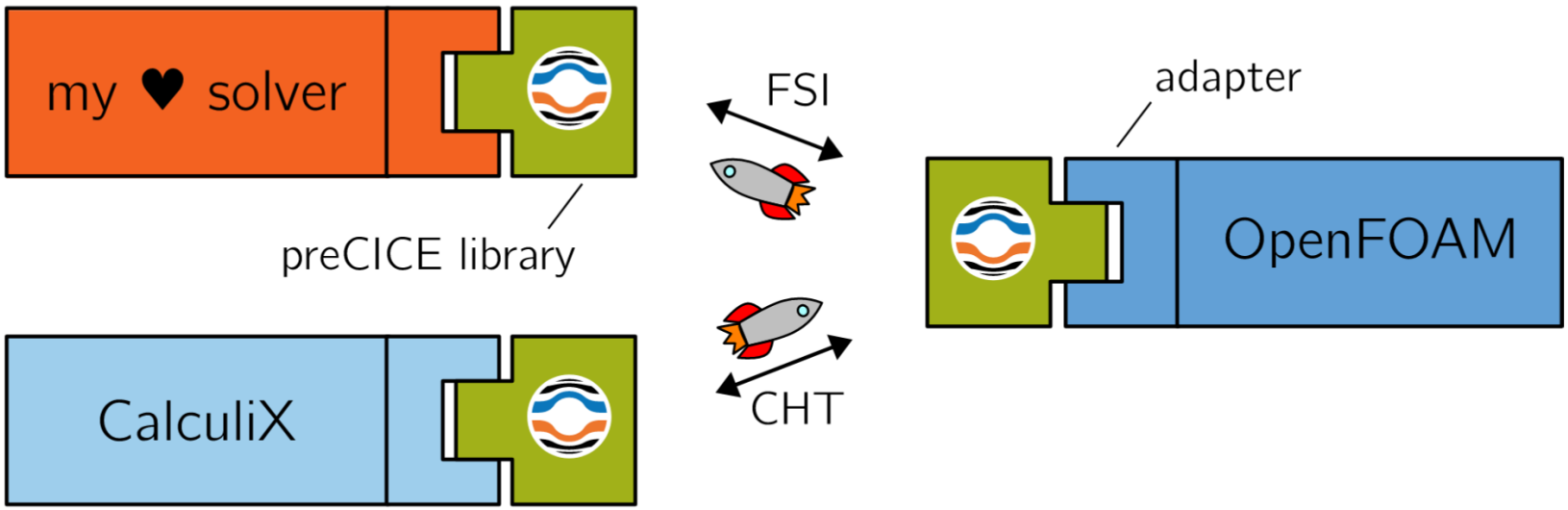


Figure 1 Diagram showing setup for coupling simulations with preCICE library.

Time stepping schemes

When solving a PDE of the form:

$$\frac{\partial u}{\partial t} = F(u, t) \tag{1}$$

we need to discretize the time-derivative. Easiest way is the Euler explicit method:

$$\frac{u^{n+1} - u^n}{\Delta t} = F(u^n, t^n) \tag{2}$$

We focus on second-order time stepping schemes $\rightarrow$ temporal discretization error $\varepsilon_{\Delta t}$ decreases $\mathcal{O}(\Delta t^2)$.

Outline

1 Introduction

2 OpenFOAM

3 CalculiX

4 FSI simulation

5 Sources of error

6 Conclusions

OpenFOAM

The error has the form $\varepsilon_u = \varepsilon_{\Delta t} + \varepsilon_{\Delta x} + \varepsilon_{\text{num}}$.

We use Crank-Nicolson time stepping method.

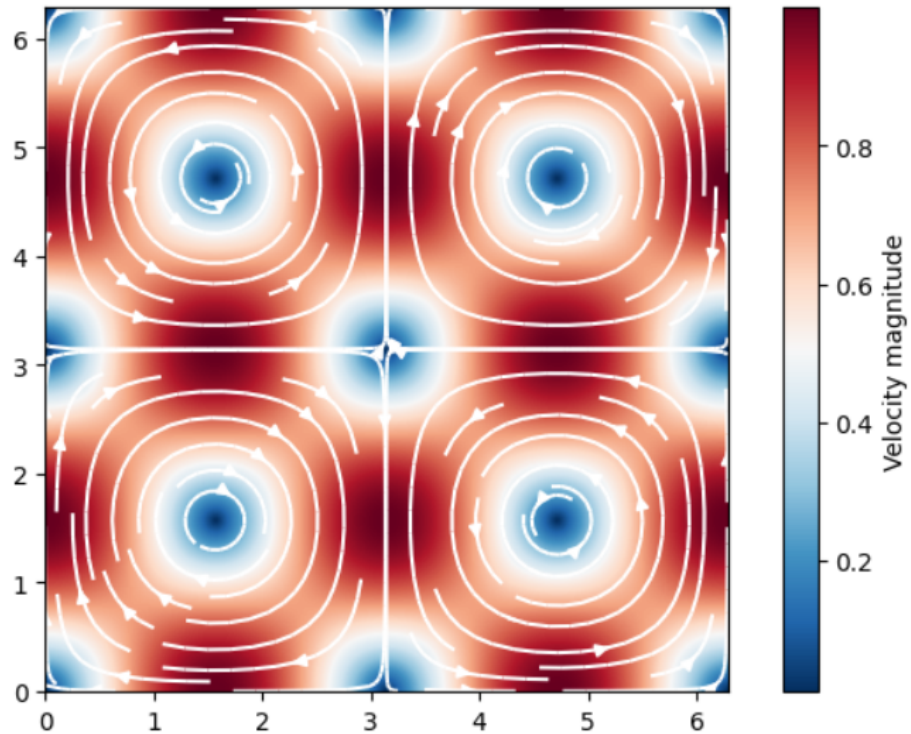
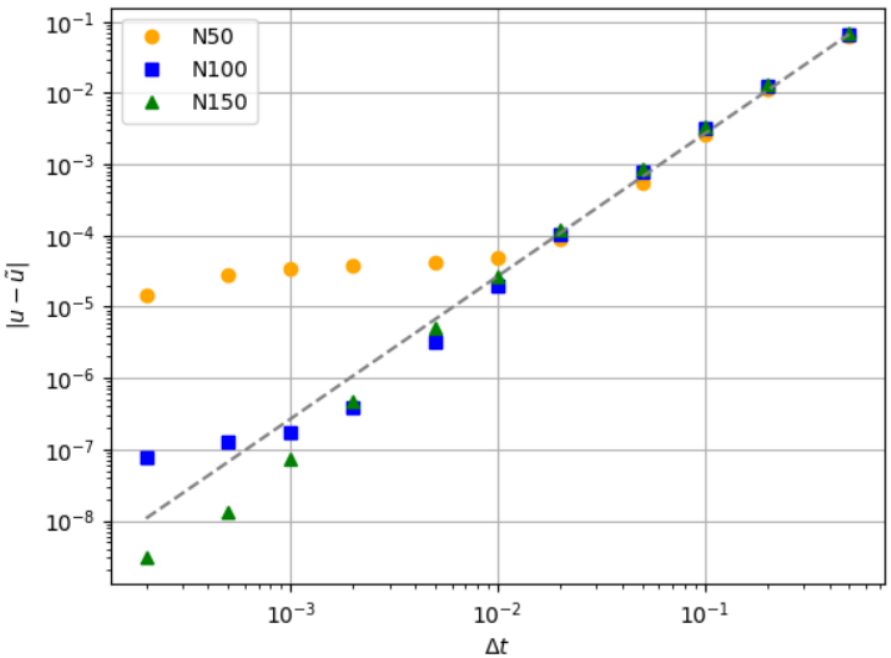


Figure 2 Visualization of the Taylor-Green vortex scenario.

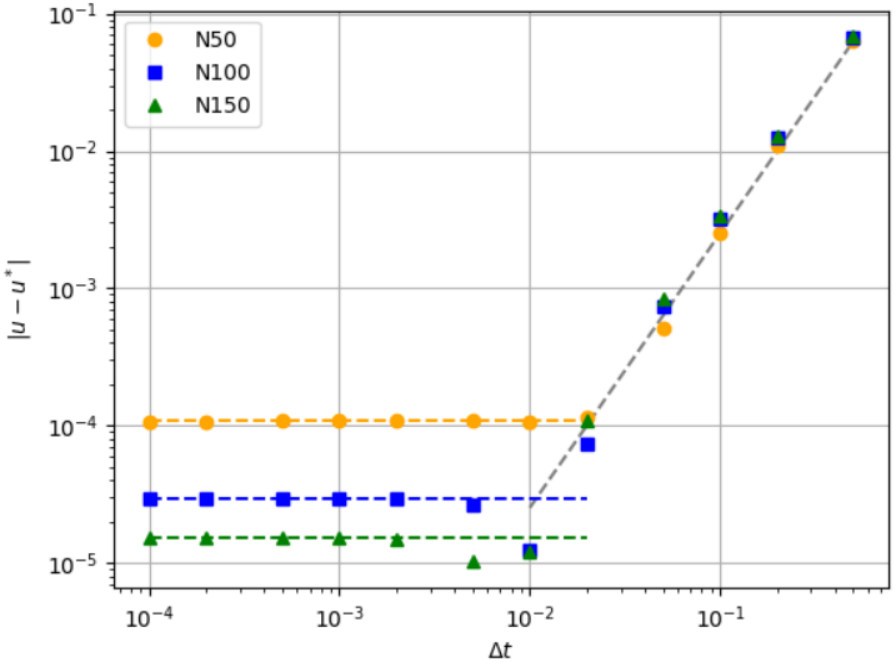
OpenFOAM - convergence study



(a) Error compared to reference ($\Delta t = 10^{-5}$).

$|u - \tilde{u}| = \varepsilon_{\Delta t} + \varepsilon_{\text{num}}$

plateau when $\varepsilon_{\Delta t} < \varepsilon_{\text{num}}$



(b) Error compared to analytical solution.

$|u - u^*| = \varepsilon_{\Delta t} + \varepsilon_{\Delta x} + \varepsilon_{\text{num}}$

plateau when $\varepsilon_{\Delta t} < \varepsilon_{\Delta x} + \varepsilon_{\text{num}}$

Outline

1 Introduction

2 OpenFOAM

3 CalculiX

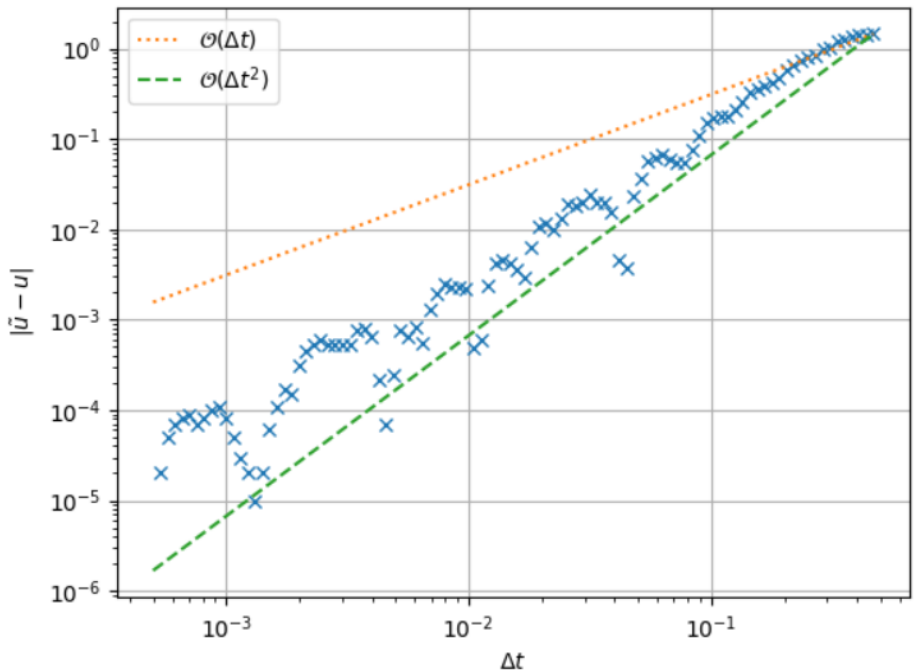
4 FSI simulation

5 Sources of error

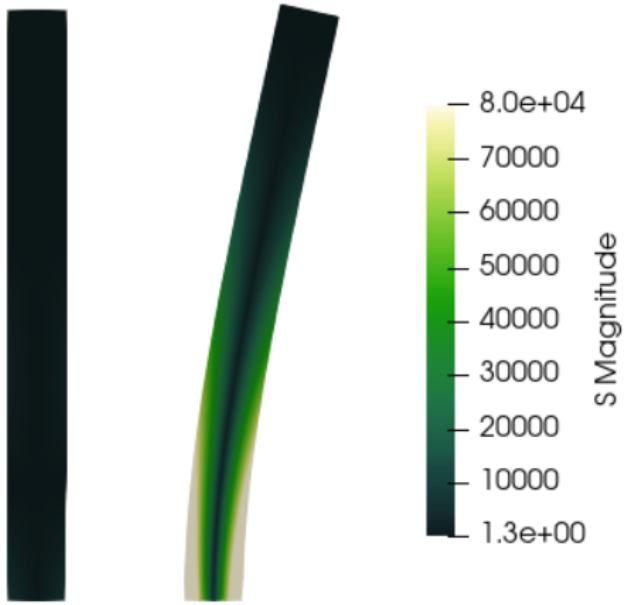
6 Conclusions

CalculiX

We use the α-method as time stepping scheme.



(a) Convergence study, showing higher-order convergence.



(b) Perpendicular elastic flap scenario.

Outline

1 Introduction

2 OpenFOAM

3 CalculiX

4 FSI simulation

5 Sources of error

6 Conclusions

FSI simulation

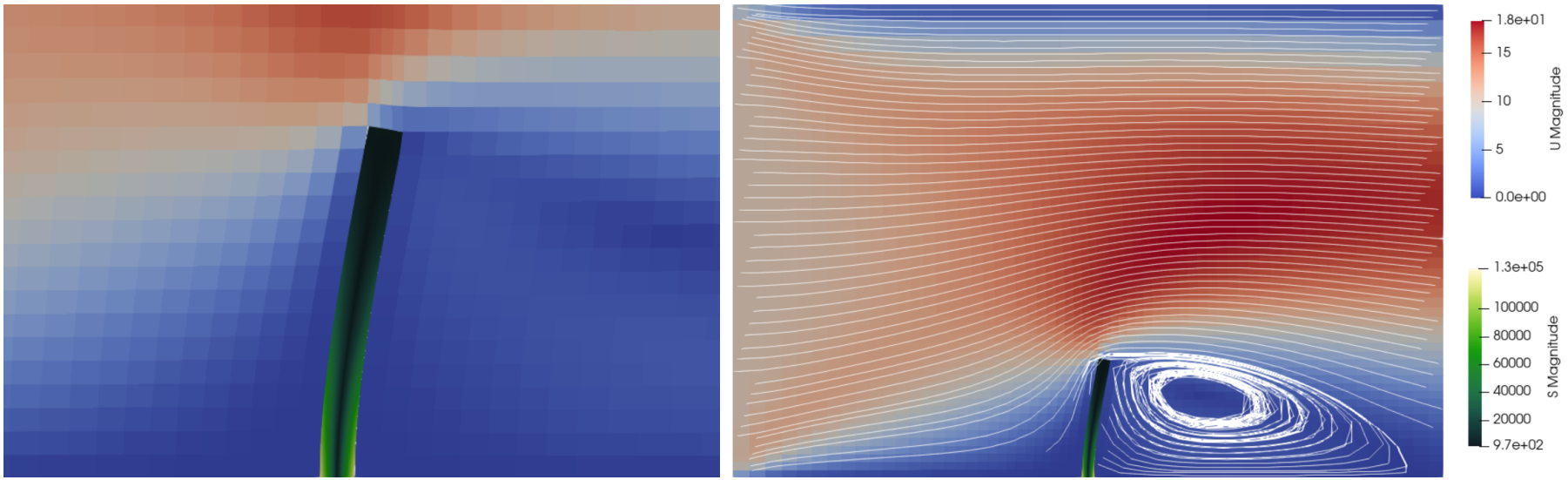


Figure 5 Example solution of the FSI simulation, coupled with preCICE.

FSI Simulation - convergence study

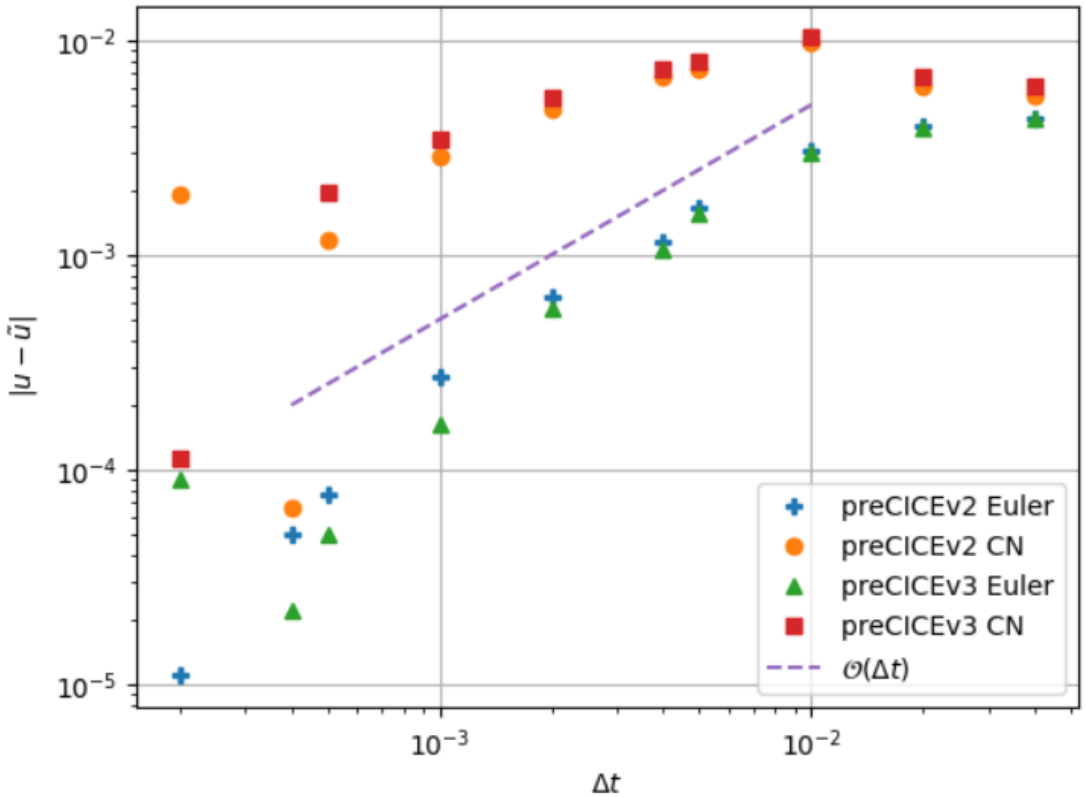


Figure 6 Convergence study of the coupled perpendicular flap scenario. Results with the Crank-Nicolson (CN) and the implicit Euler time stepping schemes, and using v2 and v3 of preCICE.

Outline

1 Introduction

2 OpenFOAM

3 CalculiX

4 FSI simulation

5 Sources of error

6 Conclusions

Verification of CalculiX adapter

We coupled the CalculiX adapter with a fake-fluid participant that applied a force $f^n = f_{max} \sin(t^n + \phi)$ on the tip.

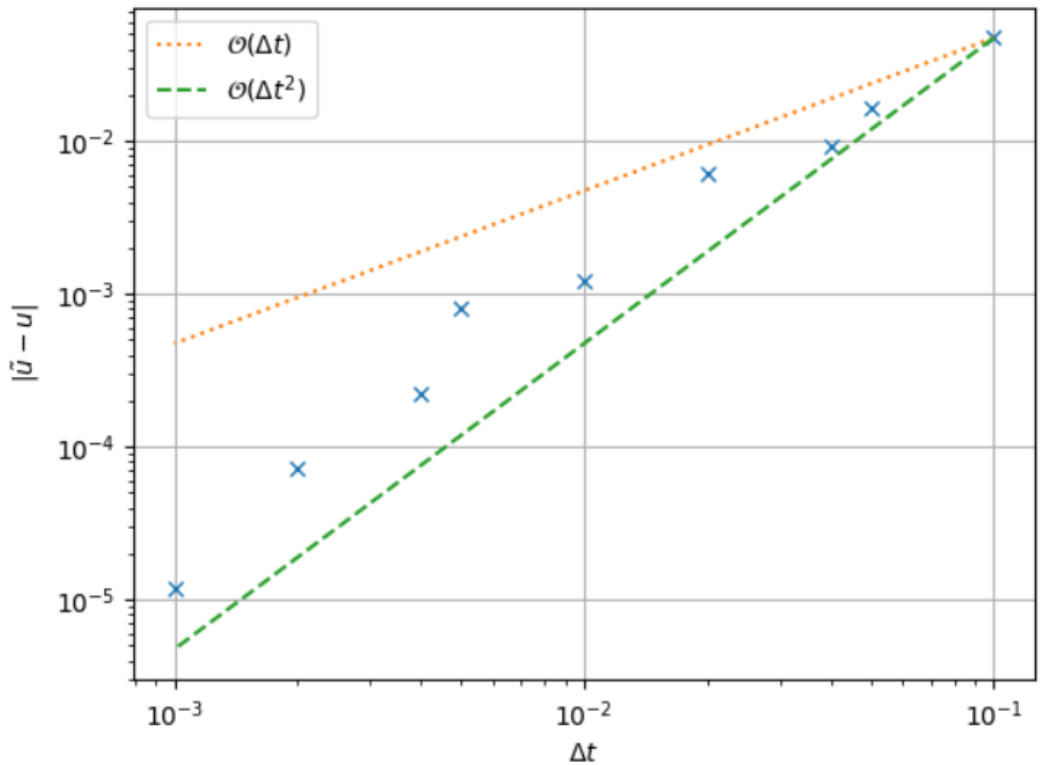


Figure 7 Convergence study of the CalculiX adapter coupled with a fake fluid participant. Reference solution is $\Delta t = 10^{-4}$.

Verification of fluid participant

We ran the fluid-participant as a single-solver scenario and found:

- Difficult convergence due to high CFL numbers.
-

Outline

1 Introduction

2 OpenFOAM

3 CalculiX

4 FSI simulation

5 Sources of error

6 Conclusions

Conclusions and future work

- Does it make sense to use second order methods? Yes, but not always.
- Single-solver simulations showed how CalculiX and OpenFOAM can reach higher-order convergence.
-