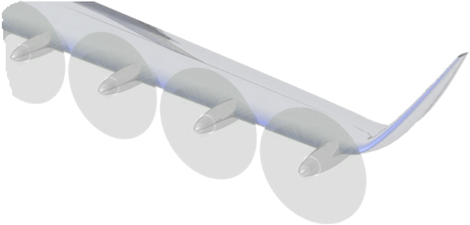
**ECCOMAS Coupled Problems 2021**
Minisymposium "Multi-Physics Simulations with the Coupling Library preCICE"
Online Event | 13-16 June 2021

der Bundeswehr
Universität München

# Aeroelastic simulation of slender wings for electric aircraft

## a partitioned approach with DUNE and preCICE

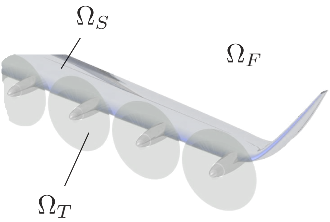


Max Firmbach[1] Rainer Callies[2]

[1] Institute for Mathematics and Computer-Based Simulation (IMCS), University of the Bundeswehr Munich (UniBw M), Germany
[2] Department for Numerical Analysis, Technical University Munich, Germany

# Motivation & Goal

- New propulsion concepts for electric aircraft include:
  - Large, slender wings similar to those of sailplanes
  - Several electric motors distributed over the wing span
- Such systems are:
  - Prone to oscillations
  - Complex to simulate, due to several physical domains $\rightarrow$ fluid, structure, turbine each modeled differently




## Goal

Use a partitioned coupling approach with the help of preCICE to handle each domain and it's corresponding solvers independently in terms of physical modeling and programming language.

[1] Image: DLR (CC BY-NC-ND 3.0)

# Coupling approach

## Structure: Linear Elasticity

$$\rho \frac{\partial^2 u}{\partial t^2} + \nabla \cdot \sigma(u) = f$$
$$\sigma(u) = C : \epsilon(u)$$
$$\epsilon(u) = \frac{1}{2}(\nabla u + (\nabla u)^T)$$

Implemented inside the C++ framework provided by the Distributed and Unified Numerics Environment (DUNE).

OpenFOAM is used as a black box solver for the incompressible Navier-Stokes equations modeling the fluid domain.

## Fluid: Navier-Stokes Equations

$$\frac{\partial u}{\partial t} + (u \cdot \nabla)u = -\frac{1}{\rho}\nabla p + \nu \Delta u$$
$$\nabla \cdot u = 0$$

## Coupling

preCICE is utilized for communication, data mapping and coupling algorithms

## Turbines: Blade Element Theory

The turbine implementation is omitted here $\rightarrow$ still part of active research

# Coupling approach

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# Structural solver in DUNE

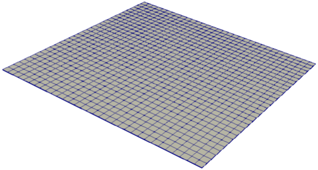
**dune-elastodynamics**

The structural solver is a finite element code based on the core modules inside DUNE. It contains:

- Local and global matrix assemblers
- Timestepping methods (Newmark, Runge-Kutta-Nyström)
- Different mass lumping techniques
- Interfaces to Gmsh and Paraview

→ Support for 2D and 3D solid elements

→ Future support for structural elements like rods/trusses, beams and plates



Thin membrane discretized with hexahedron elements

# Structural solver in DUNE

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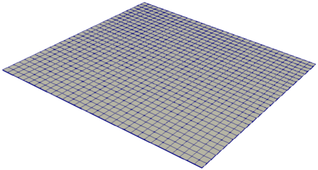
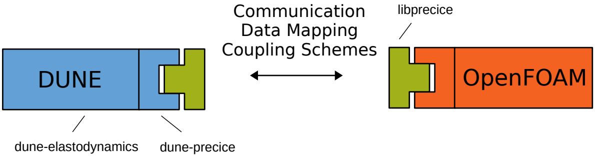


Thin membrane discretized with hexahedron elements

An adapter is needed to couple the DUNE code to the preCICE library and thus to OpenFOAM.

# A preCICE adapter for DUNE




core modules:
- dune-common
- dune-geometry
- dune-grid
- dune-istl
- dune-localfunctions

**dune-precice**

The DUNE adapter for preCICE handles:

- Conversion of data structures
- Definition of the coupling interface
- Storing and loading of checkpoints

For now only FSI scenarios are considered. The goal is to expand and test the adapter for other simulation setups.

# Conversion of data structures

DUNE uses a nested data structure approach:

```
Dune::BlockVector<Dune::FieldVector<double, dim>> displacement;
```

↕ dune-precice

A plain vector for preCICE:

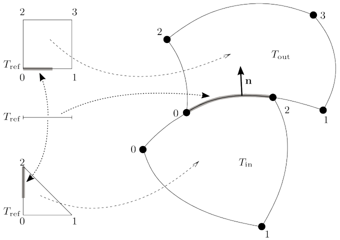
```
std::vector<double> displacement;
```

# Definition of the coupling interface

**Intersections in DUNE**

Dune uses the concept of intersections:

- additional entity between elements
- also defined on the boundary




[2]

Which points on the coupling interface should be used ?

- grid vertices
- support points of the basis

[2] O. Sander: DUNE — The Distributed and Unified Numerics Environment

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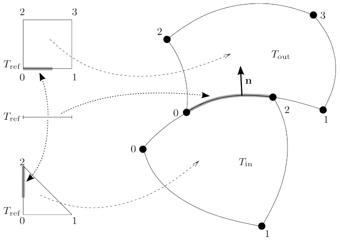


2

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In this case, the support points of the finite element basis on the coupling interface are used for the computation.

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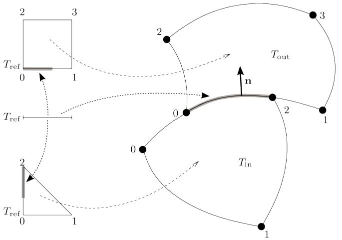



2

Which points on the coupling interface should be used ?

- grid vertices
- support points of the basis

In this case, the support points of the finite element basis on the coupling interface are used for the computation.

With all parts together, let's try to simulate some FSI scenarios!

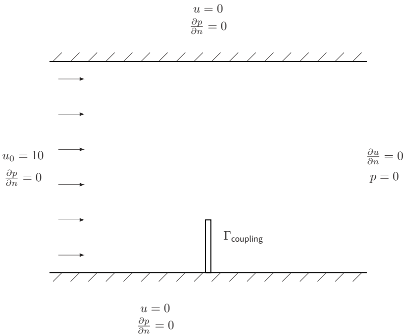
[2] O. Sander: DUNE — The Distributed and Unified Numerics Environment

# Vertical flap in a channel

## Simulation setup

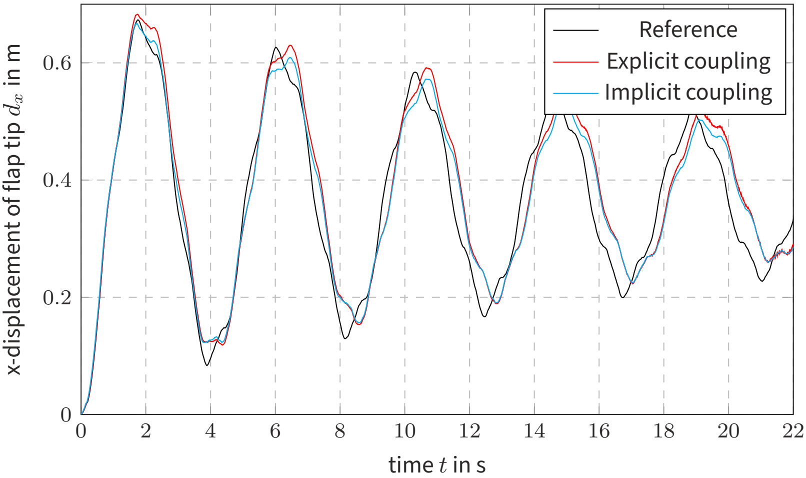
- Laminar channel flow
- Flexible flap installed at the bottom

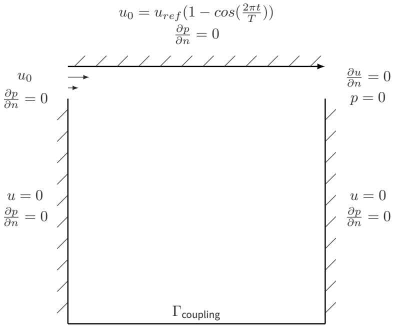
| | | |
|---|---|---|
| fluid density | $\rho_F$ | 1.0 kg/m$^3$ |
| dynamic viscosity | $\nu$ | 0.001 kg/(ms) |
| inlet velocity | $u_0$ | 10.0 m/s |
| structure density | $\rho_S$ | 3000 kg/m$^3$ |
| Young's modulus | $E$ | 400000 N/m$^2$ |
| Poisson ratio | $\nu$ | 0.3 |
| coupling window | $\tau$ | 0.01 s |
| simulation time | $t_{end}$ | 22 s |



# Vertical flap in a channel

Comparison of the horizontal displacement of the flap tip



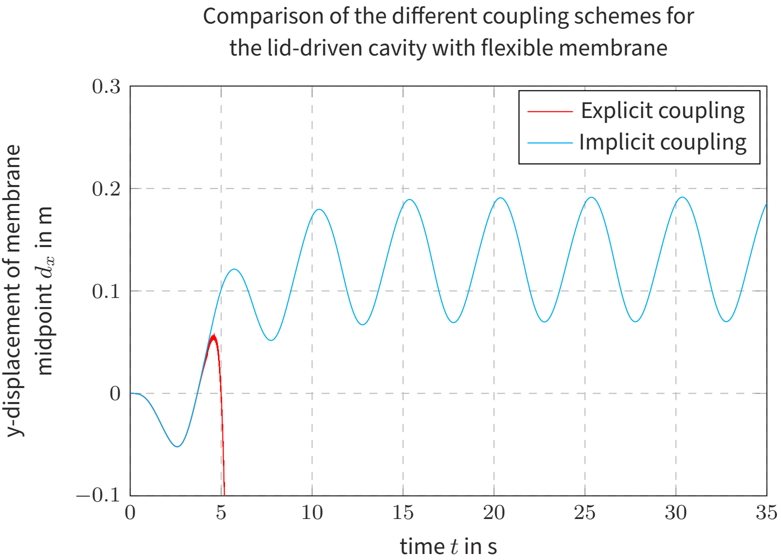



## Simulation setup

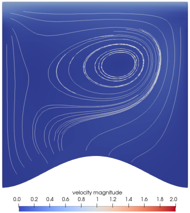
- Modified Lid-driven cavity
- Bottom wall is a membrane
  $\rightarrow$ flexible
- Additional inflow and outflow
  $\rightarrow$ volume change

| | | |
|---|---|---|
| fluid density | $\rho_F$ | 1.0 kg/m$^3$ |
| dynamic viscosity | $\nu$ | 0.01 kg/(ms) |
| reference velocity | $u_{ref}$ | 1.0 m/s |
| structure density | $\rho_S$ | 500 kg/m$^3$ |
| Young's modulus | $E$ | 25000 N/m$^2$ |
| Poisson ratio | $\nu$ | 0.0 |
| coupling window | $\tau$ | 0.01 s |
| simulation time | $t_{end}$ | 35 s |

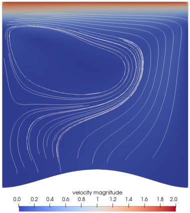
# Lid-driven cavity with flexible bottom



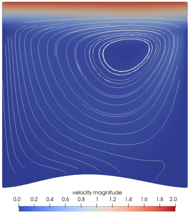
# Lid-driven cavity with flexible bottom



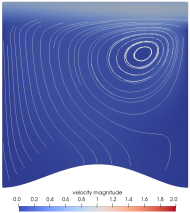

t=16s



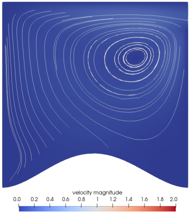

t=17s



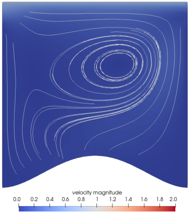

t=18s




t=19s

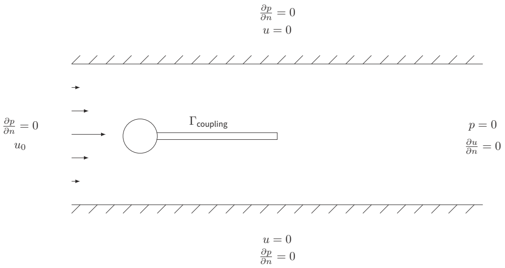



t=20s




t=21s

# Turek-Hron FSI benchmark three

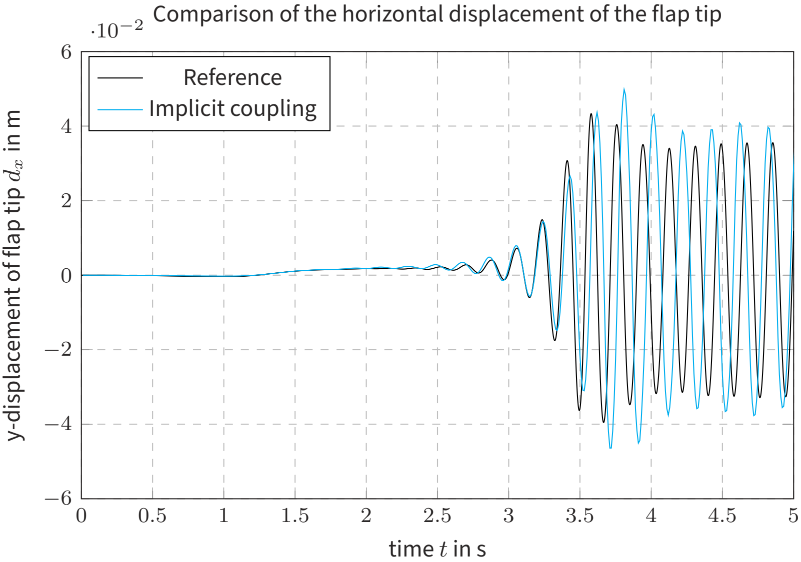



## Simulation setup

| | | |
|---|---|---|
| fluid density | $\rho_F$ | 1000 kg/m$^3$ |
| dynamic viscosity | $\nu$ | 0.001 kg/(ms) |
| structure density | $\rho_S$ | 1000 kg/m$^3$ |
| Young's modulus | $E$ | 5.6·10$^6$ N/m$^2$ |
| Poisson ratio | $\nu$ | 0.4 |
| coupling window | $\tau$ | 0.0075 s |
| simulation time | $t_{end}$ | 5 s |

- Laminar channel flow
- Parabolic inflow profile
- Obstacle with attached flap

# Turek-Hron FSI benchmark three



# Thank you!

## DUNE and preCICE work together quite nicely ...

- Still things to do!
- Questions?
- Contact: max.firmbach@unibw.de

References:


- O. Sander: DUNE - The Distributed and Unified Numerics Environment
- M. Firmbach: Aeroelastic simulation of slender wings for electric aircraft: a partitioned approach with DUNE and preCICE