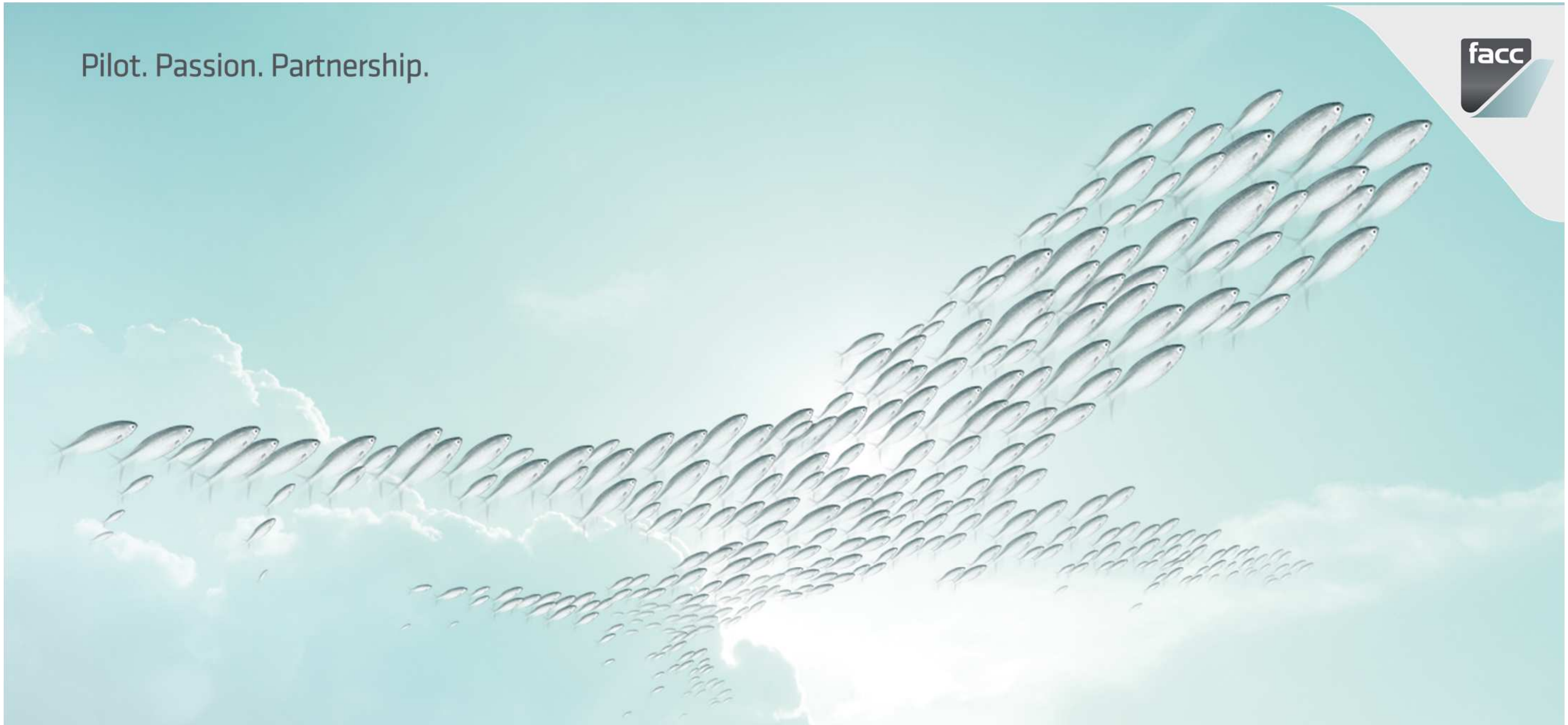


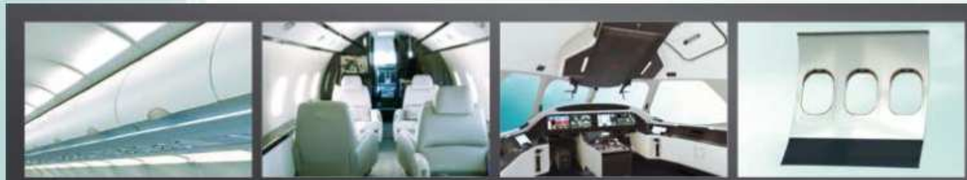
Extend Your Expectations

Our activities are focused

on a defined product portfolio from the product idea to customer tailored solutions

AEROSTRUCTURES

ENGINES & NACELLES



INTERIORS

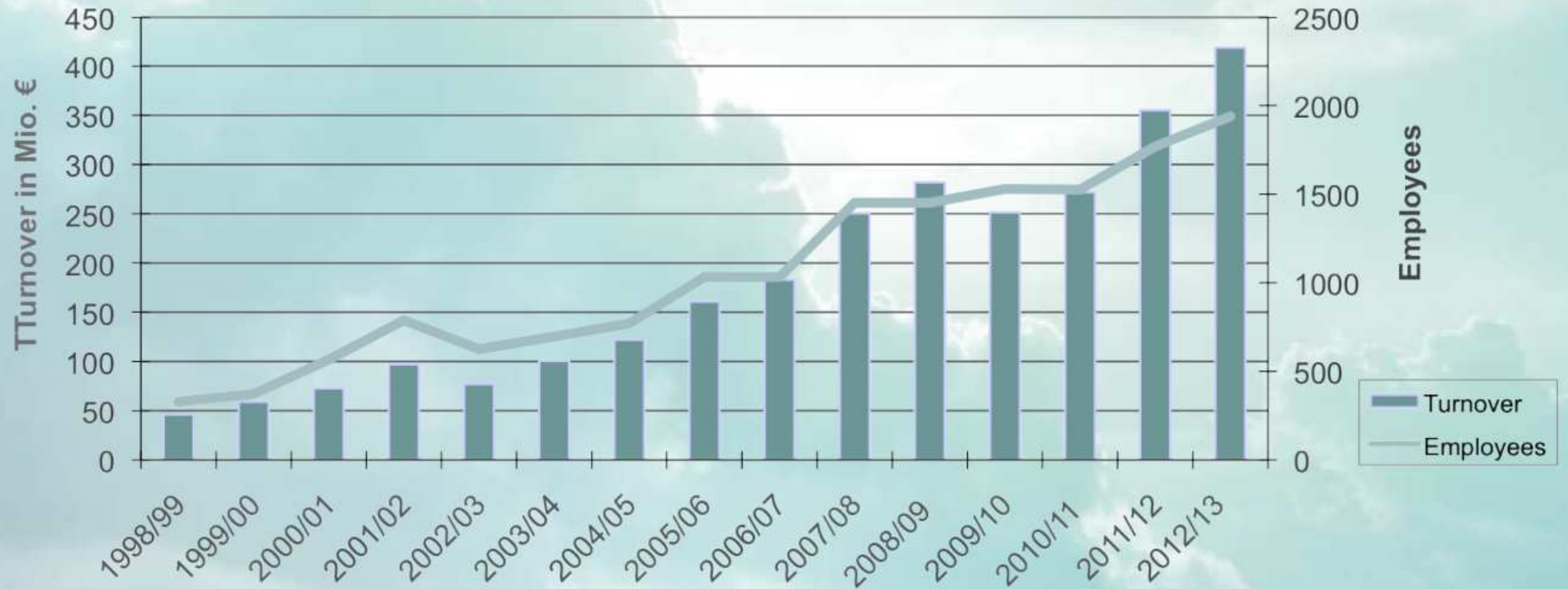
FACC is a Tier 1 partner with a wide range of services: R&D, Engineering, Manufacturing up to Business Solutions.

Pilot. Passion. Partnership.

Steady growth

as a solid foundation for the future

1981	1987	1989	today
Foundation	First major contract with McDonnell Douglas	Independent company	€ 450 million sales volume; 2,000 employees Leading player with a broad and balanced customer base Innovative product offering tailored to customer Highly experienced management and qualified staff



Global customer network

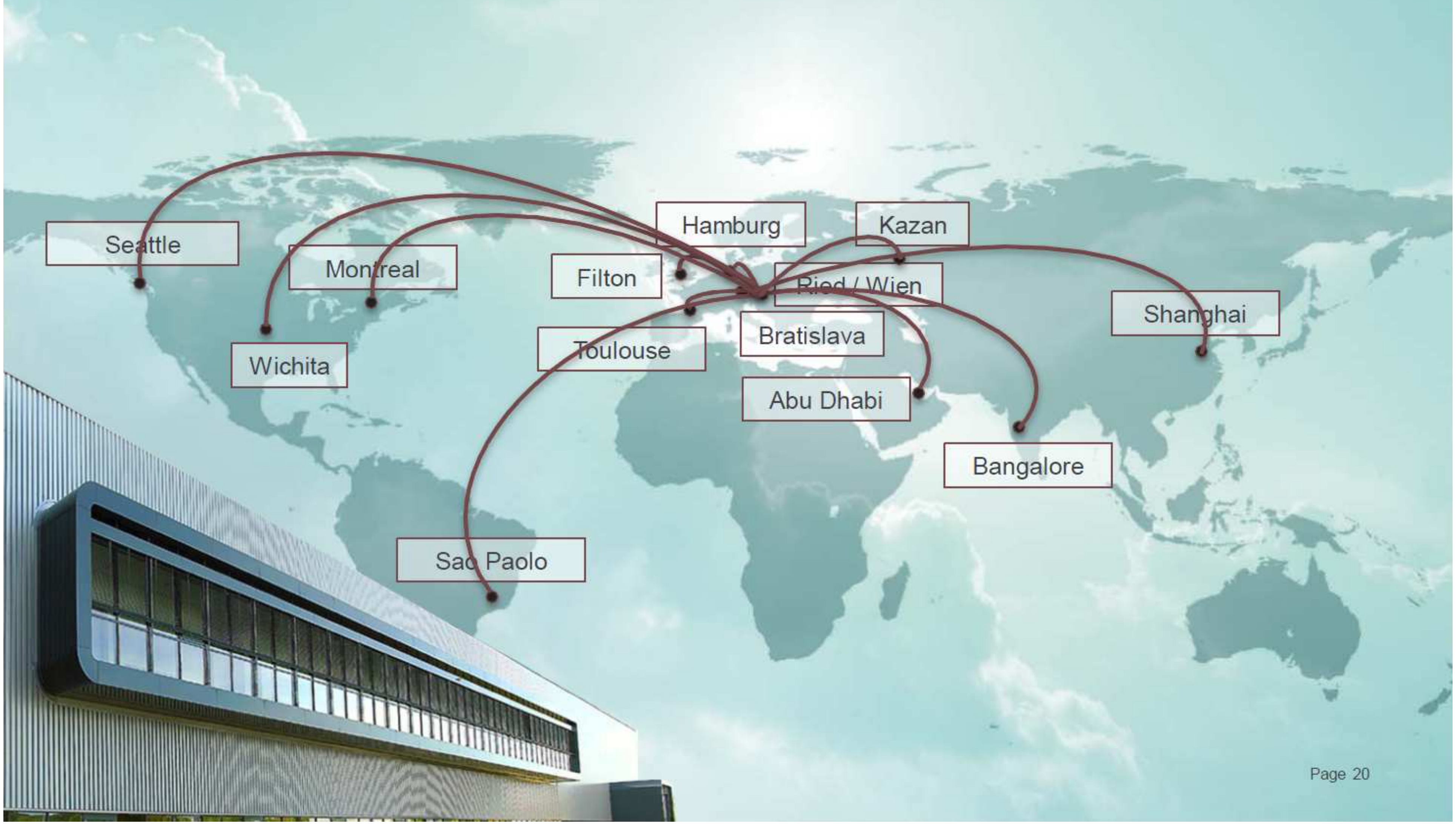
and longstanding relationship with most leading aircraft and engine manufacturers

EMBRAER
BOEING
AIRBUS
AN EADS COMPANY
BOMBARDIER
SAFRAN
Aircelle
Gulfstream®
A GENERAL DYNAMICS COMPANY
EUROCOPTER
SUKHOI
GOODRICH
DASSAULT
AVIATION
COMAC
DIEHL
Aircabin
Pratt & Whitney
A United Technologies Company
SPIRIT
AEROSYSTEMS
AleniaAermacchi
Una Società Finmeccanica
Aviation Partners, Inc.
Leaders in Advanced Winglet Technology
Lufthansa Technik
EADS
ROLLS ROYCE
Triumph Group, Inc.
UAC UNITED AIRCRAFT CORPORATION

Pilot. Passion. Partnership.

From Austria to the world

Global engineering & production footprint for more customer focus



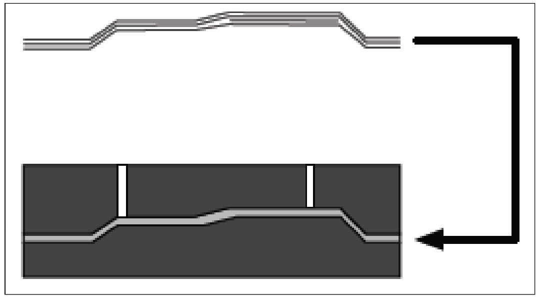
Simulation of Liquid Composite Molding using OpenFoam with Applications to Civil Aerospace Engineering

N. Happenhofer, C. Obertscheider, M. Fleischmann und J. Noisternig
(FACC AG)

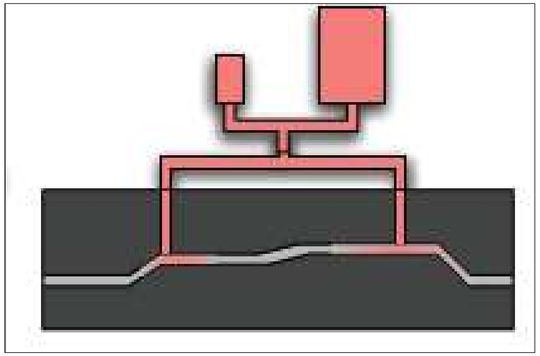
28.2.2014

4a Technology Days

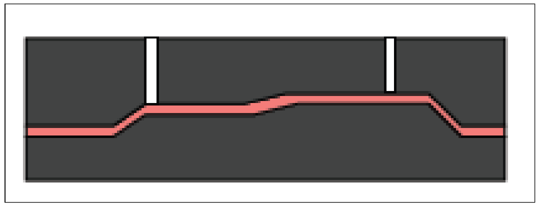
The Manufacturing Process



Step 1: Placement of dry preform
⇒*Draping simulations*
Goal: find layup strategy with minimal wrinkling and shear deformation



Step 2: Resin infusion
⇒*LCM-Simulation*
Goal: find injection strategy where voids and dry spots are prevented; predict filling time



Step 3: Resin Curing & Cooling
⇒*Curing and Spring-Back simulations*
Goal: predict deformation due to curing and cooling

OpenFoam

OpenFoam is

- a free, open source CFD software package; entails solvers for
  - compressible/incompressible/multiphase flows
  - combustion problems
  - electromagnetic problems
  - …
- distributed by OpenCFD Ltd. under the GPL
- freely available for Linux operating systems

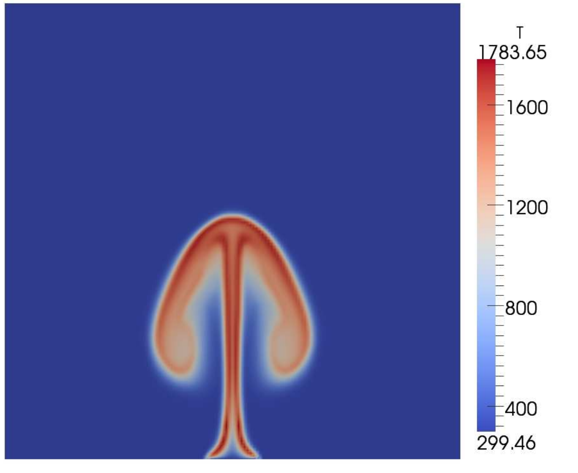


Fig: Simulation of a darting flame

OpenFoam ships with

- Mesh generation and mesh conversion tools:

  fluentMeshToFoam/ starToFoam/ gambitToFoam/ ideasToFoam/ cfx4ToFoam
- Postprocessing via ParaView
- Parallel processing utilities

OpenFoam

Adequate solvers for the modeling the LCM process

porousInterFoam: Solver for 2 incompressible, isothermal immiscible fluids using a VOF phase-fraction based interphase capturing approach, with explicit handling of porous zones

=> **Setup:** cavity is filled with air, resin is injected at the inlet and pushes air out the predefined outlet

cavity filled entirely with air

cavity filled partly with resin

OpenFoam

Solver „porousInterFoam“ (OpenFoam 2.1.1)

Underlying set of equations:

$$\nabla \cdot \vec{v} = 0 \qquad (1)$$

$$\frac{\partial(\epsilon\gamma)}{\partial t} = -\nabla \cdot (\gamma\vec{v}) - \nabla \cdot (\vec{v}_r\gamma(1-\gamma)) \qquad (2)$$

$$\frac{\partial}{\partial t}(\rho\vec{v}) = -\nabla \cdot (\rho\vec{v}\vec{v}) - \nabla P + \nabla \cdot \tau + \rho\vec{g} + S \qquad (3)$$

Porous media modeled by sink term: $S = -\frac{\eta}{K}\vec{v}$

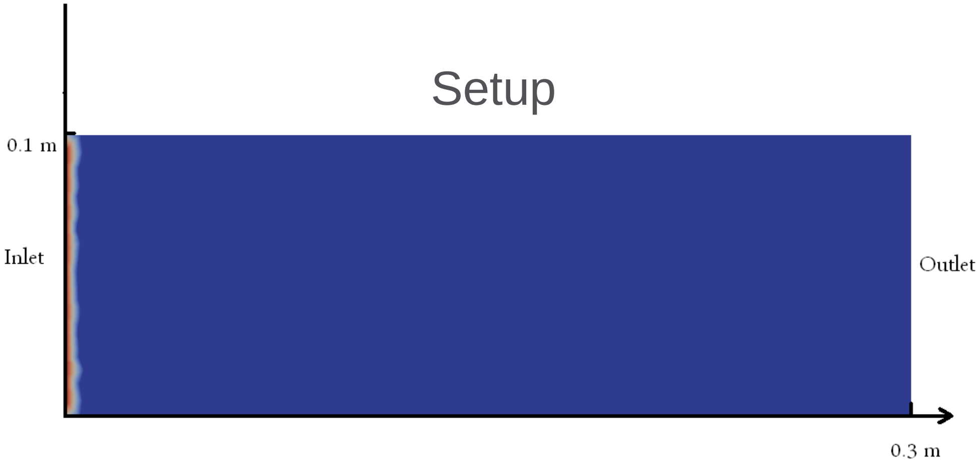
K…. Permeability

μ….. viscosity

Verification

Rectilinear Flow

Setup

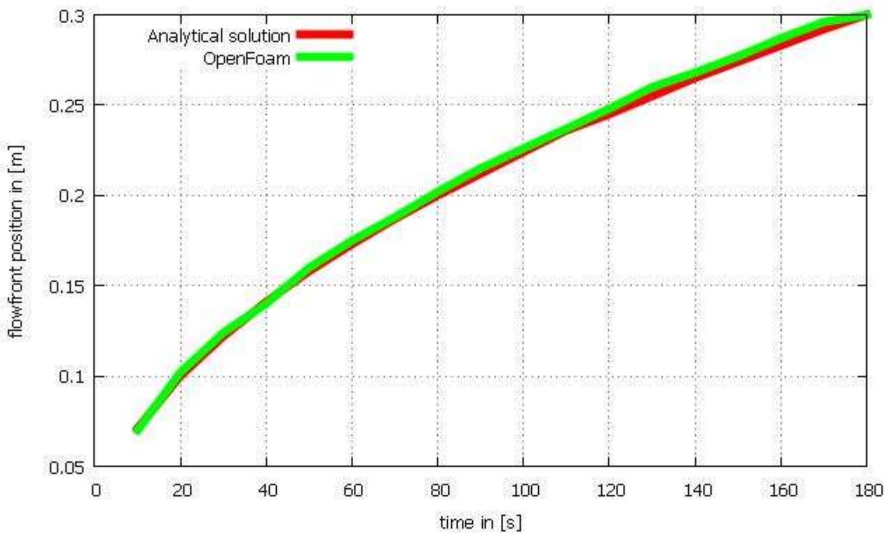


Analytical solution

$$x_f = \sqrt{\frac{2KP_0t}{\mu\epsilon}}$$

Parameter (Rapseed Oil):

P_0 = 35000 Pa
K = 3*10^{-11} m^2
ϵ = 0.7
η = 0.06 Pa s
ρ = 920 kg/m^3



Analogous example: radial flow in an isotropic medium

Validation

Permeameter Experiment (IWK, G0926 fabric (ORCA layup))

ϵ = 0.4445 (FVC 55,55%)

K = $2 \cdot 10^{-11}$ m^2

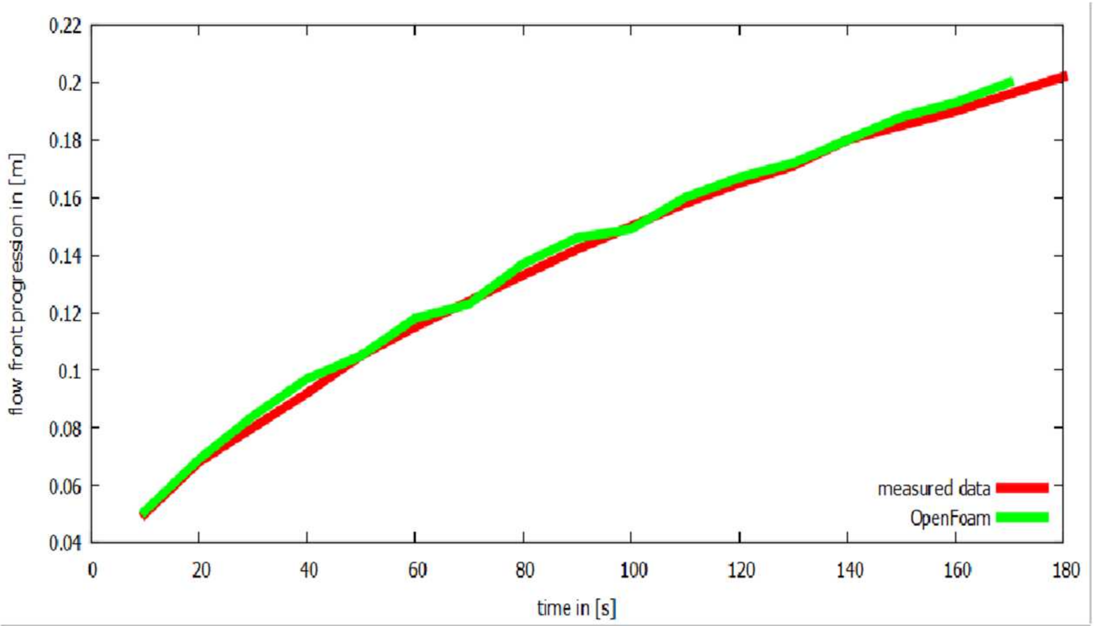
fl = $1.1 \cdot 10^{-6}$ m^3/s // $1.0 \cdot 10^{-6}$ m^3/s // $8.0 \cdot 10^{-7}$ m^3/s

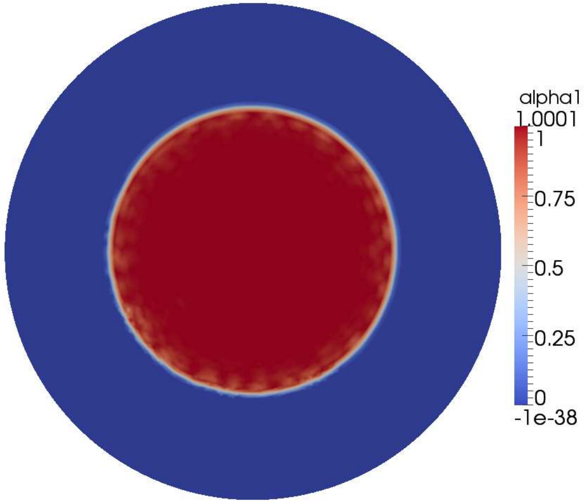
Gylcerine-water mixture:

ρ = 1220 kg/m^3

η = 0.1 Pa s

wallclocktime (1 core): ~36 min





Simulation with OpenFoam at t=50s

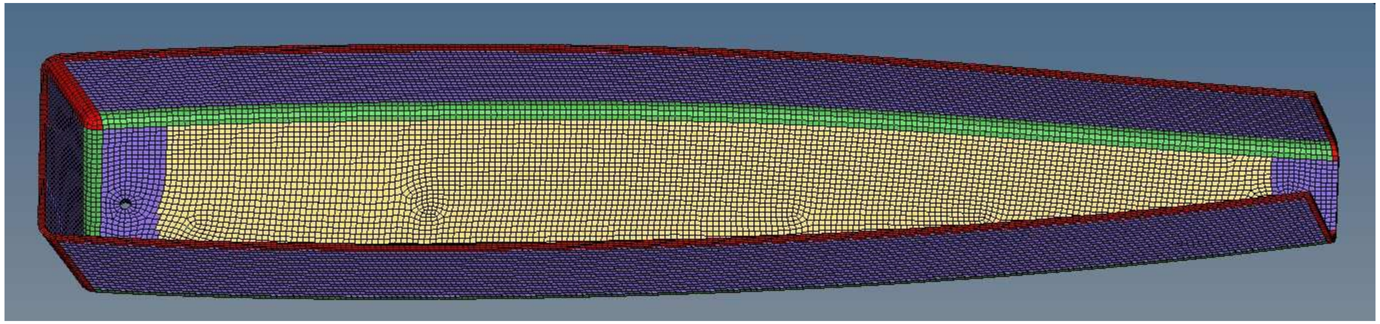
SARISTU Winglet Spars

Manufacturing of Winglet Spars by MARI (P) AT 511 113

Modeling assumptions:

- Thickness negligible => 2.5D simulation (part thickness 3-6 mm)
- Use combined permeability K_{comb} in areas where flow enhancing layer is placed

Preparation of geometry:



Zone 1 (yellow): $K_{comb} = 2 \cdot 10^{-9}\ m^2$

Zone 2 (green): $K_{rad} = 8 \cdot 10^{-12}\ m^2$

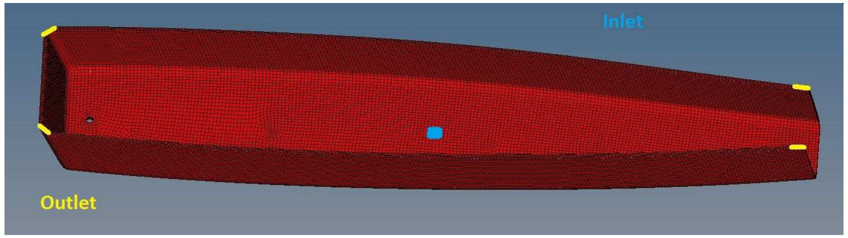
Zone 3 (violet): $K_{pref} = 2 \cdot 10^{-11}\ m^2$

Zone 3 (red): $K_{race} = 2 \cdot 10^{-10}\ m^2$

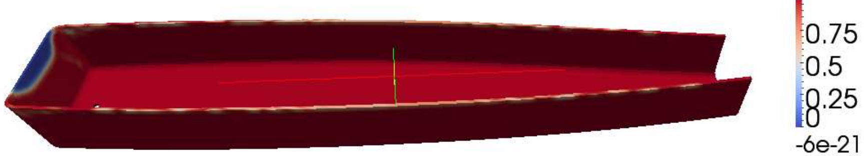
SARISTU Winglet Spars

Saristu Winglet Endrib: Different injection strategies

Injection strategy 1

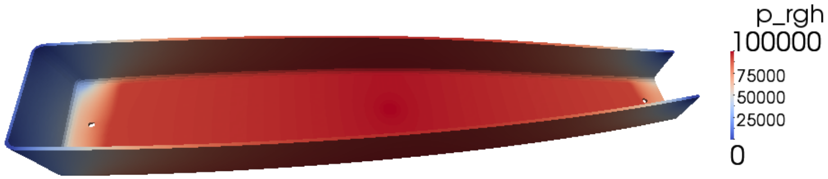


Volume fraction



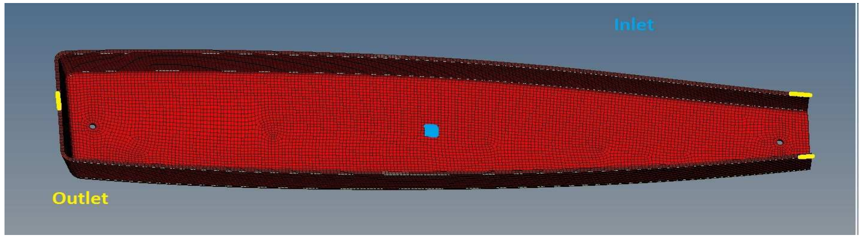
t=50 s

Pressure

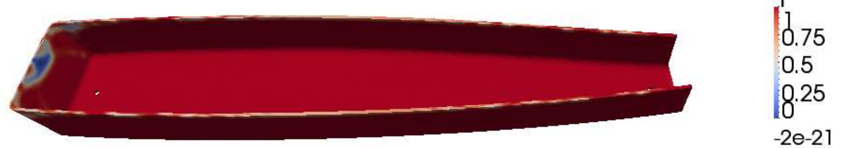


Total filling time: 75 s

Injection strategy 2



Volume fraction



t=45 s

Pressure

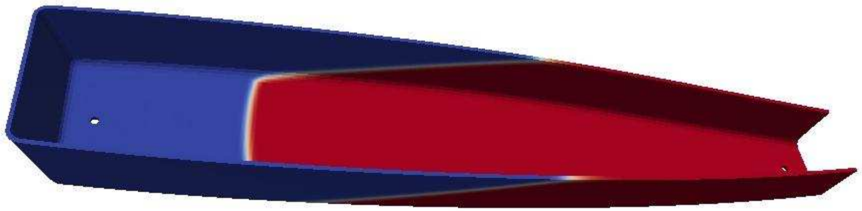
Total filling time: 65 s

SARISTU Winglet Spars

Saristu Winglet Endrib: Permeability variability

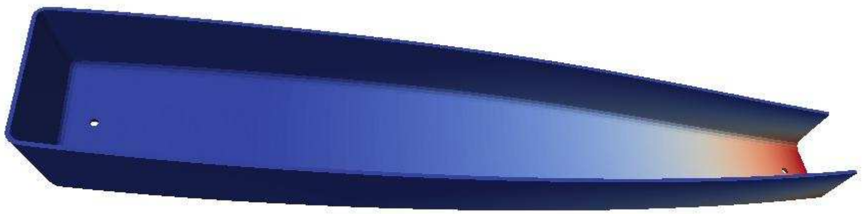
$K_{pref} = 1 \cdot 10^{-10}\ m^2$

Volume fraction



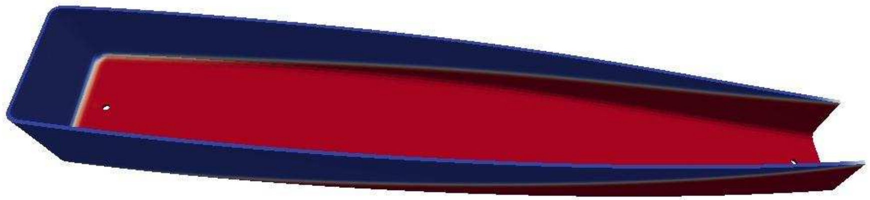
t = 30 s

Pressure



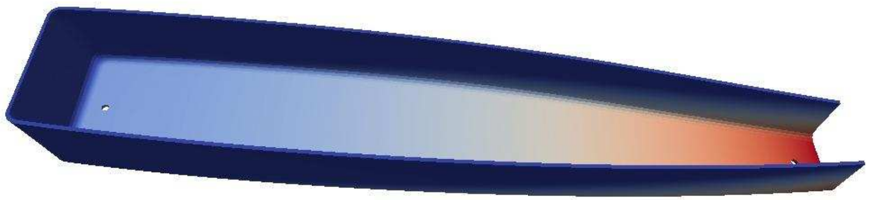
$K_{pref} = 1 \cdot 10^{-11}\ m^2$

Volume fraction



t = 30 s

Pressure



=> Reliable permeability values are important.

Summary & Conclusions

Use of OpenSource Software OpenFoam for simulation of the LCM process

- Choice of appropriate OpenFoam solver and its adaptation to the LCM process.
- Verification & Validation of model and solver

→ **solver works correctly**

Simulation of the filling process in the Saristu Winglet components

- 2.5D simulation
- Effects such as racetracking and preform variability are taken into account
- valid estimation of filling time (if correct permeability values are used)

→ **accurate filling simulation of real part**

Outlook

More detailed mathematical model for vacuum assisted resin infusion:

- Perform entire 3D-simulation taking the flow enhancing layer as a separate structure into account
- Taking preform thickness variation into account (dry/wet compaction behaviour of the material)

Simulation of the entire process chain:

- Taking draping effects into account (changes FVC => changes in K => important for filling simulation) by importing FiberSim data in OpenFoam

Thank you for your attention!