CASE STUDY ON DATA INFRASTRUCTURE AND DATA PROCESSING FOR PROCESS CONTROL IN VACUUM INFUSION PROCESSES

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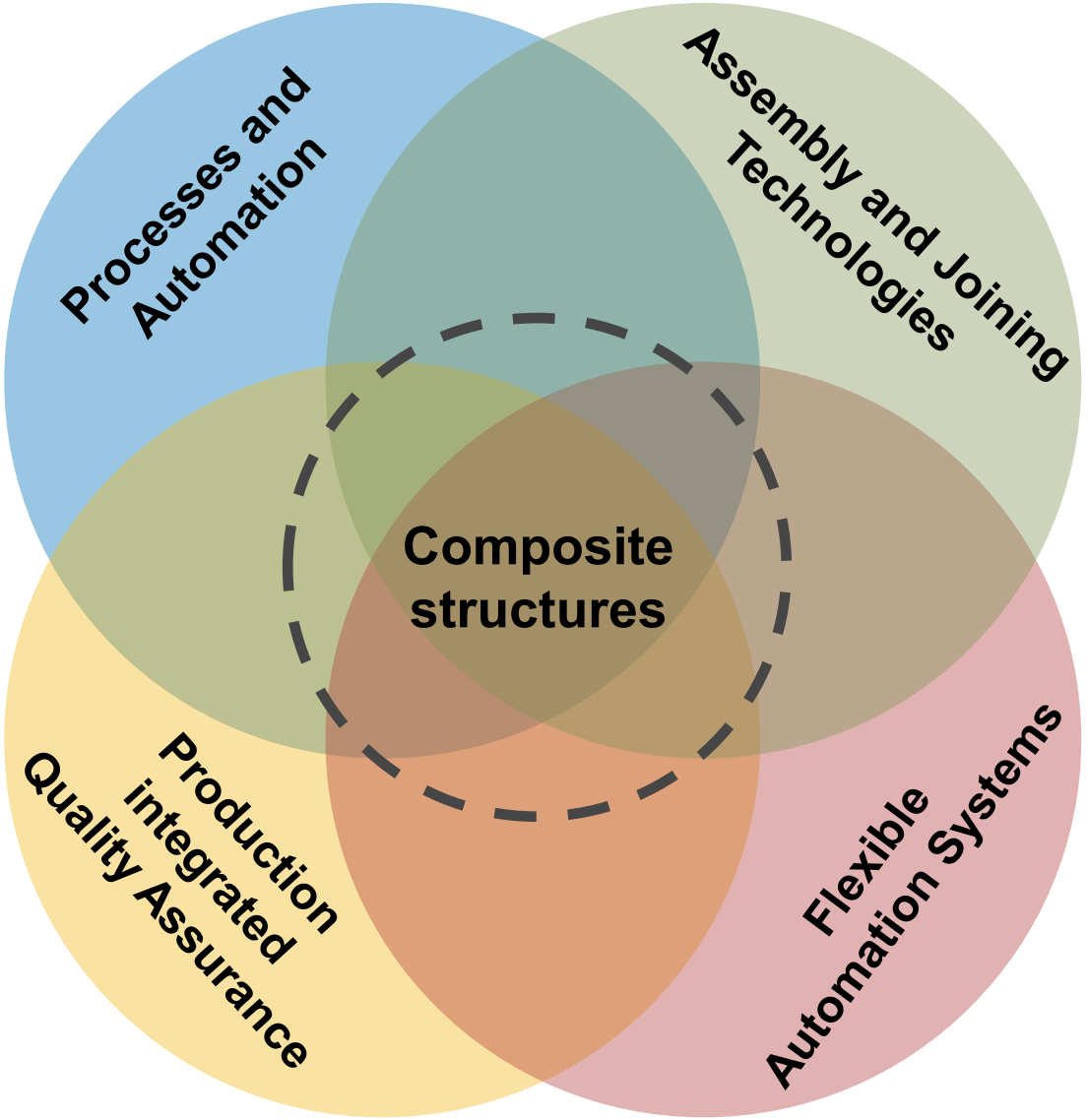
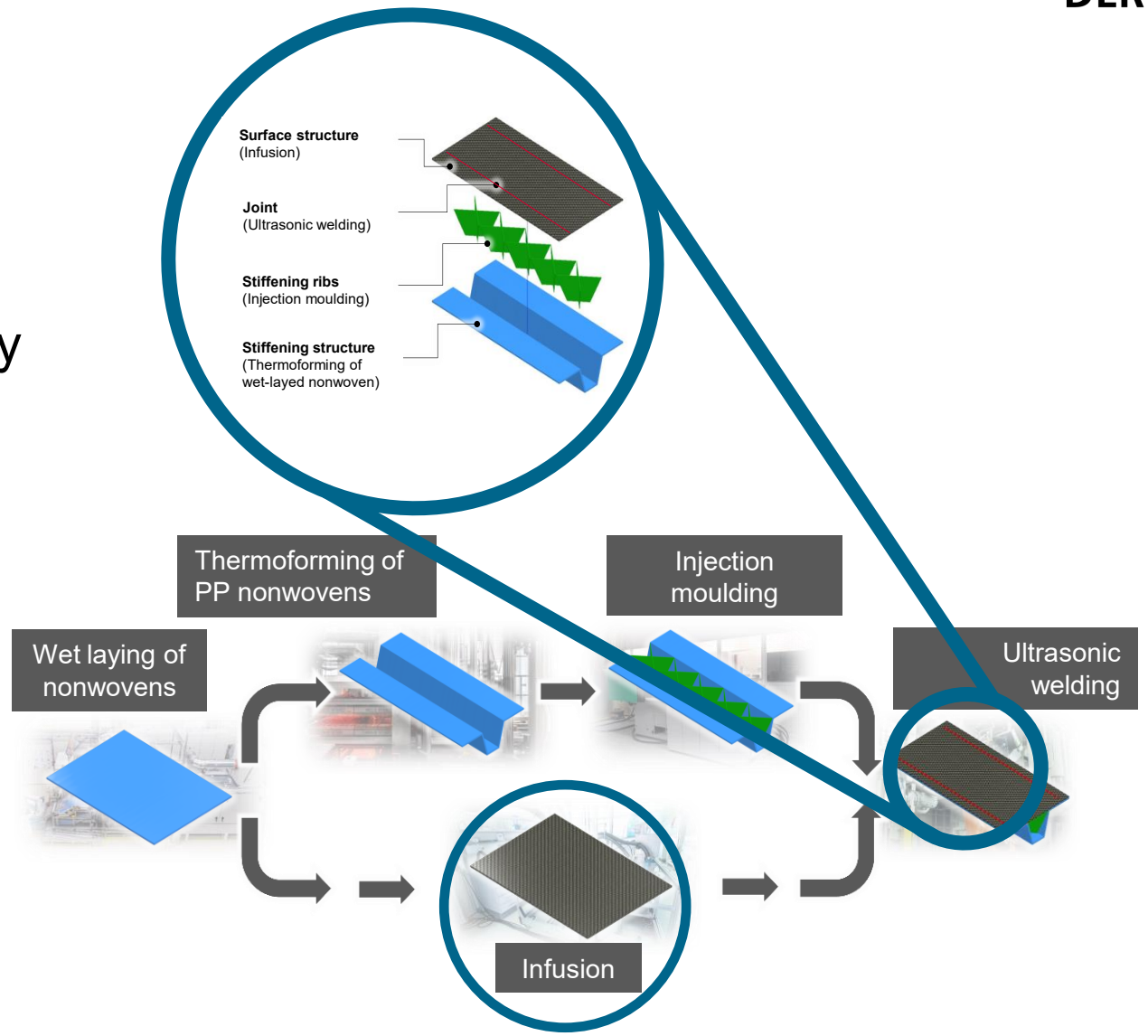
DLR – Center for Lightweight Production Technology



Source: Google Maps

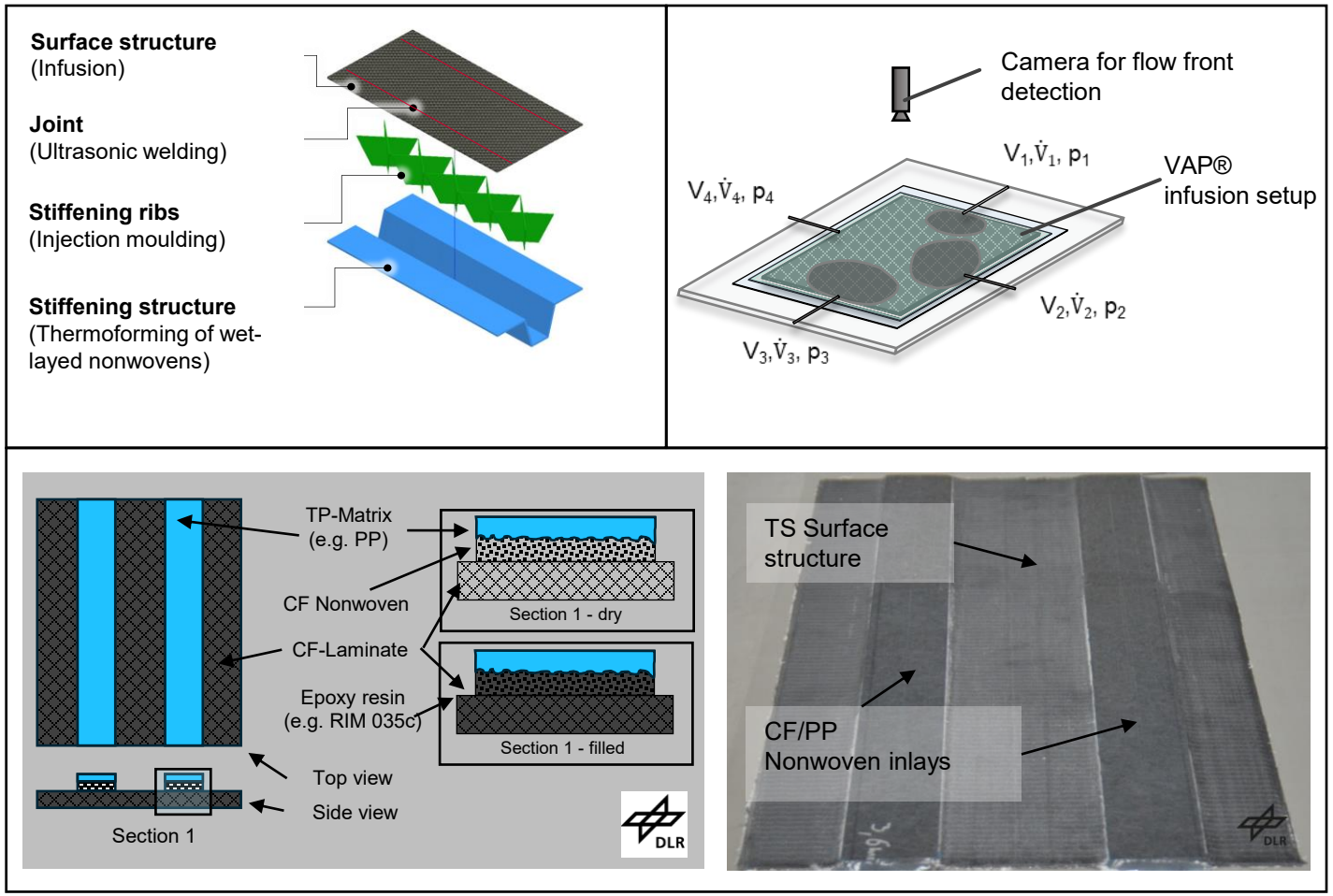
Research Network FORinFPRO

- Process control for intelligent manufacturing processes and closed-loop-production
- 14 Partners from academia and industry
- Expertise in process control, process modelling, materials science, engineering
- Merging of several manufacturing technologies
  - Wet laying of nonwoven fabrics
  - Thermoforming
  - Injection Moulding
  - Vacuum infusion
  - Ultrasonic welding



Use case – hybrid composite surface structure

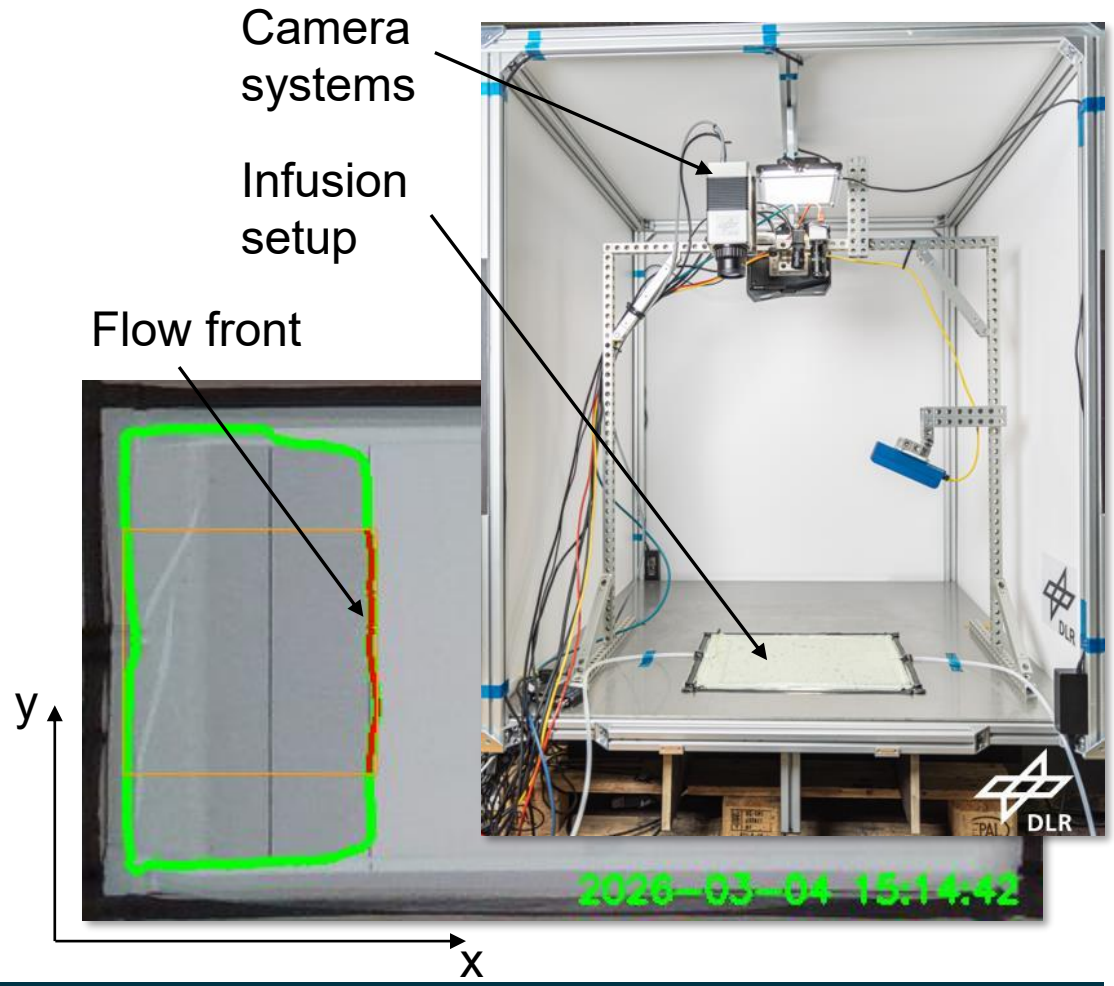
- Flow front manipulation for optimized saturation
- VAP® infusion setup with semipermeable membrane
- Hybrid nonwoven patch for ultrasonic welding
  - Thermoplastic matrix: polypropylene
  - Thermoset matrix: Epikote RIMR035c + Epikure RIMH1366



Camera-based flow front monitoring

- Testbed for flat panels (2D)
- Computer-vision-based flow front detection
  - Python – OpenCV
  - Edge detection by gray scale images
- Pixel-based information on flow front position

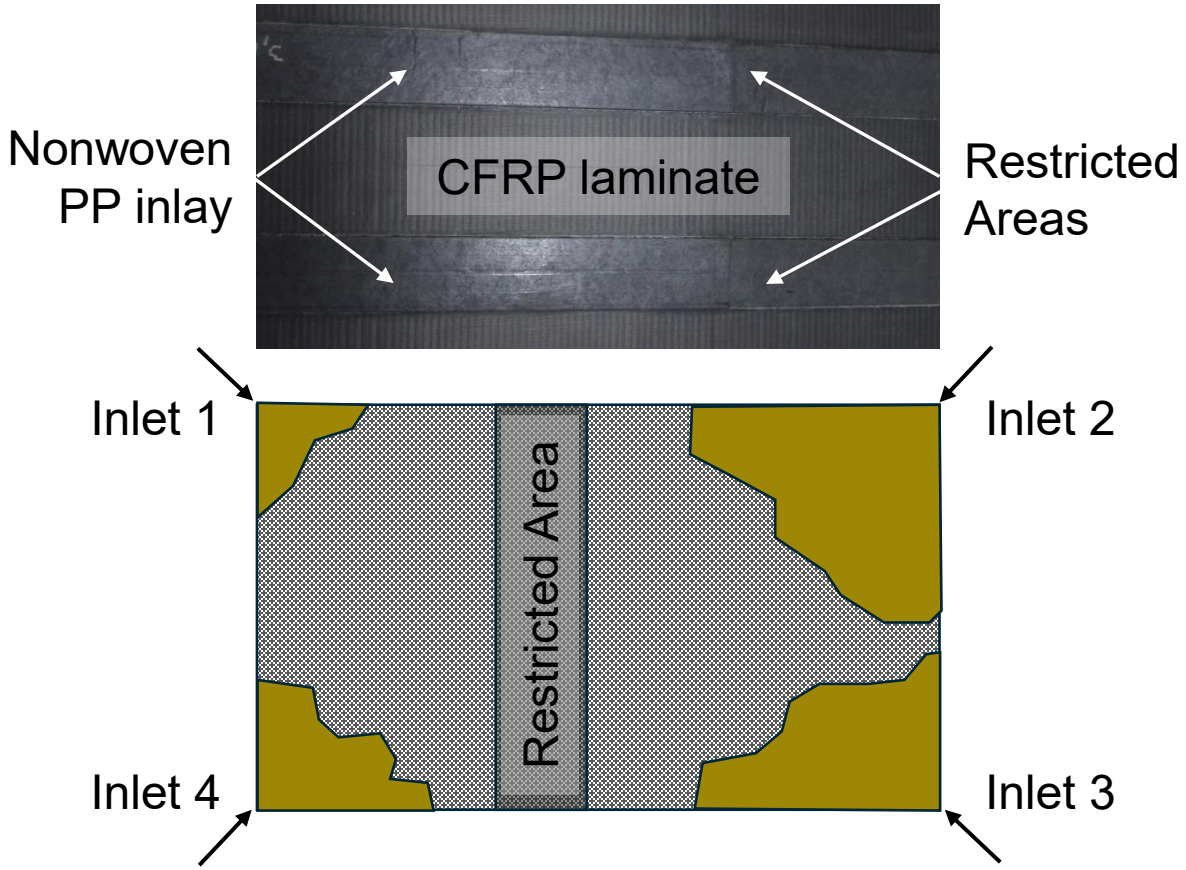
►Flow front velocity: $v_{FF} = \frac{dx}{dy}$



- Flow front velocity as control variable for flow front manipulation

Approach

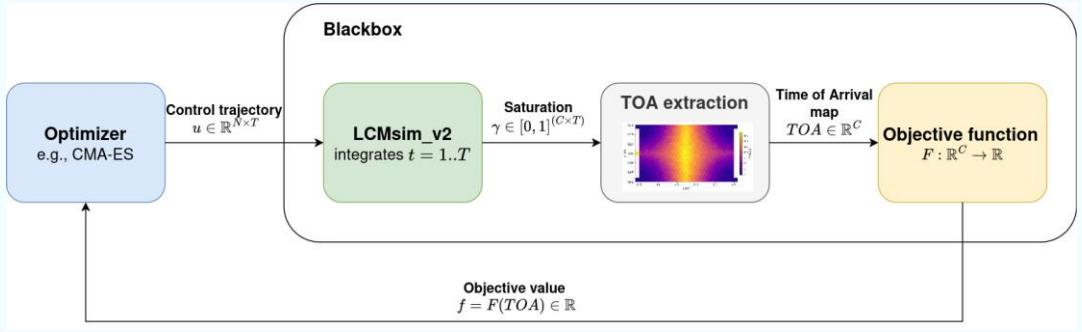
- Goal
  - Complete filling
  - Minimum porosity
  - Minimum filling time
  - No flow front collision underneath the nonwoven PP inlay („restricted area“)
- Setup
  - Variation of volume flow
  - Manipulation of valve position and status (eg. open/closed)
  - Detection of flow front velocity



- FVM flow simulation (LCMsim_v2)
- Three-stage objective: ► filling ratio ► restricted area ► filling time

Process simulation and modelling

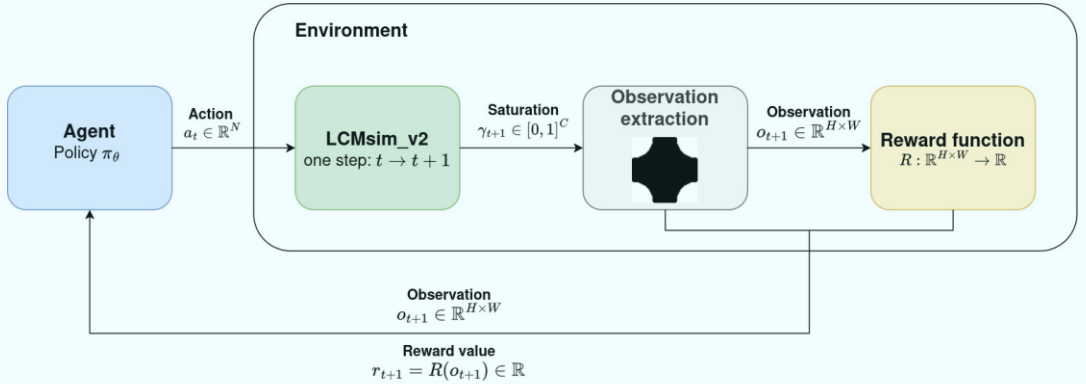
Covariance Matrix Adaptation Evolution Strategy (CMA-ES)



1. Each generation, the optimizer proposes a population of full control trajectories
2. LCMsim_v2 simulates the entire filling
3. The resulting TOA maps are scored by the objective function

Source: Covariance Matrix Adaptation Evolution Strategy (CMA-ES) · GitHub

Proximal Policy Optimization (PPO)



1. Agent selects valve action using its policy
2. LCMsim_v2 advances one step and returns next observation and reward
3. Agent runs next action

Source: Proximal Policy Optimization (PPO) Agent - MATLAB & Simulink

	CMA-ES	PPO
Type	gradient-free, population-based optimiser	trial-and-error policy learner
Output	fixed valve trajectory (offline)	reactive policy: camera image → next valve setting (decided at runtime)
Input	full Time-of-Arrival (TOA) map	camera image of flow front (current step)
Information	complete flow field, all time steps	restricted — as available in reality

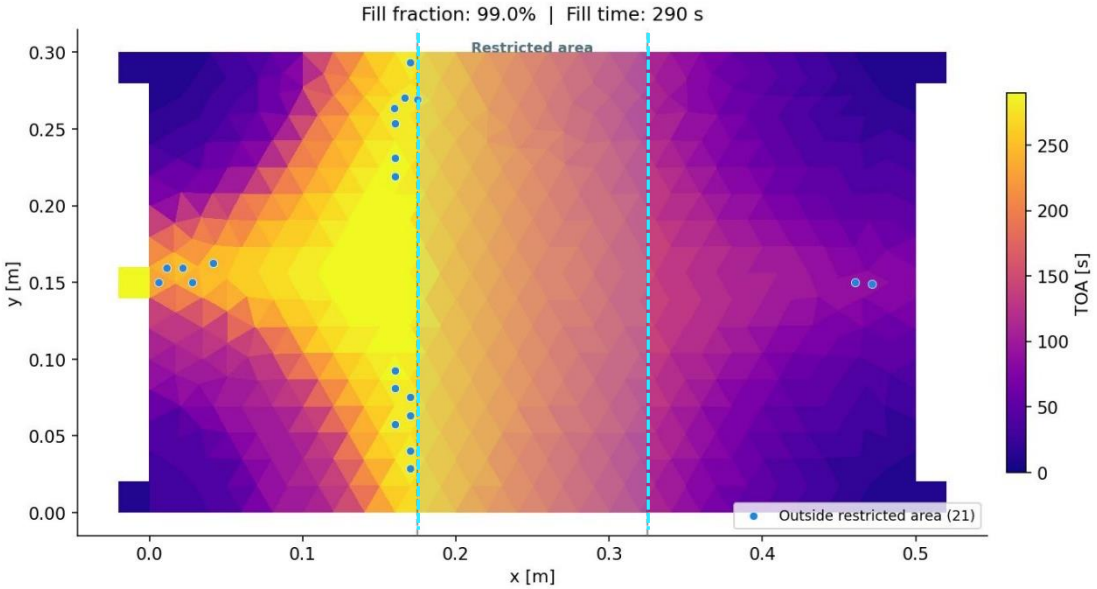
Process simulation and modelling

Proof of concept

- CMA-ES satisfies all constraints, reached step by step: complete filling (gen. 20), restricted area (gen. 66), best overall solution (gen. 284, filling time 290 s)
- Flow fronts merge outside the restricted area (dashed)
- Asymmetric strategy found automatically → right inlets open, left throttled

Ongoing

- Comparison with a reactive RL policy (PPO) How much solution quality is lost under restricted, camera-only observation?



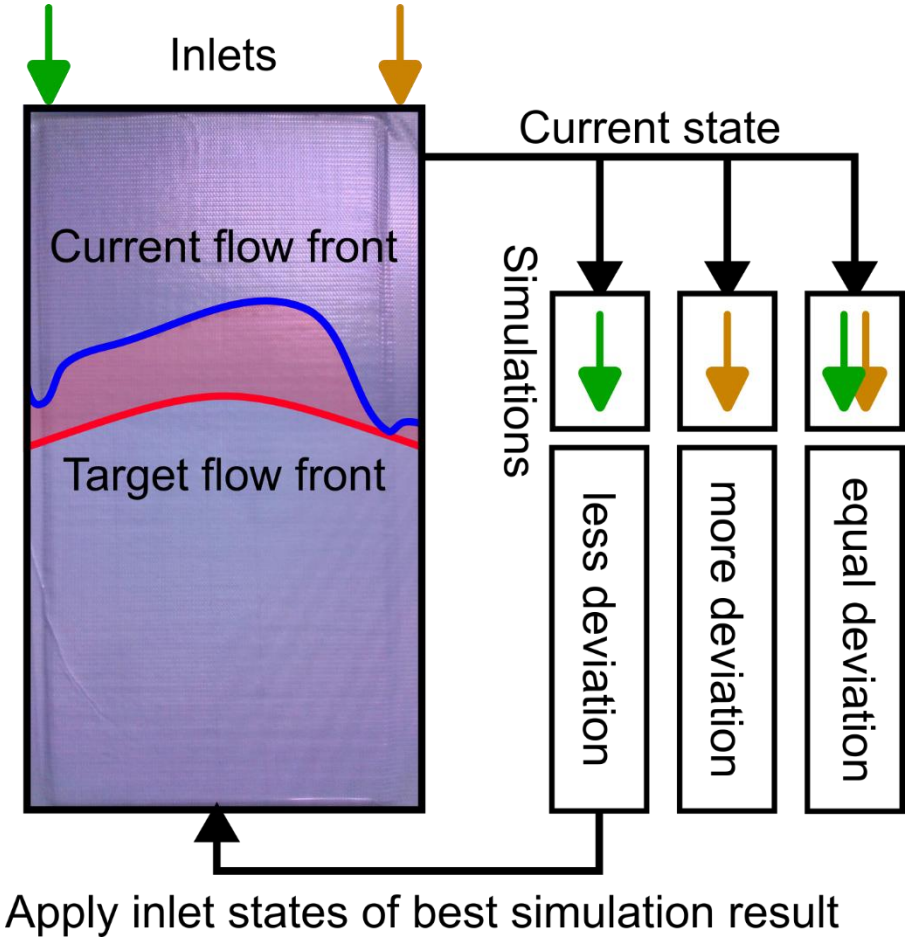
Time-of-arrival map of the best CMA-ES solution: complete filling in 290 s

Control concept: Compensation of deviations by Model Predictive Control

- Evaluation of discrepancies between current flow front (blue) and simulated CMA-ES target flow front (red)
- Model Predictive Control:
  - Run multiple parallel simulations for different inlets (open/closed)
  - Apply altered inlet states that give the best result for tracking the CMA-ES flow front movement

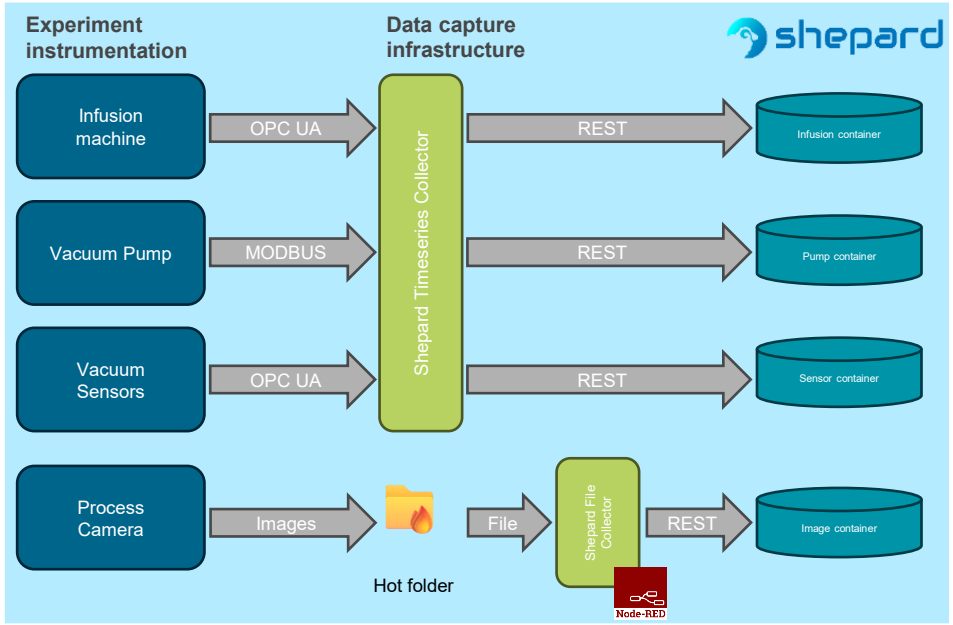
Ongoing:

- Validation of CMA-ES data and camera-based flow front data
- Mapping of filling state on CAD models



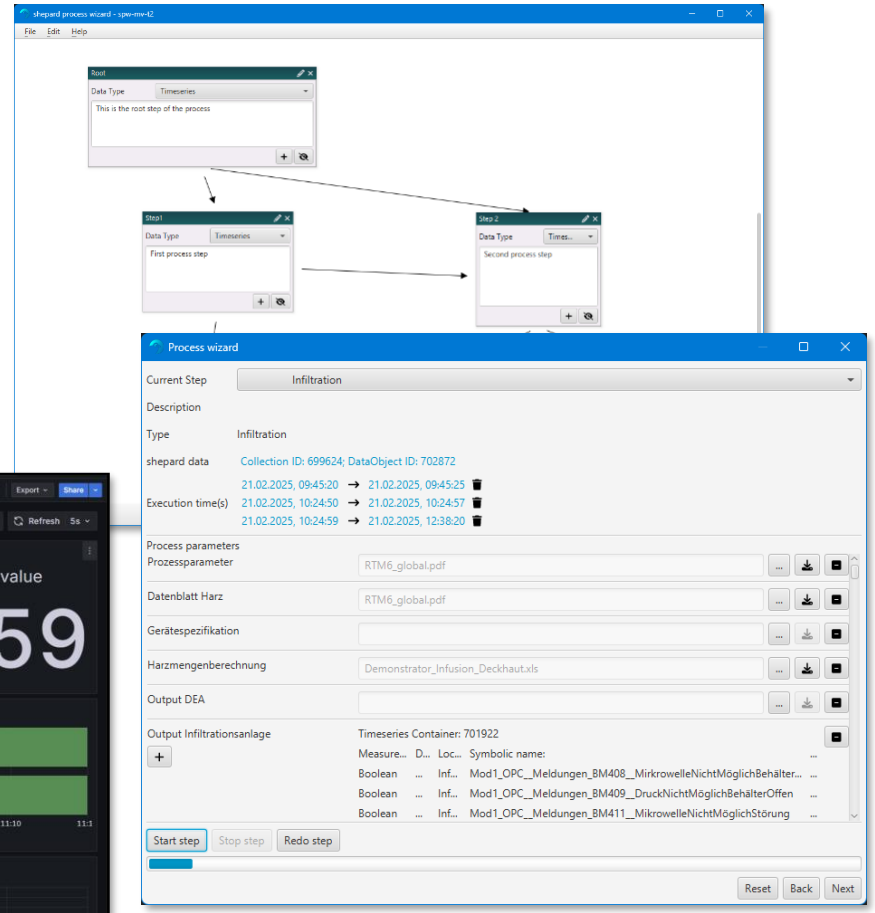
Data Management
step 1: data capturing

- Shepard
  - Centralized data management system
  - Storage of data (timeseries, binaries, …)
  - Organization/Structurization of data
  - REST API
  - Open Source development at DLR
- Automatic capture of real-time data
  - shepard Timeseries Collector connect to sources
    and stores timeseries data
  - Multi-protocol (OPC/UA, Modbus TCP, …)
- Storage of live pictures



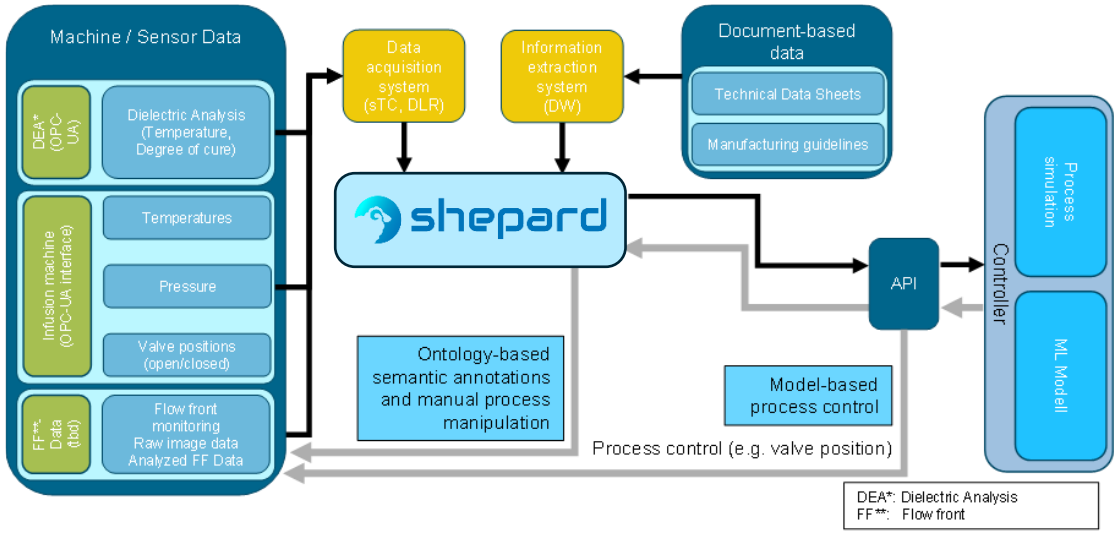
Data Management
step 2: data contextualization and visualization

- Continuously stored data needs context
  - current process step, part number, etc.
- Supported by graphical process wizard
- “Real-time” visualization using Grafana dashboard

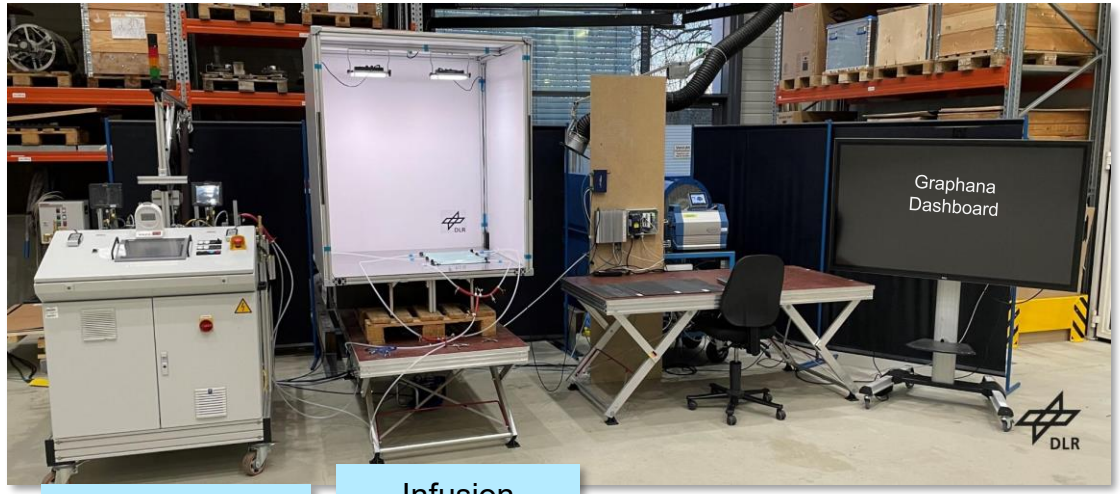


Process validation with data acquisition testbed

- Centralized data management
- Time series data and document based process data (e.g. TDS)



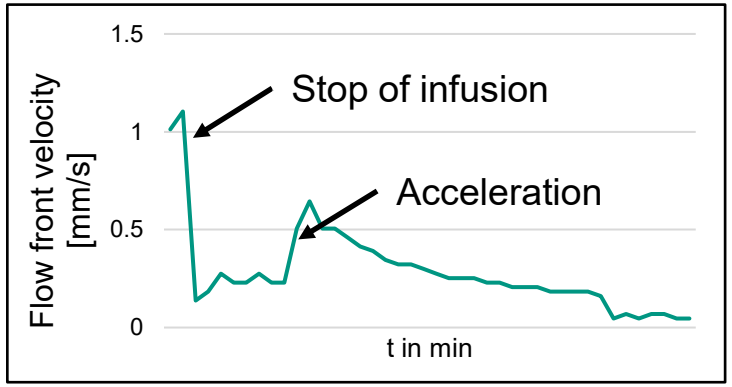
- Online visualization of process parameters (e.g. temperatures, pressures flow front, valve position)

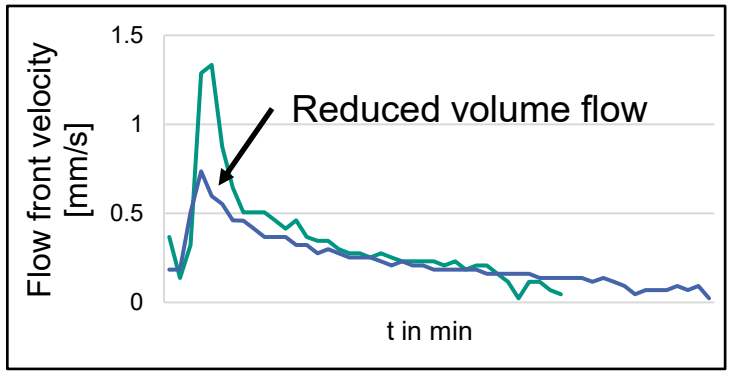


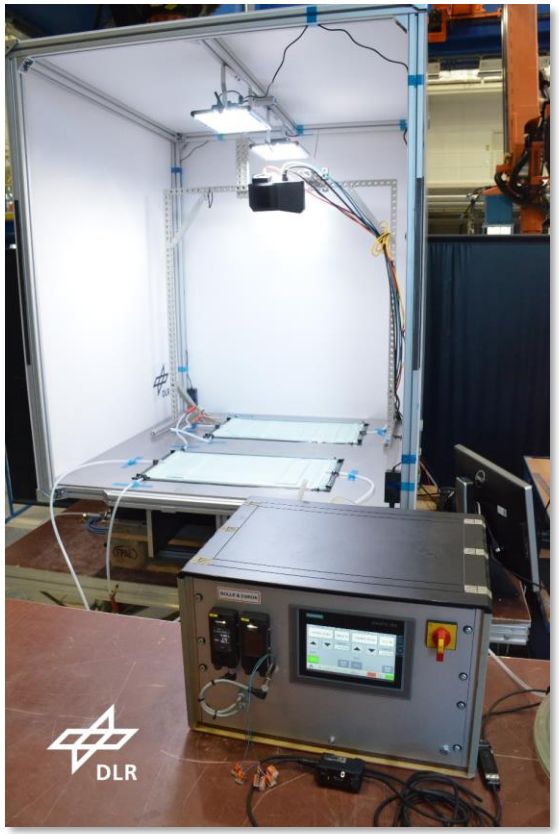
Infusion machine | Infusion testbed with camera | Data interface | Dashboard

Flow front manipulation

- Testbed with controlled inlet valves
- Flow front manipulation (start, stop, acceleration, deceleration)
- Manual flow front manipulation with defined volume flows



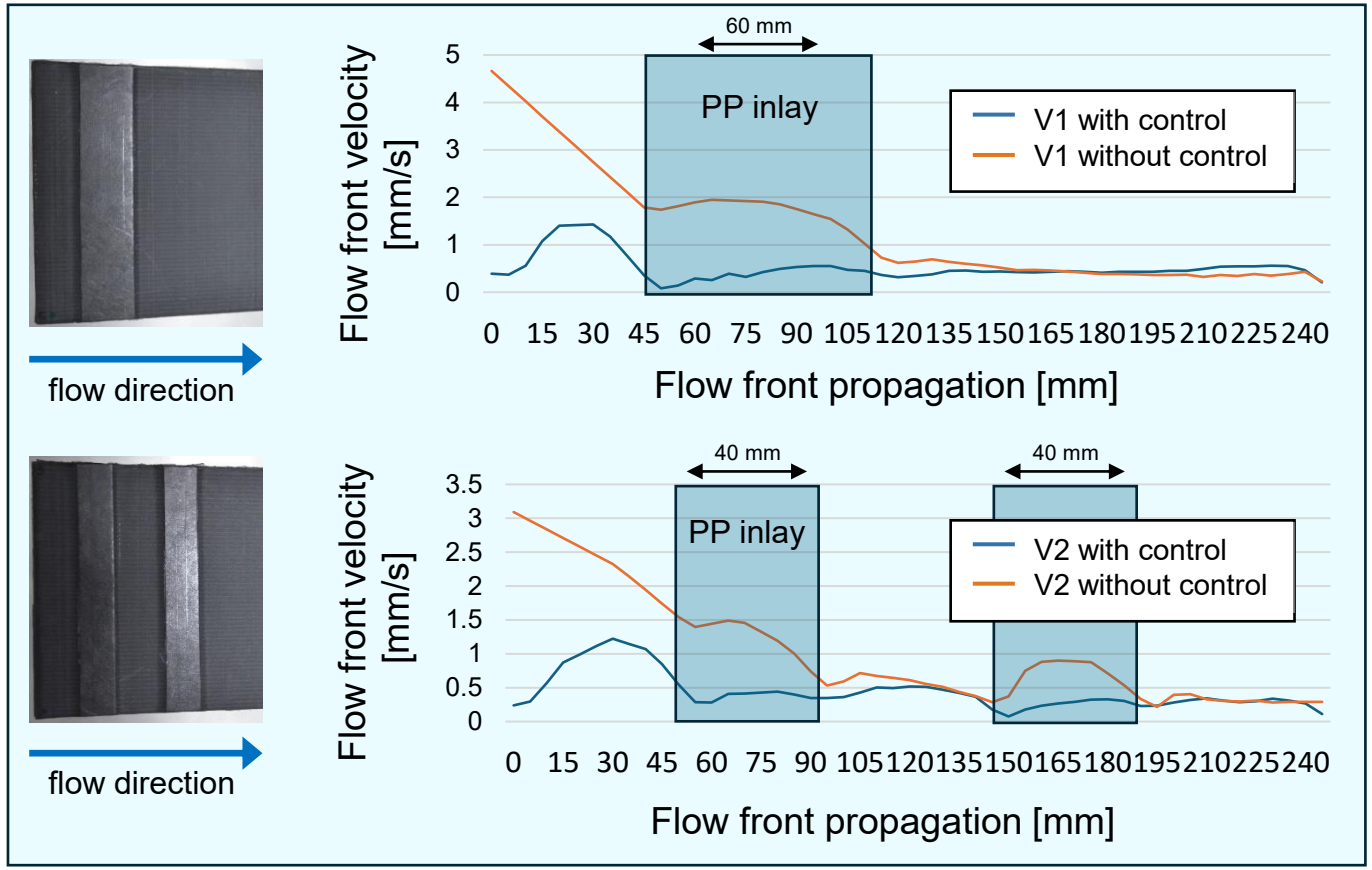


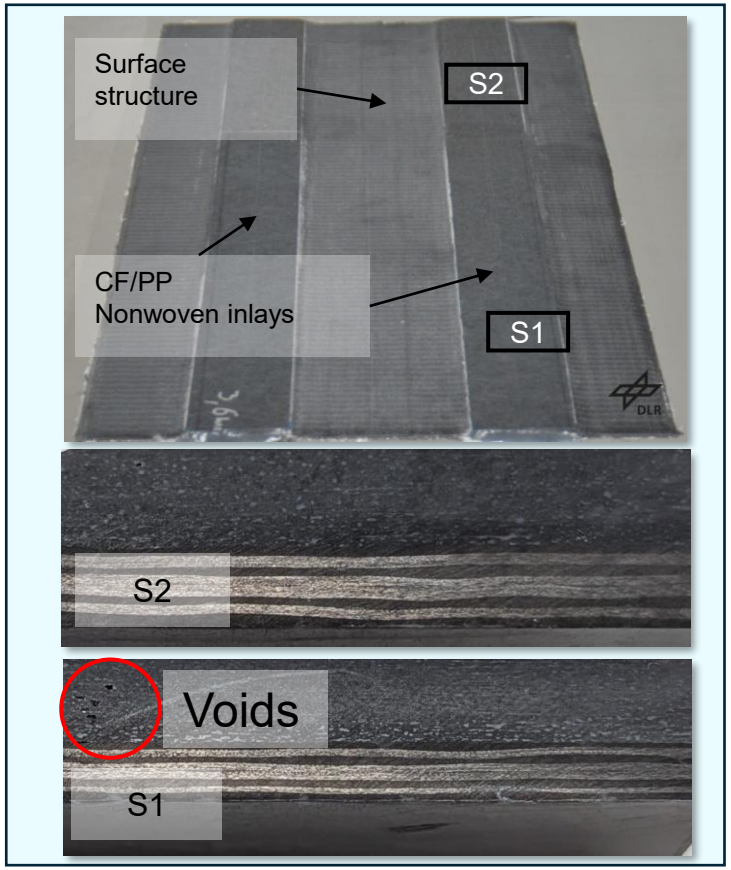


Volume flow control
Bolle&Cords

- Volume flow control system by Bolle&Cords, Germany
- Pneumatic valve manipulation and volume flow measurement

Validation on hybrid composite surface structure





Flow front manipulation with flow length of 300 mm

Porosity varies with flow front velocity

Summary and Outlook

- Data infrastructure set for comprehensive process monitoring
- Simulation model set for process control
- Control concept defined
- Equipment validated for manual flow front manipulation

►Validation of void propagation based on infusion setup

►Evaluation of control concept

►Upscaling for more complex geometries and alternativ hybrid composites (e.g. RTM6 + PEI)

Thank you very much!

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