Virtual PaintShop – Simulation of Electrocoating

Cluster Conference 2023

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Virtual Paint Shop

Novel methods, algorithms and software tools to optimize paint and surface treatment processes to be more environmentally friendly, more energy and cost efficient, and give a better product quality

Spray painting

- Unique algorithms for coupled simulation of air flows, electrostatics and charged paint particles
- Full car spray painting simulations overnight on a standard computer

Hanging optimization

- Optimization of collision free hanging pattern

Sealing

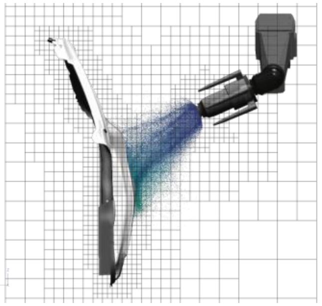
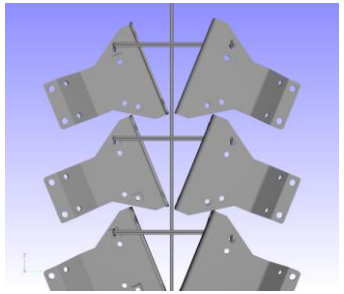
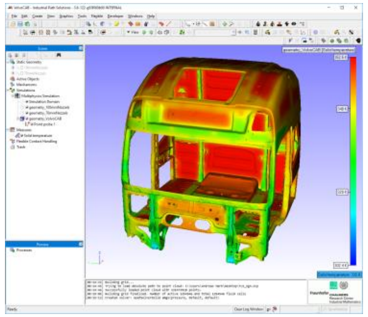
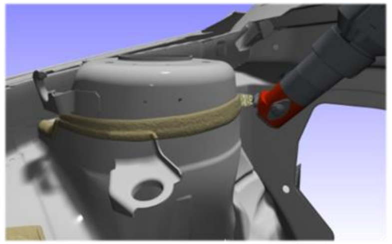
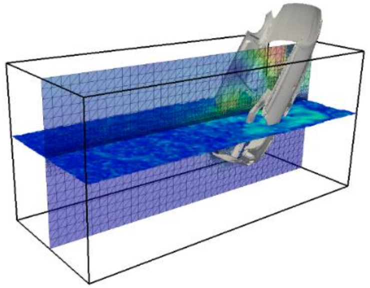
- Fast and accurate process simulation of the material laydown
- Automatic generation and programming of efficient robot motions

Oven Curing

- Robust and accurate CFD-based approach including conjugated heat transfer of air and solid temperatures

Electrocoating

- Ongoing research activities

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VOLVO

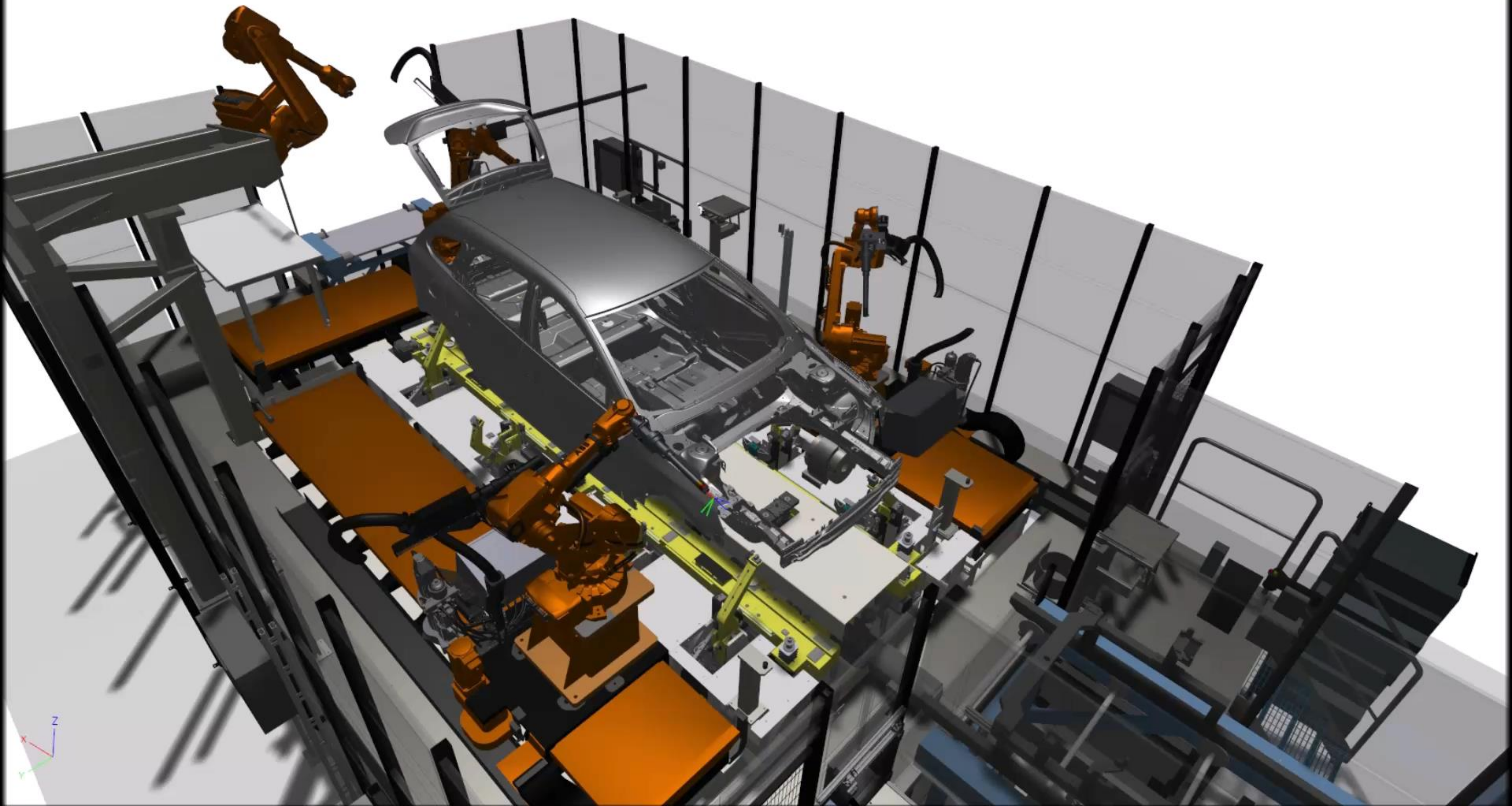
SCANIA

VOLVO

FORDONS KOMPONENT GRUPPEN

RISE


Z
X




VolvoCAB [Solid temperature]
0 K
0 K

Simulation of Electrocoating – Vinnova FFI Project

Develop methods, techniques and software, and supporting measurement methodology, for efficient and reliable simulation of the electrodeposition and electroplating processes

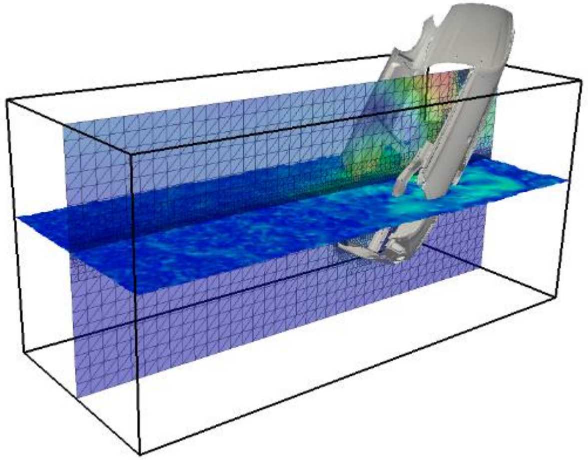
Expected results

- Improved **quality** of E-coat finish and corrosion protection
  - Identify and solve fluid access and drainage problems
  - Reduce level of phosphate contamination
- Reduced **commissioning time** for new products
- Reduced **environmental impact** by significantly less testing on physical prototypes
- Increased **flexibility** to meet ever-increasing product and material variants
- Technology and **knowledge transfer** between different industries and actors

VOLVO SCANIA VOLVO IPS RISE IKEA® swedecote PROTON finishing PROVEXA Surface Technology FRAUNHOFER CHALMERS RESEARCH CENTRE FOR INDUSTRIAL MATHEMATICS

Simulation Challenges in Electrocoating and Electroplating

- Complex moving geometries
  - Multiple scales (bath, object, paint layer)
  - Small gaps and holes
  - Multi material combinations
- Long residence times in baths of several minutes
- Complex multiphase flow
  - Fluid access and drainage
  - Predict location of air pockets
- Electrochemistry in the bath and coating layer build-up during electrocoating and electroplating
- Object deformation during dipping motion caused by the tank surface pressure



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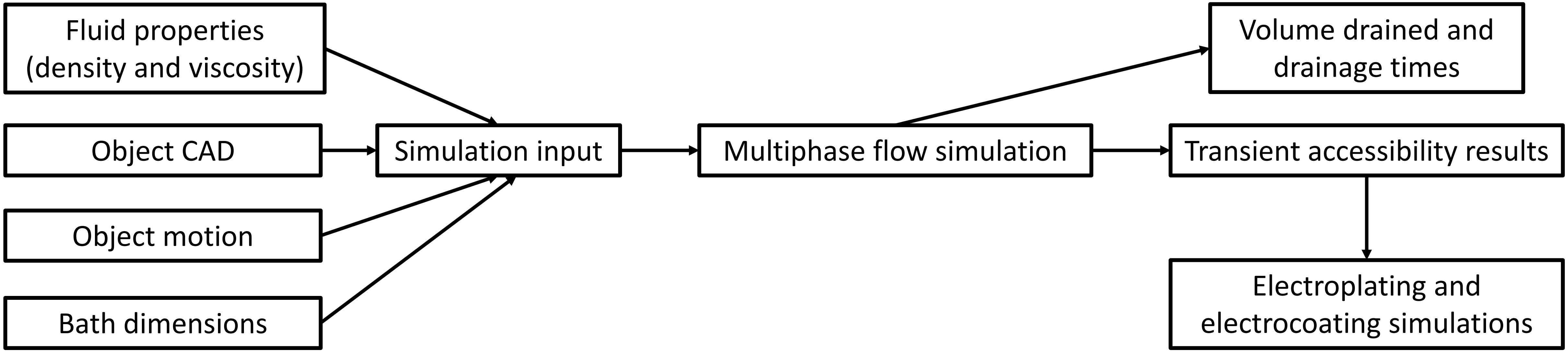
Physics-based Modeling Approach

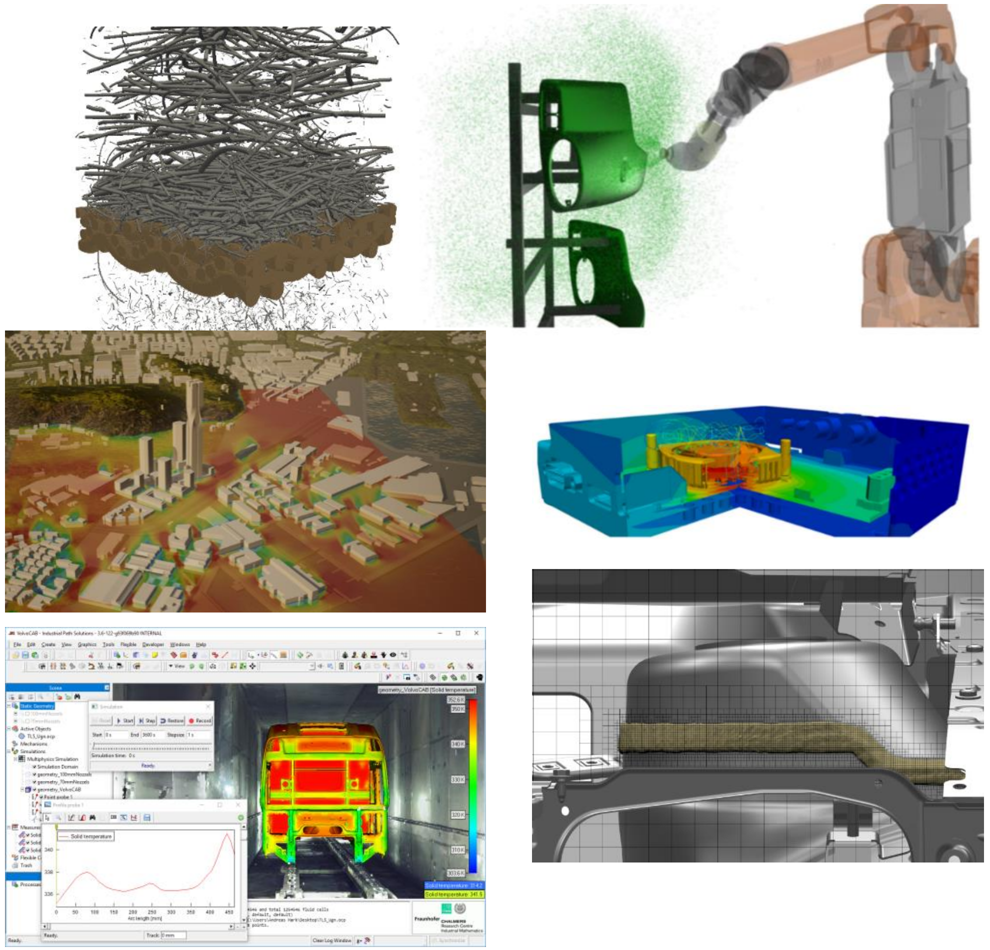
- Fluid access and drainage simulations
  - Multiphase flow simulation using VOF
  - Transient accessibility and drainage output
- Electrochemistry in the bath
  - Modeling of the electrostatics in the bath and current density on the cathode
  - Coating layer build-up during electrocoating and electroplating
- Basic assumption: Electrostatic model of the bath can be decoupled from the VOF simulation



IBOFlow

- Solver for complex flow and multiphysics
  - Unique immersed boundary techniques
  - GPU acceleration
  - Multiphase flow (Volume of Fluids)
  - Complex rheology
  - Conjugated heat transfer
  - Particle and sprays
  - Electrostatics

- Interfaces to other tools
  - LaStFEM™ for fluid-structure interaction
  - Demify® for DEM-CFD applications
  - CST Microwave Studio for electronics cooling



IPS IBOFLOW®

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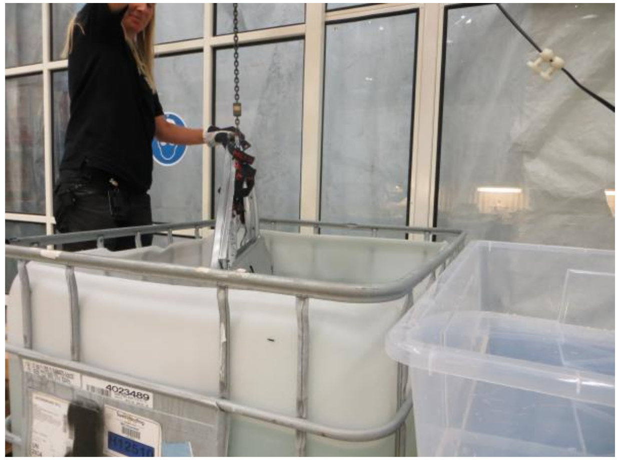
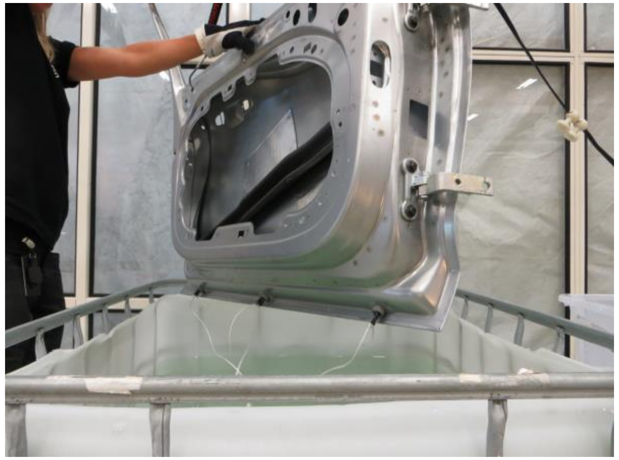
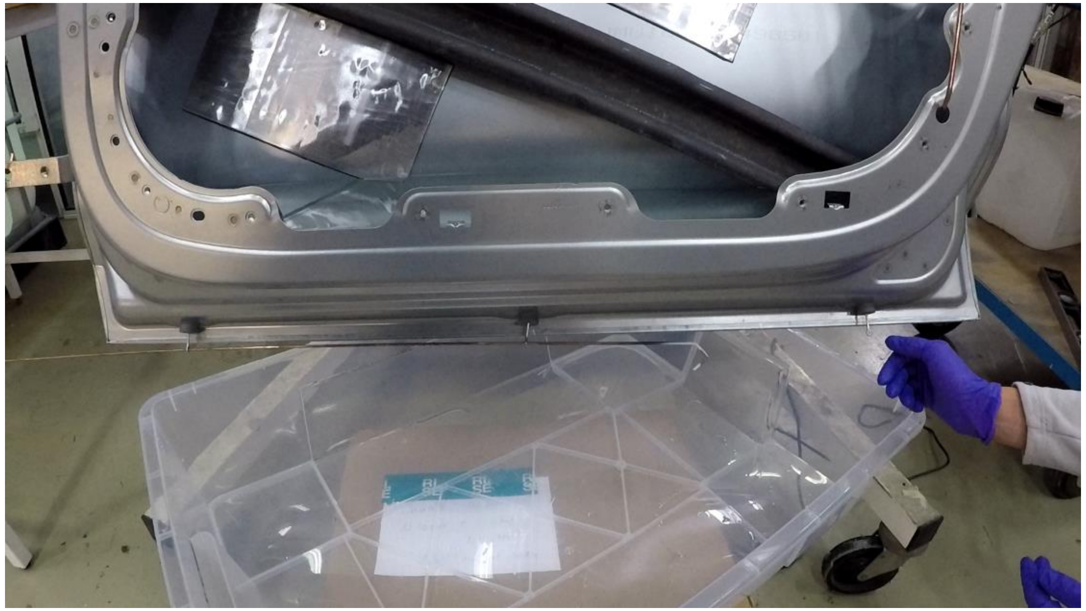
Experimental setup at RISE – Drainage VCC door







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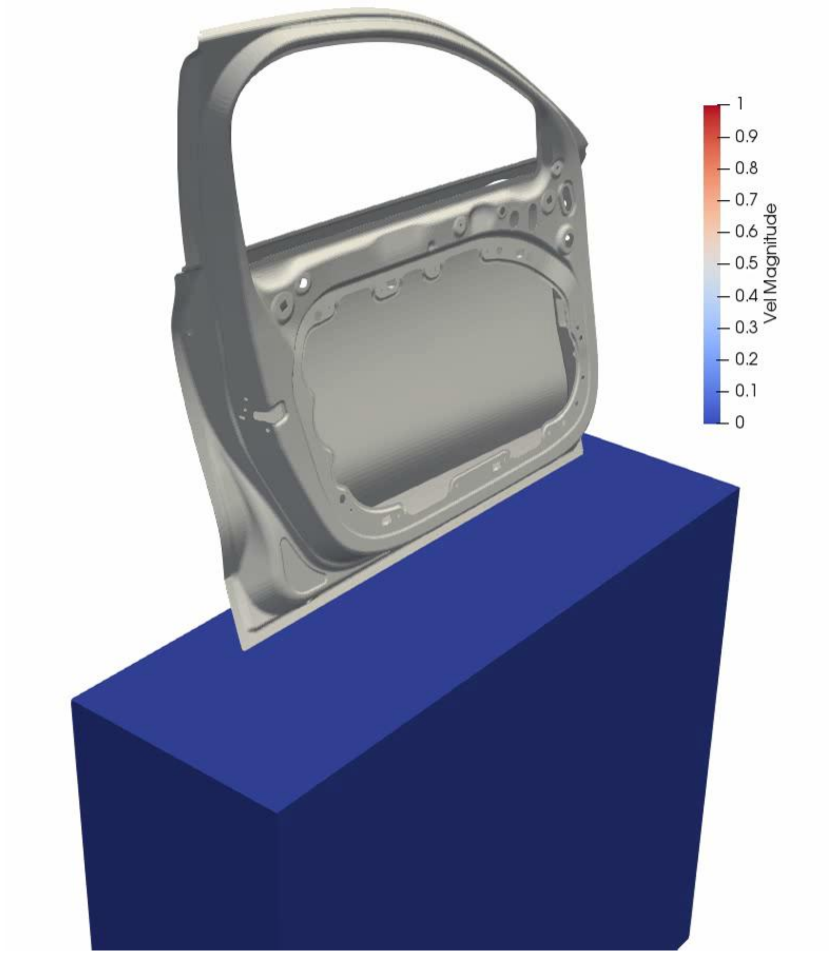
Dynamic Drainage and Accessibility Simulation

- Multiphase flow simulation
  - Immersed boundary conditions
  - Flexible octree grid
  - Volume of fluids
- Four seconds downward motion
  - Filling of the door
- Four seconds upward motion
  - Initial drainage of the door
- Static drainage for 22 seconds
  - Until the water is drained
- Accessibility data continuously stored
  - Each triangle has a state
    - Contact/no contact with liquid



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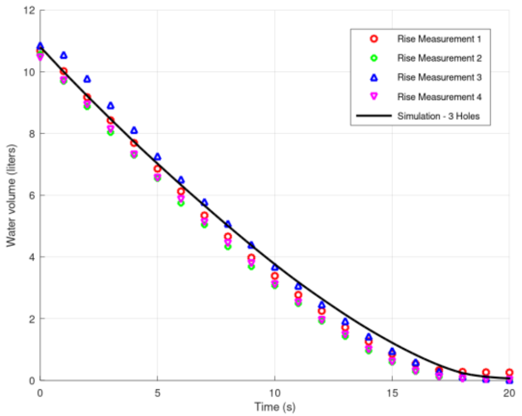
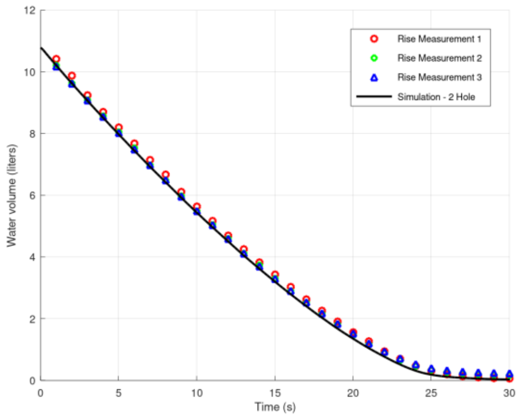
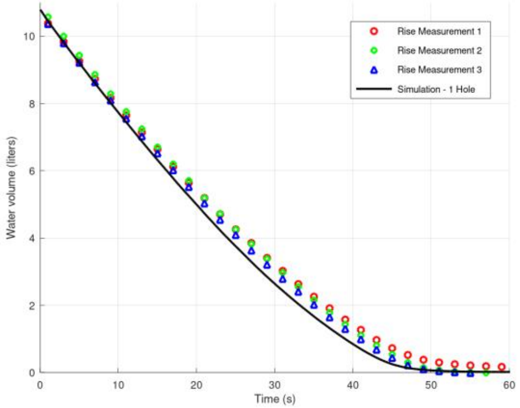
Drainage of Static Door

- Drainage through holes
- Transient agreement is good

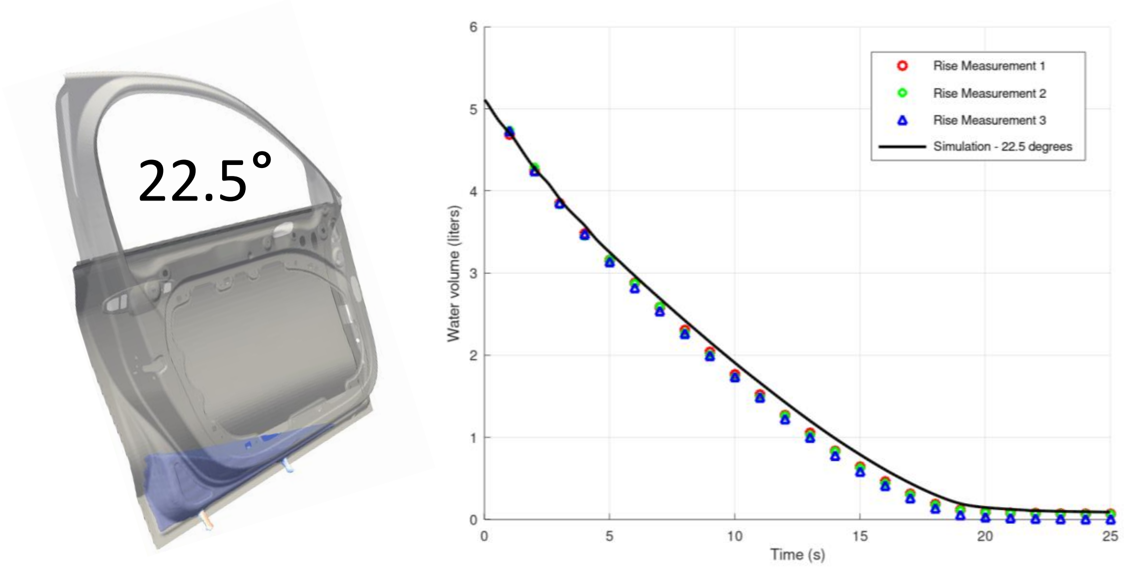


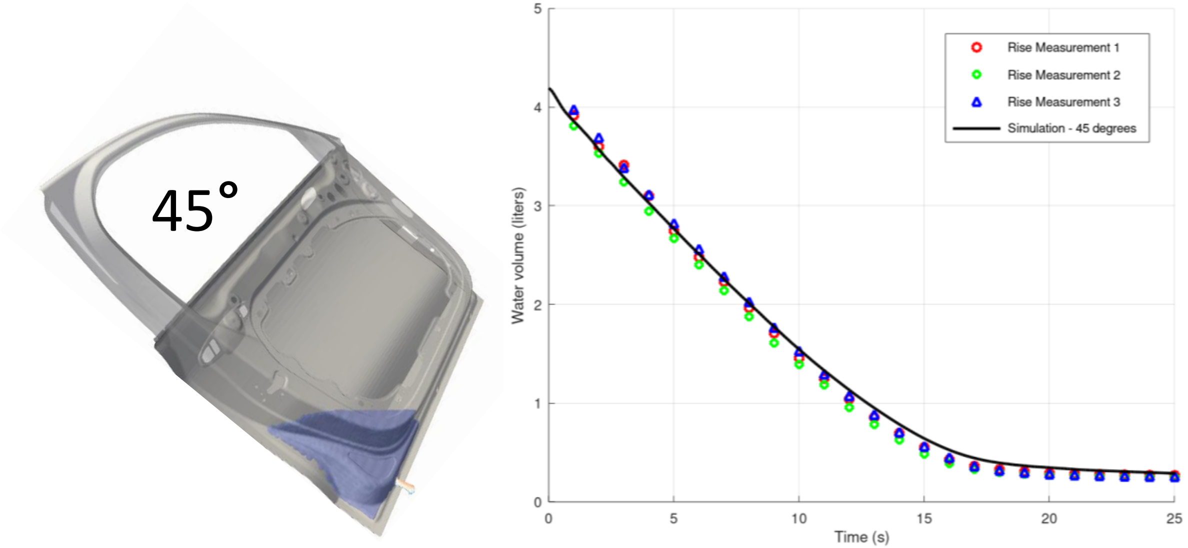




Drainage of Static Tilted Door

- Initial and final volumes correspond to experimental data
- Transient agreement is good





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Quasi-static Dipping Model

- Quasi-static model
  - Geometry-based model including movement and rotations
  - Captures volume of air pockets and trapped liquid
  - Convection not included, hence drainage time not captured
- Transient surface exposure exported to the deposition simulation
- Fast run time performance
  - Full car or truck cab can be simulated in a few hours

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Door Results with Plugged Holes – Trapped Water Volume

Time (s)	Refs	Volume [l]
4	5	9.17
19	6	10.22
125	7	10.54
929	8	10.69
-	Experiment	10.61 ± 0.2

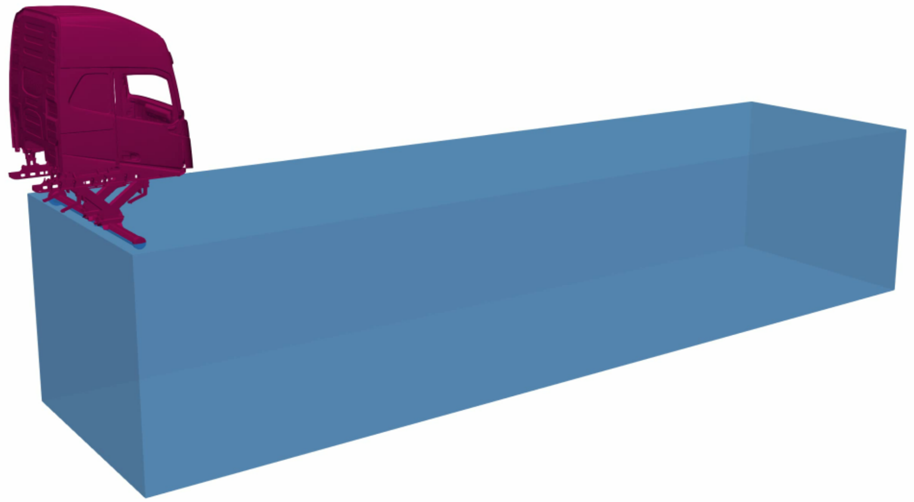
Refinement	Volume [l]
5	6.04
6	5.14
7	5.20
8	5.22
Experiment	5.14 ± 0.1

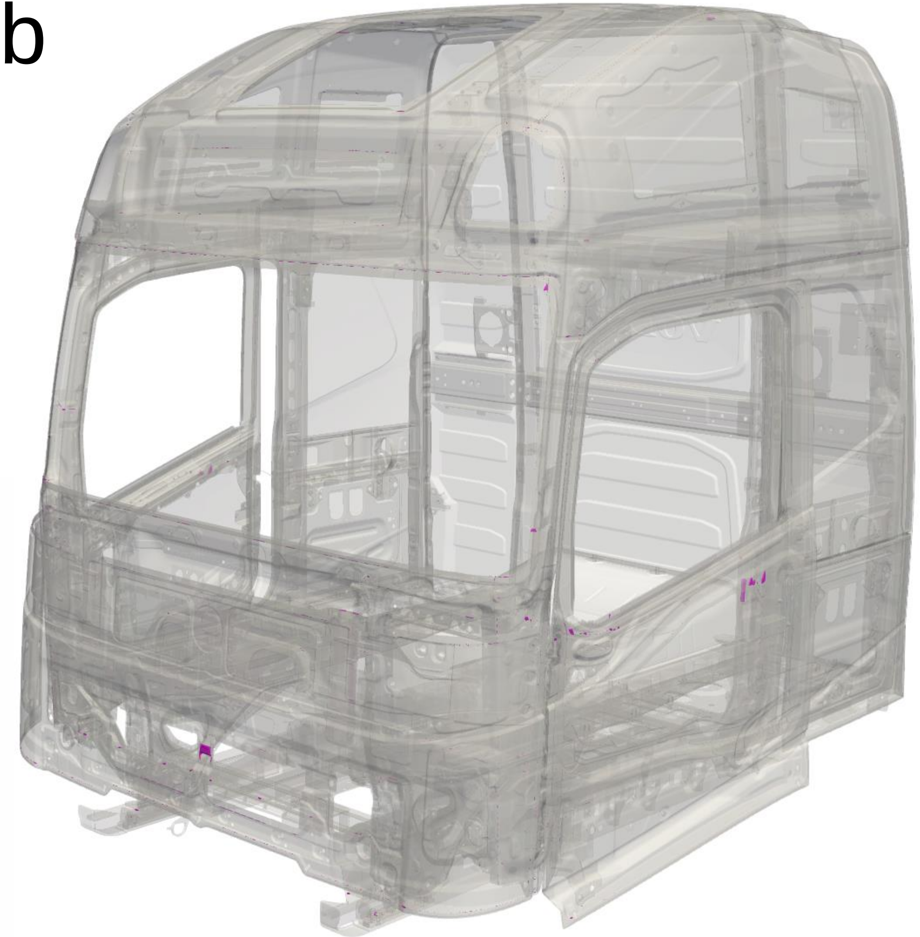
0°

22.5°

Drainage and Accessibility of a Truck Cab

- Simulation with truck cab and motion from Volvo Trucks
- 79 M computational cells
  - Resolution down to holes of 1.25 mm
- Transient data of air pockets and trapped fluids
- Roughly 6 hours simulation time
  - Adaptive time stepping based on rotation and translation





Trapped liquid when over the surface: **6 cl**

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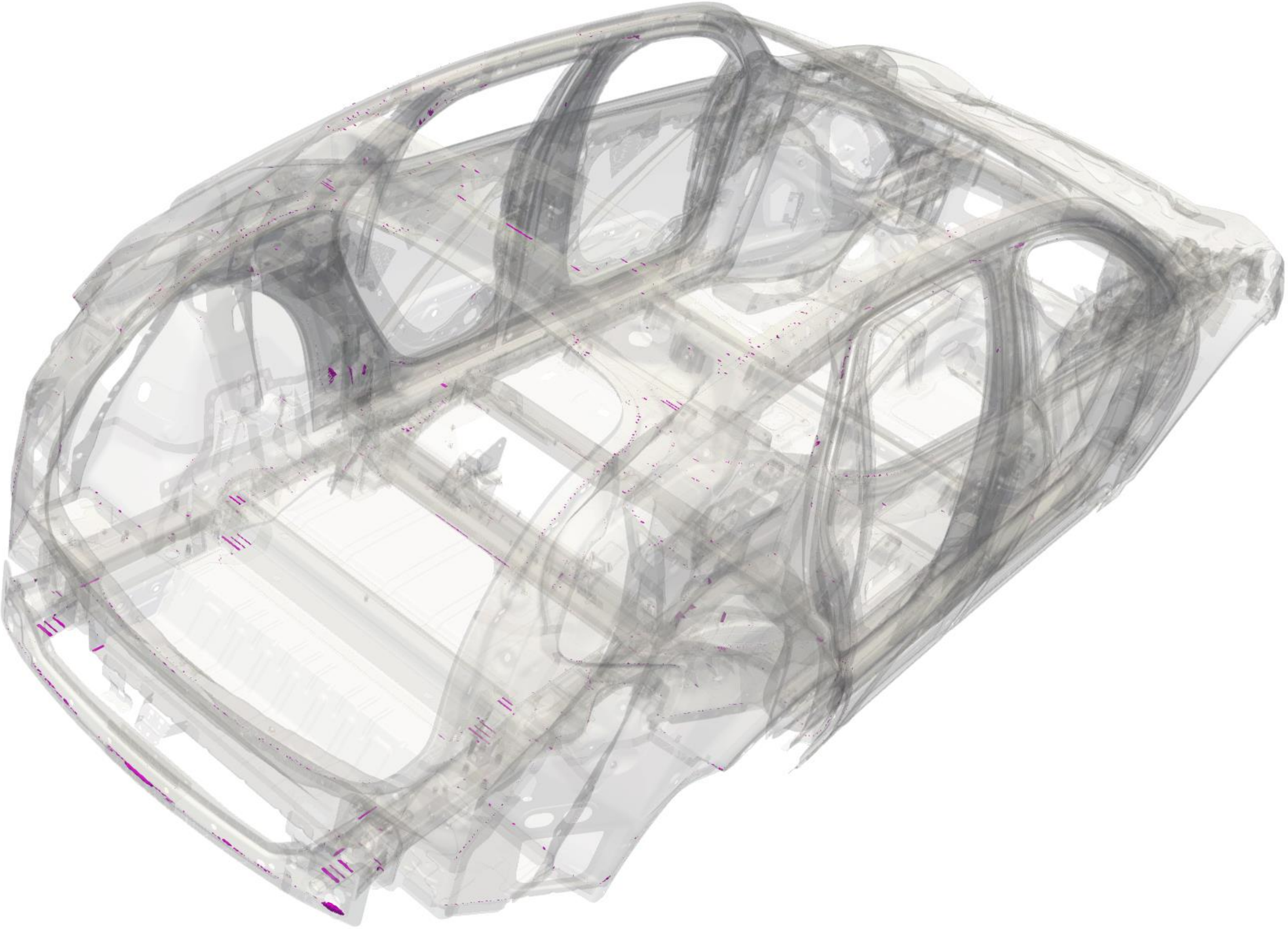
Drainage of a Car

- 73 M computational cells
  - Resolution down to holes of 2.5 mm
  - 6 hours simulation time
- Adaptive time stepping
  - Based on rotation and translation
- 4 cl liquid left
  - Shown in purple



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Electrostatic Bath Modeling

- Assume local electroneutrality and constant ion concentration
- The electric field and bulk current density are given by Gauß' and Ohm's laws
  - $\nabla \cdot E = 0$
  - $J = \sigma E$
- The current density at the cathode is modeled separately with the Butler-Volmer equation
  - $J = J_0 \exp\{- \alpha F \frac{\eta}{RT}\}$
  - η is the over-potential, i.e., the potential drop across the deposited layer
  - η is estimated from the thickness of the deposited layer in Hull cell experiments
- The deposition is governed by Faraday's law of electrolysis
  - $\frac{dh}{dt} = \frac{JM}{\rho z F}$

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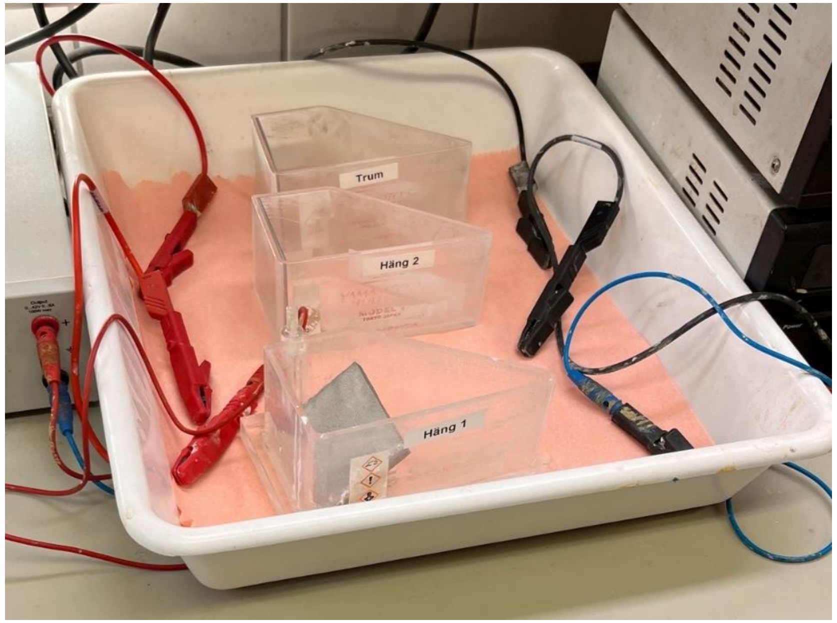
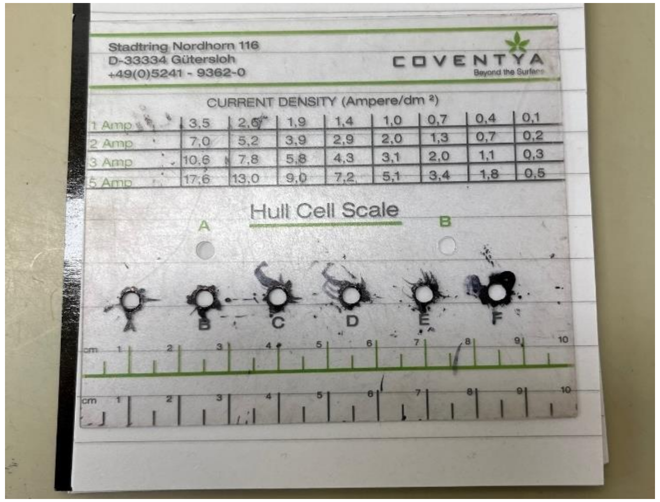
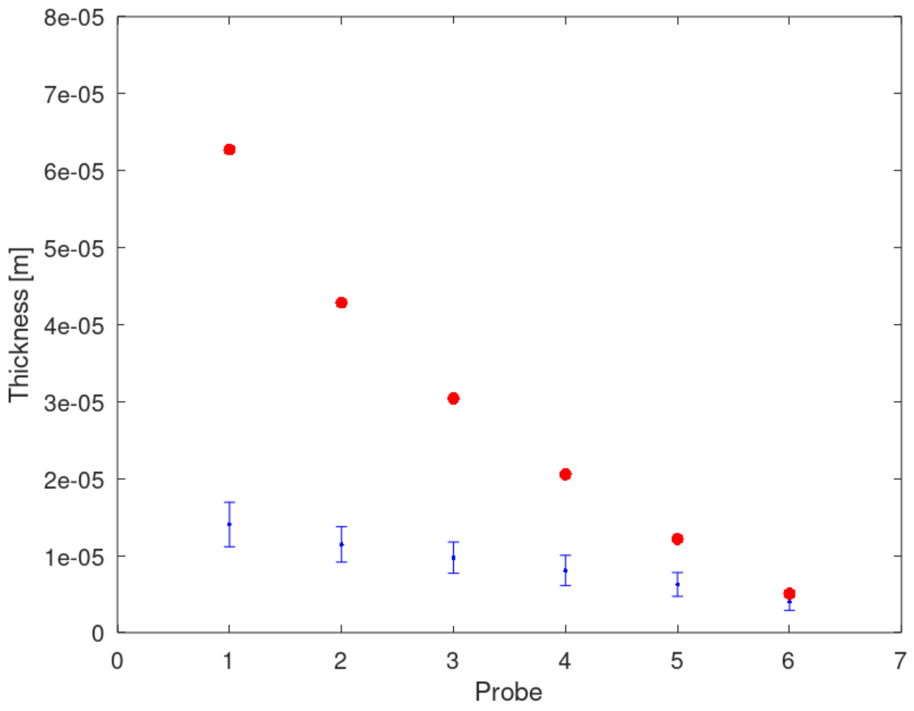
Hull Cell – Proton

- Used to estimate the performance of the bath at high and low current
- Slanted plate in a bath
- Received one week of hull cell measurements
- 6 points
- 2 A for 30 minutes
- Estimate resistance from thickness
- Decrease the current according to the Butler-Volmer equation

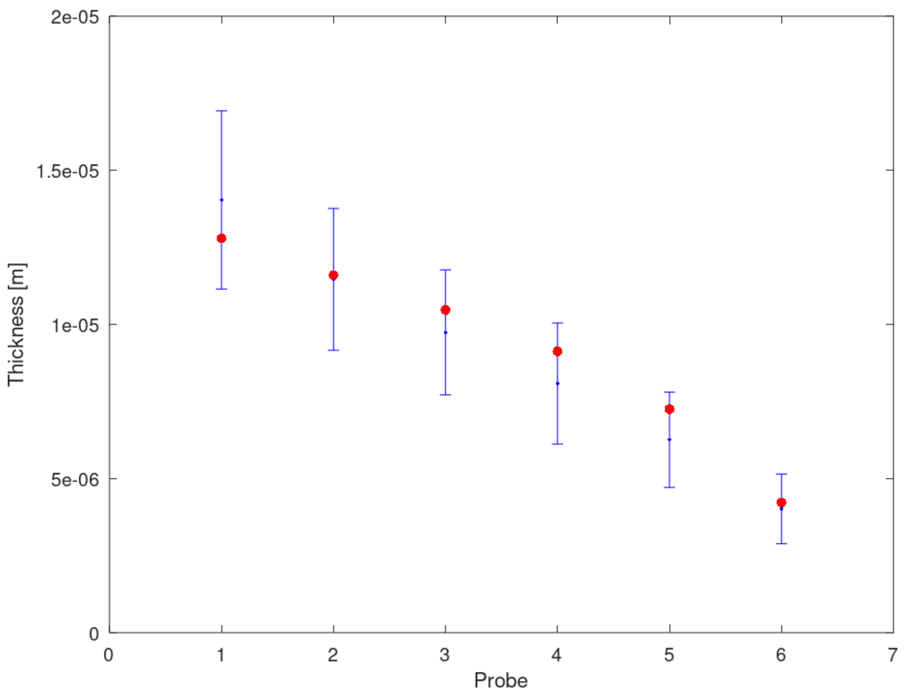




Hull Cell with Resistance (40 Ω/m)



No resistance



Resistance modeled with Butler-Volmer

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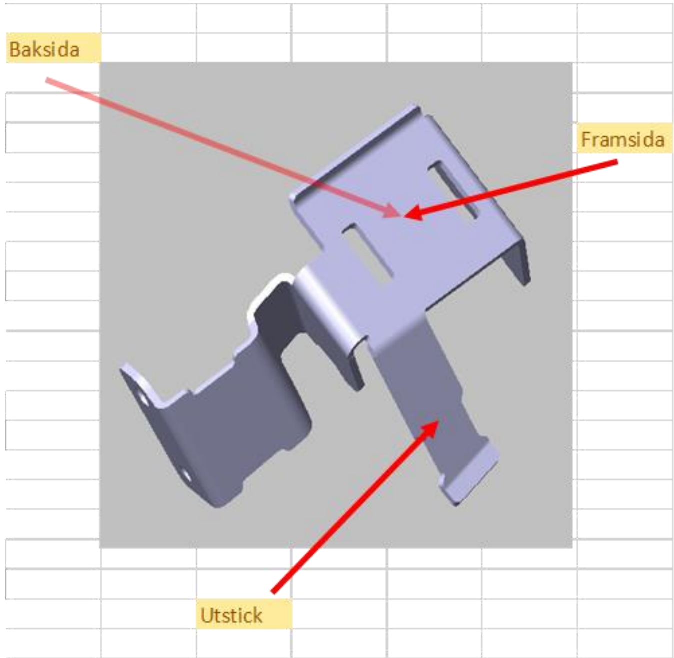
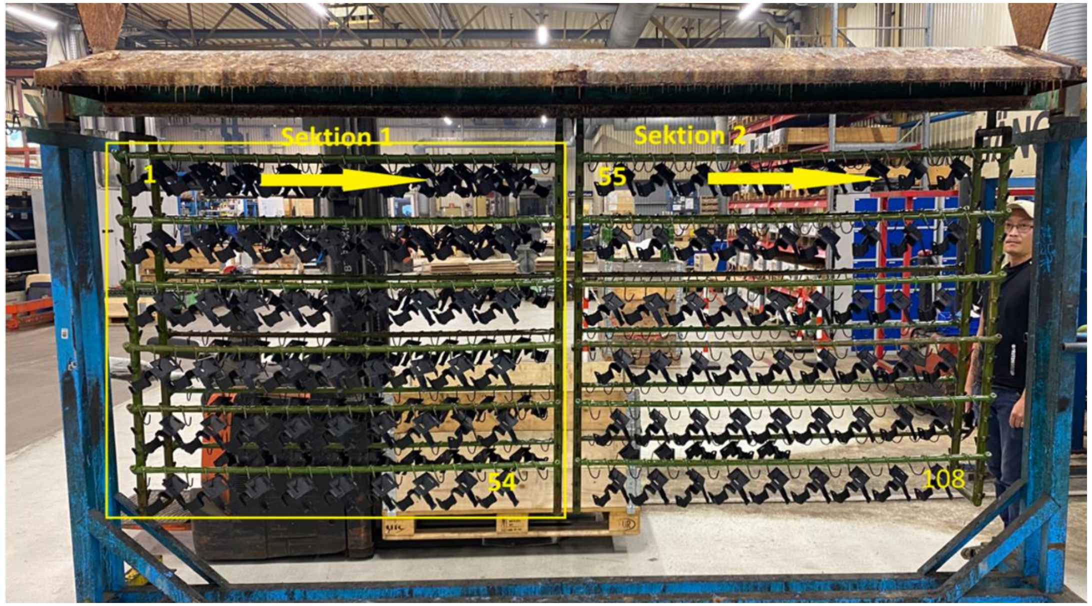
Electroplating Simulation Status – Proton

- 216 objects on two hangers
- CAD on hangers and object
- Set up using the IPS Hanging Optimization module





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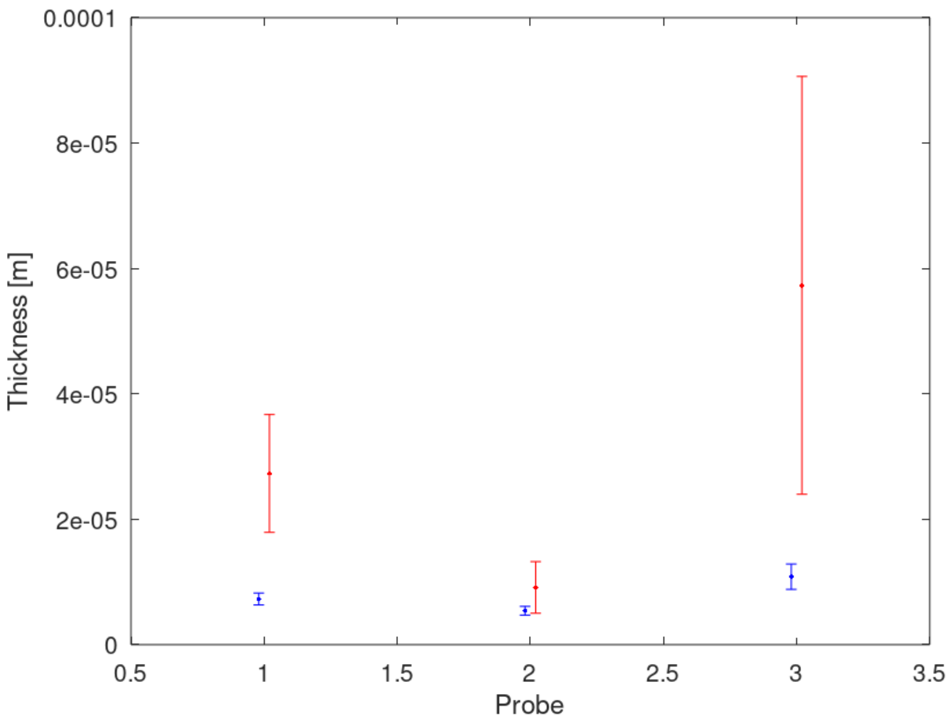
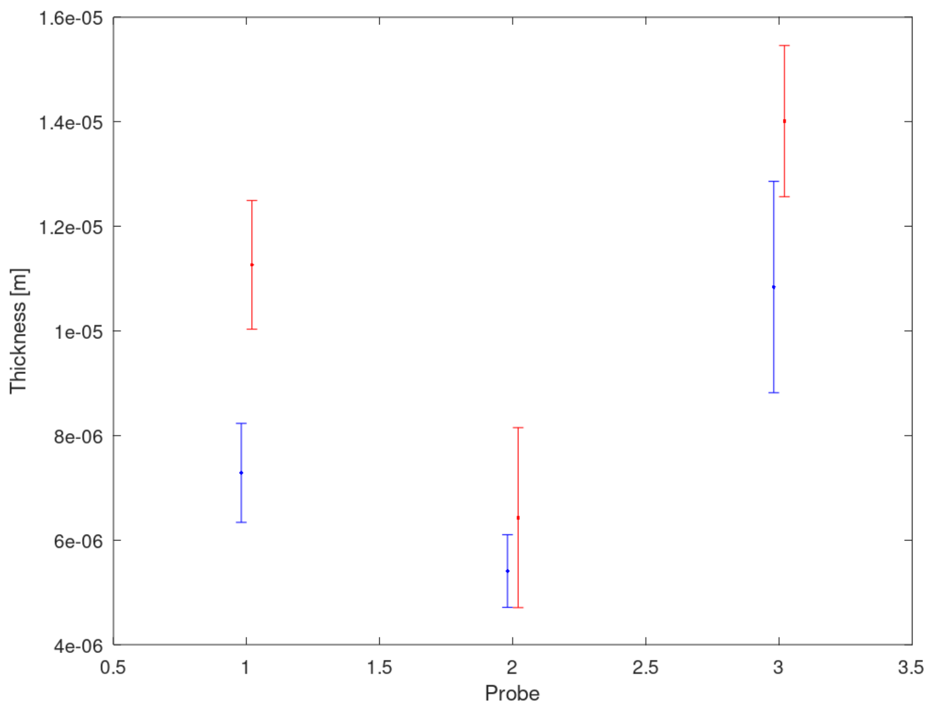
Electroplating – Proton Case (40 Ω/m)



No resistance



Resistance modeled with Butler-Volmer Hull cell

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Summary

- Future development for electrocoating
  - Replace Hull cell measurements by throwing power measurements to model the resistance
  - Ongoing measurement and validation campaign
- Our aim is the virtual paintshop where modeling, simulation and optimization are used to
  - increase quality
  - reduce energy and material consumption
  - shorten product preparation time
  - facilitate efficient automation
- IPS Virtual Paint used by more than 20 companies
  - Global customers are automotive OEMs and suppliers, furniture industry
  - Official release of electrocoating module during 2024

Thank you!

Get in touch:

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