Advanced Methods for Automatic Shape Optimization of Road Vehicles Driven by RBF Mesh Morphing

Master's Degree Thesis in Energy Engineering

University of Rome ‘Tor Vergata’

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Advisor:
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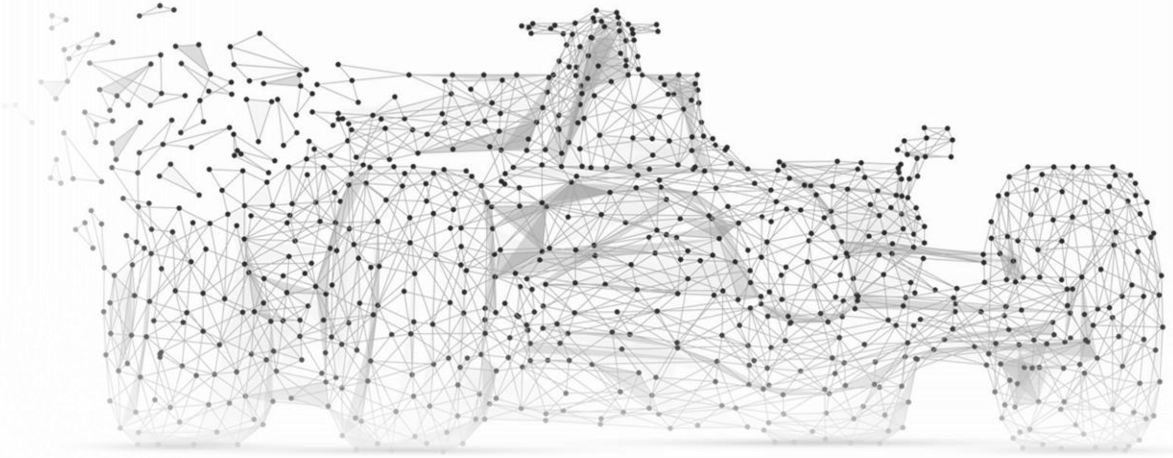
Industrial Advisor:
Torbjörn Virdung (*Volvo Cars*)

Co-Advisors:
Ubaldo Cella
Stefano Porziani



Outline

- Introduction and motivation
- Radial Basis Functions (RBF)
- Materials and methods
- Applications
  - ASMO
  - Side-view mirror
- Conclusions

$$s(\vec{x}) = \sum_{i=1}^{m} \gamma_i \varphi\left(\left\|\vec{x} - \vec{x}_{s_i}\right\|\right) + h(\vec{x})$$

Motivation

- Optimization techniques are gaining a high importance in design and manufacturing of new products
- The aerodynamic department of Volvo needs advanced tools for shape optimization
- Volvo has already used RBF Morph in the past within Ansys Fluent, but now transitioned to STAR-CCM+
- Collaboration between RBF Morph, Tor Vergata and Volvo in the development of a fully automated workflow combining disjointed software and tools

Radial Basis Functions & mesh morphing

$$\begin{cases} s^x(\vec{x}) = \sum_{i=1}^{m} \gamma_i^x \varphi\big(\overbrace{\|\vec{x} - \vec{x}_{s_i}\|}^{\text{Distance from the } i^{th} \text{ source point}}\big) + \beta_1^x + \beta_2^x x + \beta_3^x y + \beta_4^x z \\ s^y(\vec{x}) = \sum_{i=1}^{m} \gamma_i^y \varphi\big(\|\vec{x} - \vec{x}_{s_i}\|\big) + \beta_1^y + \beta_2^y x + \beta_3^y y + \beta_4^y z \\ s^z(\vec{x}) = \sum_{i=1}^{m} \gamma_i^z \underbrace{\varphi\big(\|\vec{x} - \vec{x}_{s_i}\|\big)}_{\text{radial basis}} + \underbrace{\beta_1^z + \beta_2^z x + \beta_3^z y + \beta_4^z z}_{\text{polynomial}} \end{cases}$$

- ✓ Fast and reliable
- ✓ Mesh-less method
- ✓ No re-meshing required
- ✓ Highly parallelizable

- X Computationally expensive for large grids (HPC)
- X The topology cannot be altered
- X Back to CAD procedure required

Design Number	Traditional approach
1	Geometry → Meshing → Solving
2	Geometry → Meshing → Solving
3	Geometry → Meshing → Solving
⋮	
n	Geometry → Meshing → Solving

RBF morphing approach

Geometry → Meshing → Solving

Morphing

→ RBF → Solving

→ RBF → Solving

→ RBF → Solving

Software & Tools

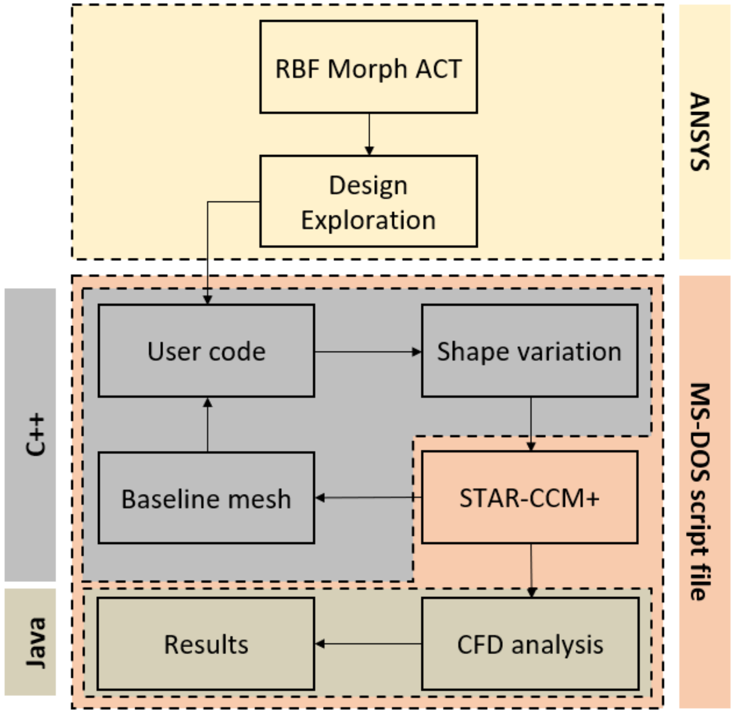
Mesh morphing — rbf™

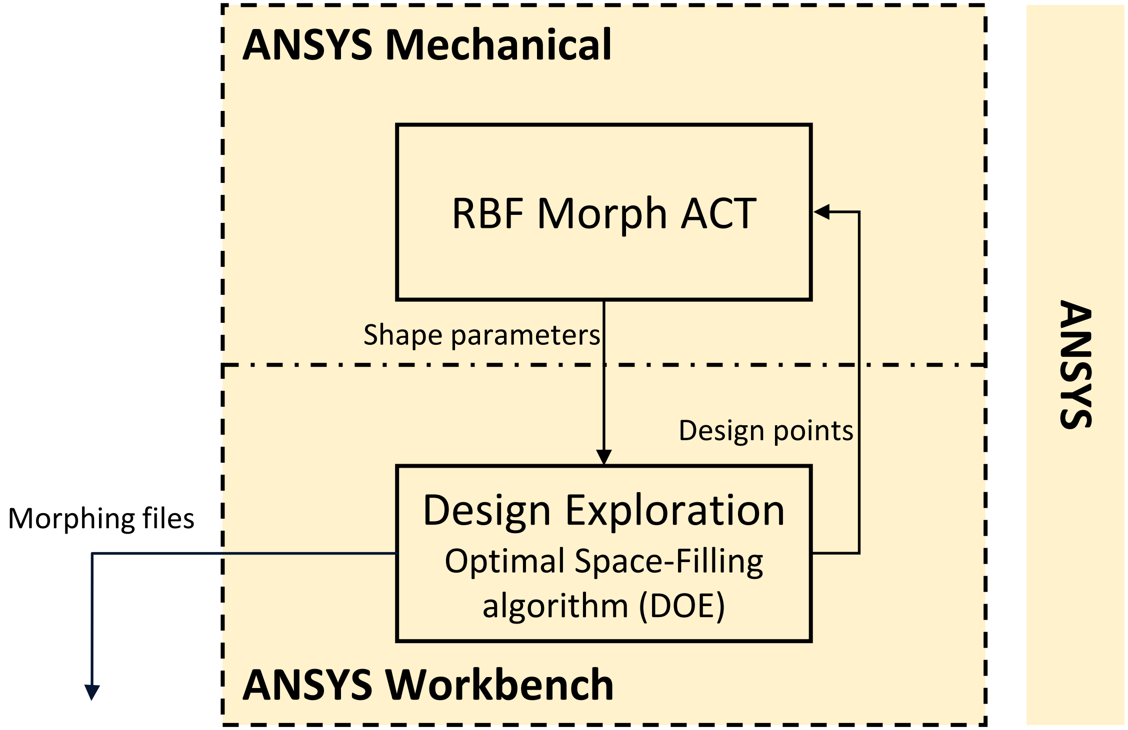
Design exploration — Ansys

CFD analysis — STAR-CCM+®

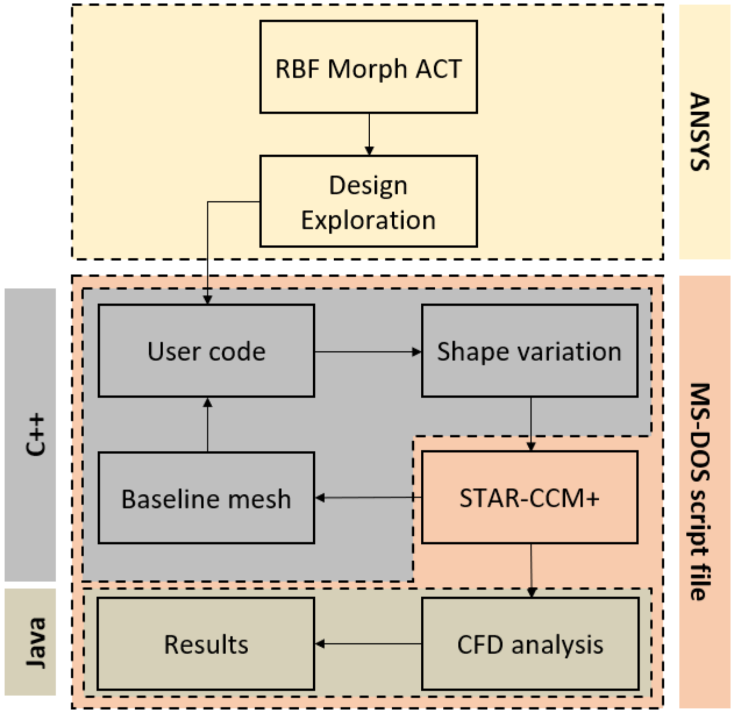
Coupling & automation — C++, Java, MS DOS

Flowchart


RBF Morph ACT
Design Exploration
ANSYS
User code
Shape variation
Baseline mesh
STAR-CCM+
Results
CFD analysis
C++
Java
MS-DOS script file


ANSYS Mechanical
RBF Morph ACT
Shape parameters
Design points
Design Exploration
Optimal Space-Filling algorithm (DOE)
Morphing files
ANSYS Workbench
ANSYS

Flowchart


RBF Morph ACT
Design Exploration
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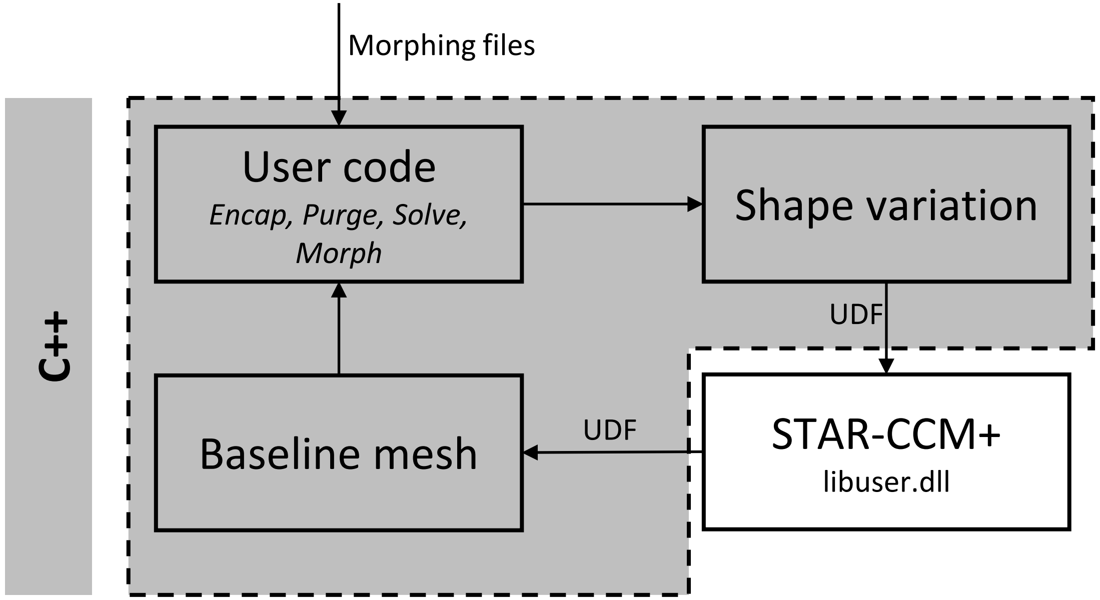
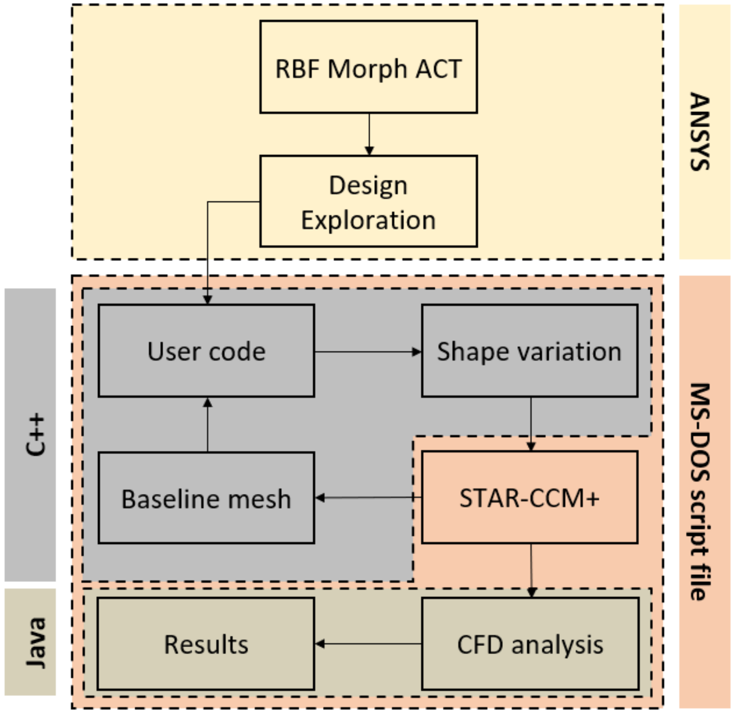
STAR-CCM+
MS-DOS script file
Java
Results
CFD analysis


Morphing files
C++
User code
Encap, Purge, Solve, Morph
Shape variation
UDF
Baseline mesh
UDF
STAR-CCM+
libuser.dll

Flowchart


RBF Morph ACT
Design Exploration
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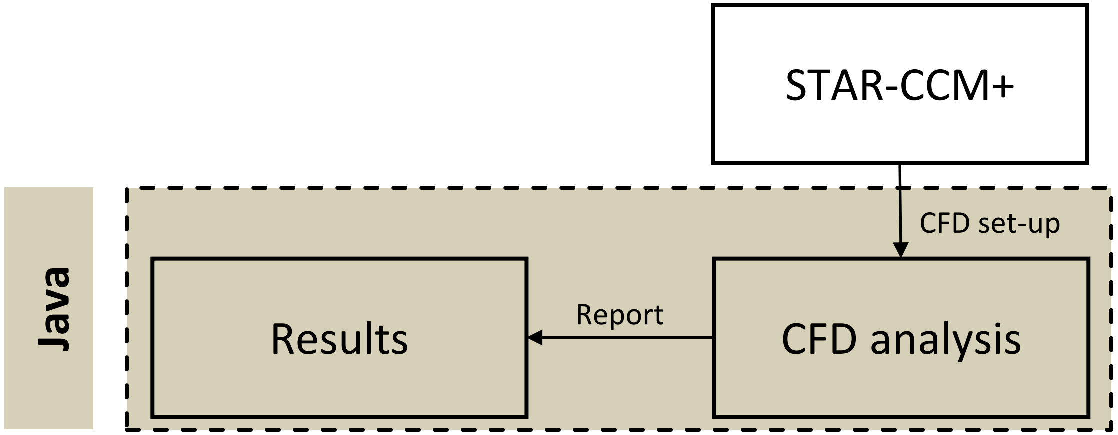
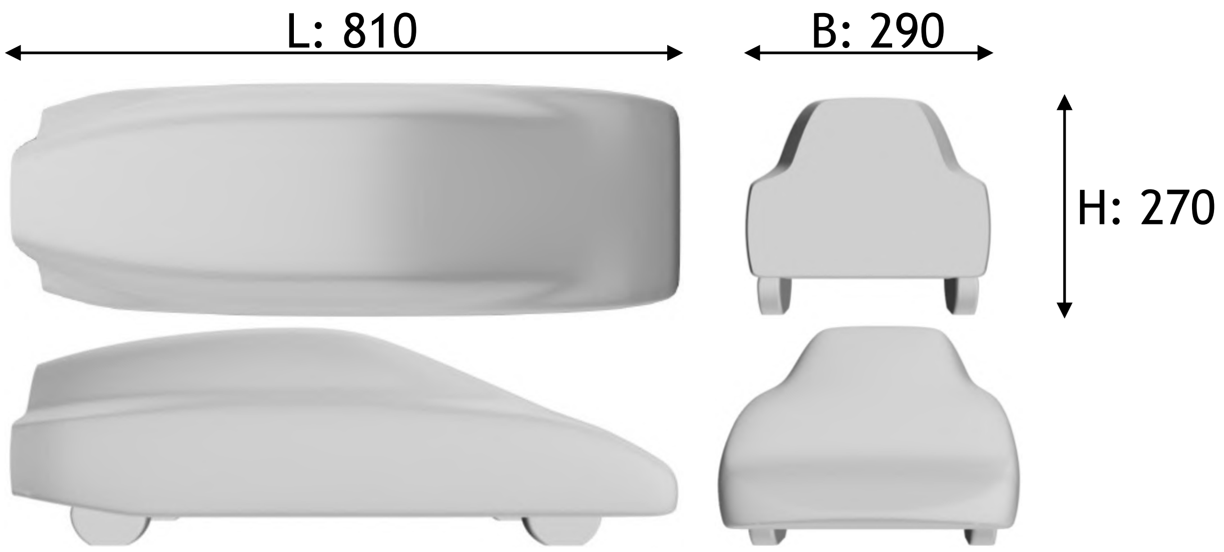
C++
Java
MS-DOS script file

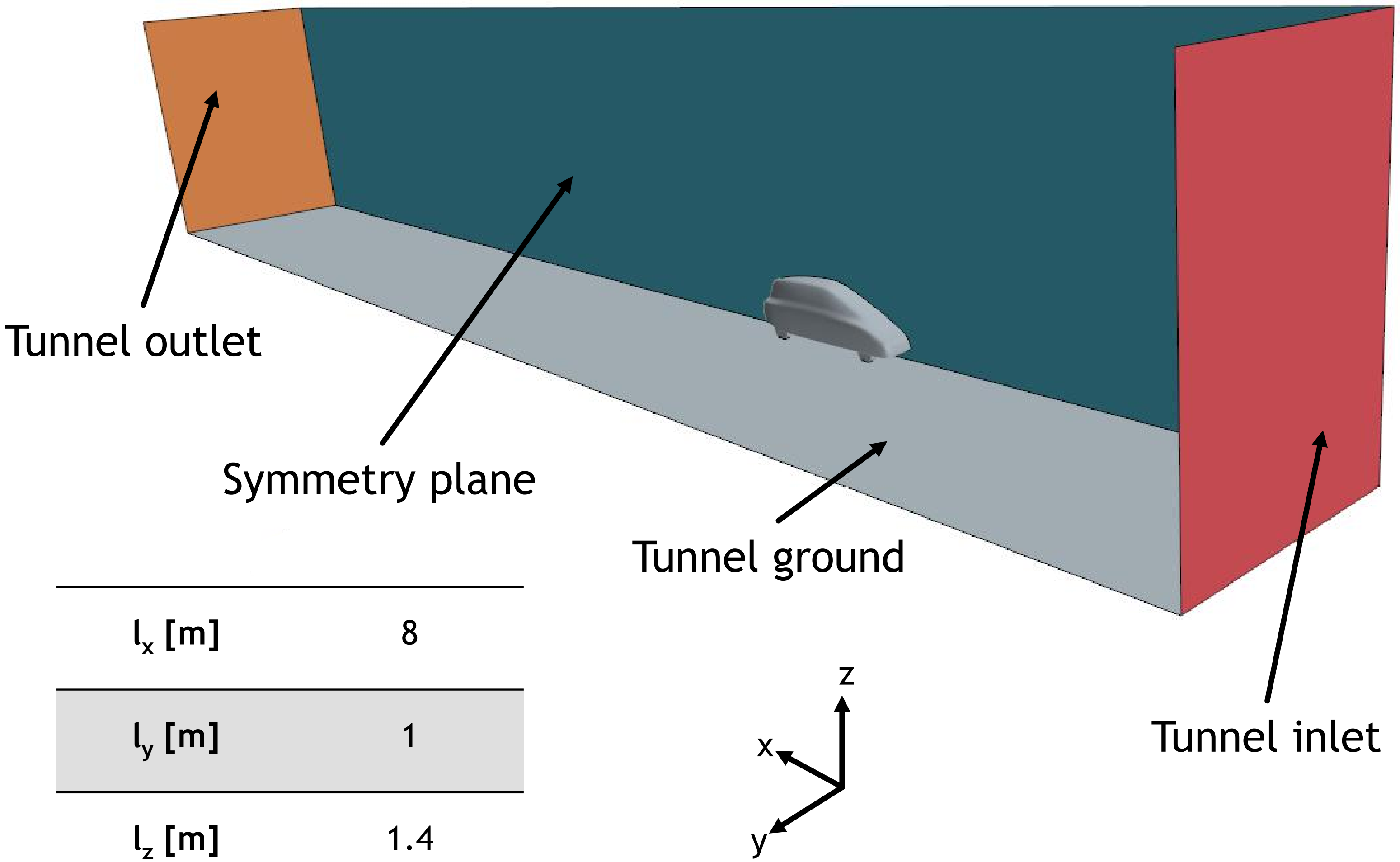

STAR-CCM+
CFD set-up
Java
Results
Report
CFD analysis

ASMO idealized car body shape



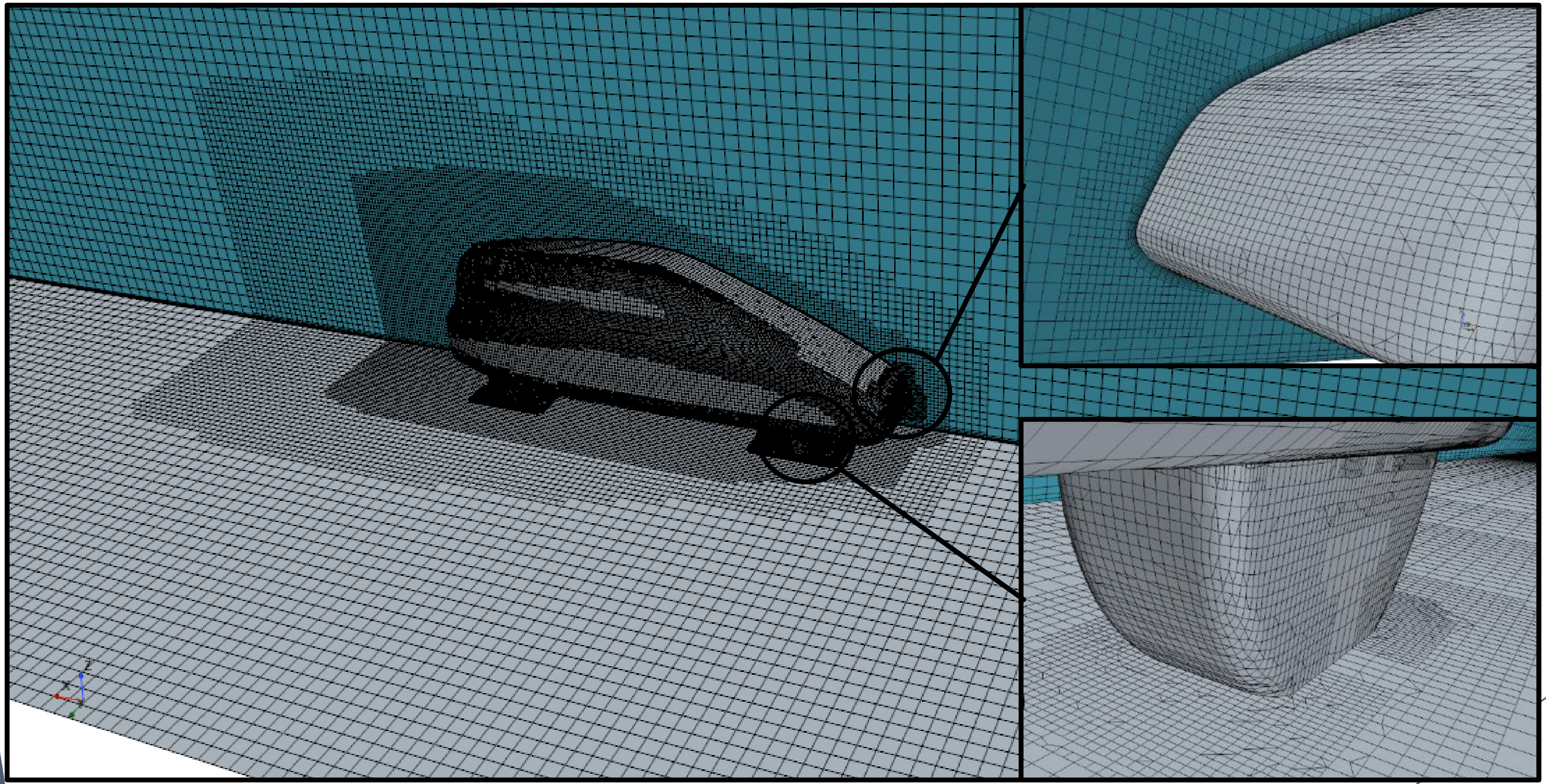
- Surface mesh comprising 291.166 cells
- Volume mesh comprising 1.257.966 cells
- Steady-state 3D simulation
- Finite volume discretization
- Implicit segregated flow solver (SIMPLE algorithm)
- K-Epsilon turbulence model
- 50 m/s inflow velocity

Wind tunnel

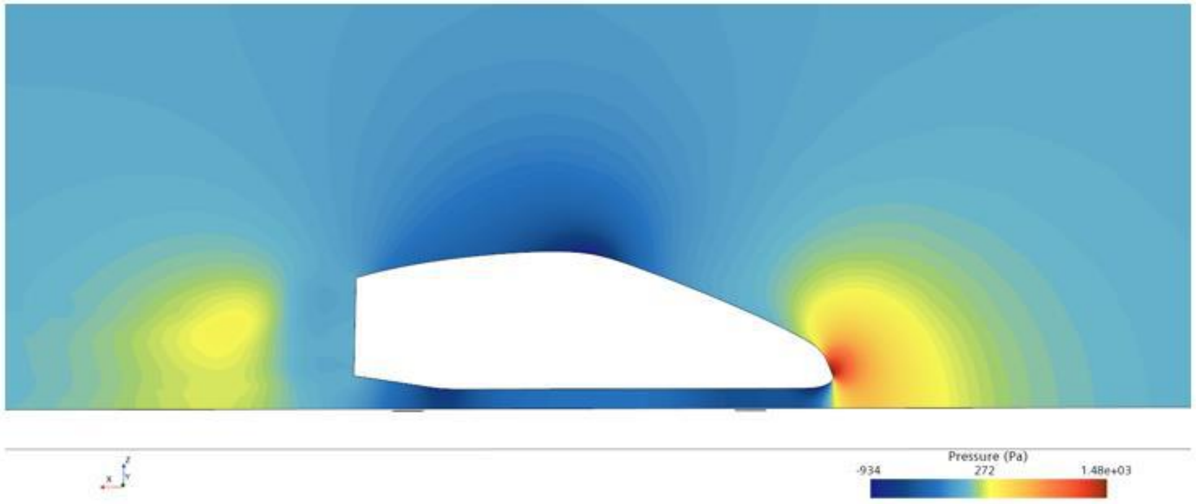


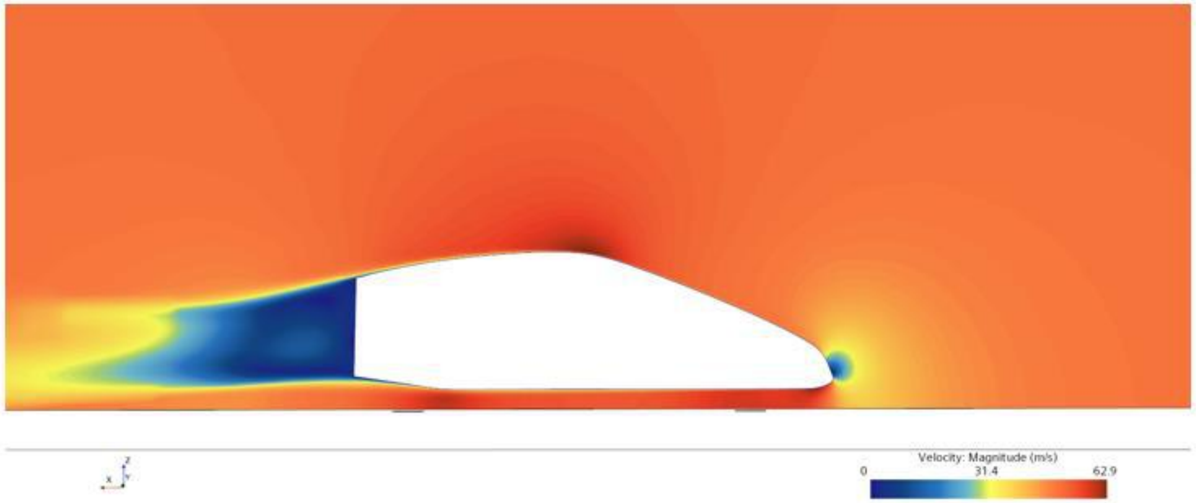
l_x [m]	8
l_y [m]	1
l_z [m]	1.4

Volume meshing

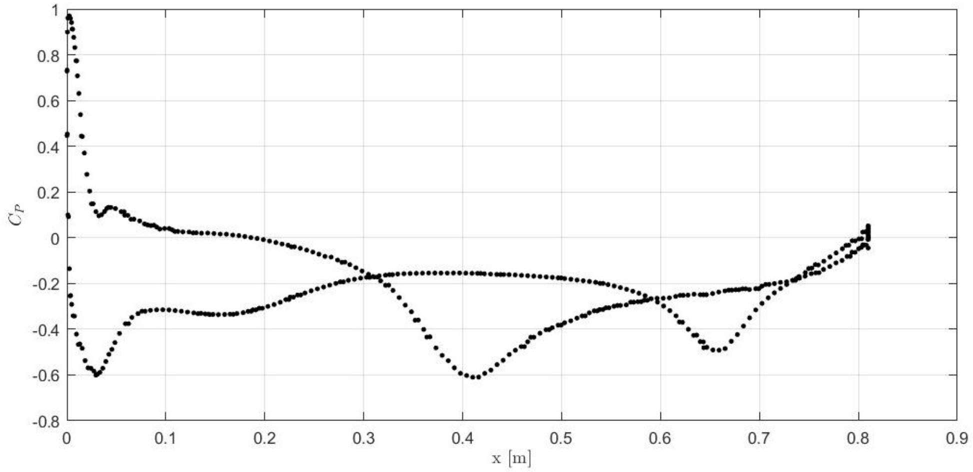


Pressure and velocity fields

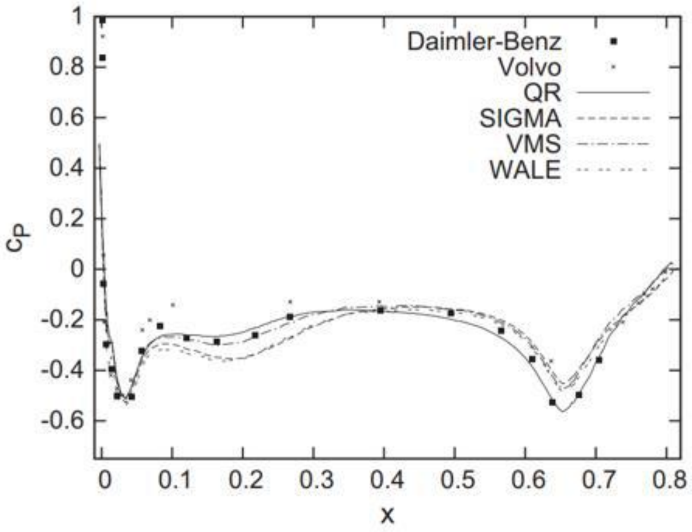


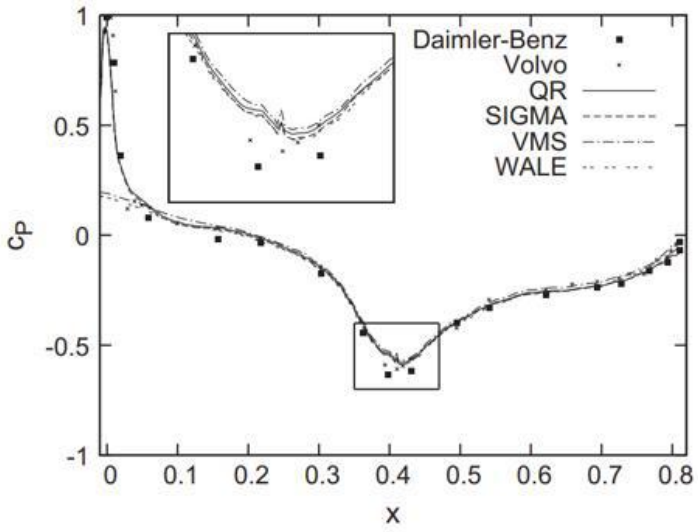


Validation



	C_D	C_L
Numeric	0.143	-0.035
Exp. (Volvo)	0.158	/
Exp. (Daimler Benz)	0.153	/

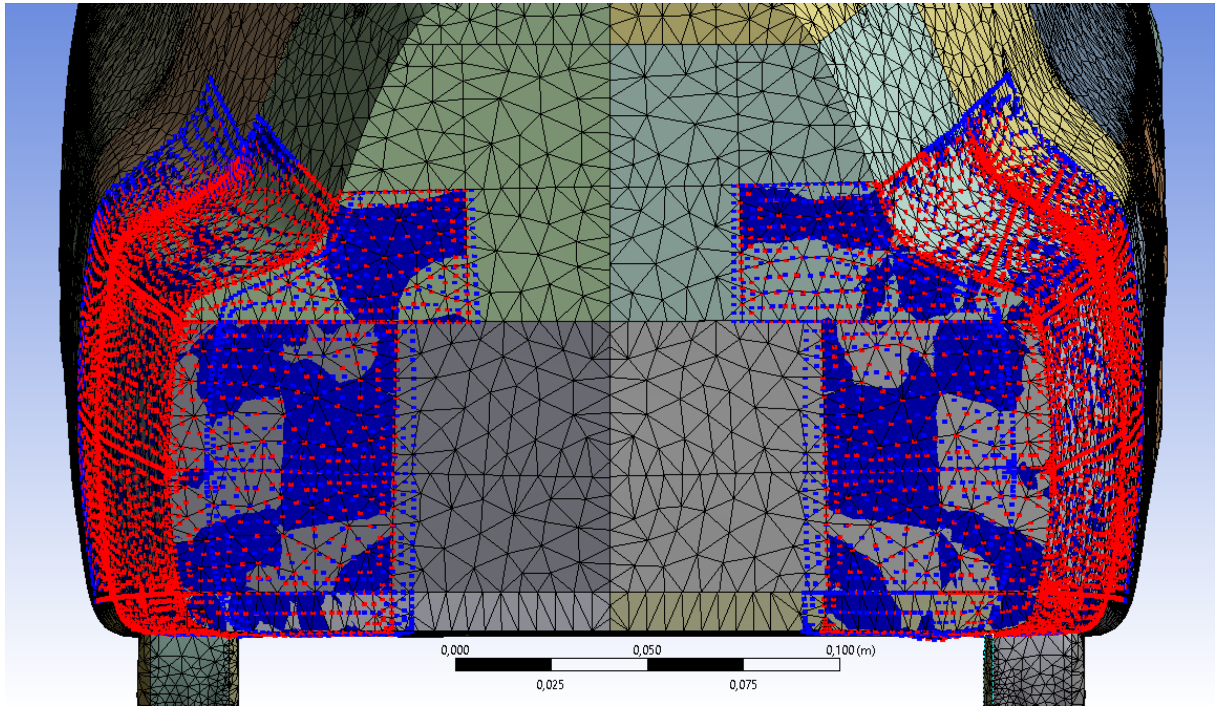




*

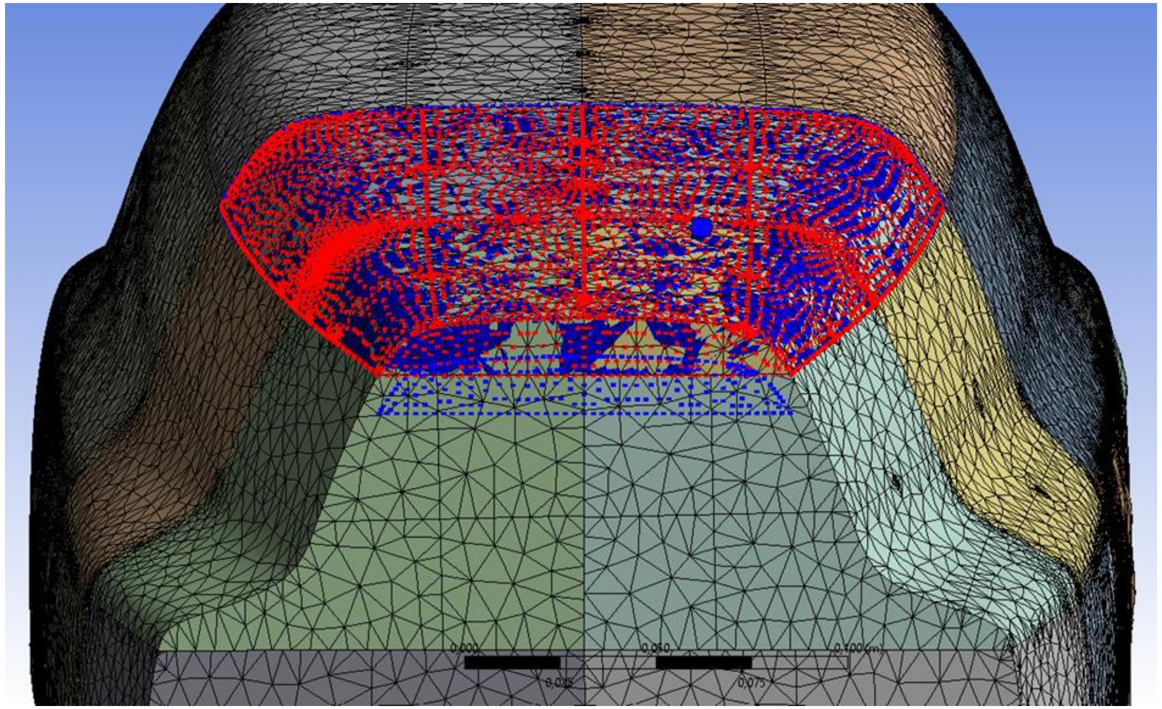
* D. Aljure, O. Lehmkuhl, I. Rodriguez and A. Oliva, "Flow and turbulent structures around simplified car models," Computers & Fluids, vol. 96, 2014.

Parametrization & mesh morphing



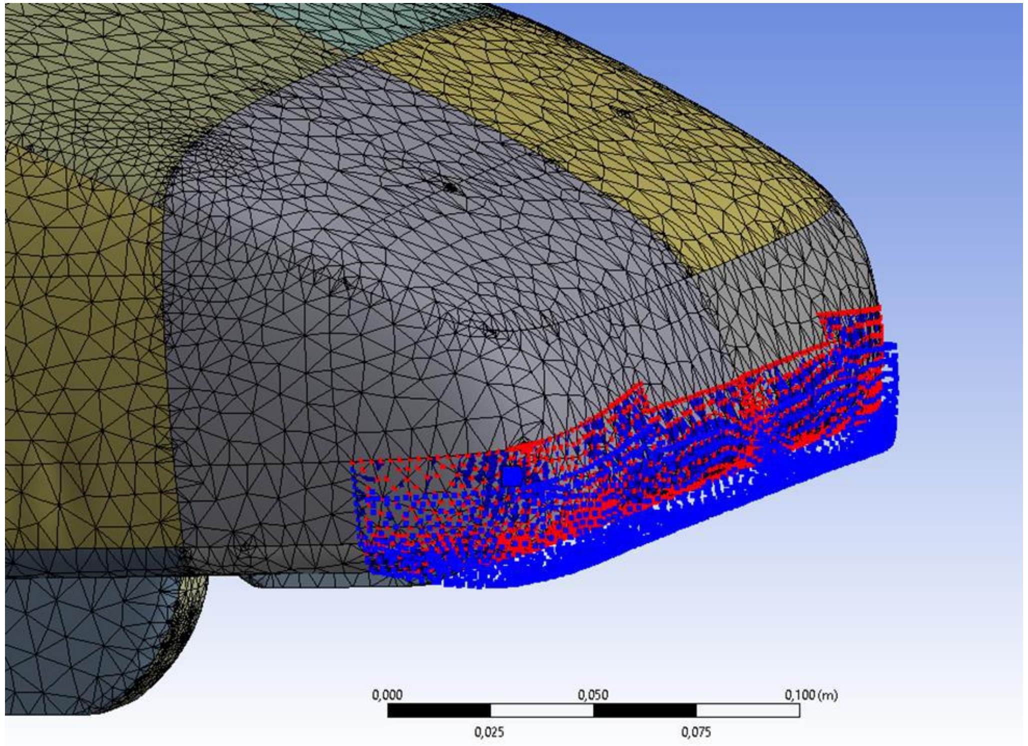
	Lower limit [m]	Upper limit [m]
Boat Tail (left side)	-0.01	+0.02
Boat Tail (right side)	-0.02	+0.01

Parametrization & mesh morphing



	Lower limit [m]	Upper limit [m]
Roof Drop	-0.02	+0.01

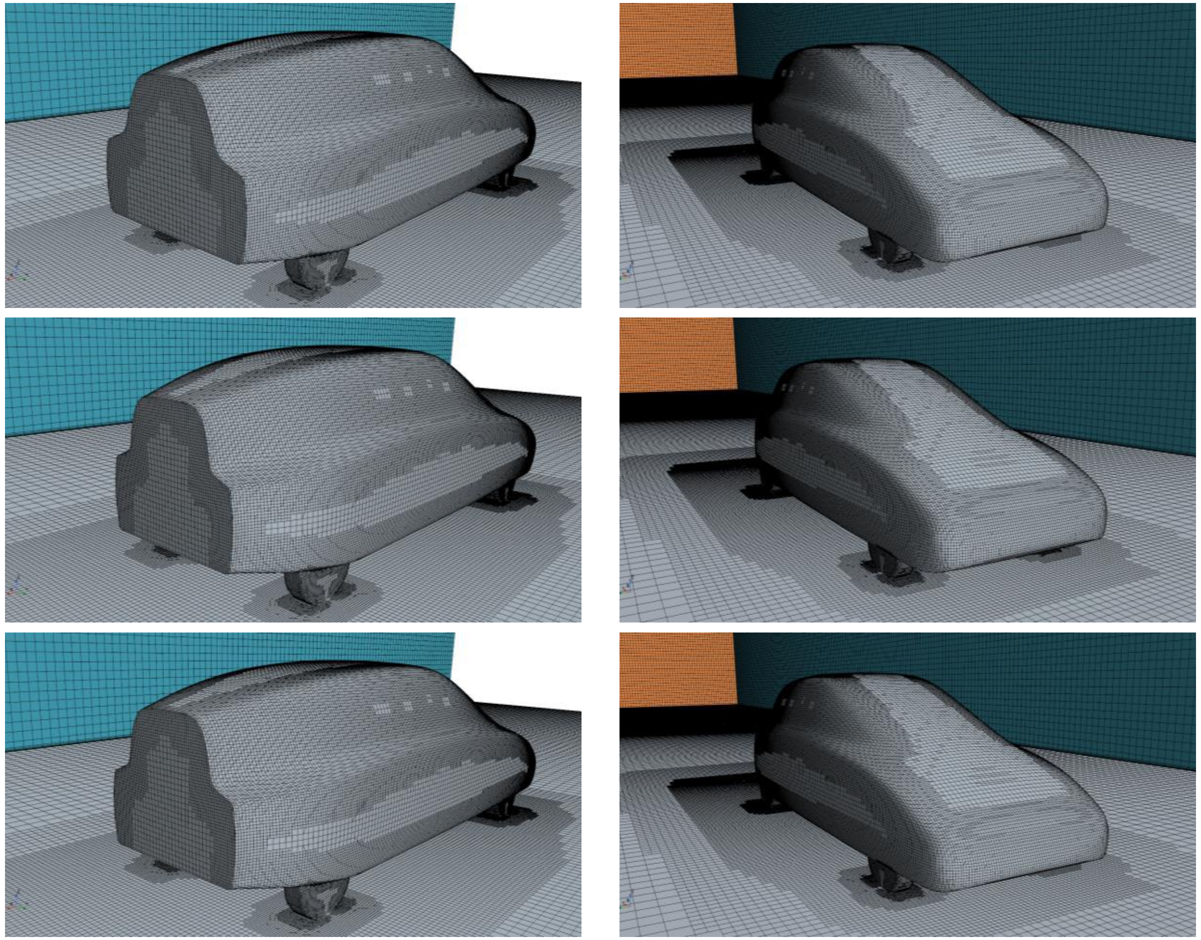
Parametrization & mesh morphing

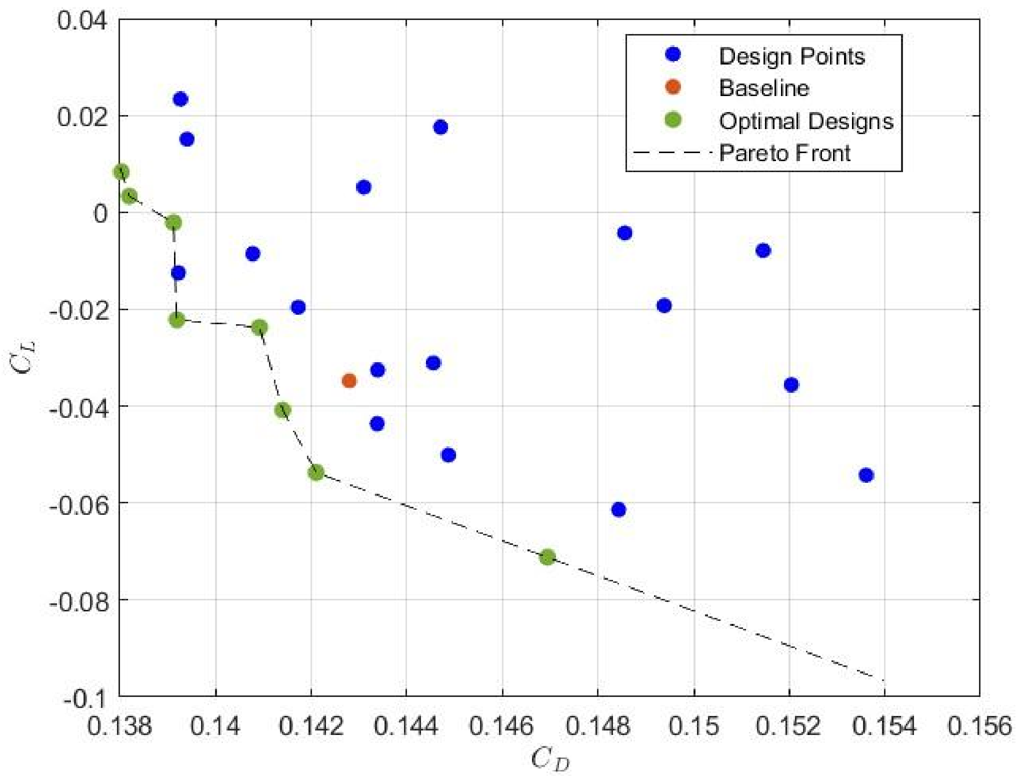


	Lower limit [m]	Upper limit [m]
Front Spoiler	-0.0025	+0.02

Parametric CFD analysis

- 25 shape variants

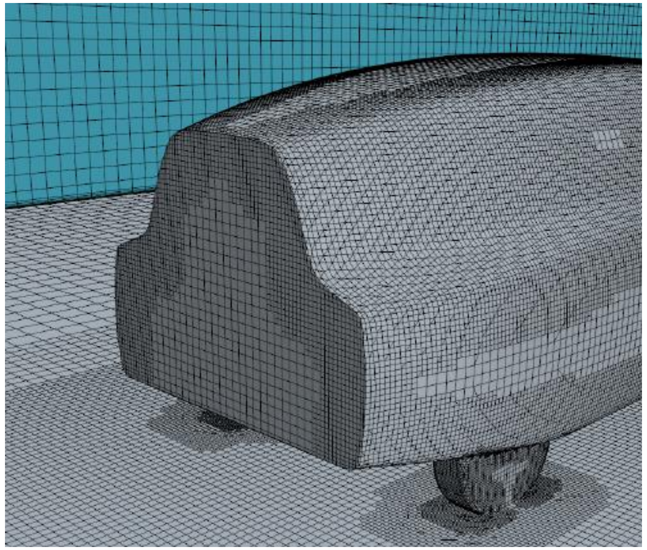


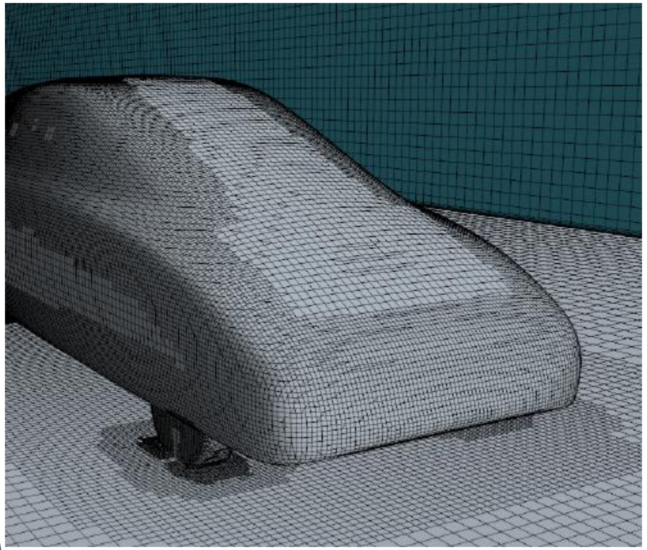


Baseline

$C_D = 0.143$

$C_L = -0.035$

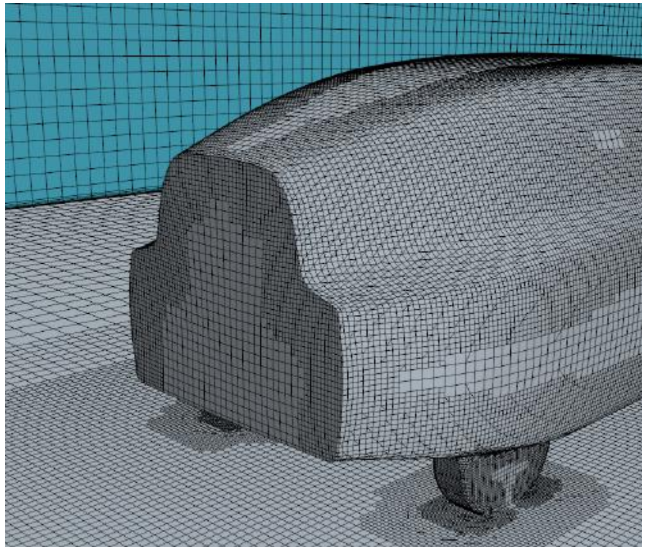


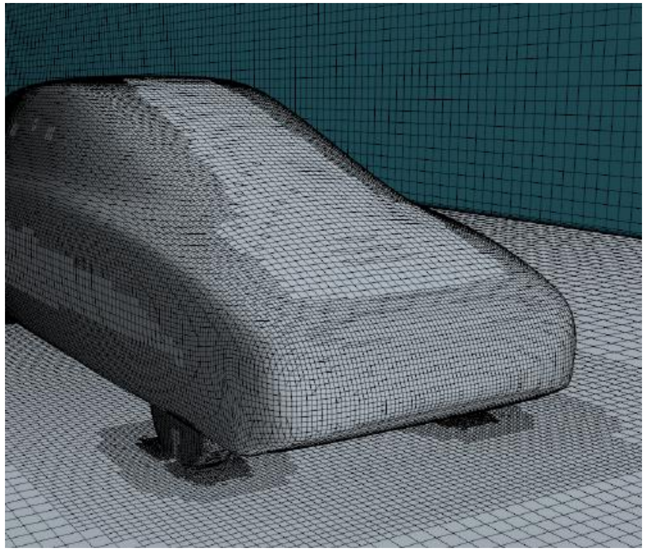


Lowest drag

$C_D = 0.138 \downarrow$

$C_L = -0.008 \uparrow$

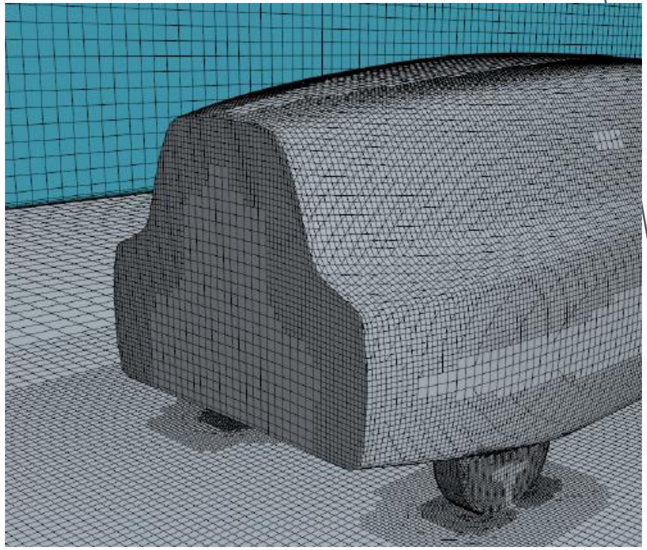


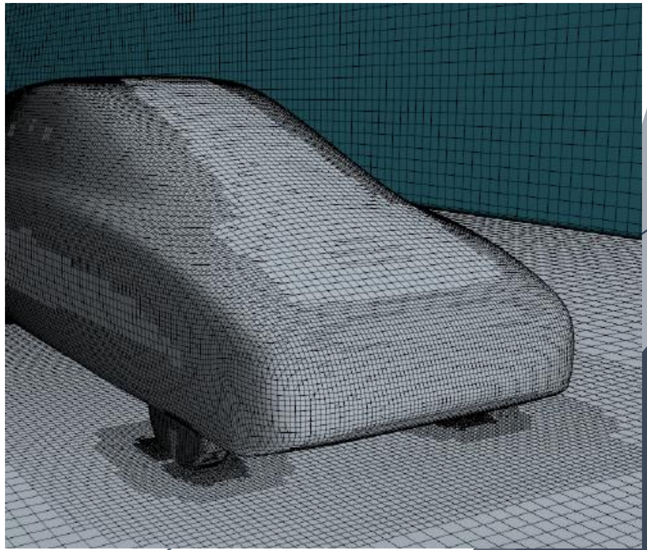


Highest downforce

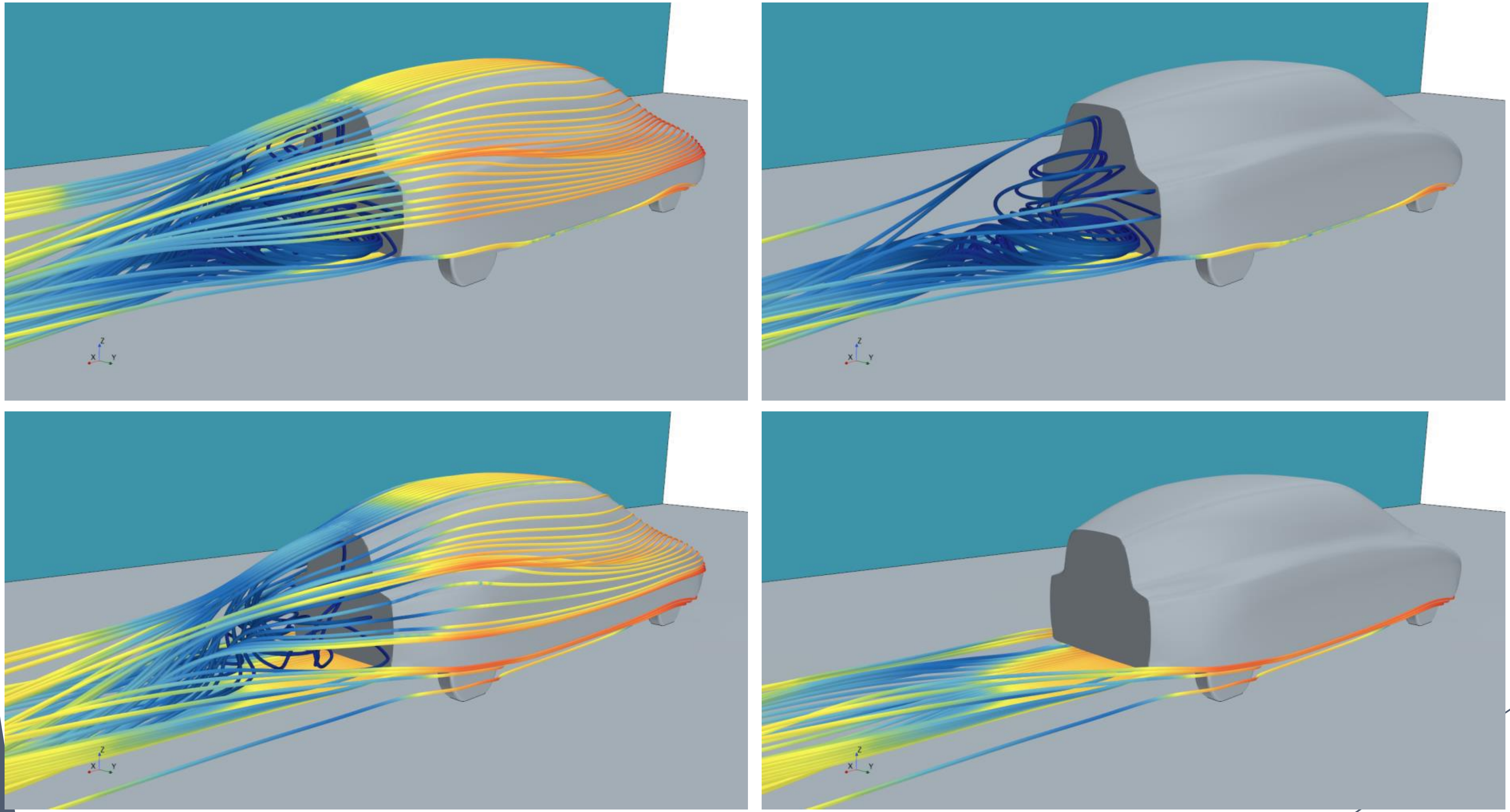
$C_D = 0.147 \uparrow$

$C_L = -0.071 \downarrow$





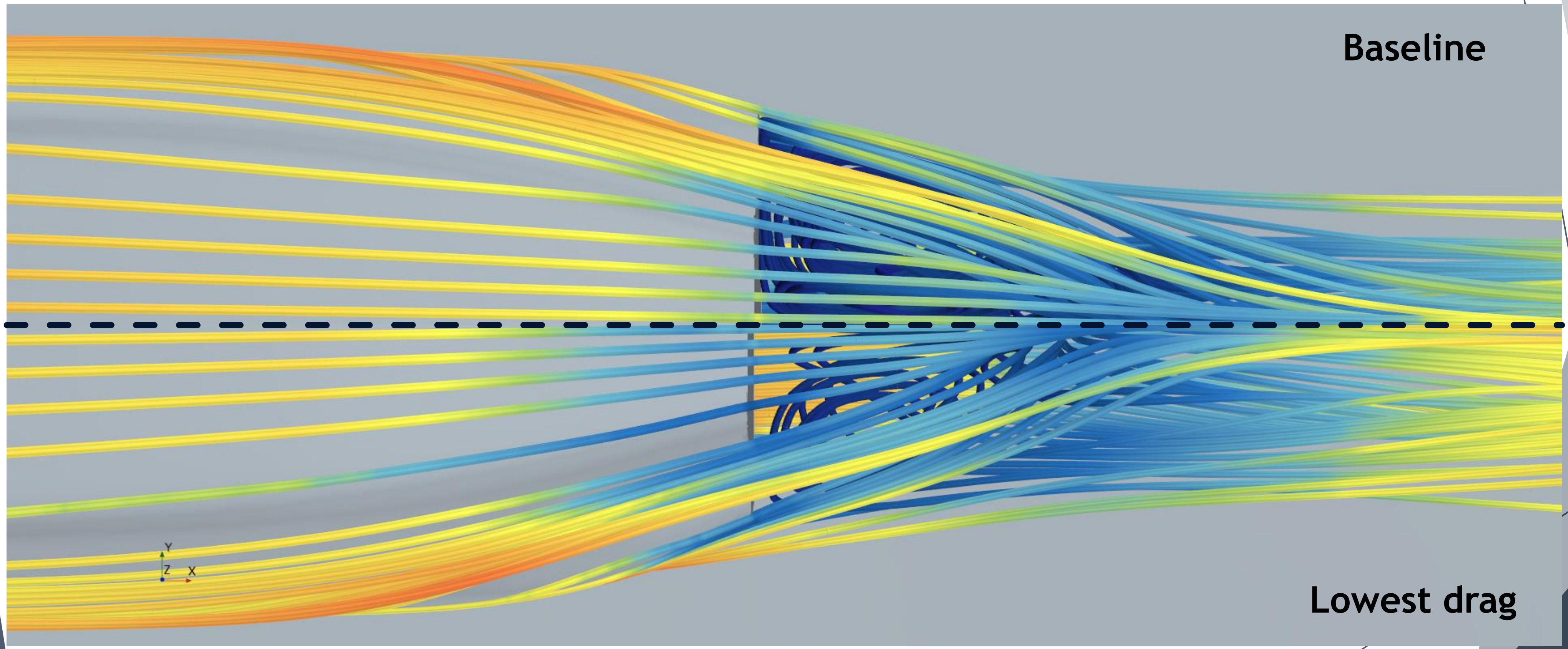
Streamlines



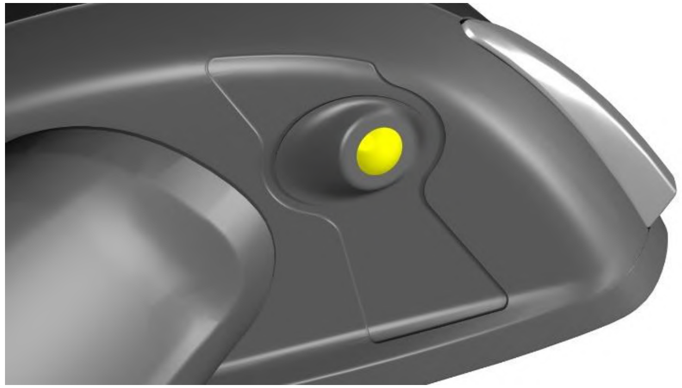
Baseline configuration

Lowest drag configuration

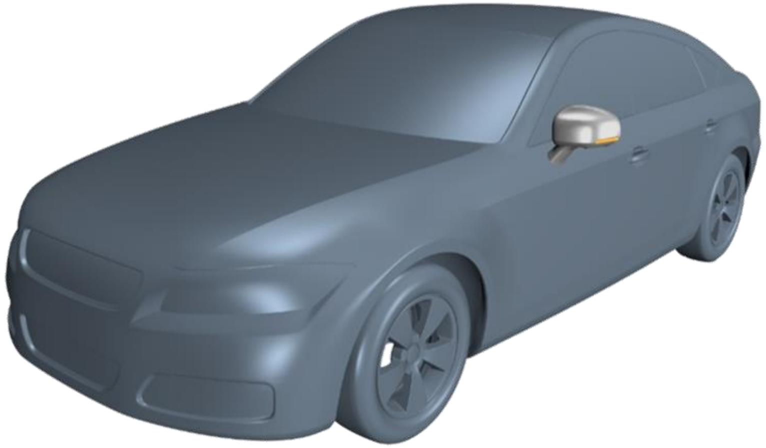
Streamlines



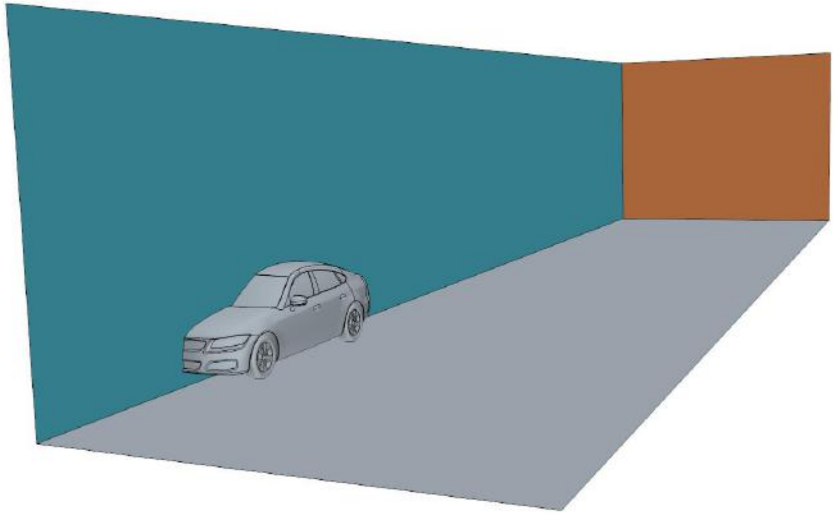
Volvo car side-view mirror

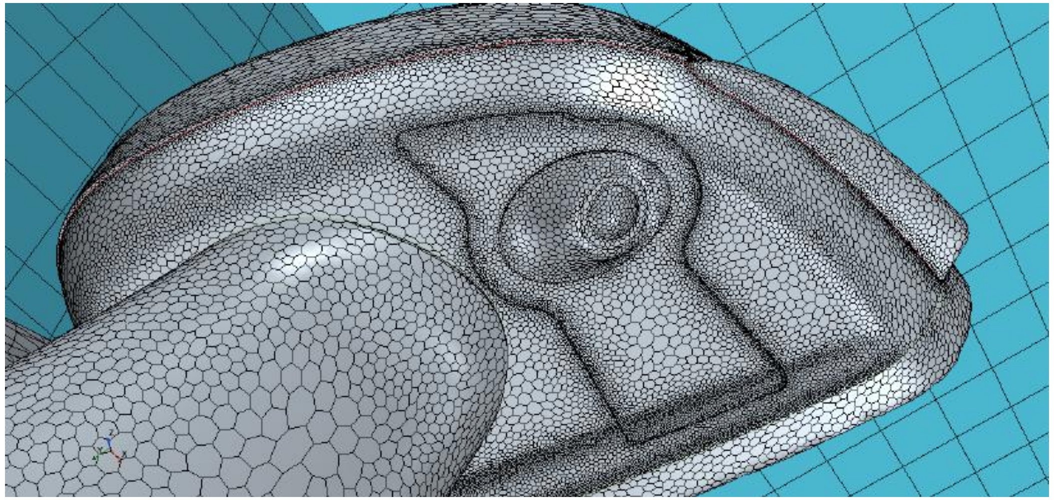


- The side-view mirror geometry is attached to the DrivAer model
- Minimization of the mean fluid film thickness on the camera lens



Volvo car side-view mirror



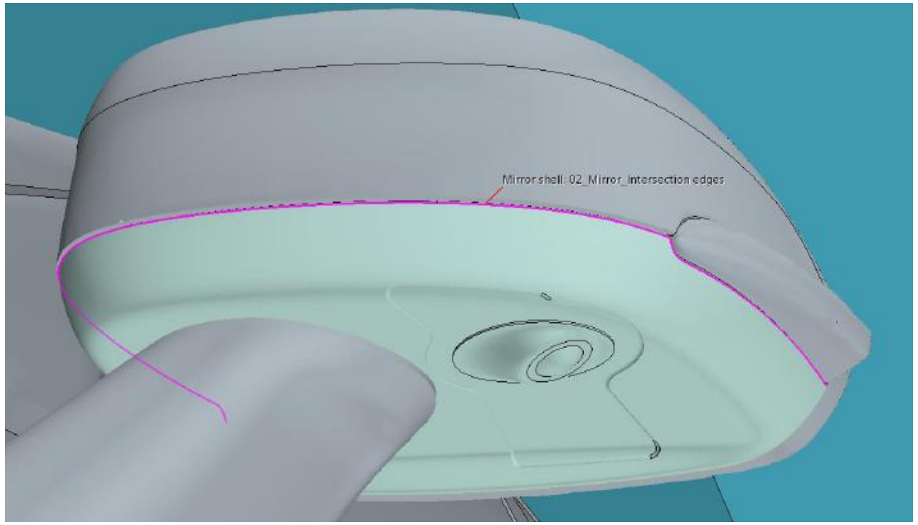


l_x [m]	27.5
l_y [m]	6.5
l_z [m]	5.2

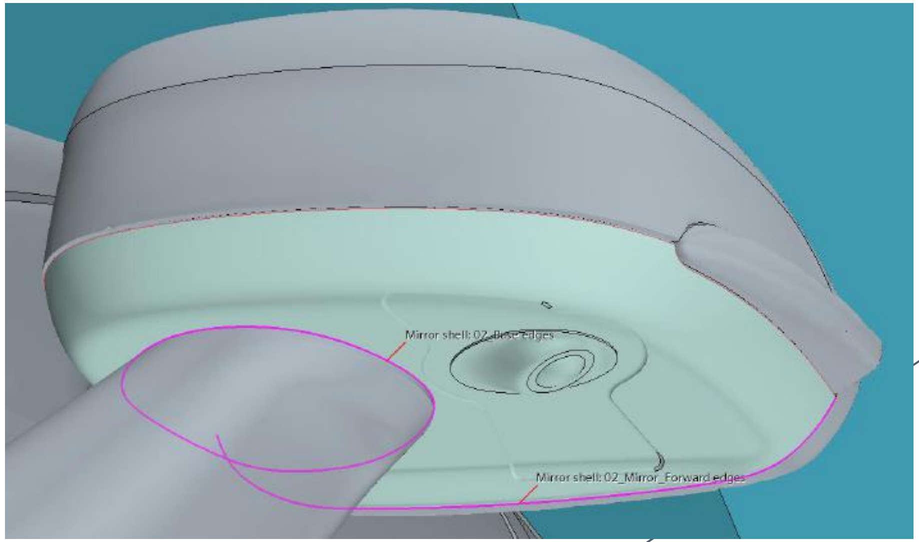
- Two parts analysis:
  - Single-phase steady state simulation (air)
  - Multi-phase transient simulation (air / water film)

Multiphase simulation

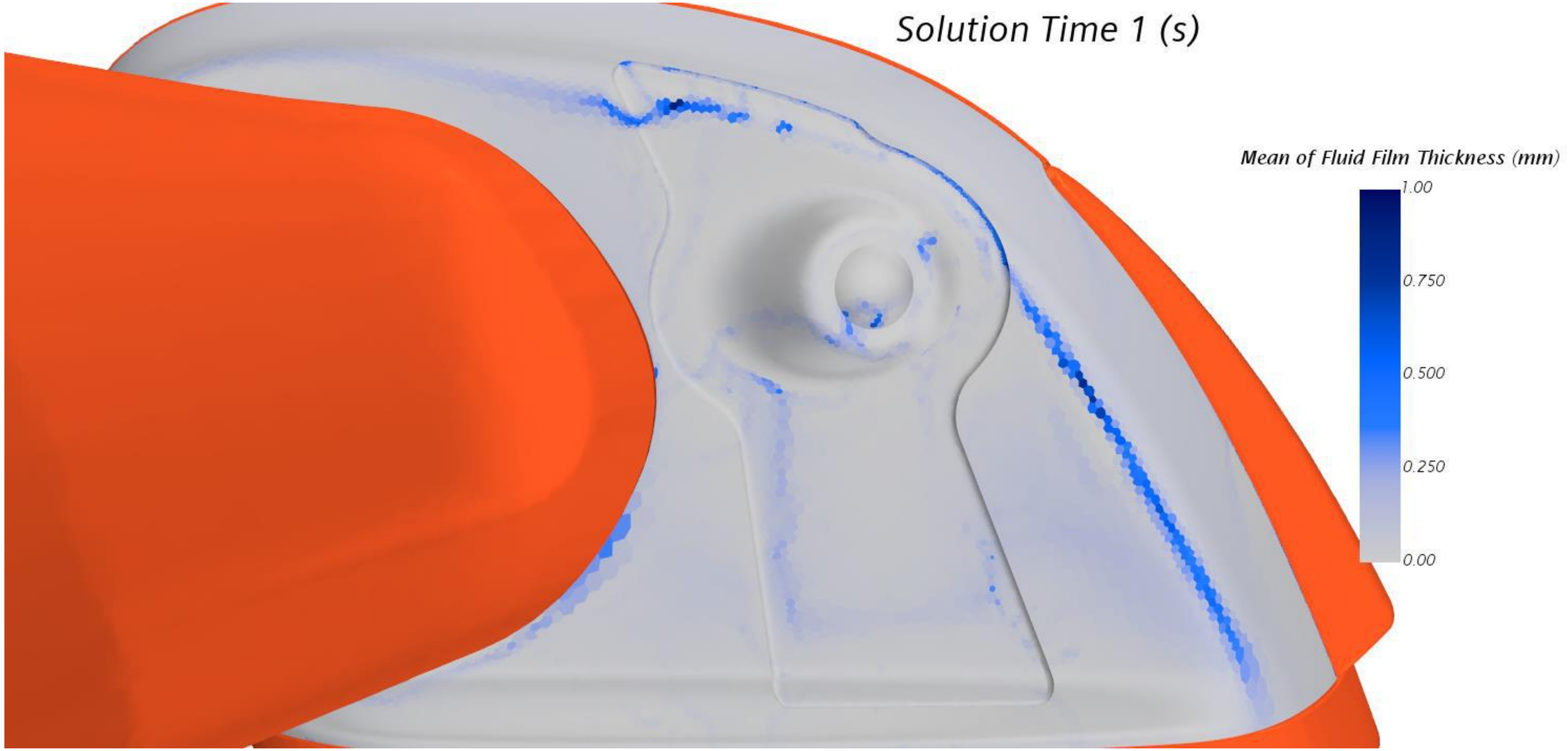
Fluid film inlet



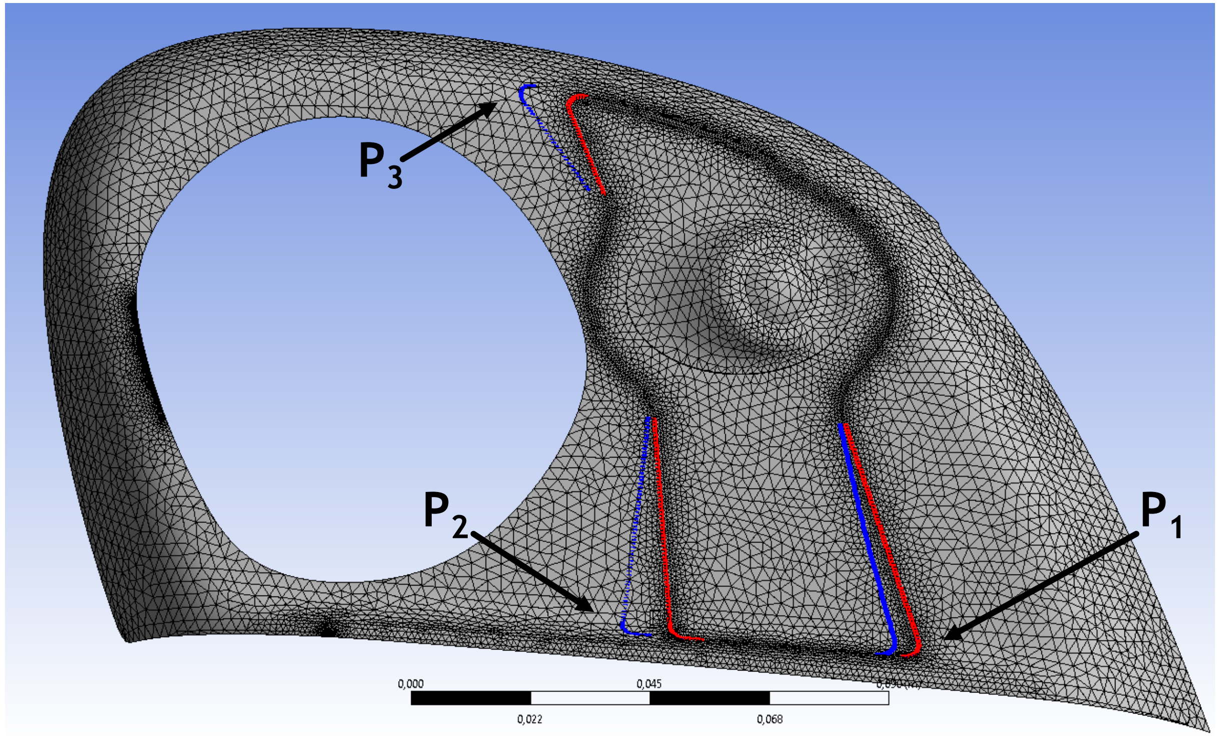
Fluid film outlet



Multiphase simulation

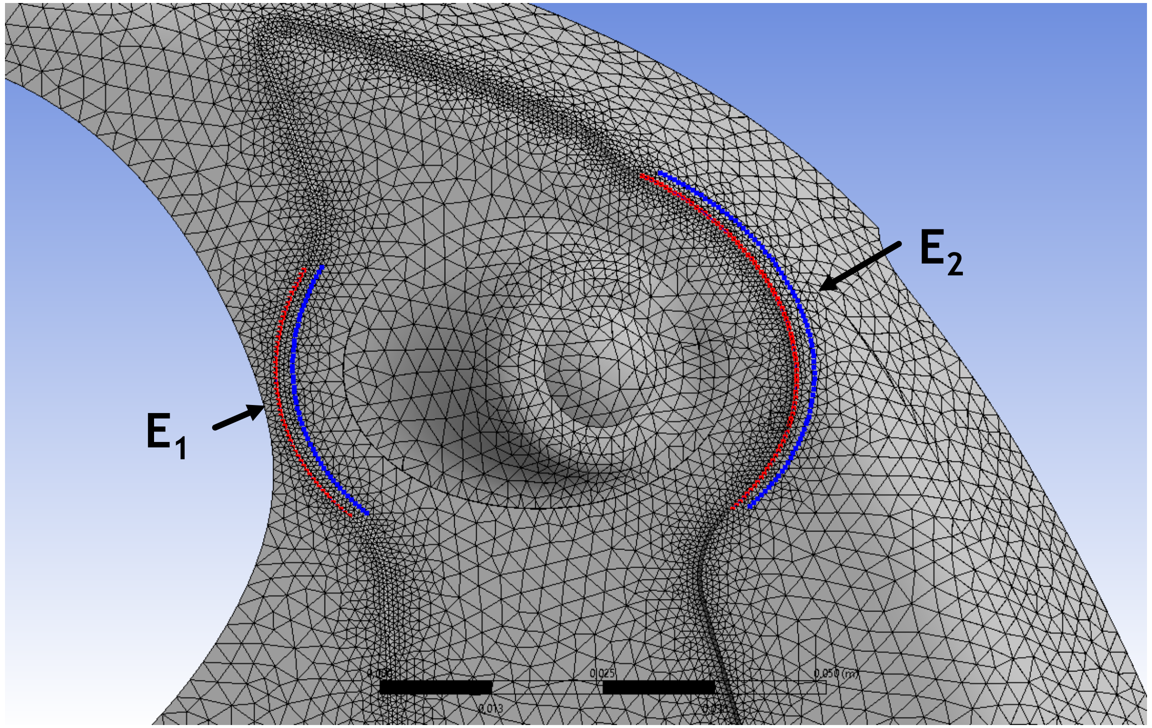


Parametrization & Mesh Morphing



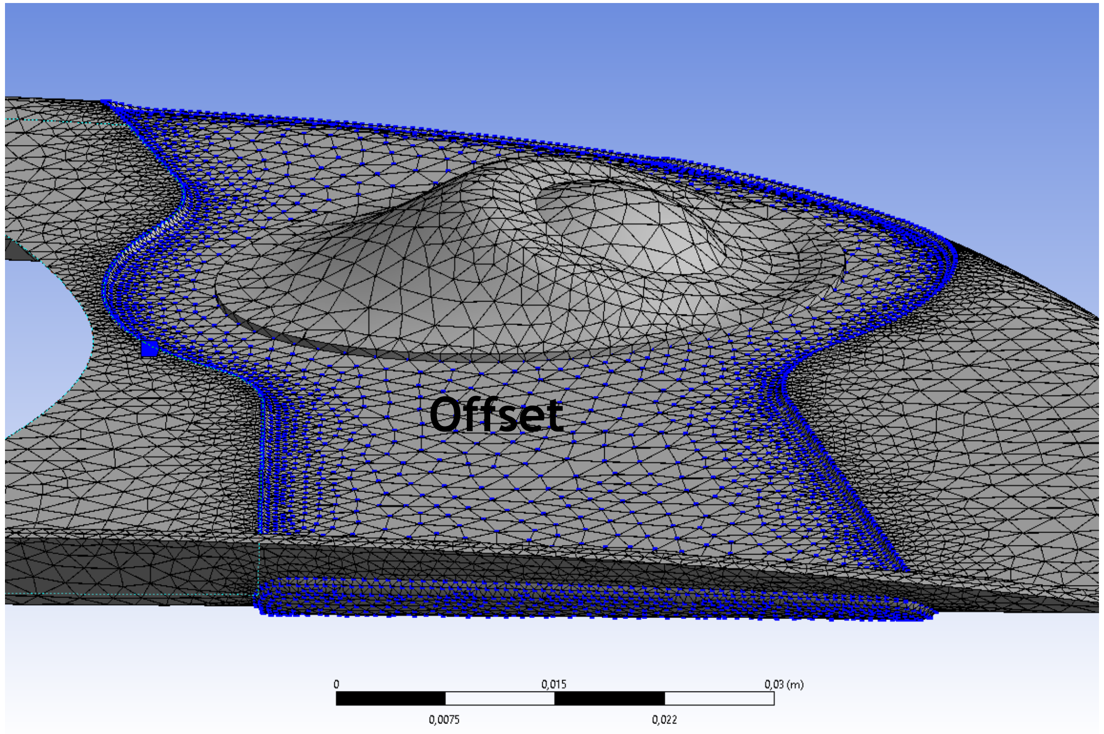
	Lower limit [m]	Upper limit [m]
P_1	-0.005	+0.010
P_2	0.000	+0.015
P_3	0.000	+0.015

Parametrization & Mesh Morphing



	Lower limit [m]	Upper limit [m]
E_1	-0.002	+0.000
E_2	-0.002	+0.004

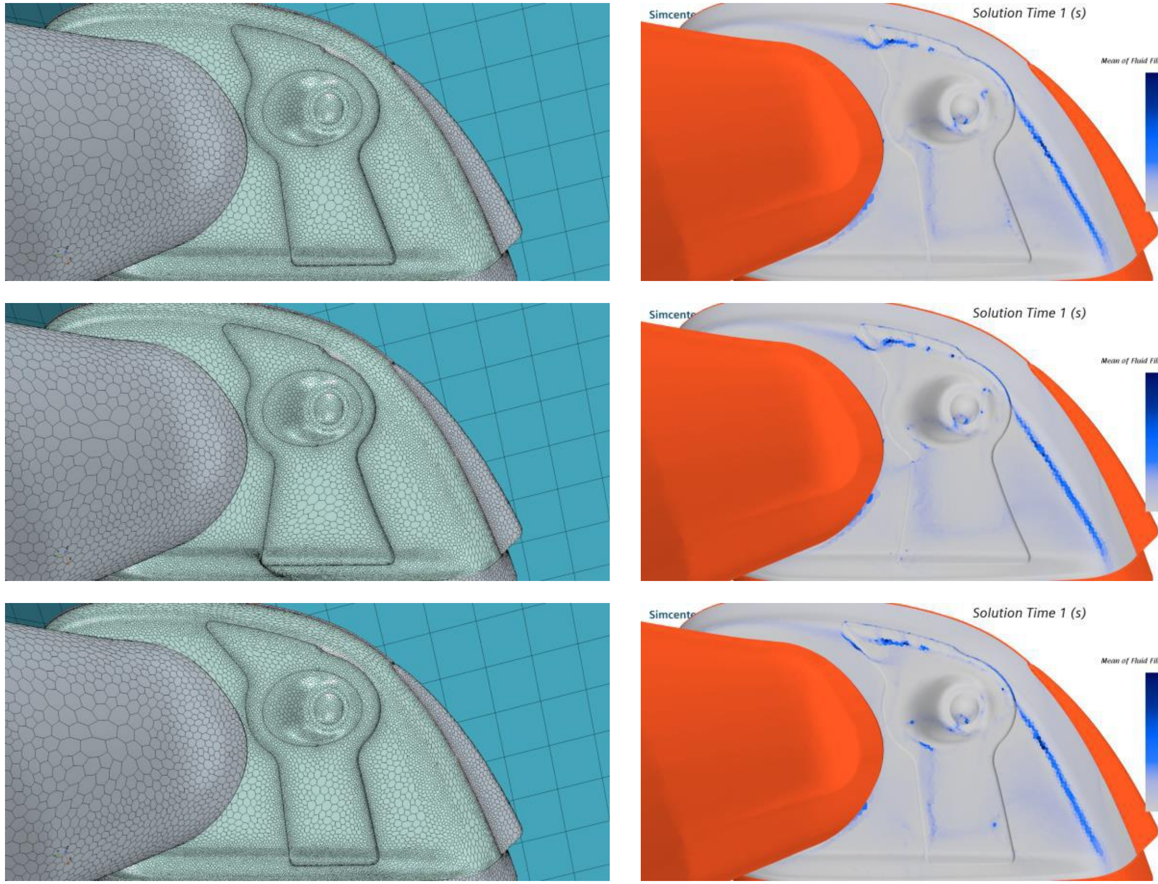
Parametrization & Mesh Morphing

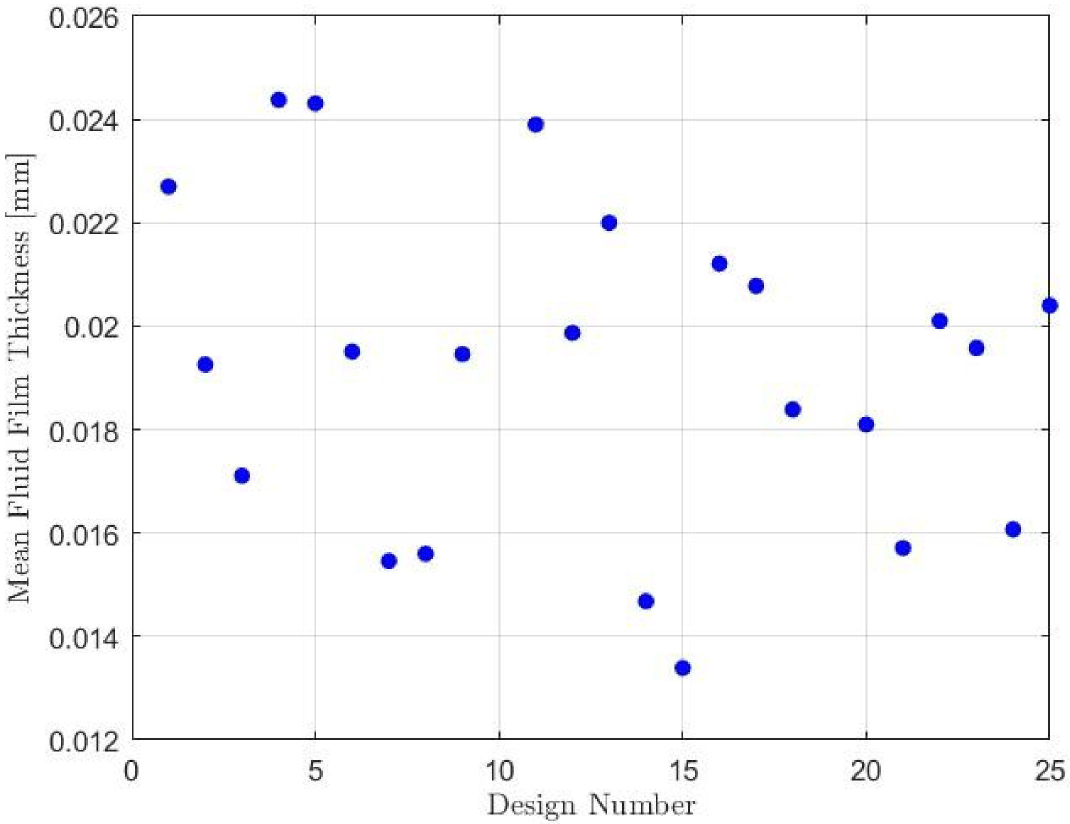


	Lower limit [m]	Upper limit [m]
Offset	0.0000	+0.0005

Parametric CFD analysis

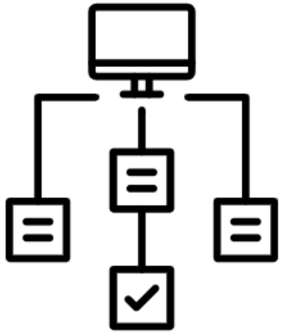
- 25 shape variants





Conclusions

- Advanced technological prototype of an orchestrator
- Efficient, fully automated design exploration workflow
- Pilot for the new Stand-Alone version of *RBF Morph*
- Technological innovation for *Volvo Cars*



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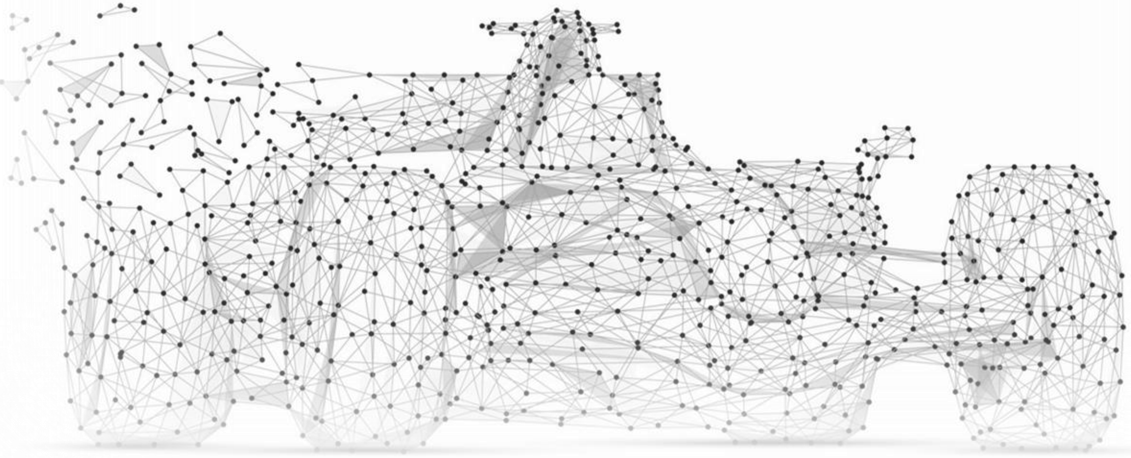
Thank you for your attention



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