Application of OpenFOAM® for Automotive Aerodynamics Development

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Acknowledgements

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Original work presented by Dr. Gerhard Wickern (AUDI AG)

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Requirements for Automotive Applications

- Fast meshing process is a key factor:
  - Limiting factor for acceptable turn-around times
- Use of LES or DES:
  - Unsteady, proper representation of turbulence
  - High accuracy
- Open-source software:
  - Highly customisable developments possible
  - Advanced projects can be achieved
  - No license fees for large scalability
  - Popular at Universities

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Project Overview

- Multi-year development project
  - Audi AG (project lead), Volkswagen AG, SEAT S.A.
  - Icon (applications development)
  - OpenCFD (consulting)
- Basic requirements:
  - Efficient and robust simulation methodology
  - Higher level of accuracy than previous tools
  - Increased number of vehicle projects and reduced development times → no limitation for number of processors
- Validation using experimental data from Audi-VW wind tunnels
- Productive use for vehicle development starting 01/01/2009

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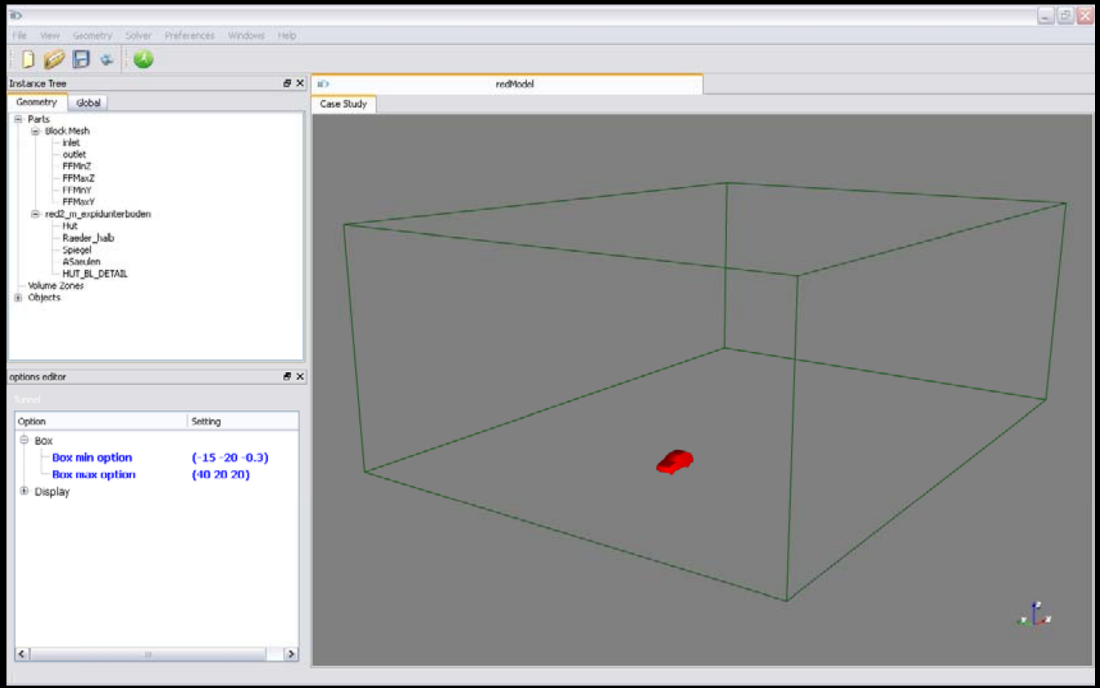
GUI | Overview

- Pre-processing tool
- Modular and extensible
- Cross platform:
  - Windows
  - Linux
- Batch execution
- Sensible defaults
- Simplifies process for non-expert users
- Enables consistent set up → less prone to user mistakes



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Meshing Process

- CAD input: faceted 'watertight' data
- **Stage 1**: Castellated mesh
  - Start with Cartesian hex-dominant block mesh with predefined regions of different refinements: x2, x4, x8, x16, etc
  - Remove 'non-wet' volumes
- **Stage 2**: Boundary-recovered mesh
  - Projection of castellated volume mesh to surface mesh
  - Quality checks and smoothing
- **Stage 3**: Final mesh
  - Boundary layer mesh addition
  - Further quality checks and smoothing

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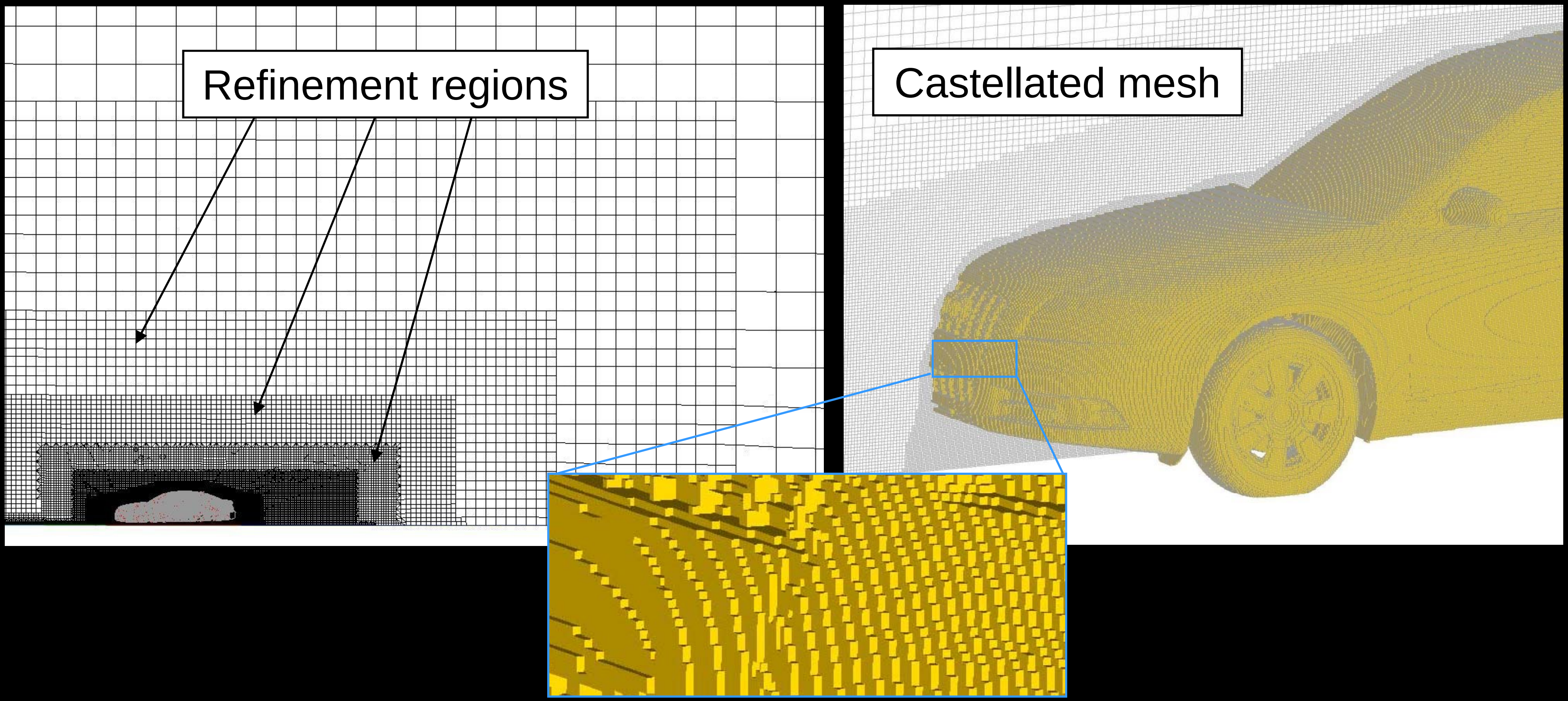
- Remove 'non-wet' volumes



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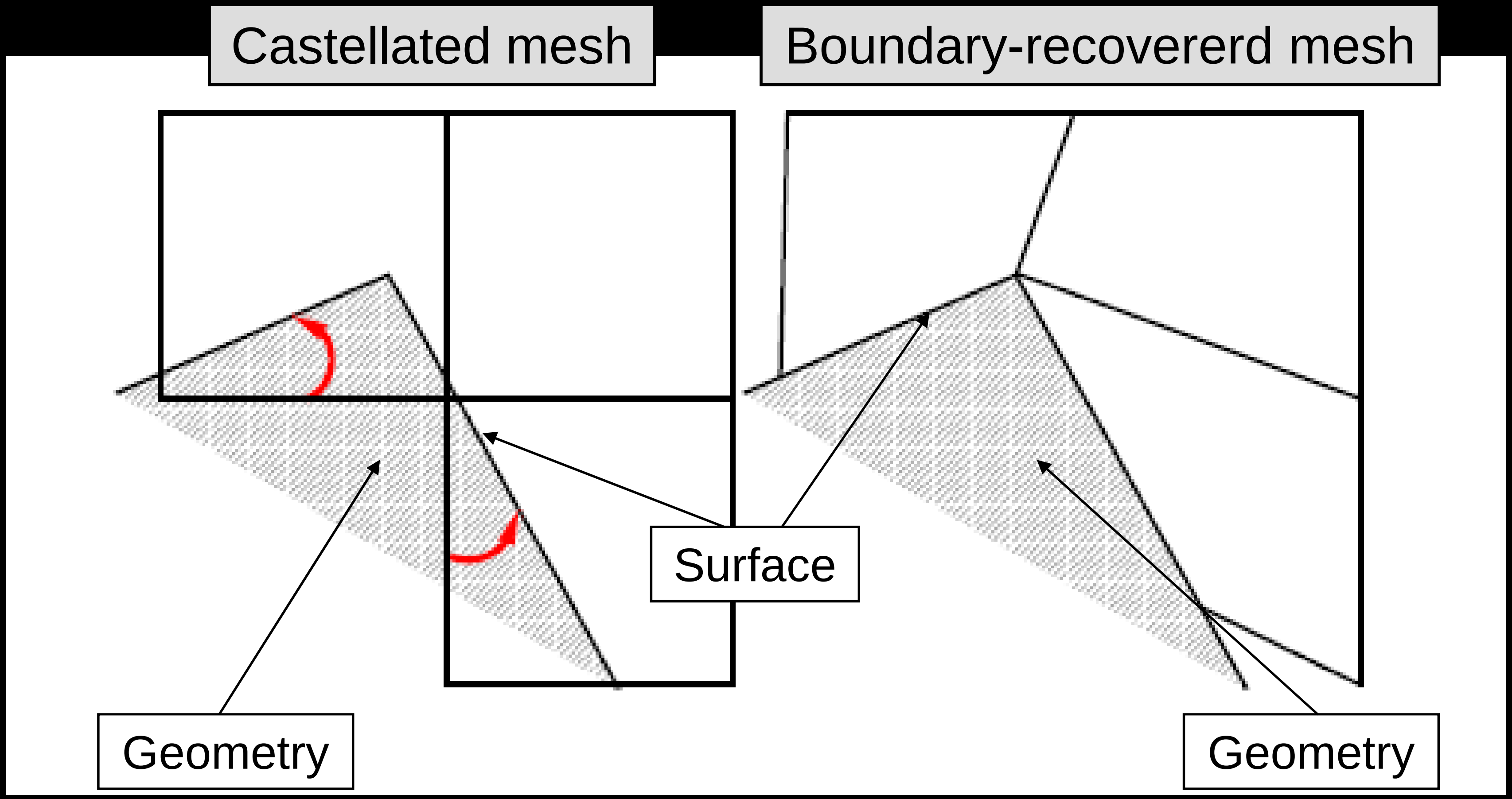
- Projection of castellated volume mesh to surface mesh
- Quality checks and smoothing



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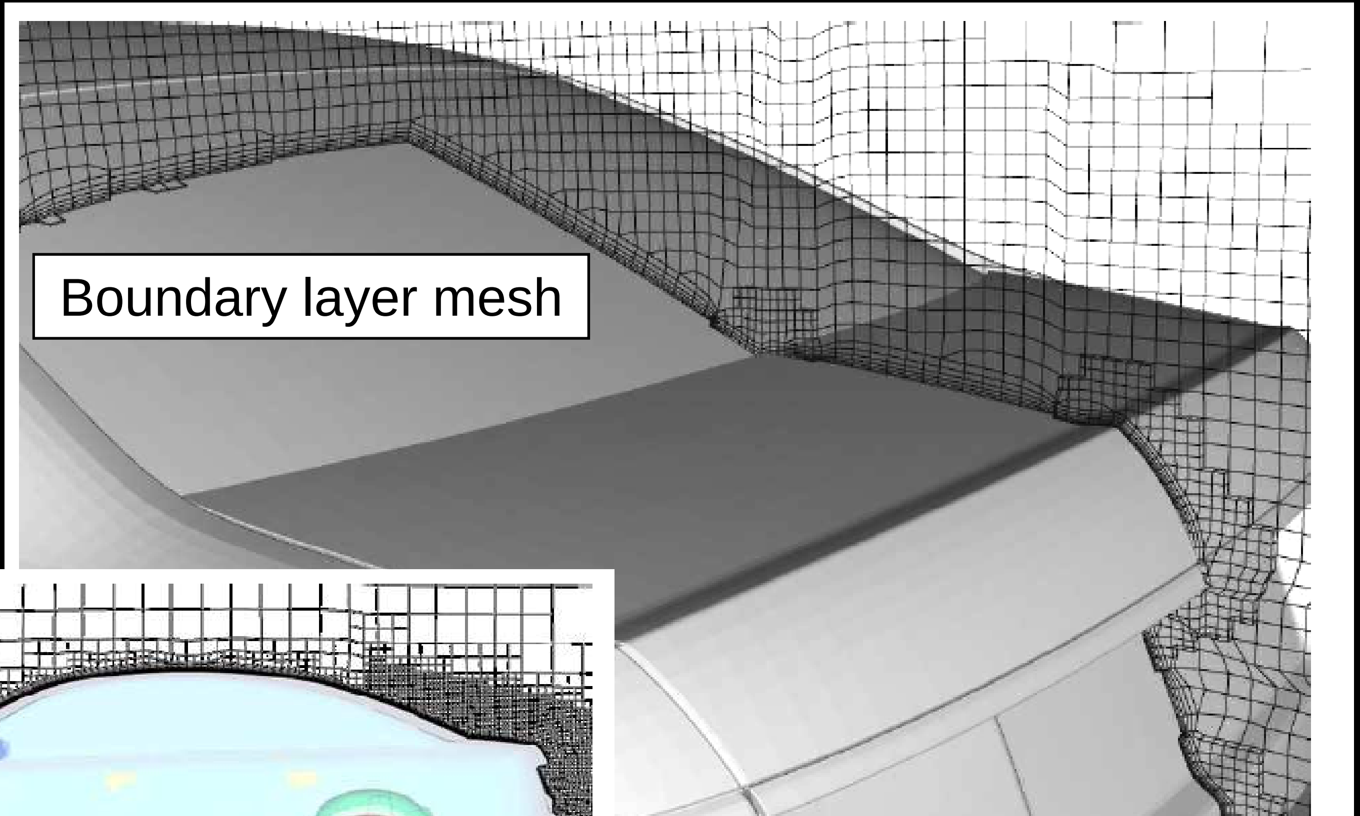
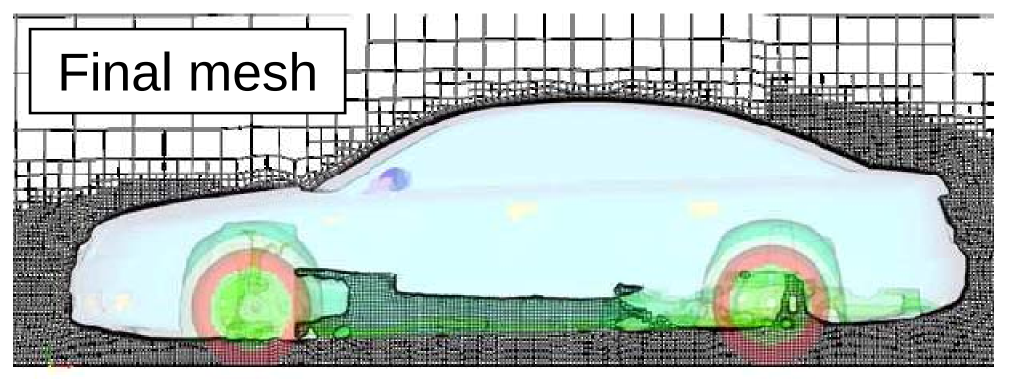
Technology • Process • Consulting

- Boundary layer mesh addition
- Further quality checks and smoothing





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CFD Solver

Technology • Process • Consulting

- Finite Volume CFD solver based on OpenFOAM®
- Detached Eddy Simulation
  - One-equation eddy-viscosity model (Spalart-Allmaras)
- High accuracy
  - Default second order accurate energy-conserving numerical schemes
- High robustness
  - Local blending to increase solver stability for high local Courant numbers (typically only a few cells)

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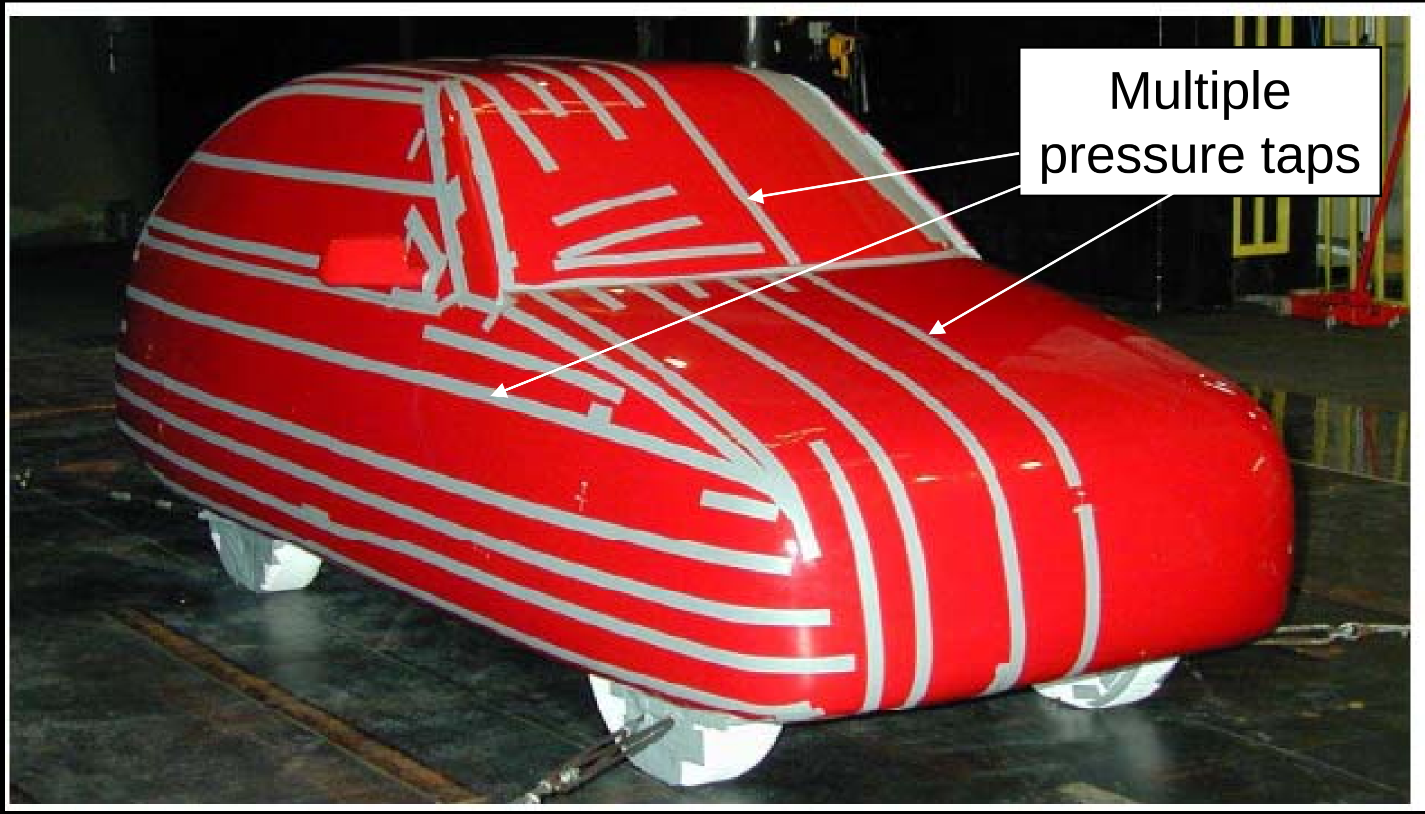
Validation I | VW Generic Red Model



	c_D [-]	c_{Lf} [-]	c_{Lr} [-]
Experiment	0.249	-0.052	0.128
Simulation	0.265	-0.048	0.118

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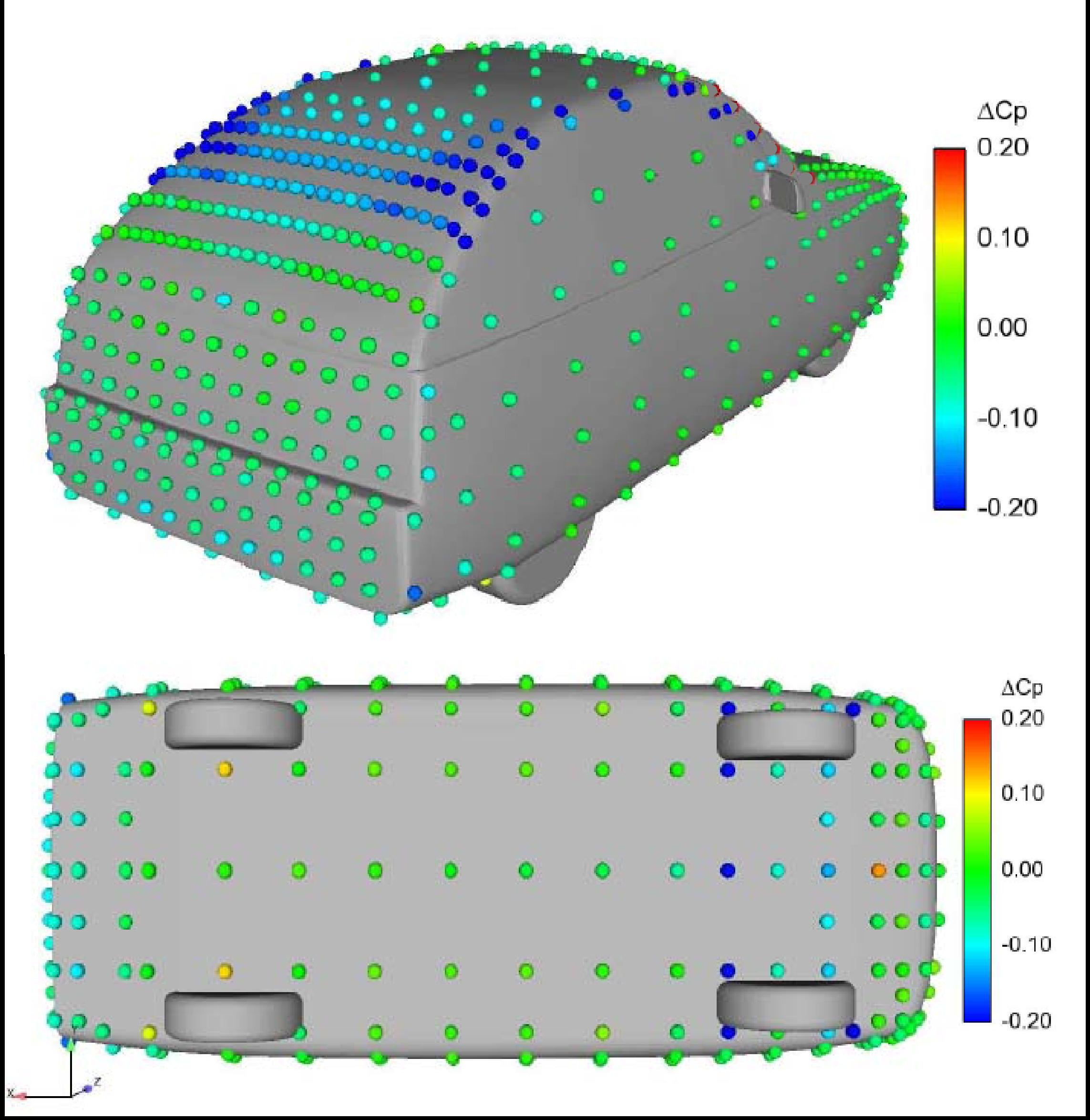

Pressure Coefficient (Cp)

Difference between
wind tunnel measurements
and simulation results

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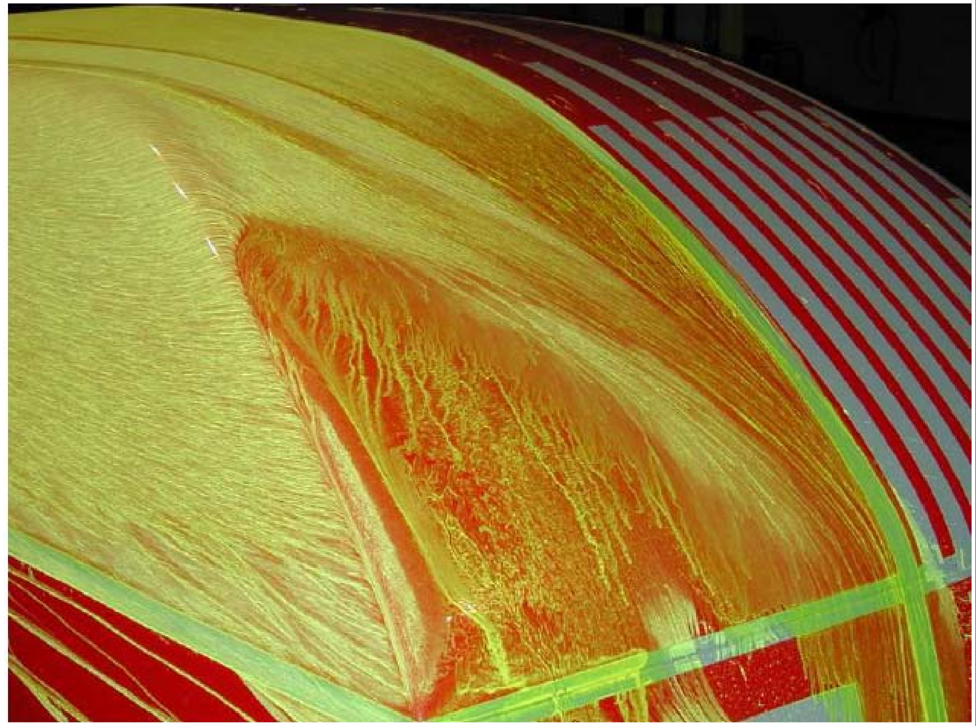
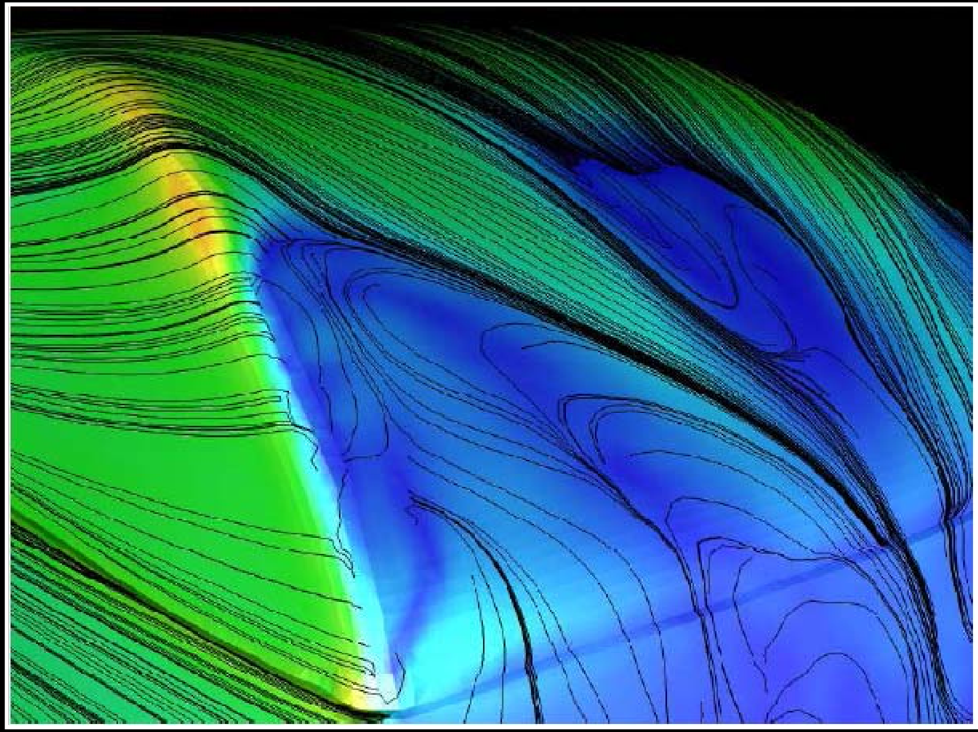
Oil-flow Visualisation



Experiment

Surface Streamlines



CFD

Validation II | Production Car: Audi A6

	c_D [-]	c_{Lf} [-]	c_{Lr} [-]
Experiment	0.271	0.068	0.116
Simulation	0.267	0.070	0.142

Closed under-hood + Static ground

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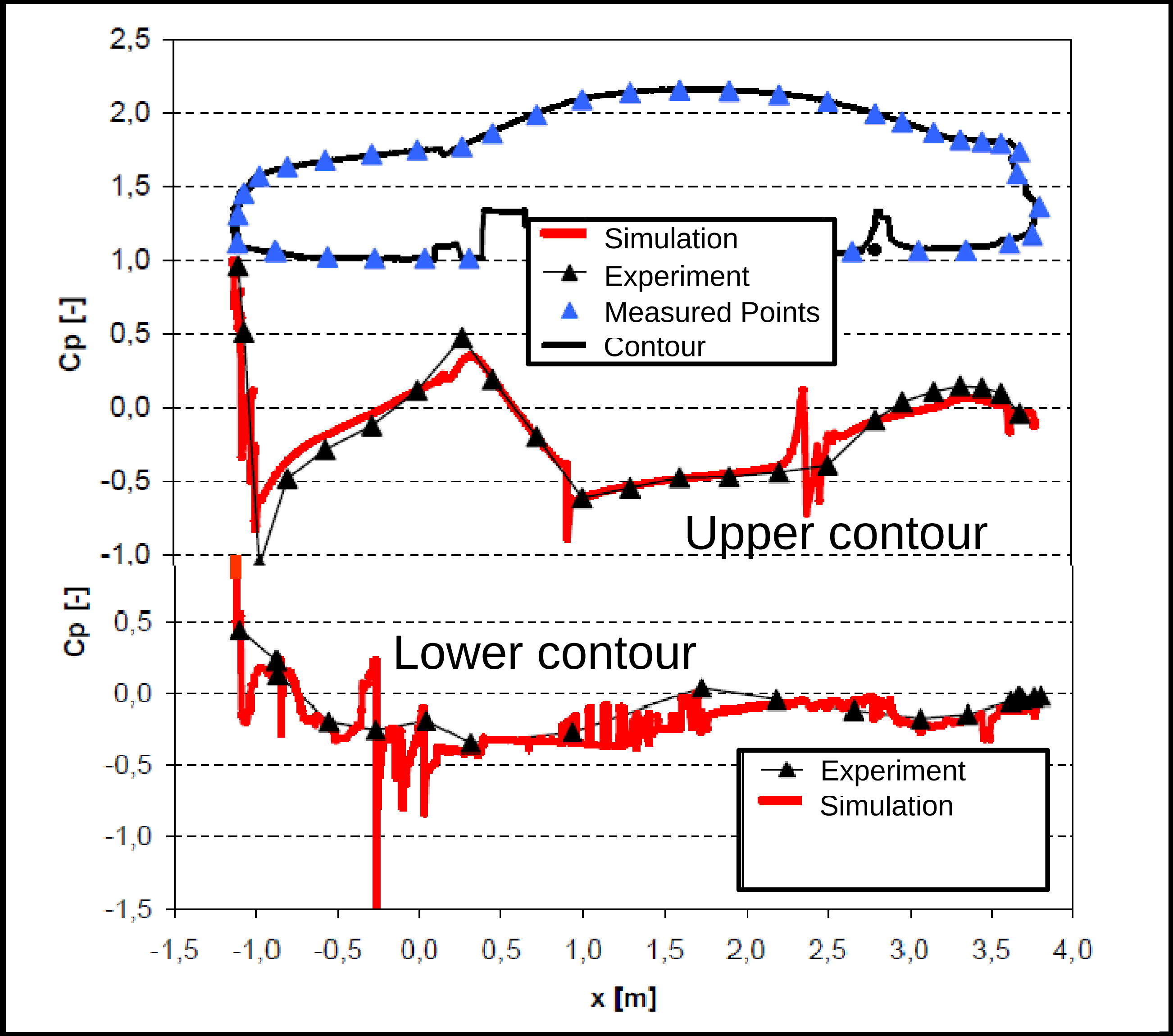

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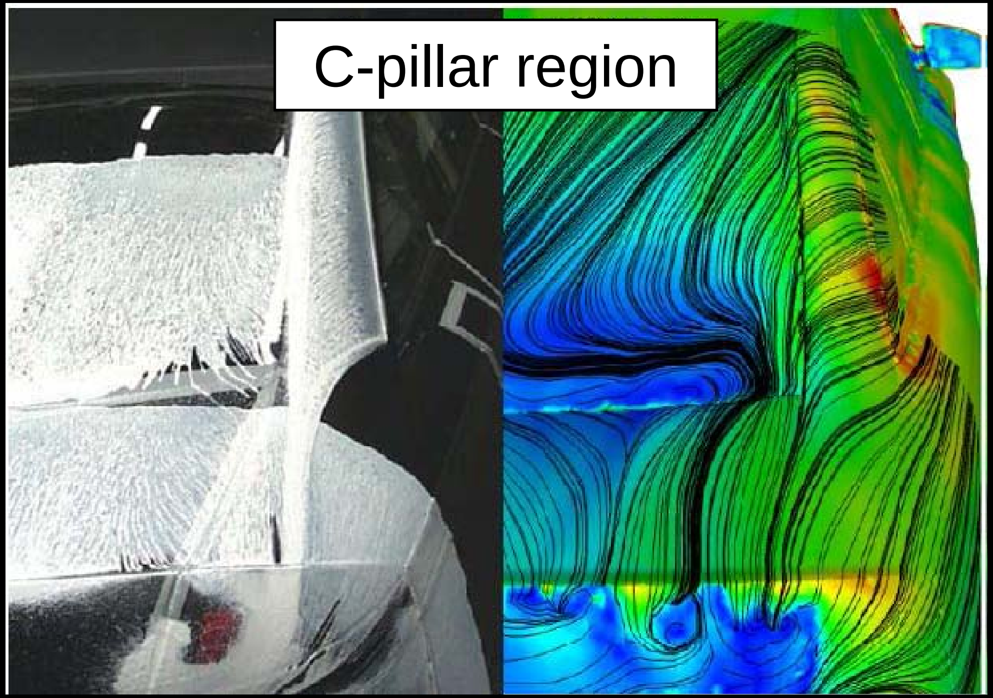
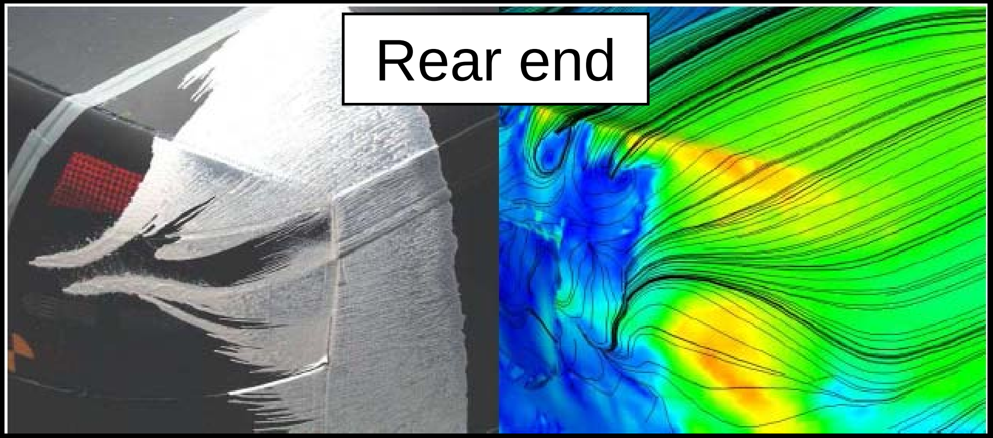
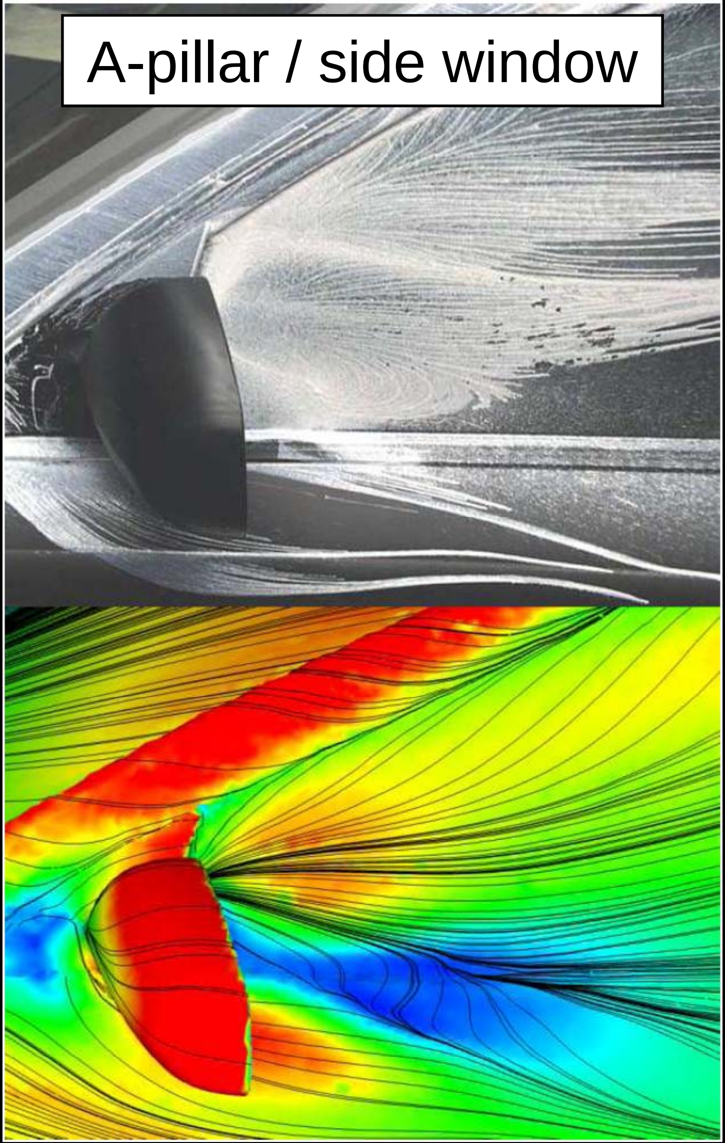
Technology • Process • Consulting







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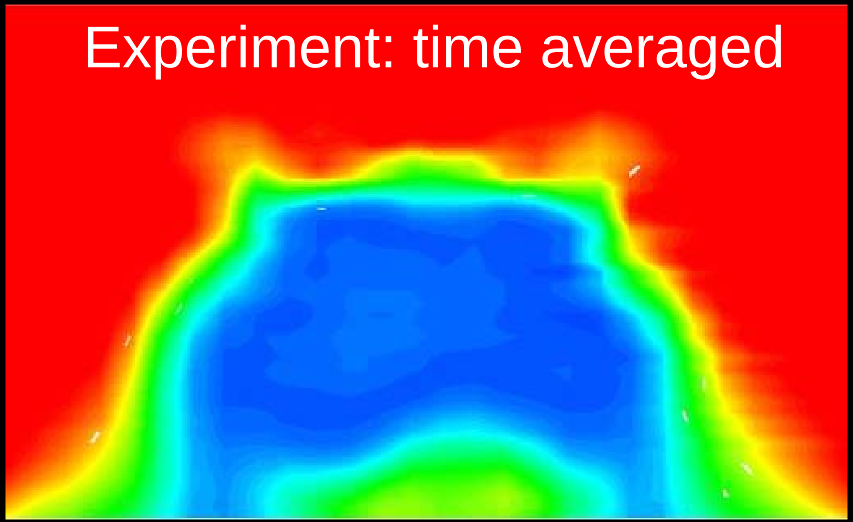
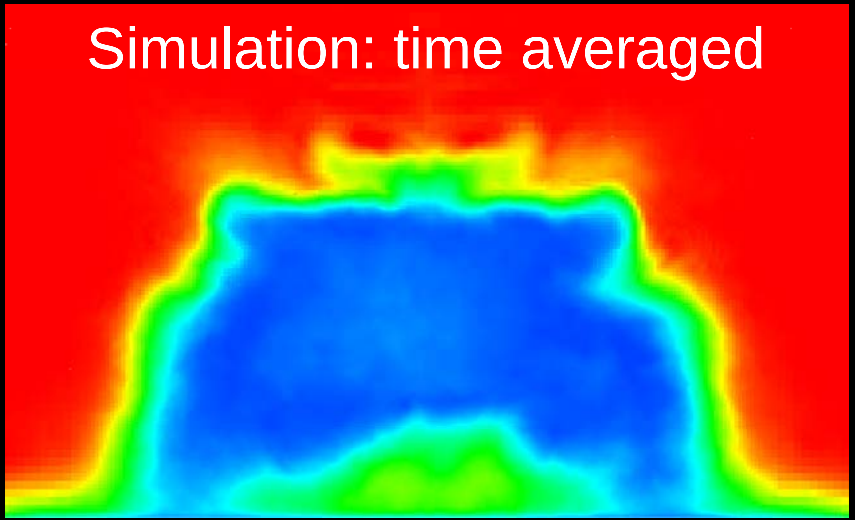
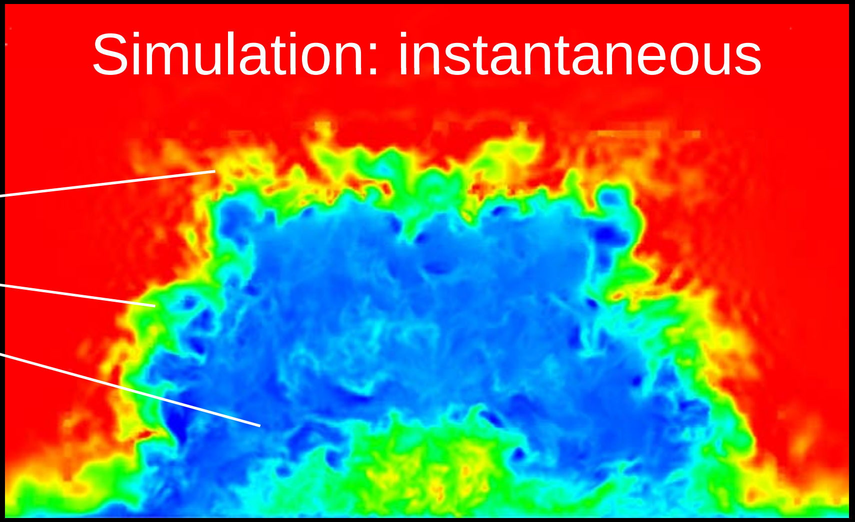
Total pressure behind the car: plane at x = 3.90 m





Small-scale turbulent structures



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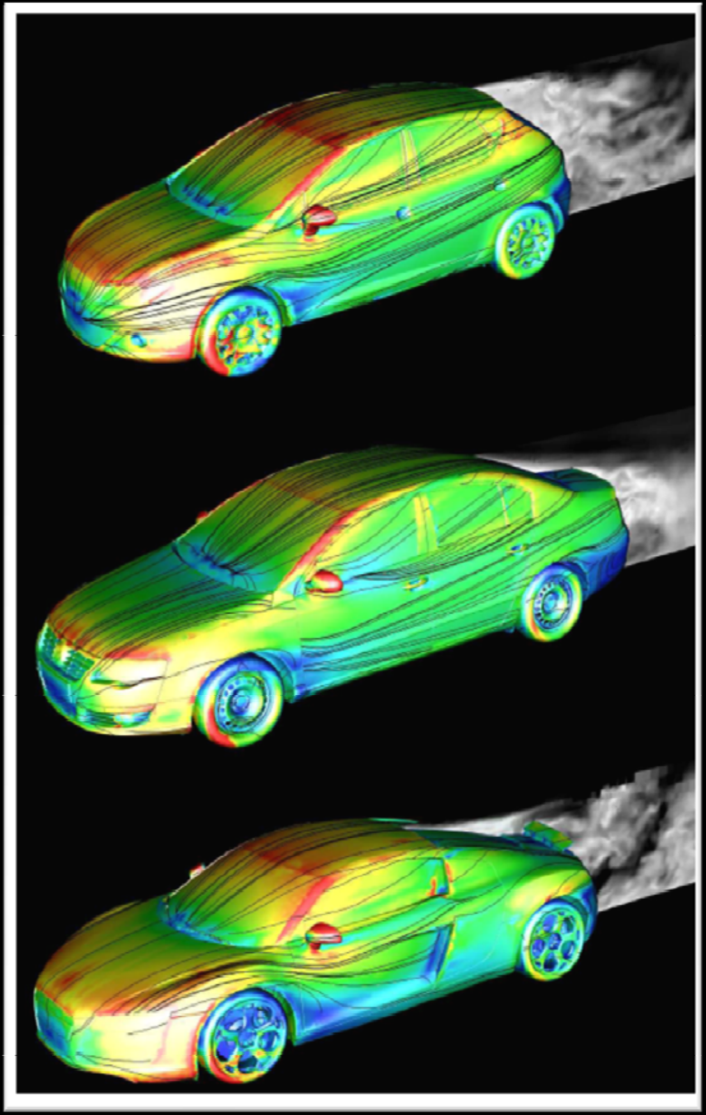
C_D- C_L- Comparison for Other Vehicles

	Δc_D [-]	Δc_{Lf} [-]	Δc_{Lr} [-]
SEAT Ibiza	0.018	-0.017	0.045
SEAT Leon	0.021	-0.005	0.030
VW Golf	0.003	0.034	0.024
VW Passat	0.011	-0.033	0.035
VW New Beetle	0.016	0.001	0.030
Audi A3	0.007	-0.018	0.034
Audi A5	0.011	-0.036	0.031
Audi A6	-0.004	0.002	0.026
Audi Q5	-0.001	-0.006	0.047
Audi TT	-0.001	-0.006	0.051
Audi R8	0.022	0.021	-0.012

Closed under-hood + Static ground



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Conclusions and Future Work

- Current DES approach used at Audi, VW and SEAT for productive vehicle development:
  - Numerics compatible with meshing practice
  - Flow details are properly resolved on generic models and production cars without cooling flow
  - Acceptable results obtained over the whole range but further improvements are required
- GUI and parallel meshing are key factors for sucess
- Future demands include:
  - Moving ground simulation with rotating wheels
  - Cooling drag and cooling lift predictions
  - Aeroacoustics capabilities

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Thank you for your attention

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