External aerodynamics with rotating wheels

Dr. Fabian Rösler (I/EK-412), German OpenFOAM User meetiNg (Braunschweig), 21.02.2018

Why do we use OpenFOAM?

Advantages

- Transparent and flexible Code
- No license costs
- Competent network, community

Disadvantages

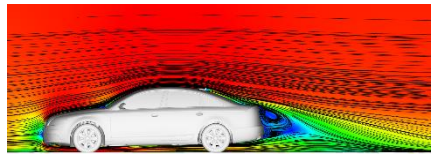
- Little documentation
- Expenses for process integration
- Missing functionalities

- OpenFOAM is successfully used in Audi and VWgroup standard applications
- We directly merge improvements and further developments to the OpenFOAM code
- Good mix of cooperation and competition in the community
- Interface to export simulation results to EnSight cases

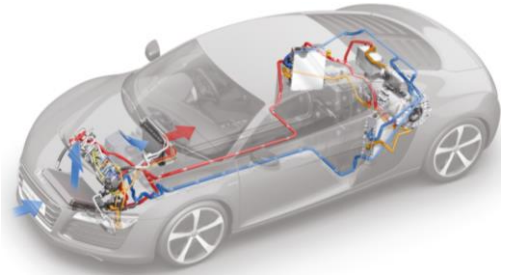
- stabilize strategy with successful future developments and sound partnerships in the community
- prove and maintain competitiveness

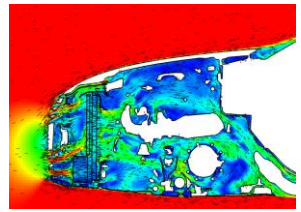
Simulation underhood flow / aerodynamics (I/EK-41)

1. External aerodynamics / aeroacoustics

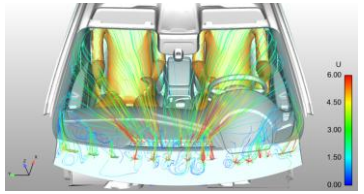


2. Thermal management for conventional and electrical vehicles (cold/warm)





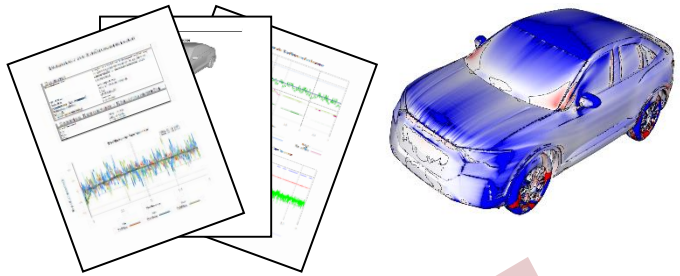
3. Heating, Ventilation and Air Conditioning (HVAC)



- Method development and process integration as well as validation are our core tasks.
- OpenFOAM open-source software is the main CFD code in all three disciplines.

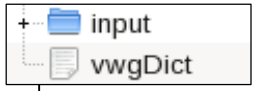
Audi OpenFOAM case setup tool

5. Delivery of results



vwgSETUP
subFOAM

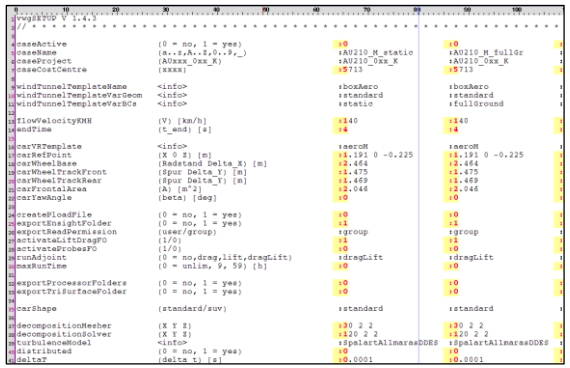
1. Start Folder



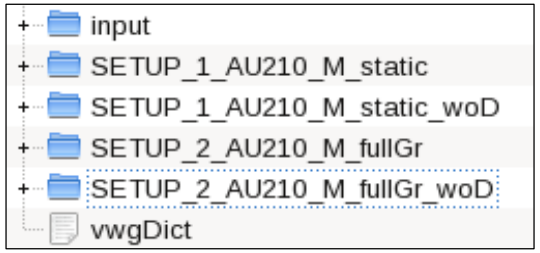

```
GEOM0930_Antenne_AU210.stl
GOPT0930_SV_KSG.stl
VRES0800_Refinement.stl
...
GRWS0930_HA_LI.stl
```

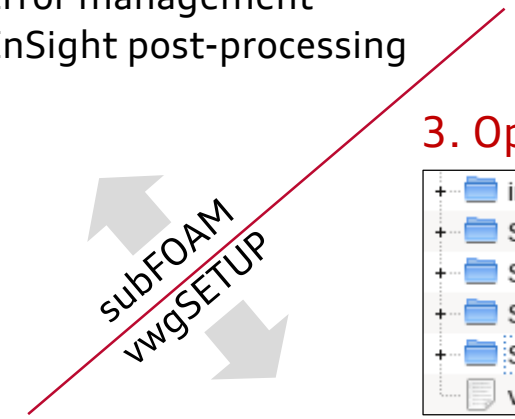
- File linking
- Prism layer
- Refinement level
- Prefix

2. vwgDict entries



3. OpenFOAM cases



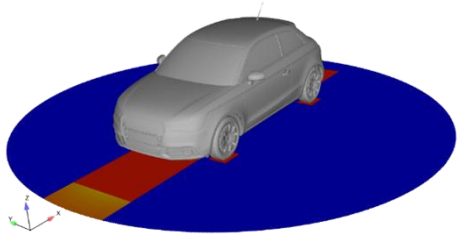


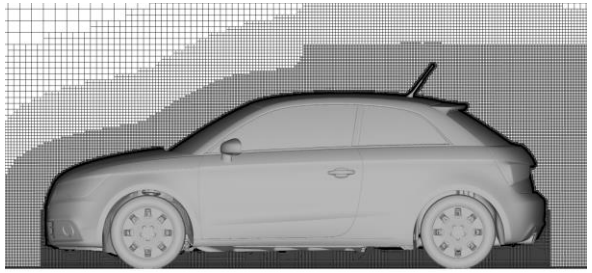
4. Submisson of cases

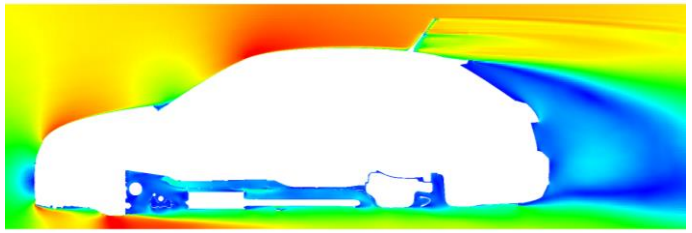
- Discipline specific workflows
- Cluster queue
- Error management
- EnSight post-processing

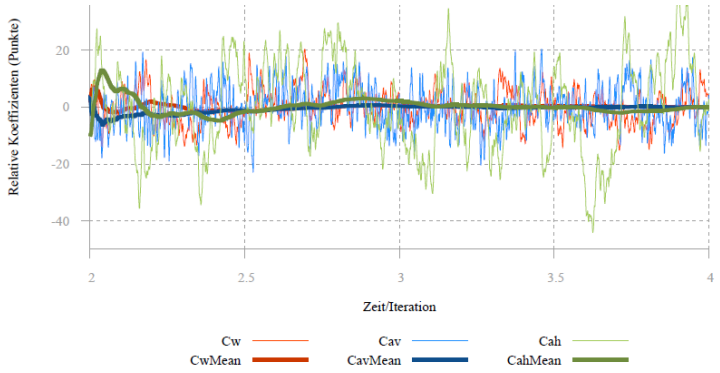
External aerodynamics

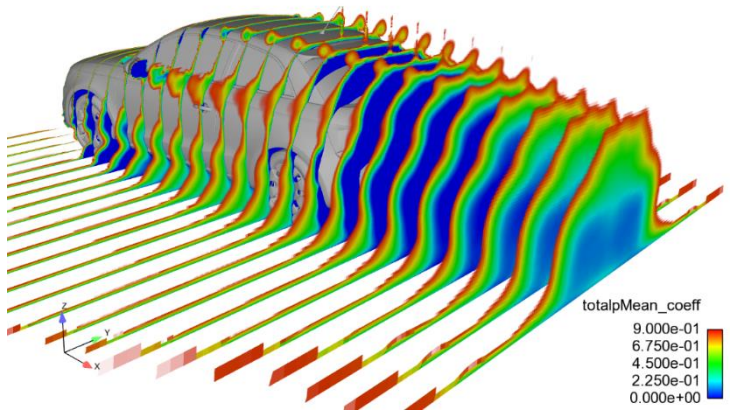
- Mockup model of the Audi A1 with full ground simulation 140 km/h
- Hexahedral dominant mesh (Approximate size 70 million cells) with prism layers
- 4 s SA-DDES simulation
  2 s averaging of the force coefficients
- Meshing with 120 cores
  Solving with 480 cores
  Post-processing on PP-node
- Force coefficients as target values









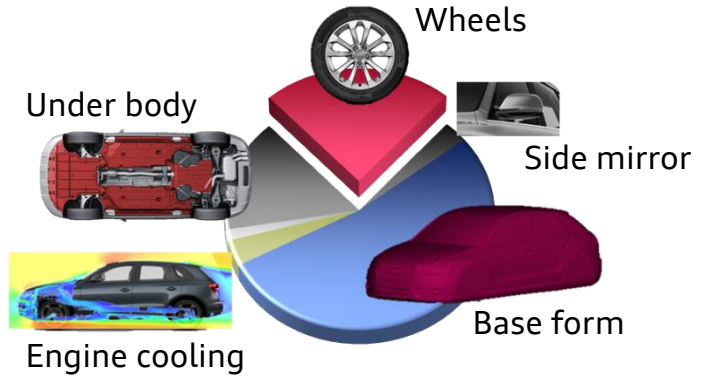


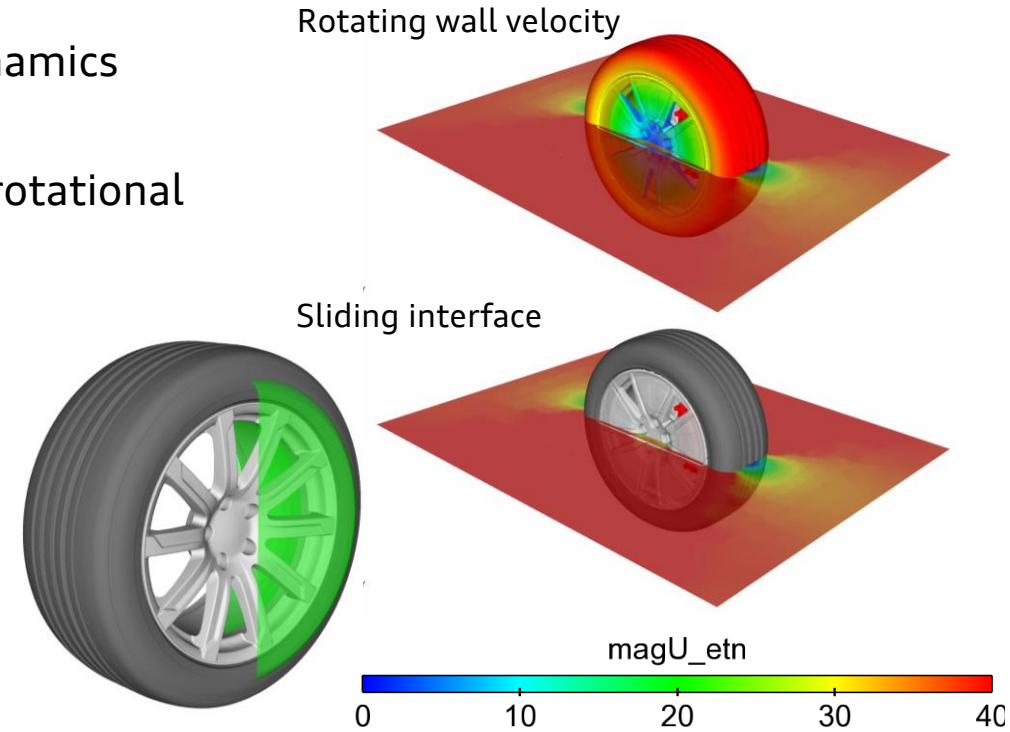
Why external aerodynamics with rotating wheels?

- Motivation
  - Contribution of wheels to the overall drag up to 25%
  - Evaluation of wheel design not possible with best practice aerodynamics simulation method

- Challenge
  - Implementation of a sliding interface into the external aerodynamics best practice
  - Conservation of good layer mesh at the wheels and ensuring a rotational symmetric sliding interface
  - Allow simulation tire deformation and longitudinal grooves

- Scientific work of Lukas Haag (TUM)
  - Flow around rotating wheels (experimental and numeric)
  - Initial workflow design and validation

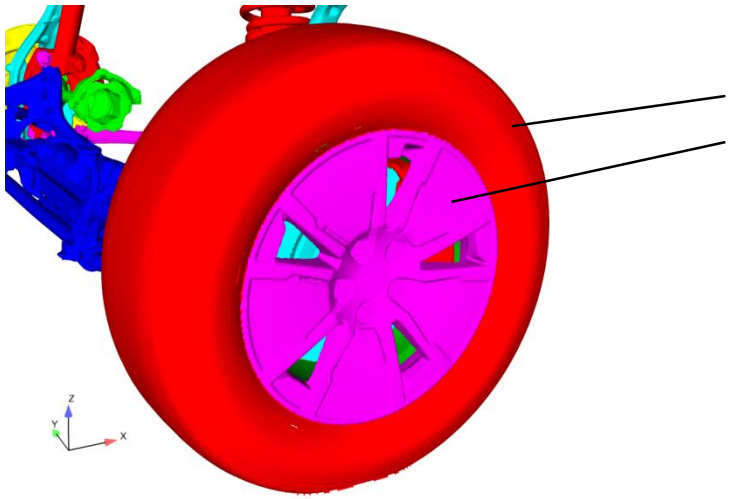




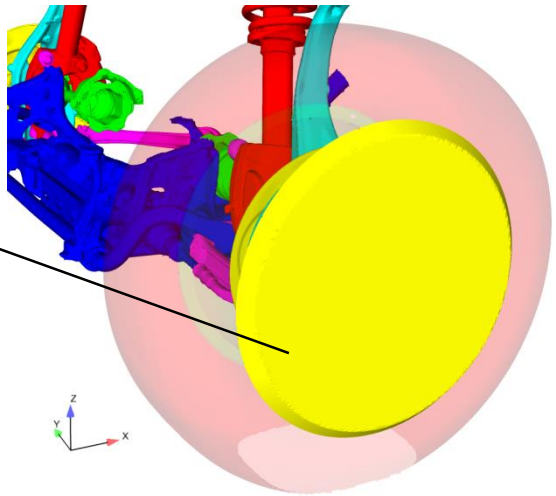
First rotating wheels setup for Audi Q5

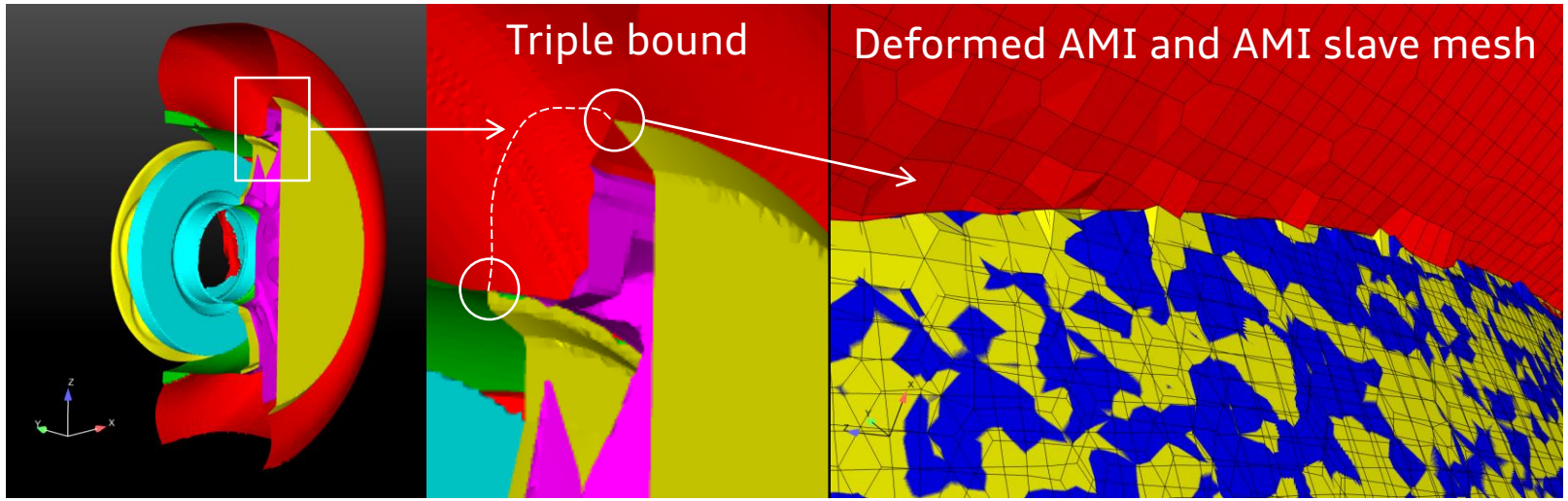
- AMI is introduced within snappyHexMesh using boundary faceType
- The outer part of the wheel group is rotating with rotatingWallBoundary
- The mesh inside the AMI surface has a rotating motion
- Triple bounds are included by features into snappyHexMesh
- Immense performance loss due to sliding interfaces

Wheel group of Audi Q5



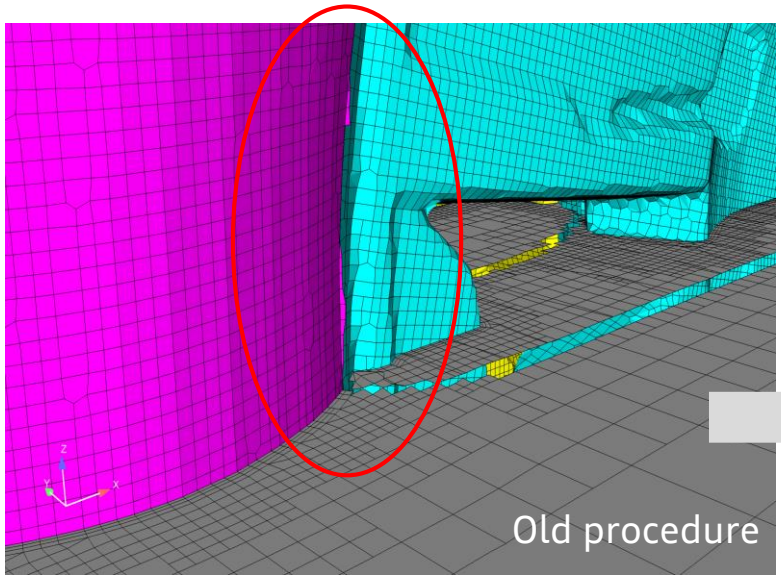
AMI interface

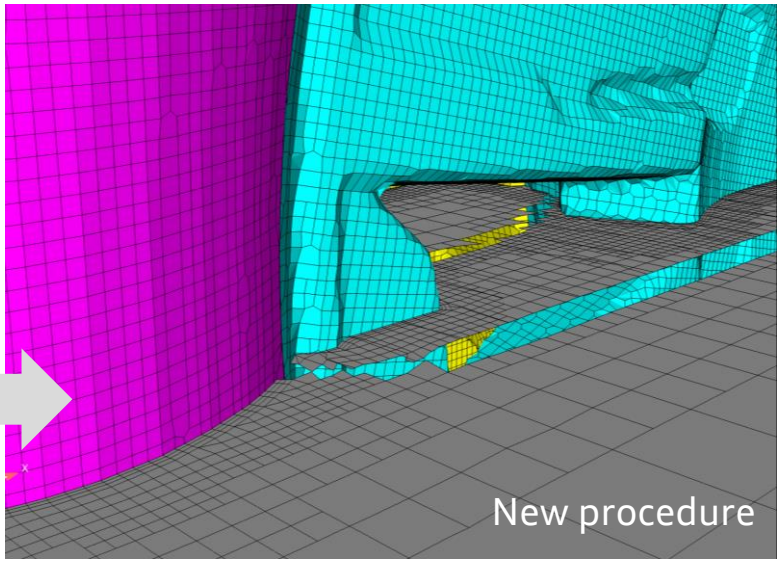


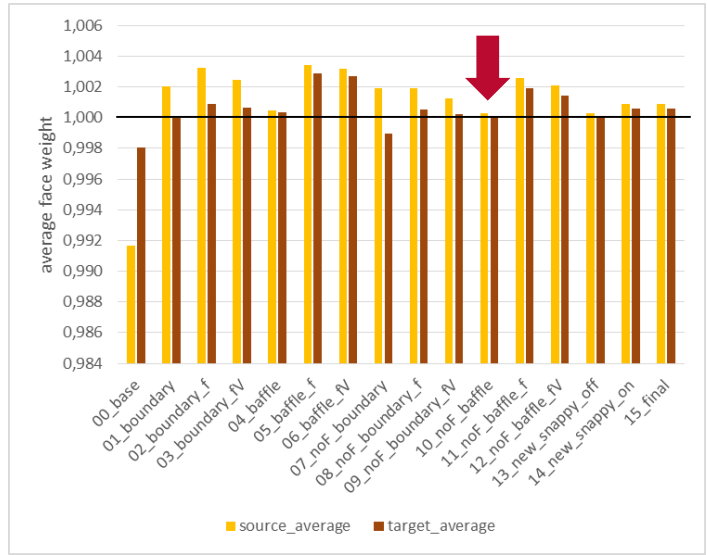


Parametric study on meshing procedure

- Two-step snappyHexMesh meshing approach
- Smooth mesh transition between static and rotating mesh regions
- Perfect face are weights for sliding interfaces close to one and equal mesh and face count on both sides

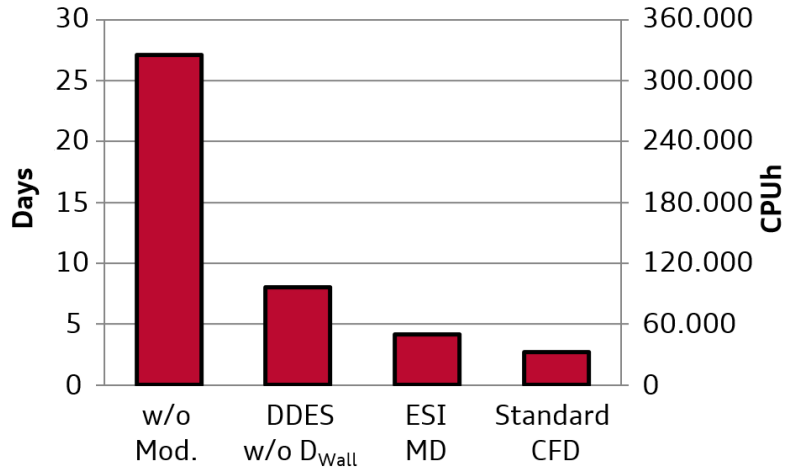






Performance increase by code adjustments

- Improved parallelization by reducing processor-to-processor communication
- Improved interpolation for moving mesh without topologically changes
- Decomposition of the sliding interface into triangles is done only once and the decomposition map is stored



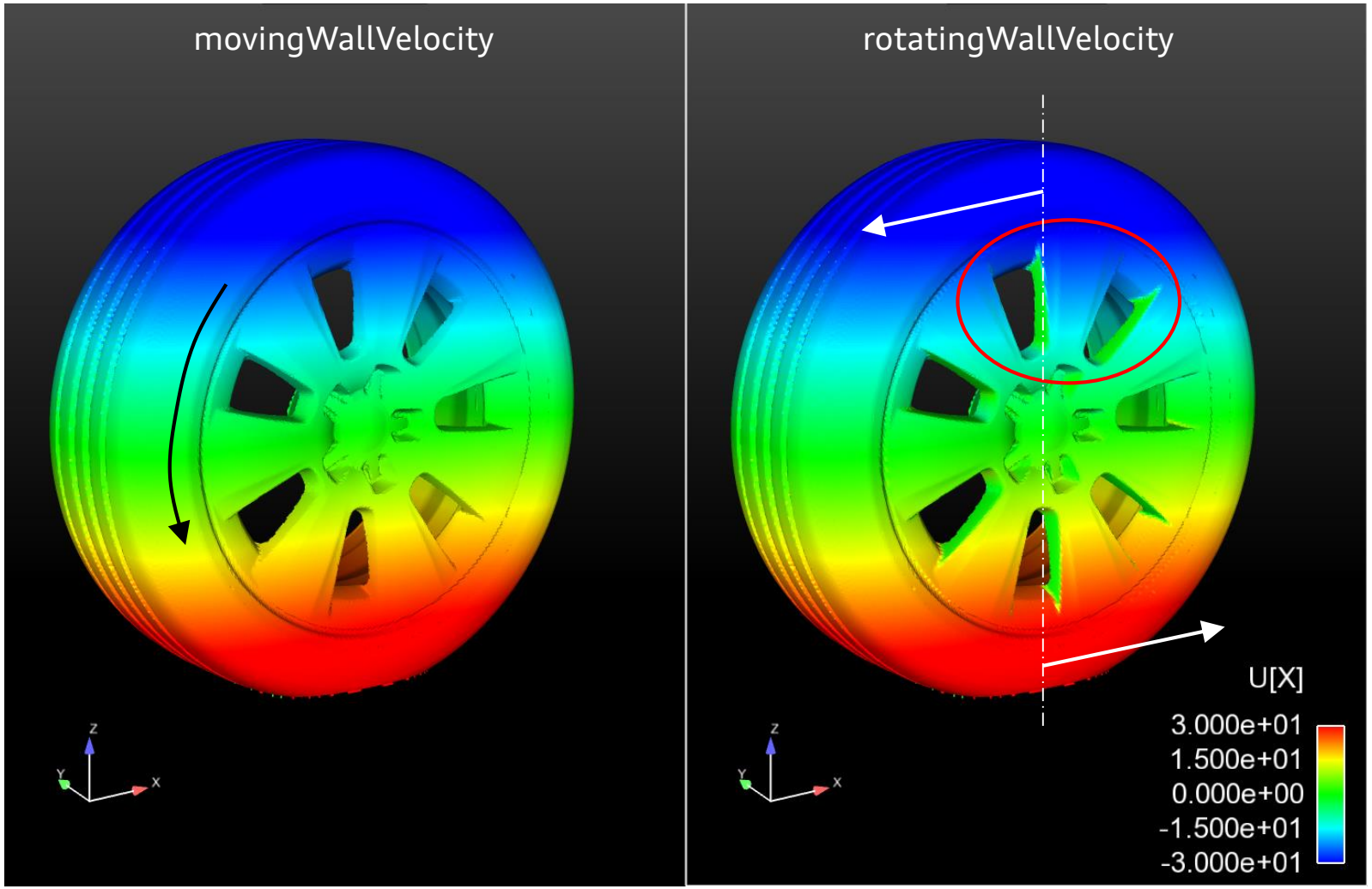
- Performance increase by round about 10 %
- Still a rotating wheels simulations runs 2 times longer than standard aero simulations for equal cell count

Still factor 2 longer simulation time

- Performance for a sliding mesh simulation depends on the face count of the sliding interface rather than the overall cell count

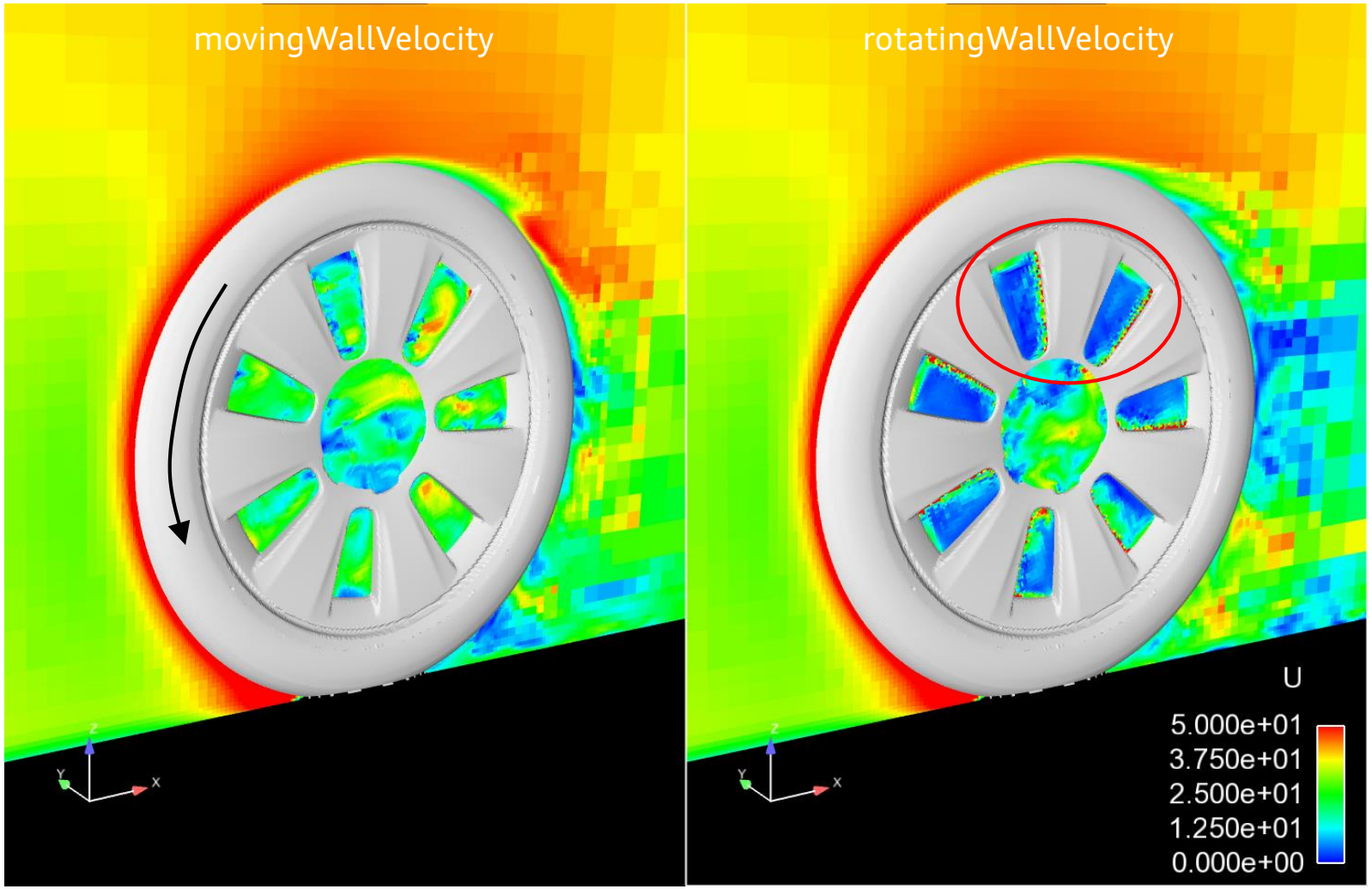
movingWallVelocity vs. rotatingWallVelocity

- Velocity U_x at the wheel patch
- Wrong velocity at the flanks of the rim



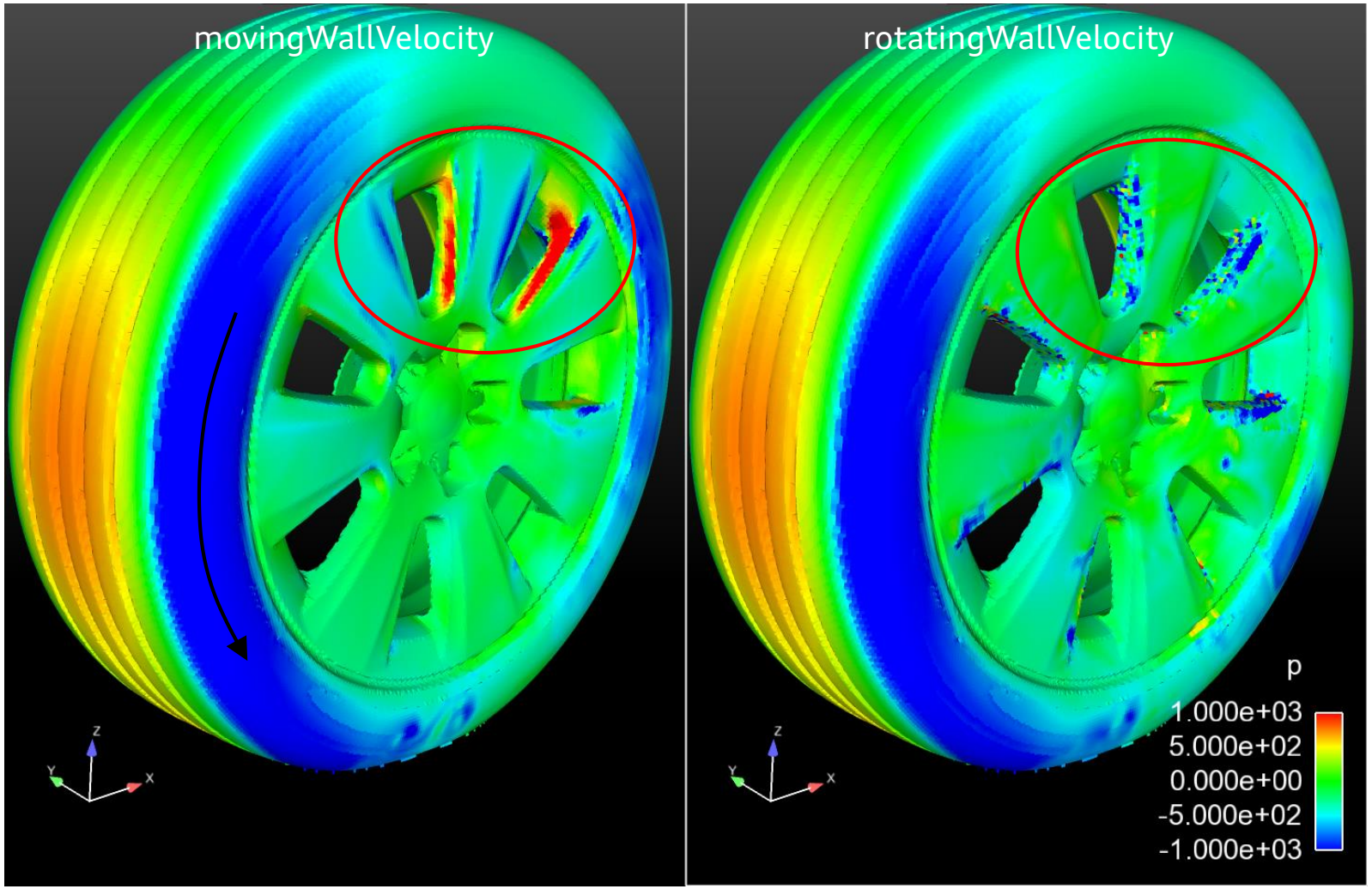
movingWallVelocity vs. rotatingWallVelocity

- Instantaneous velocity field U
- Erroneous high velocity close to flanks of the rim



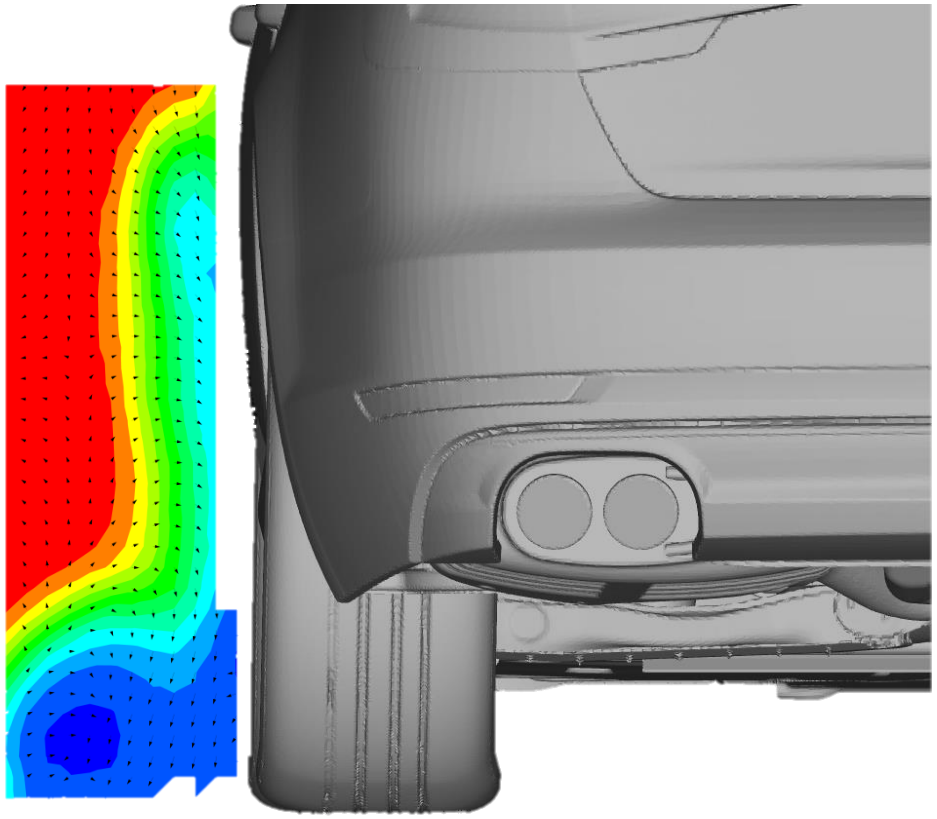
movingWallVelocity vs. rotatingWallVelocity

- Pressure p at the wheel patch
- Wrong, fluctuating pressure at the flanks of the rim
- Correct pressure increase at the top rim flanks with largest relative velocity to the flow field

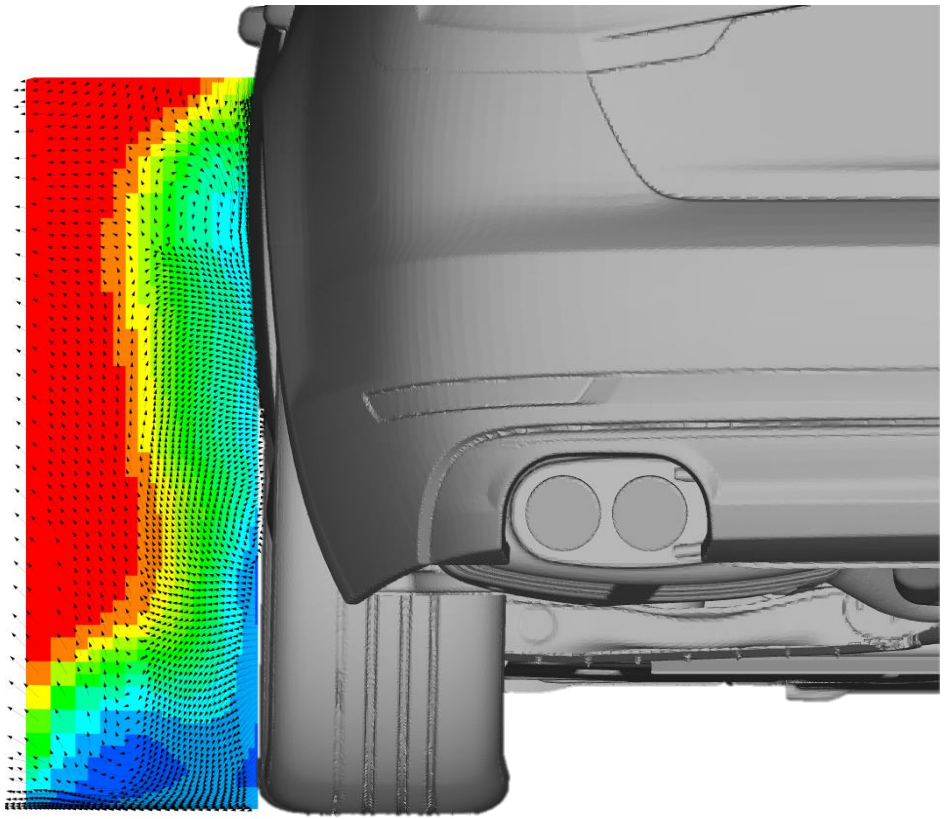


Audi A4 wheel wake total pressure

Experiment

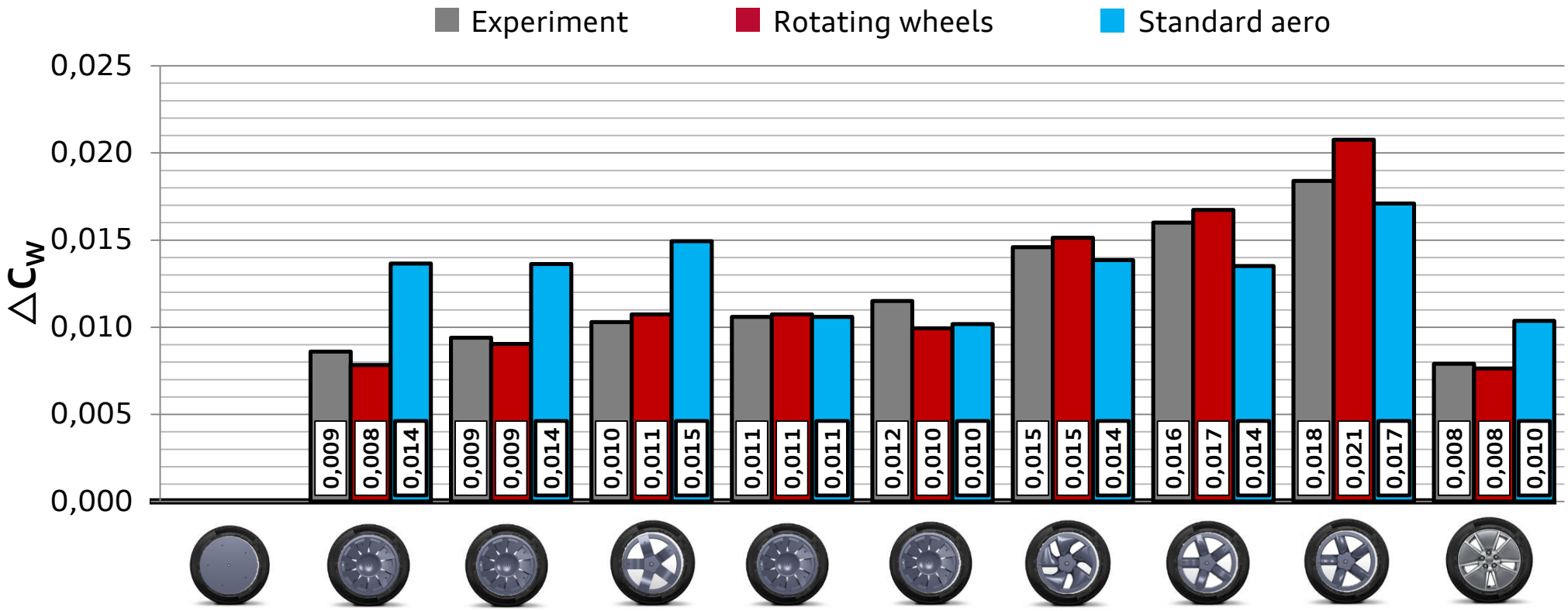


Simulation



Source: PhD Lukas Haag, TUM

Wheel drag deltas



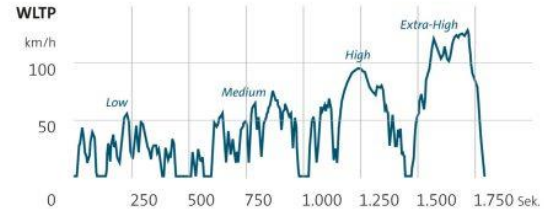
› Delta-delta drag values for rotating wheel setup are smaller than for standard workflow

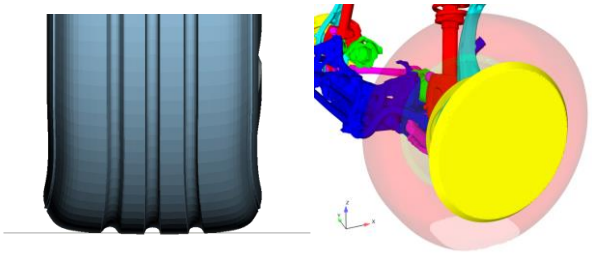
› Absolute drag values correspond better to the experimental data

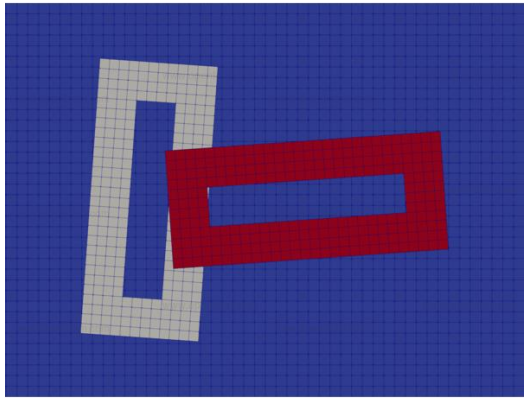
Source: PhD Lukas Haag, TUM

Summary and outlook

- Audi consequently uses OpenFOAM for external aerodynamics simulation
- Rotating wheels are getting more and more important for WLTP
- The new aerodynamics workflow takes real wheel rotation into account by means of sliding interfaces
- To allow tire deformation, only the rim uses dynamic mesh
- A parametric study was performed to find the best meshing setting to gain good mesh quality and rotational symmetric mesh at the interfaces. Solver performance is still poor and has to be increased.
- For the future, performance of the workflow has to be increased and the new overset functionality is studied for its usability in external aerodynamics simulation







Thank you