Unsteady CFD for Automotive Aerodynamics

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Institute of Aerodynamics
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Outline

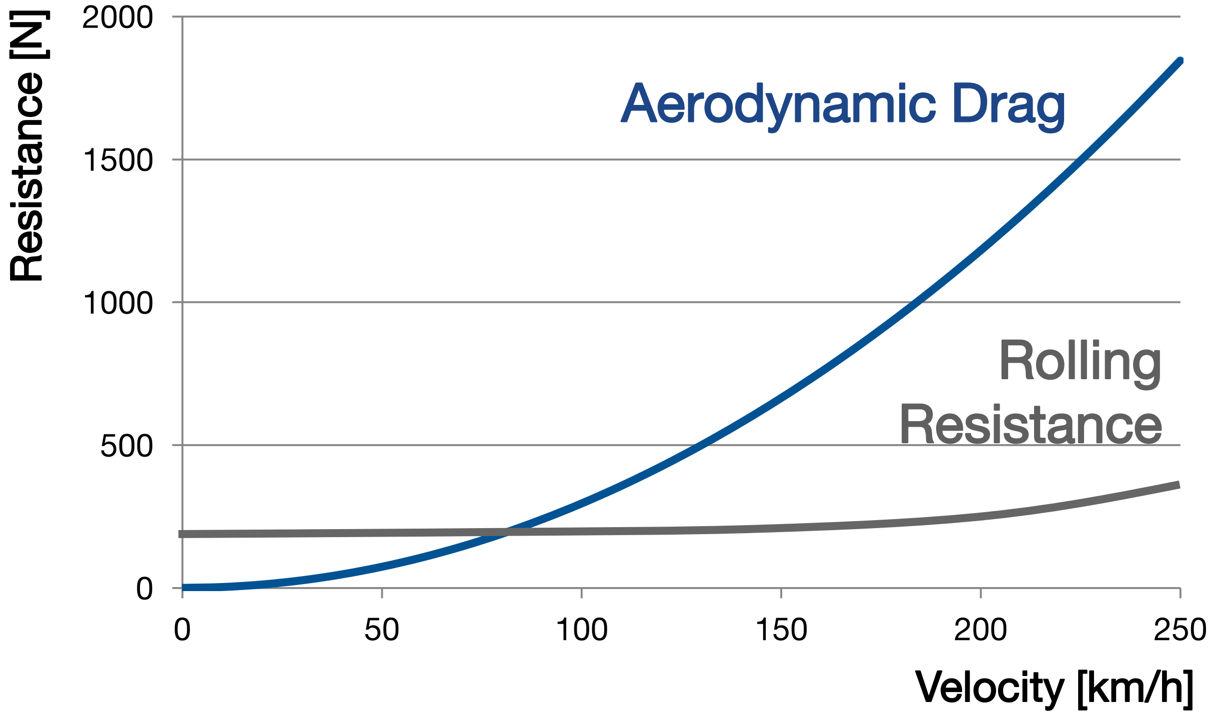
Motivation

Applications of Unsteady CFD

- Dynamic Mode Decomposition (DMD)
- Efficient Implementation of Lattice-Boltzmann Method
- Wheel / Tire Aerodynamics

Summary & Outlook

Motivation



- CO2 emissions, electric vehicle range
  Driving dynamics / stability

→ **Automotive Aerodynamics**

- Transient nature of the vehicle wake, rotating wheels, interacting vortices, crosswind gusts

→ **Unsteady CFD**

Dynamic Mode Decomposition

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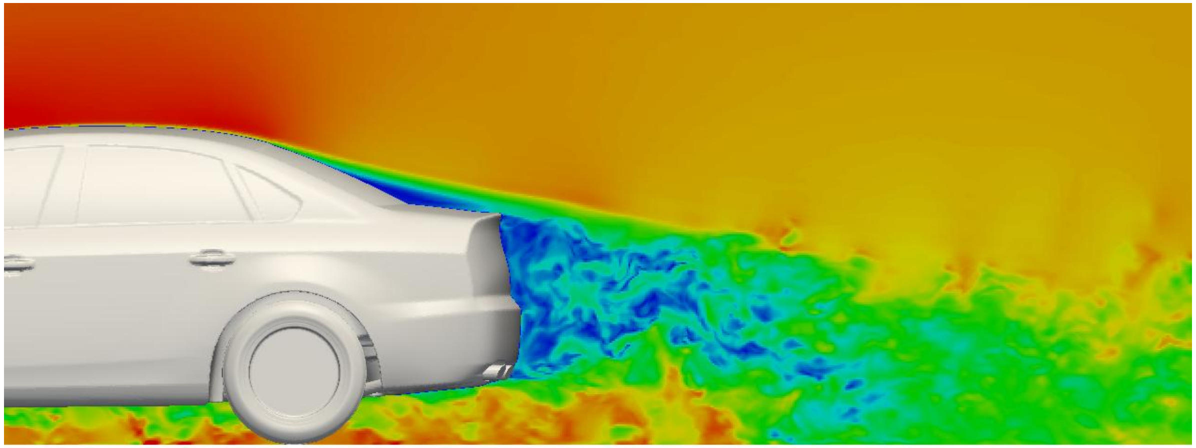
Audi
Vorsprung durch Technik

Motivation

- Flow fields in automotive aerodynamics are unsteady and three-dimensional with a wide range of time and length scales.
- The mode decompositions are intended as a post-processing tool for unsteady data.



Velocity magnitude in the y=0 Plane of the DrivAer body

Theory

- The dynamic behaviour of the flow is described by a mapping in time
- The system matrix **A** maps the flow fields $\{v_1 \dots v_{N-1}\}$ to $\{v_2 \dots v_N\}$

$$AV_1^{N-1} = V_2^N$$

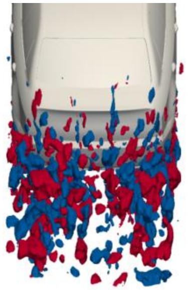
- The idea of the DMD is to compute Eigenvalues and Eigenmodes of a reduced representation of the system matrix **A**

First 6 DMD Modes

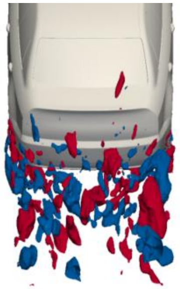
Stream wise velocity component (red: positive, blue: negative):

DMD Mode 1
(f = 0 Hz)

DMD Mode 2
(f = 11.3 Hz)



DMD Mode 3
(f = 7.2 Hz)



DMD Mode 4
(f = 4.4 Hz)

DMD Mode 5
(f = 6.0 Hz)

DMD Mode 6
(f = 2.0 Hz)

Resources

- OpenFOAM
- Base simulation:
  - Turbulence: DDES (detached eddy simulation)
  - 60 million cells
  - 5 sec physical time
  - 800 CPU cores
  - 200.000 - 300.000 core hours
  - up to 10 TB HDD for time step storage
- DMD:
  - 4 - 8 TB RAM (future: 16 TB)
  - 35 core hours

Efficient Implementation of Lattice-Boltzmann Method

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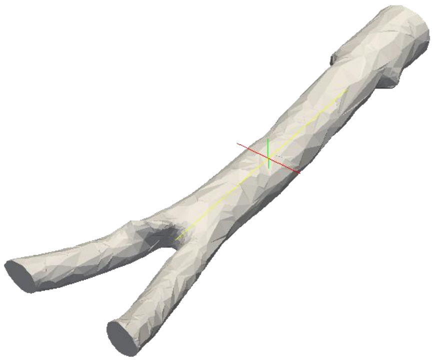
Motivation

- The Lattice-Boltzmann Method (LBM) is a mesoscopic description of flow.
- The solution describes the temporal and local development of the velocity distribution function.
- The Algorithm can be separated in a collision step and an advection step.
- No system of equations has to be solved
  → good performance on massively parallel systems.
- The openSource Tool openLB is being optimized to perform LBM computations on SuperMUC.

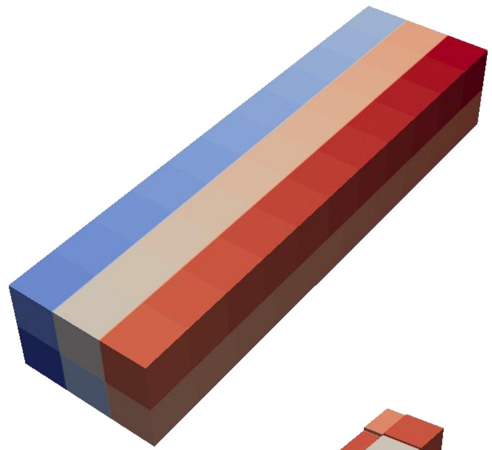
Efficient Implementation of LBM

Parallelization at the example of flow through an aorta

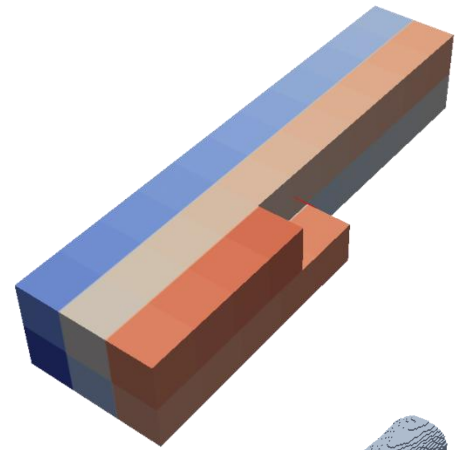
1. Original STL file

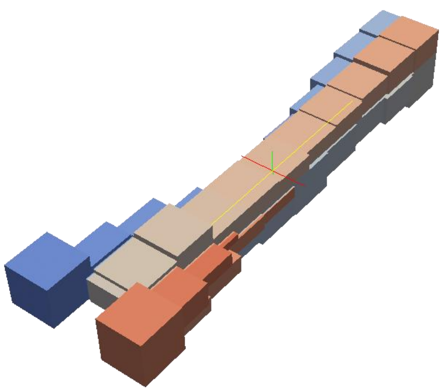


2. Generate cuboid structure

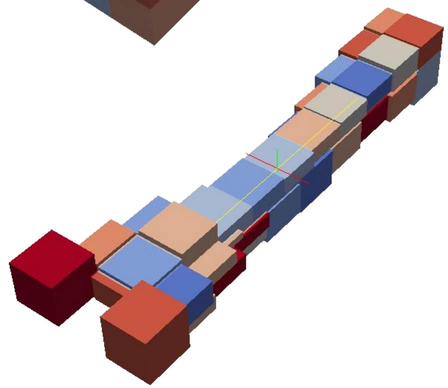


3. Remove empty cuboids

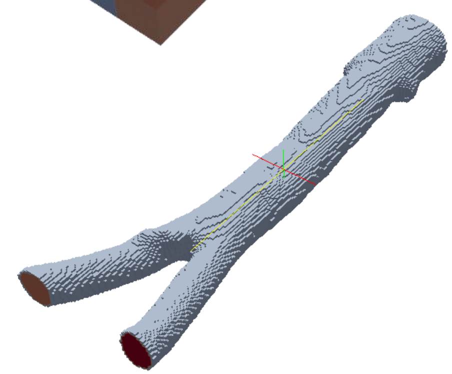




4. Shrink cuboids



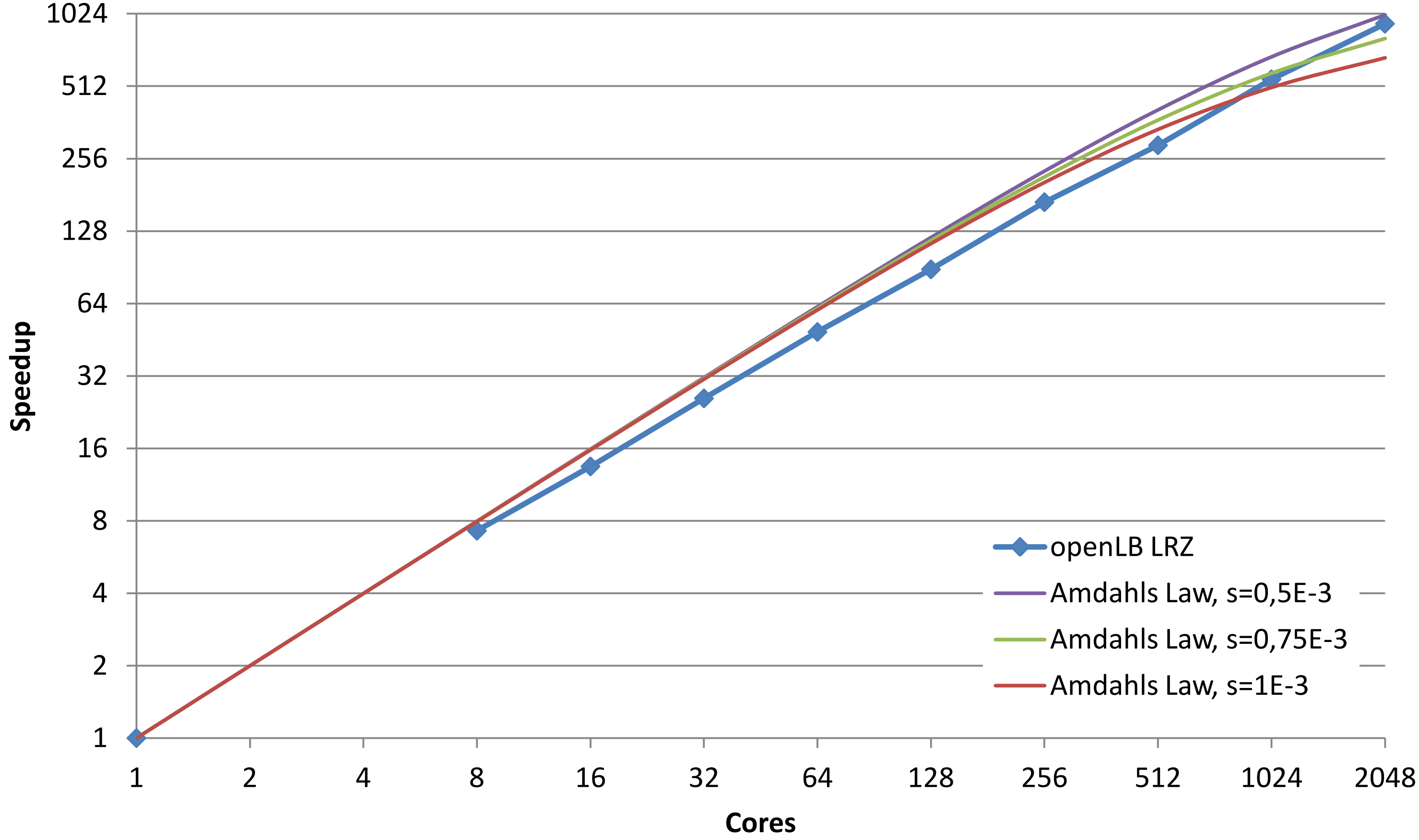
5. Loadbalancer distributes Cuboids to threads



6. Set boundary conditions and start simulation.

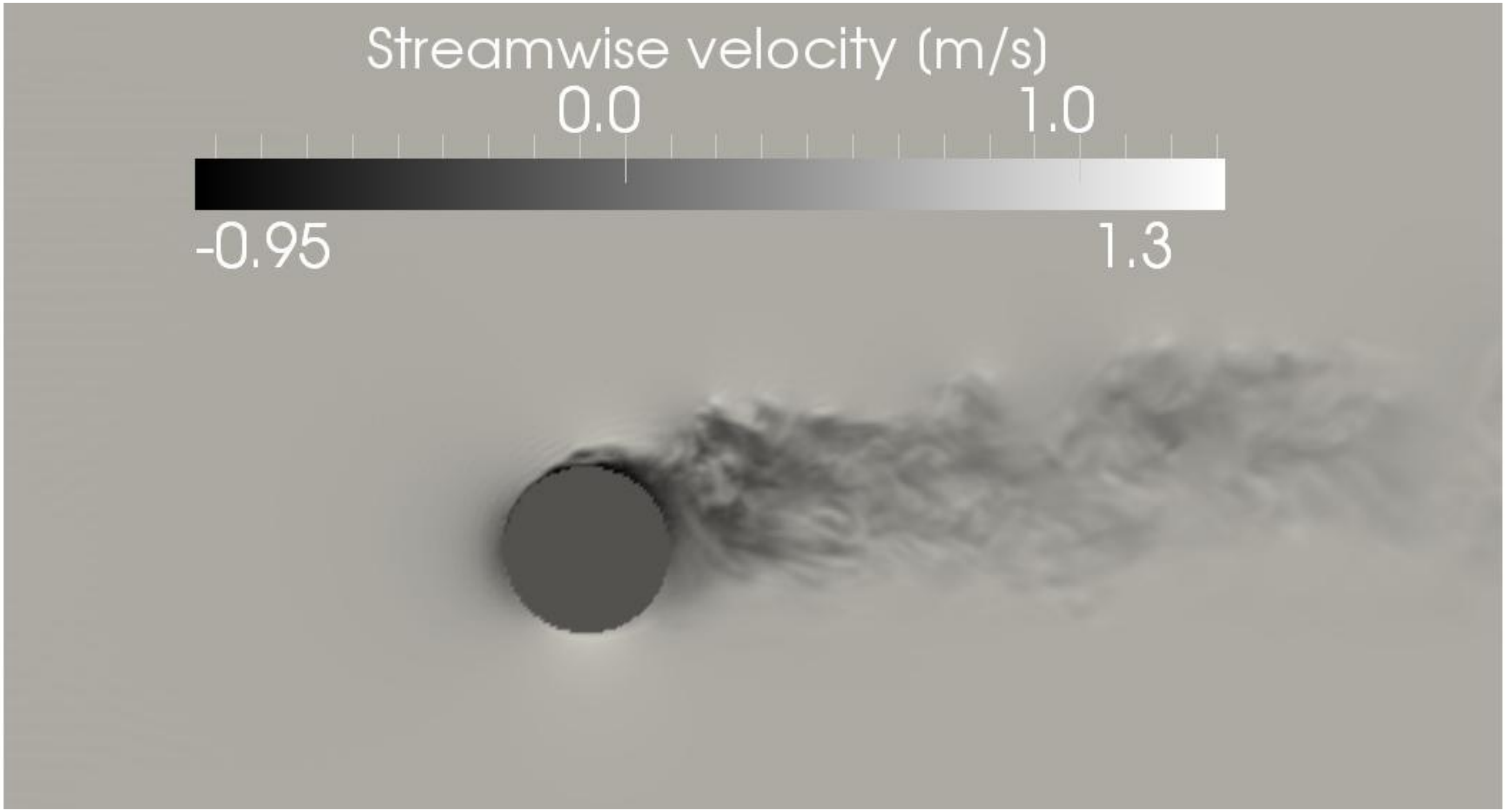
Efficient Implementation of LBM

Speedup vs. number of cores



Efficient Implementation of LBM

First turbulent 3d cases (e.g. rotating cylinder)



Wheel / Tire Aerodynamics

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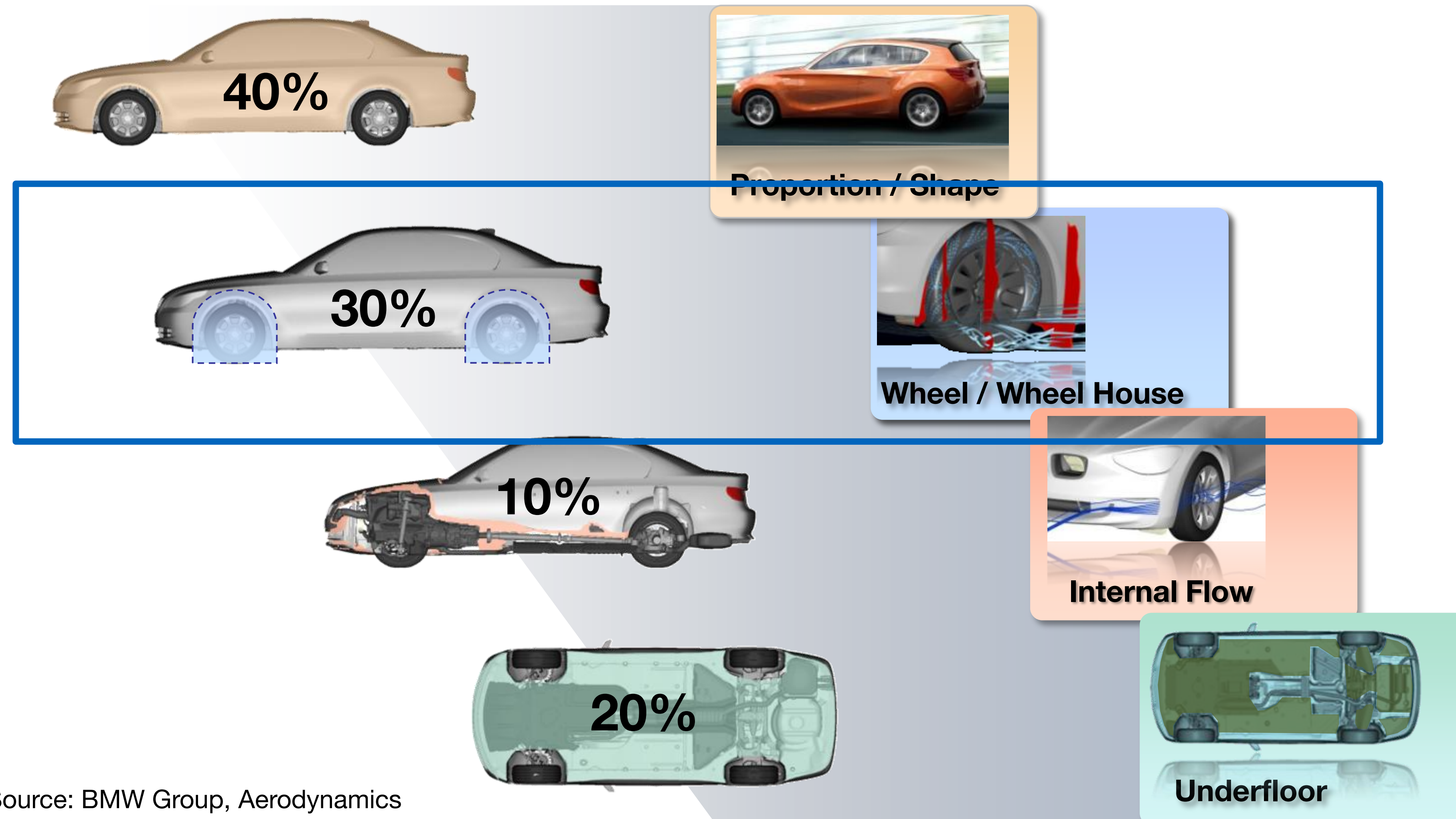
Wheel / Tire Aerodynamics

Drag contribution at total vehicle (2003 5 Series)

Field of development



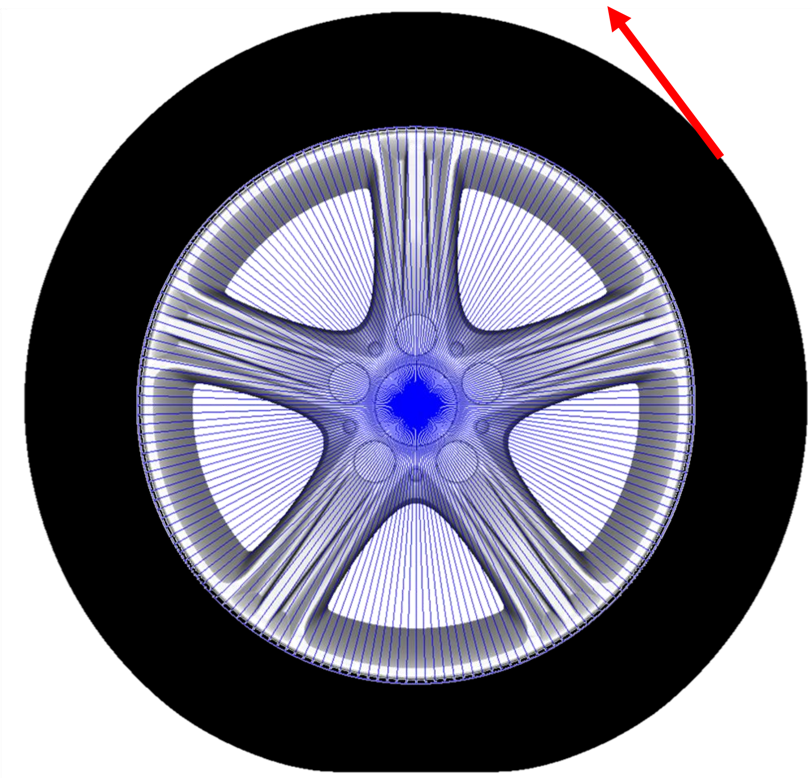
Source: BMW Group, Aerodynamics

Challenges

- OEM: CO_2 labels will have to take different wheel configurations into account. The mass of combinations cannot be measured with given wind tunnel capacities → CFD.
- Determine aerodynamic forces of different
  - wheel designs
  - tires

- Model wheel rotation in the numerical simulation
- Tire deformation (static and dynamic)
- How to get accurate tire geometries in the setup?
- Reduce turn-around time to acceptable level

Wheel Rotation Modeling



Tire:
Tangential velocity boundary condition

$$U_{wall} = \omega \cdot r$$

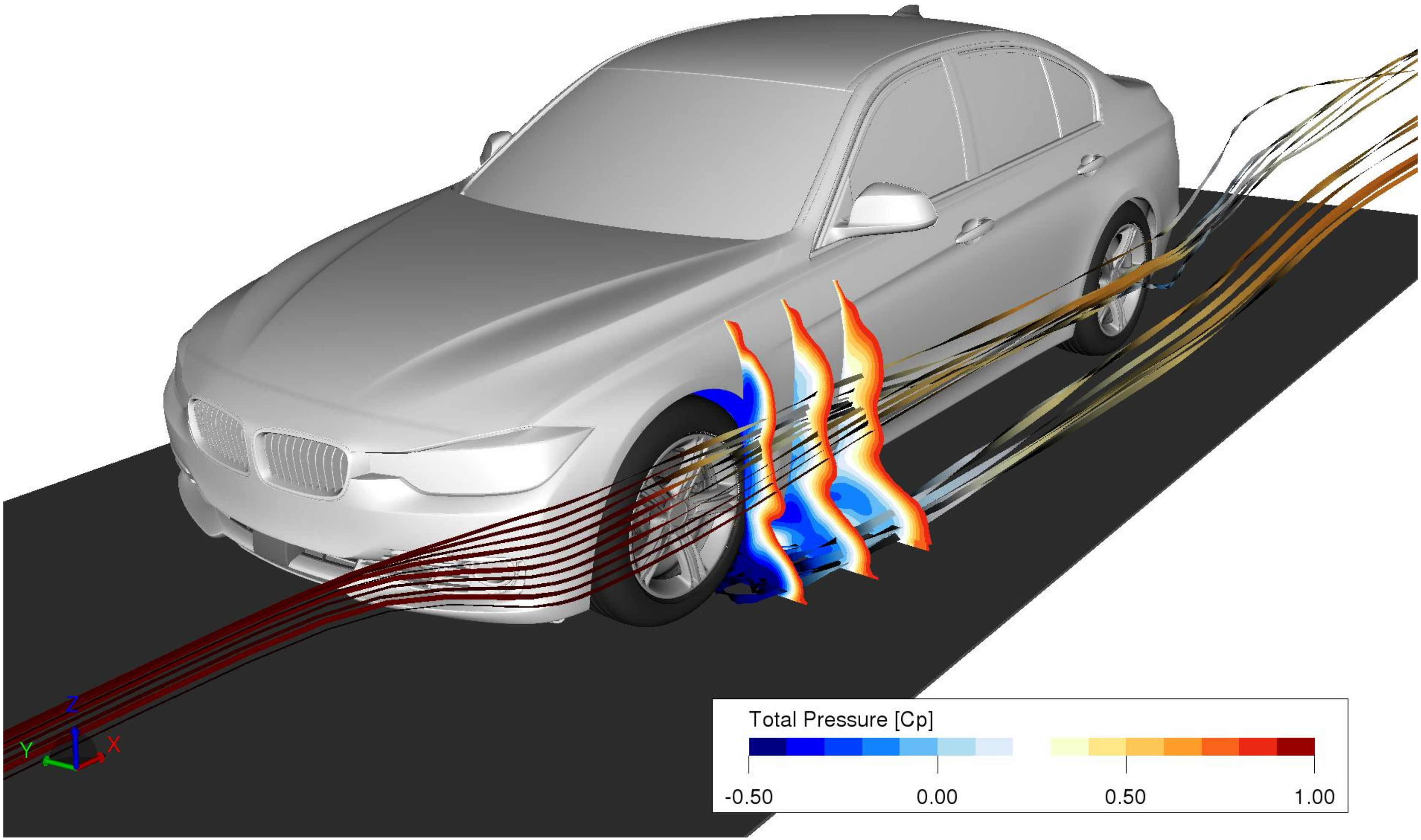
Wheel spokes:
Sliding Mesh reference frame

$$\omega = \frac{U_{inf}}{r_{dyn}}$$

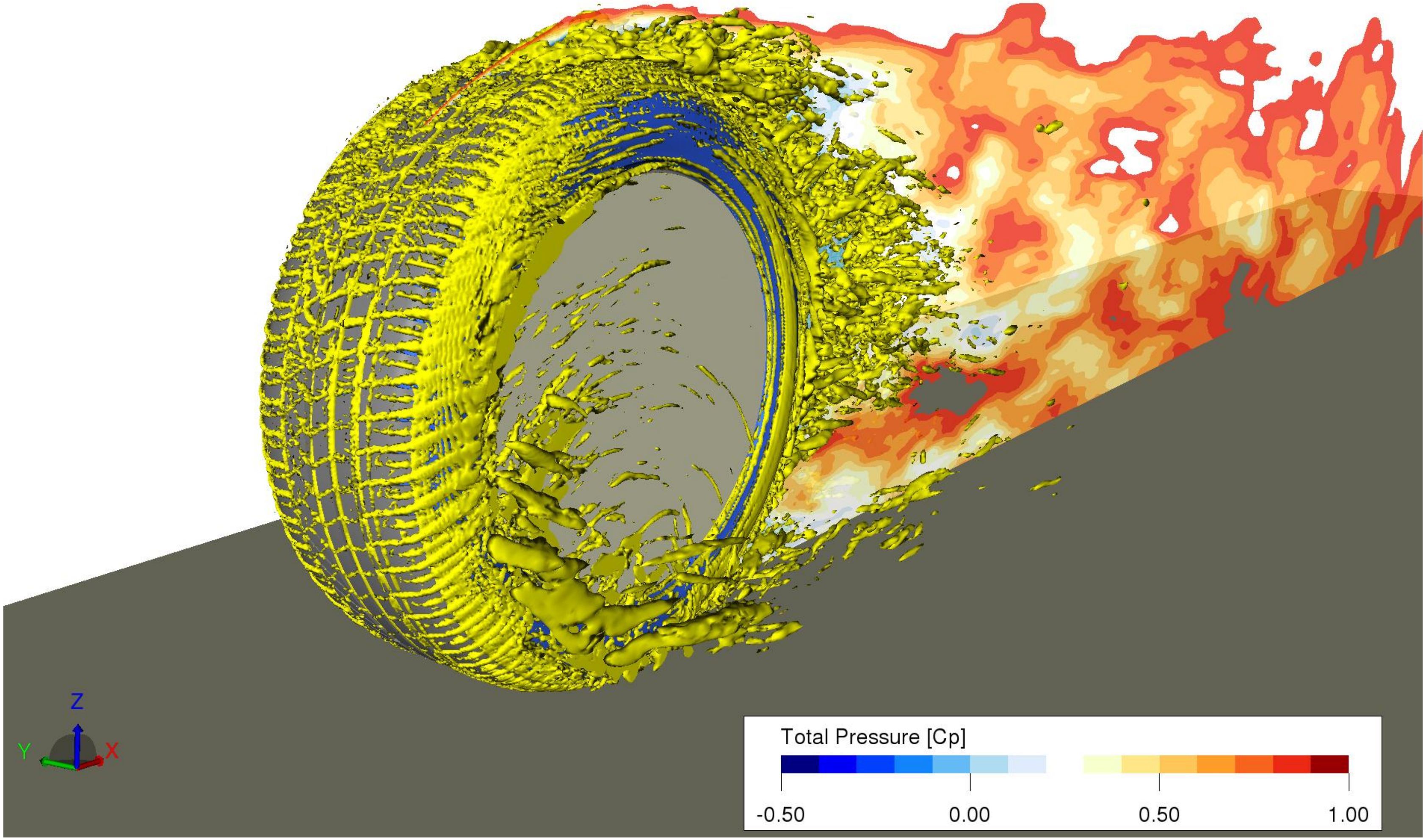
Numerical Setup (full vehicle)

- Lattice-Boltzmann Method: Exa PowerFLOW 5.0
- RNG k-epsilon turbulence model, wall-function
- smallest voxel size 0.75 mm
- 180 million voxels, 34 million surfels
- 2 sec physical time
- 752,000 time steps
- 190 GB shared memory
- 32,000 CPU core hours @ 192 cores

Wheel / Tire Aerodynamics



Wheel / Tire Aerodynamics



Summary & Outlook

- Unsteady CFD receives more attention in automotive industry:
  - Wheel aerodynamics
  - Understanding of drag creation
  - Driving stability (overtaking maneuvers, crosswind gusts)

- Future Challenges:
  - Accuracy of complex flows
  - Efficient handling of moving / rotating geometries
  - Need of good scalability to reduce turn around times to enable optimization processes (DOE, …)

Thank you very much for your attention!

Questions?