CHALMERS work in Train Aerodynamics within Gröna Tåget

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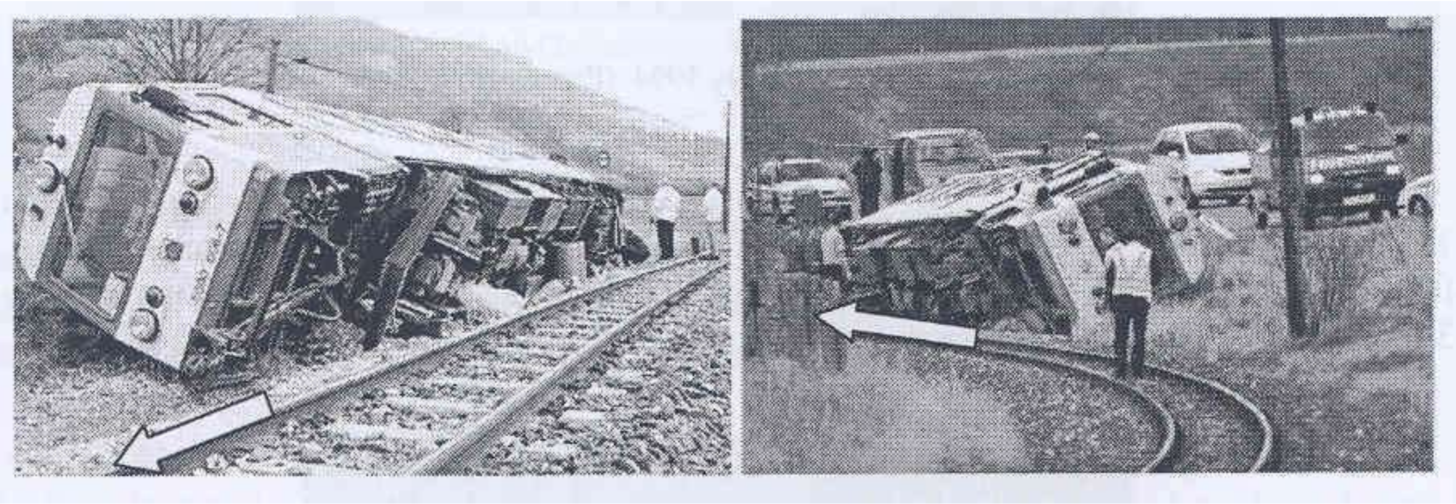
CHALMERS

Chalmers worked with two projects

- Stability of high-speed trains in wind gusts
  - The aim of the project was to develope numerical techniques that enable study of trains in wind gusts

- Aerodynamic shape optimization of trains
  - The aim of the project was to develope a robust, efficient and automatic algorithm that can do multiobjective shape optimization of trains.

Crosswind stability of trains



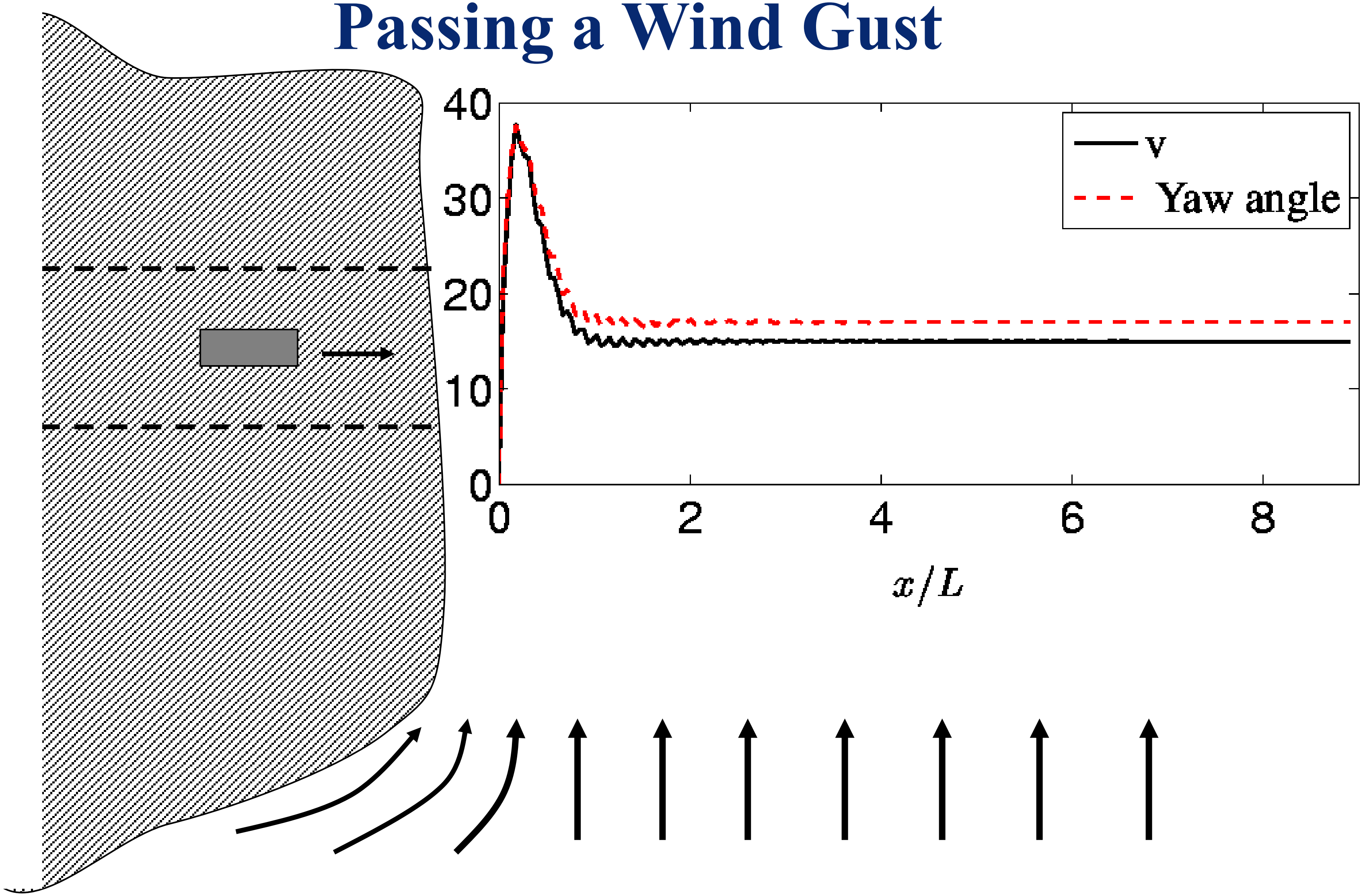
Obtaining aerodynamic loads and moments for inherently transient scenarios

- Full-scale vehicle tests: difficult to control and measure, expensive
- Wind tunnel test: difficult to obtain correct boundary conditions
- Numerical simulations: How can we obtain correct boundary conditions?

Examples of flow scenarios

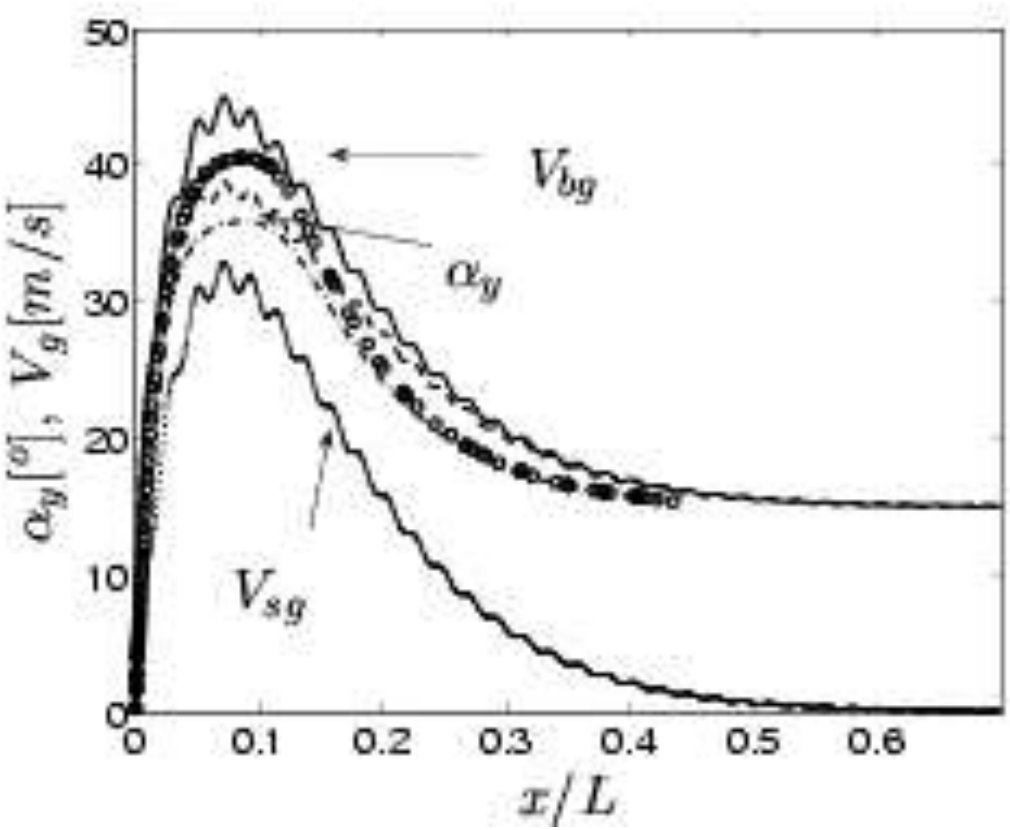
- Train is exiting a tunnel under the influence of a wind gust.
- Two trains passing by each other.
- Train traveling in a curve under the influence of a cross wind.

DES of the Flow Around an ICE2 Train Passing a Wind Gust

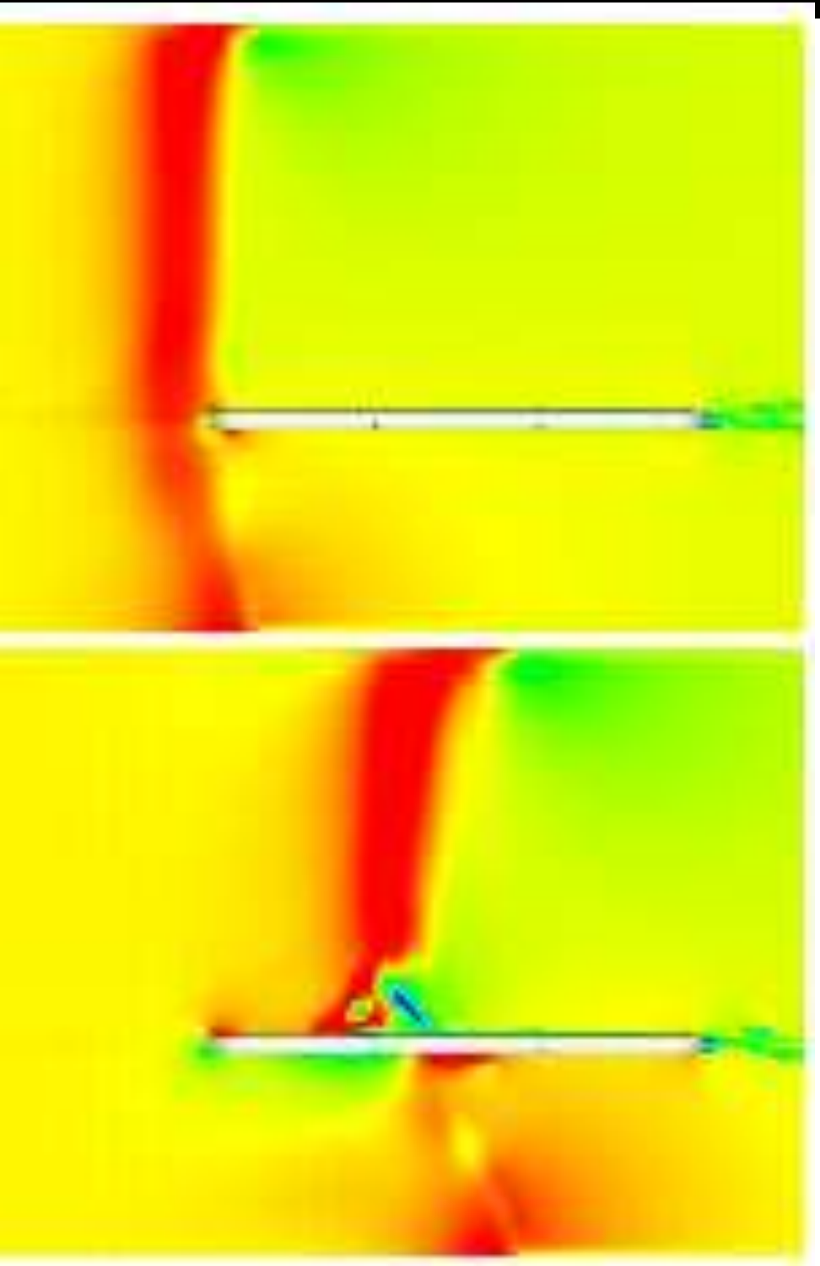


Model of the wind gust

Constructed using experiments of Ryan and Dominy (2000) .

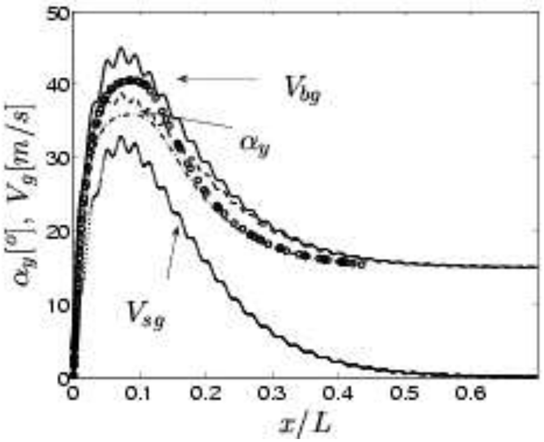


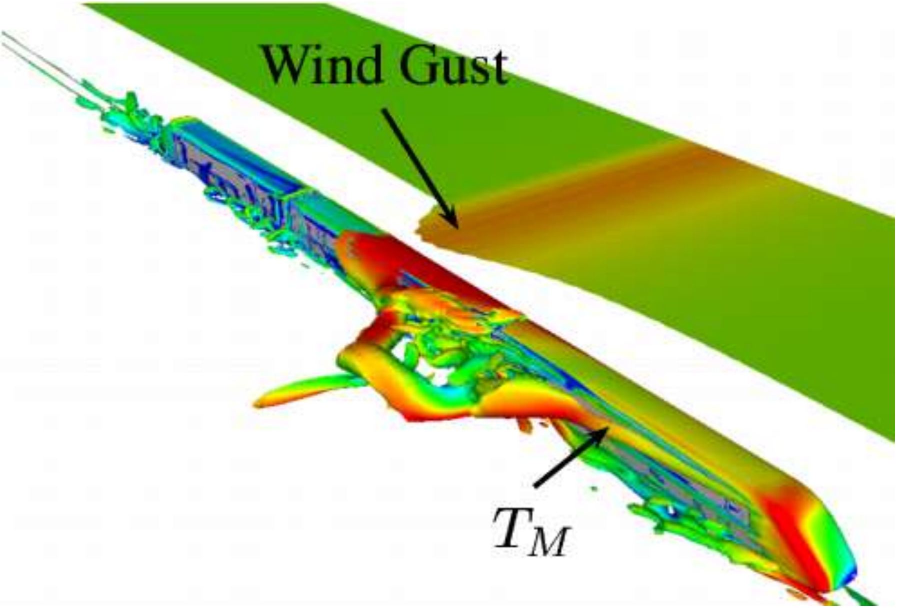
$$V(t) = B_1 t^{B_2 t} + B_3 erf(B_4 t) + 1.5 e^{B_5 t} \sin(\Omega t)$$

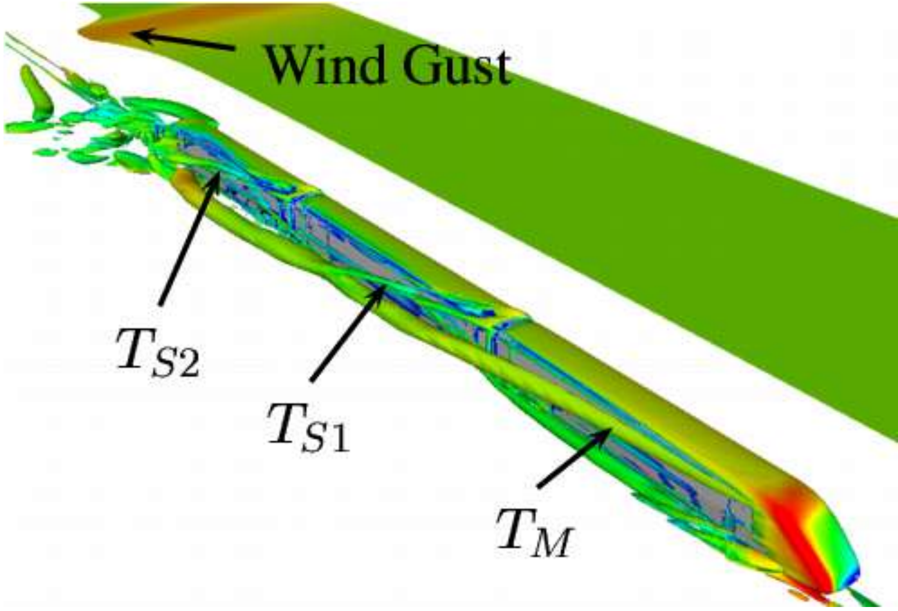


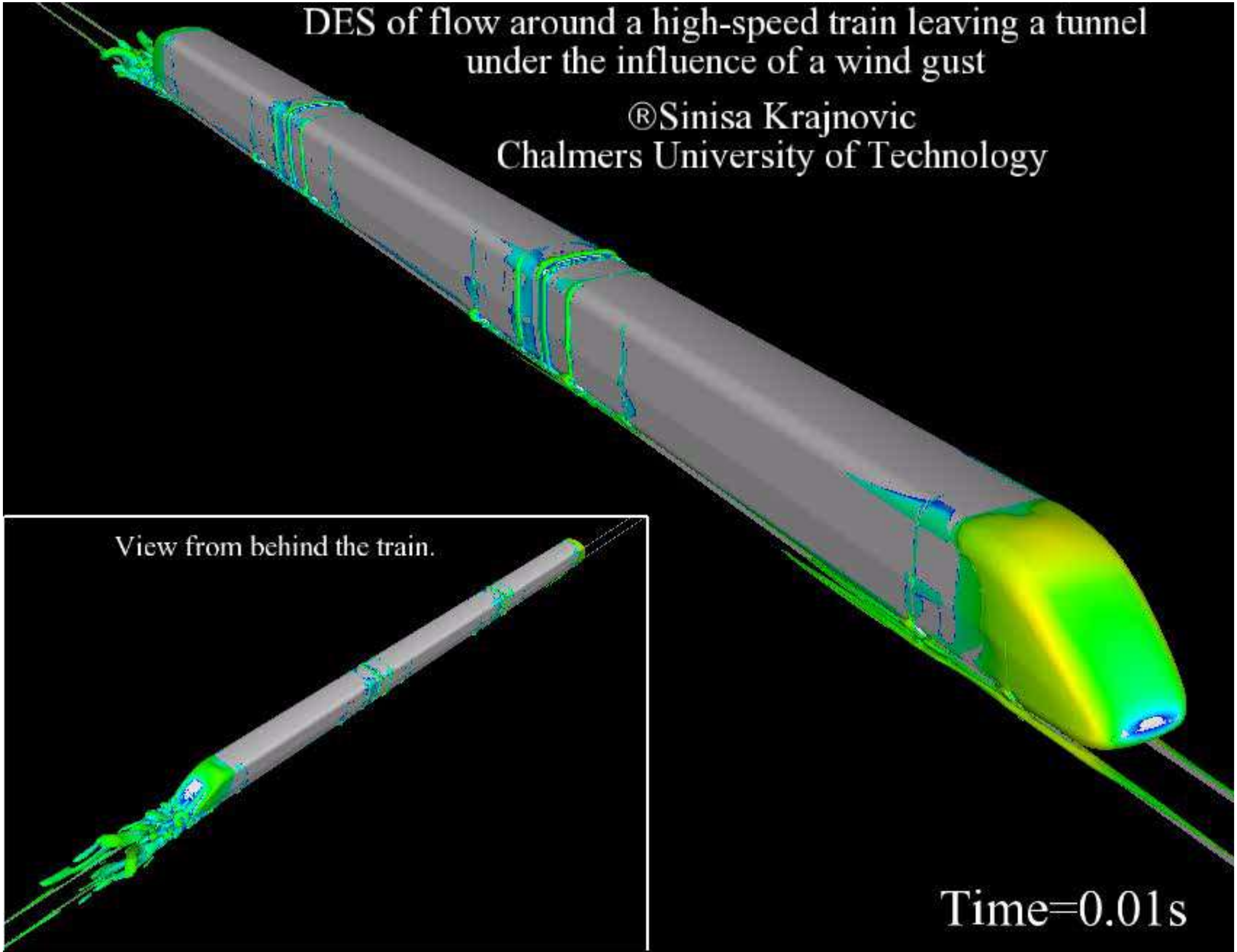
Propagation of the wind gust

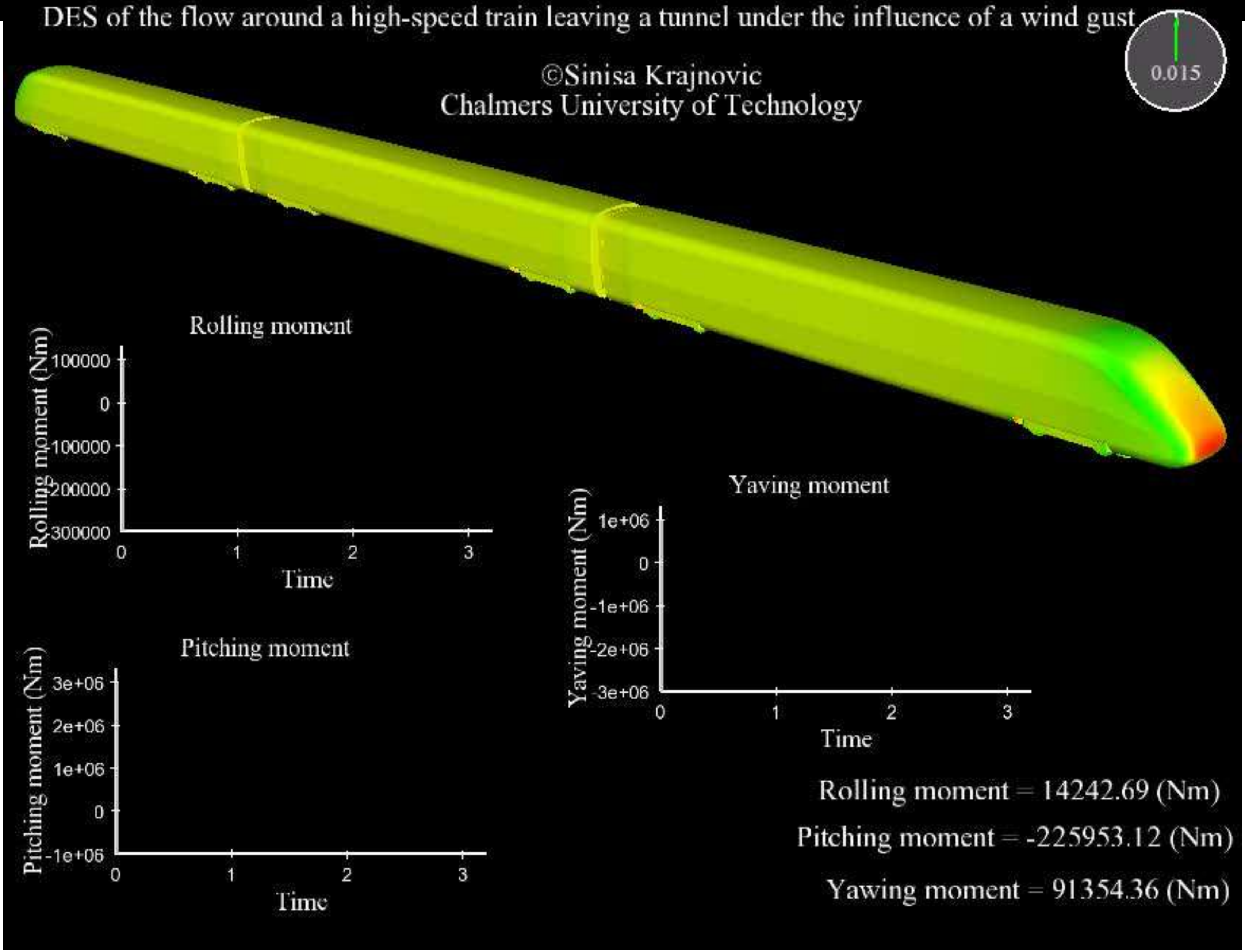
Development of the flow








DES of flow around a high-speed train leaving a tunnel under the influence of a wind gust
®Sinisa Krajnovic
Chalmers University of Technology
View from behind the train.
Time=0.01s


DES of the flow around a high-speed train leaving a tunnel under the influence of a wind gust
0.015
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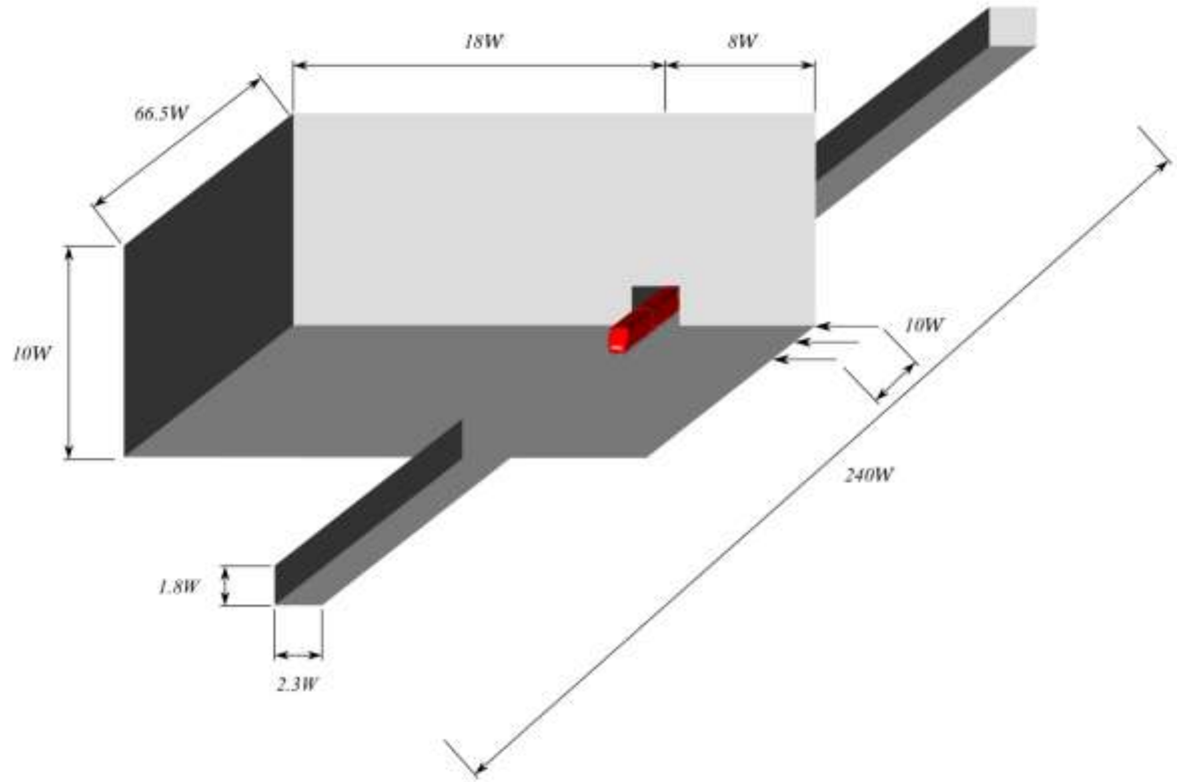
Rolling moment
Rolling moment (Nm)
100000
0
-100000
-200000
-300000
0
1
2
3
Time
Pitching moment
Pitching moment (Nm)
3e+06
2e+06
1e+06
0
-1e+06
0
1
2
3
Time
Yaving moment
Yaving moment (Nm)
1e+06
0
-1e+06
-2e+06
-3e+06
0
1
2
3
Time
Rolling moment = 14242.69 (Nm)
Pitching moment = -225953.12 (Nm)
Yawing moment = 91354.36 (Nm)

What is missing?

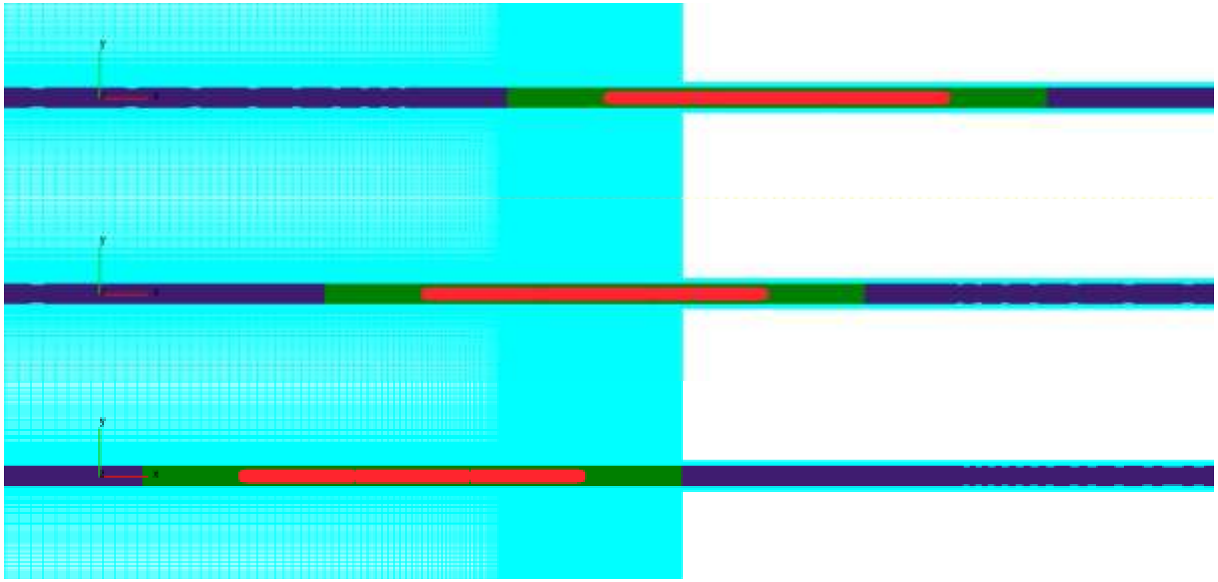
- There is no tunnel represented in these simulation. What is implications of this simplification?
- Only few flow scenarios can be simulated using this methodology.
- How should we do? We must have moving vehicles!

Train exiting a tunnel

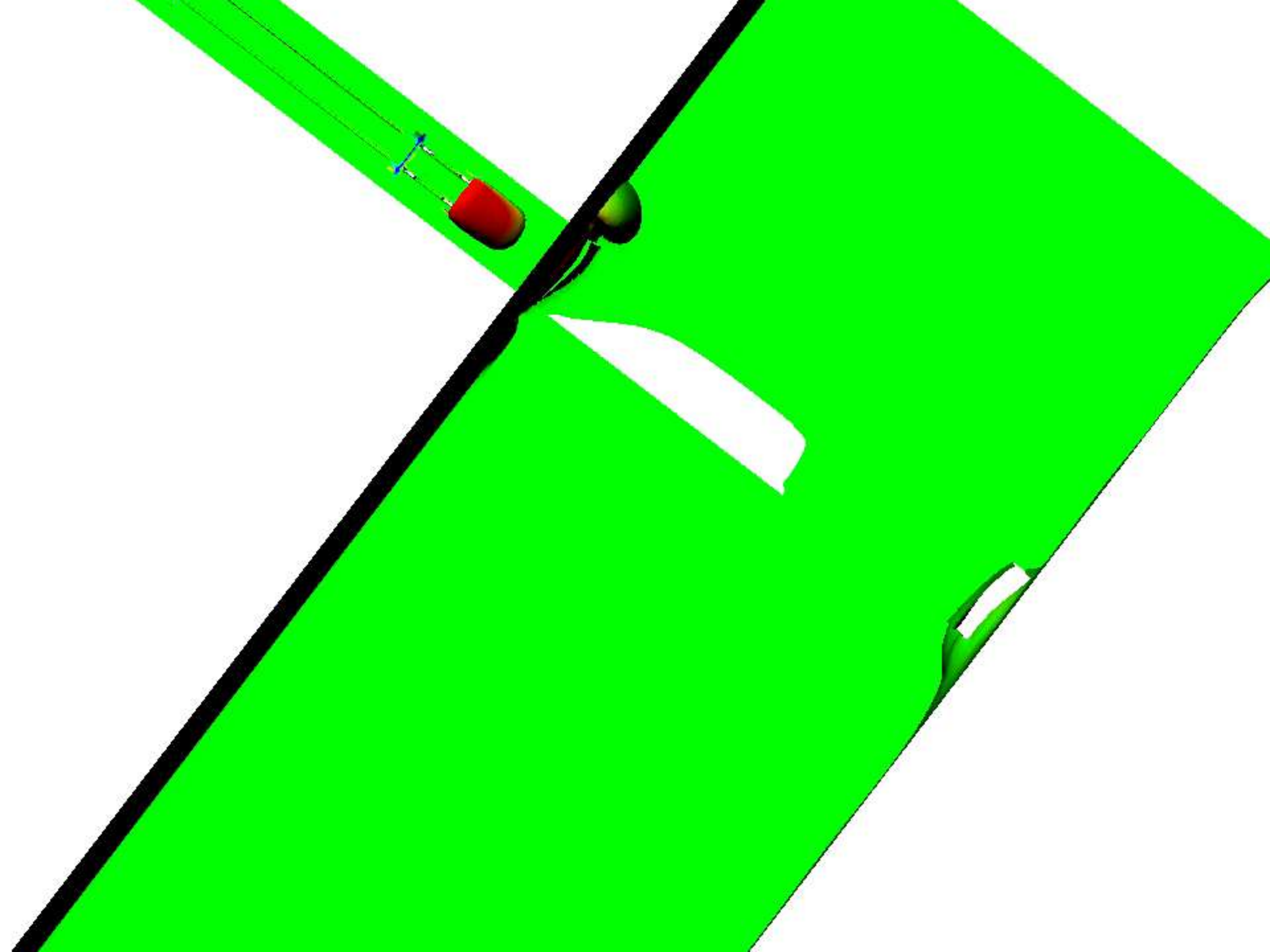


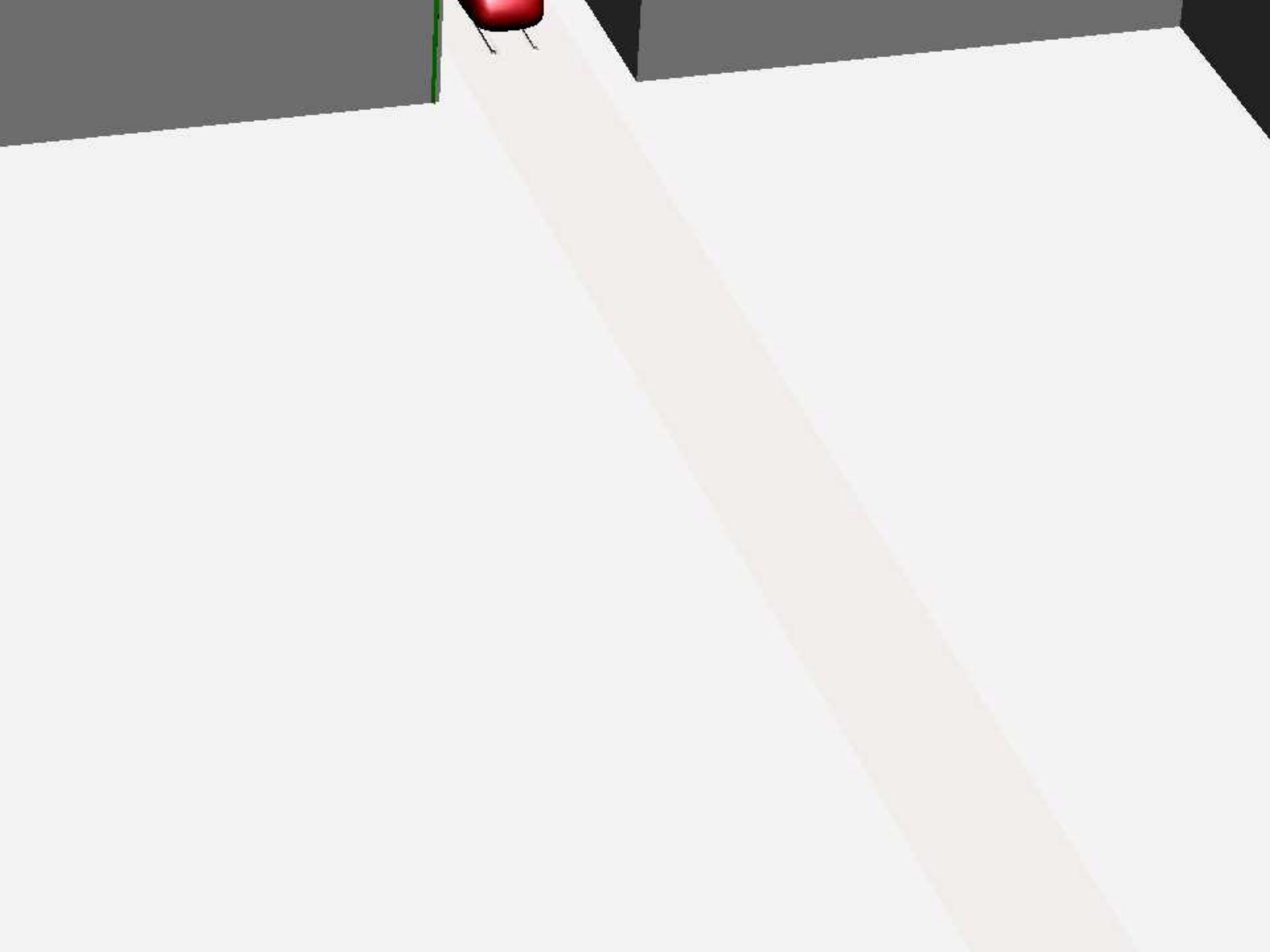
- *Geometry of the computational domain of the high-speed train exiting the tunnel.*

Train exiting a tunnel

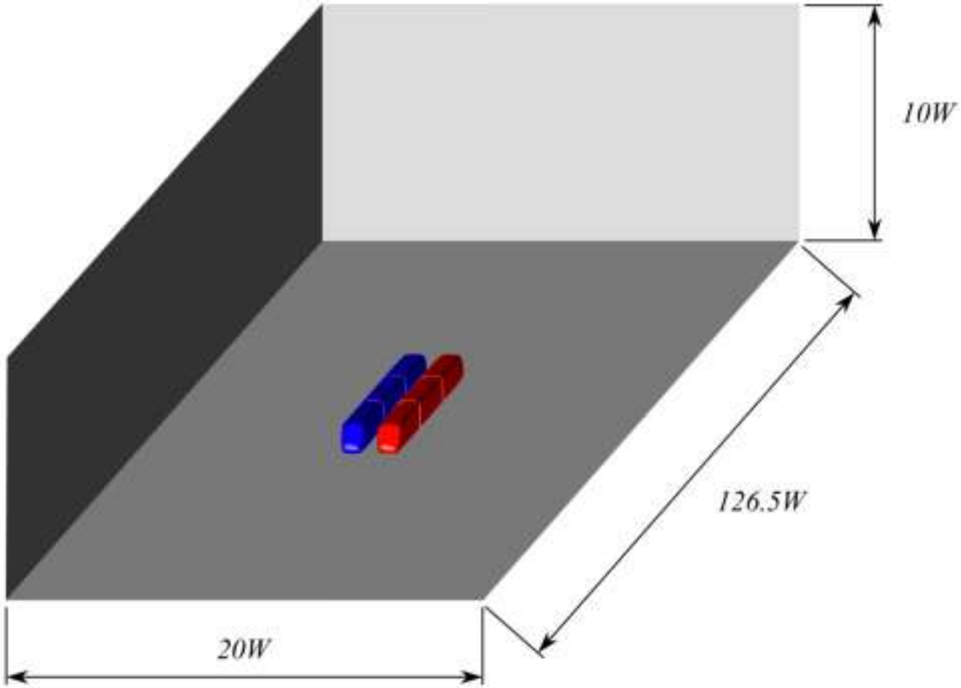


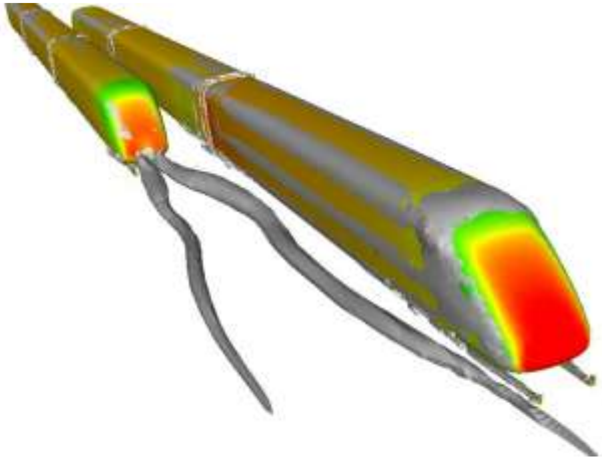
- *Deformation of the computational grid for the train exiting the tunnel at three different times.*





Two trains passing by each other



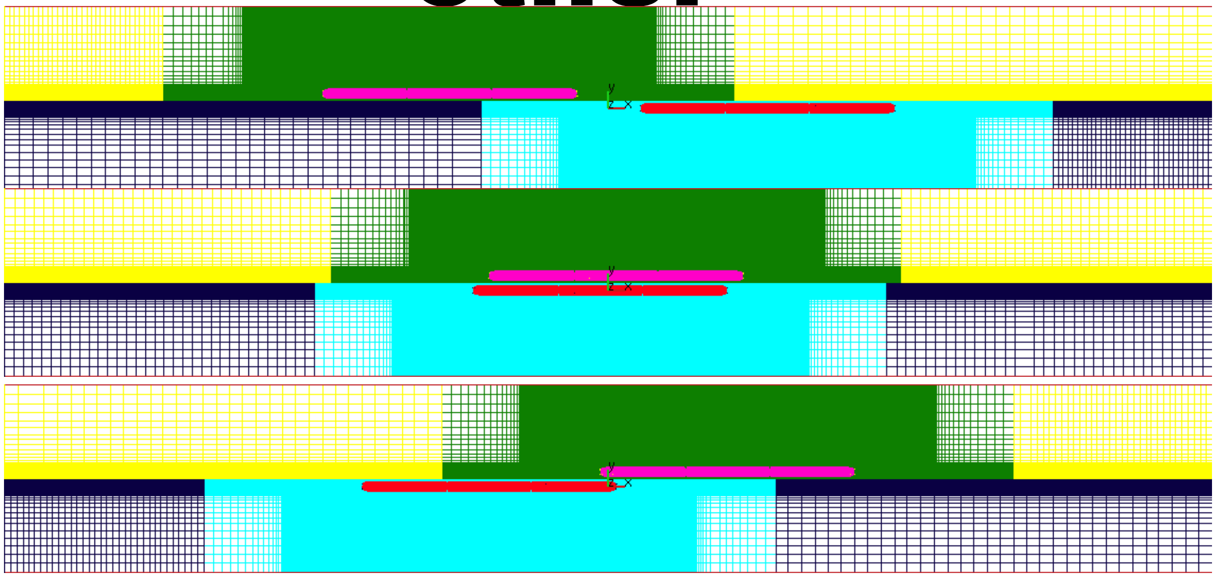


- *Set-up of the two trains passing by each other. b) Computational grid around a train.*

Two trains passing by each other

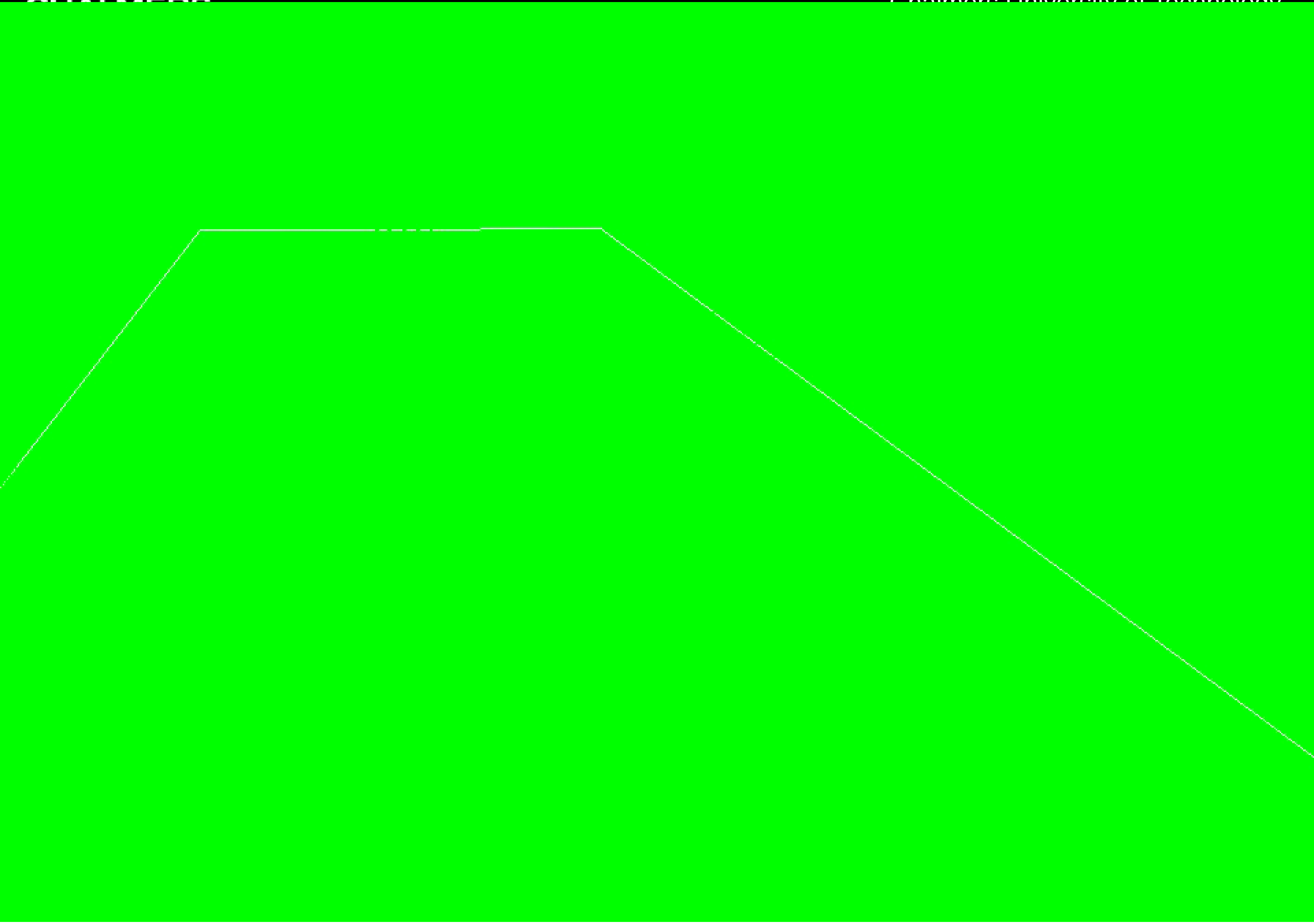
- two trains passing by each other at a speed of 67 m/s, 70 m/s or 73 m/s per train.
- Compressible simulations

Two trains passing by each other



- *Deformation of the computational grid for the trains passing by at three different times.*
- *The movement of the computational cells in the undeformed regions is described with a linear function*

x=+-Λ+-vt , Λ is the original displacement from the origin



Aerodynamic shape optimization

Task

- Minimize rolling and yawing moments of a train

Programs

- AVL FIRE® – Mesh creation and CFD simulations
- Sculptor – Mesh deformation
- modeFrontier - Optimization

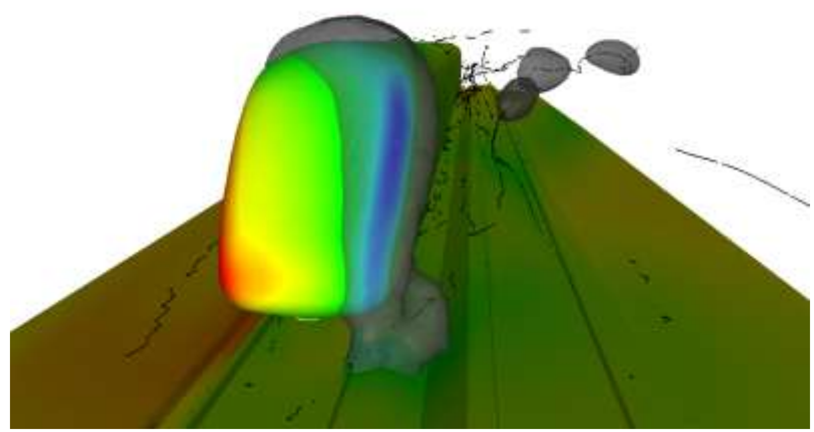
The Optimization Process

Mesh Generation → Optimization → Mesh Deformation

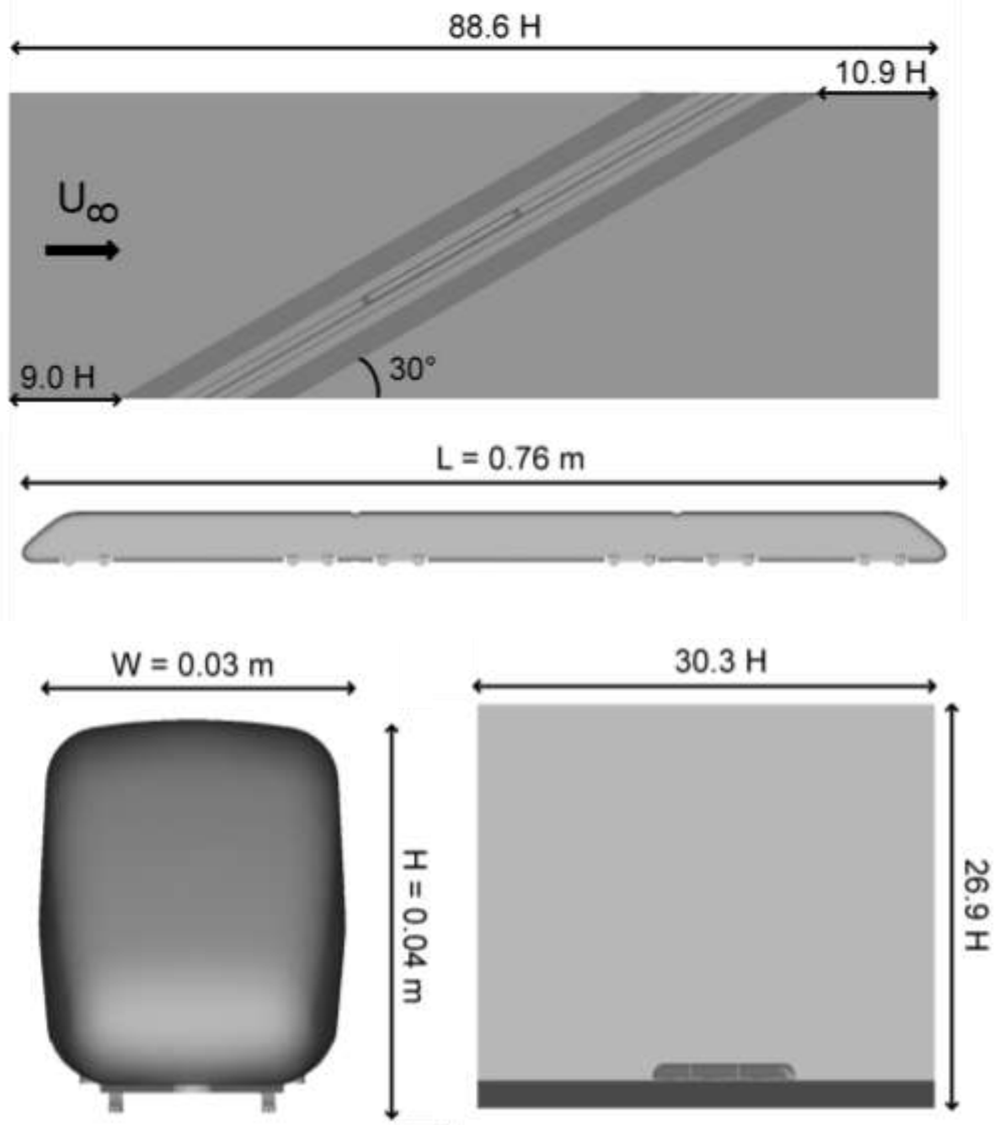
AVL fire™ → modeFRONTIER (the multi-objective optimization and design environment) → SCULPTOR OPTIMAL SOLUTIONS

↓

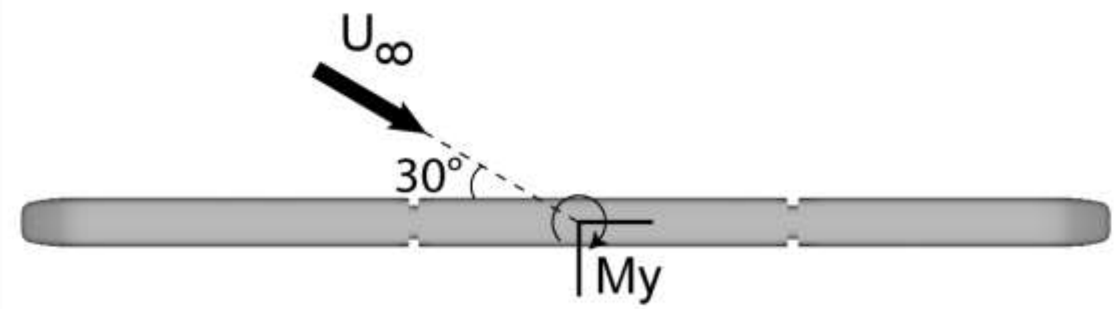
CFD Simulation AVL fire™ → Optimization

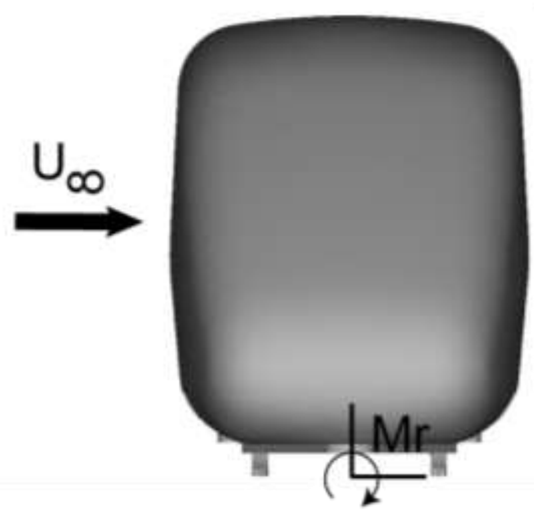


Computational Domain

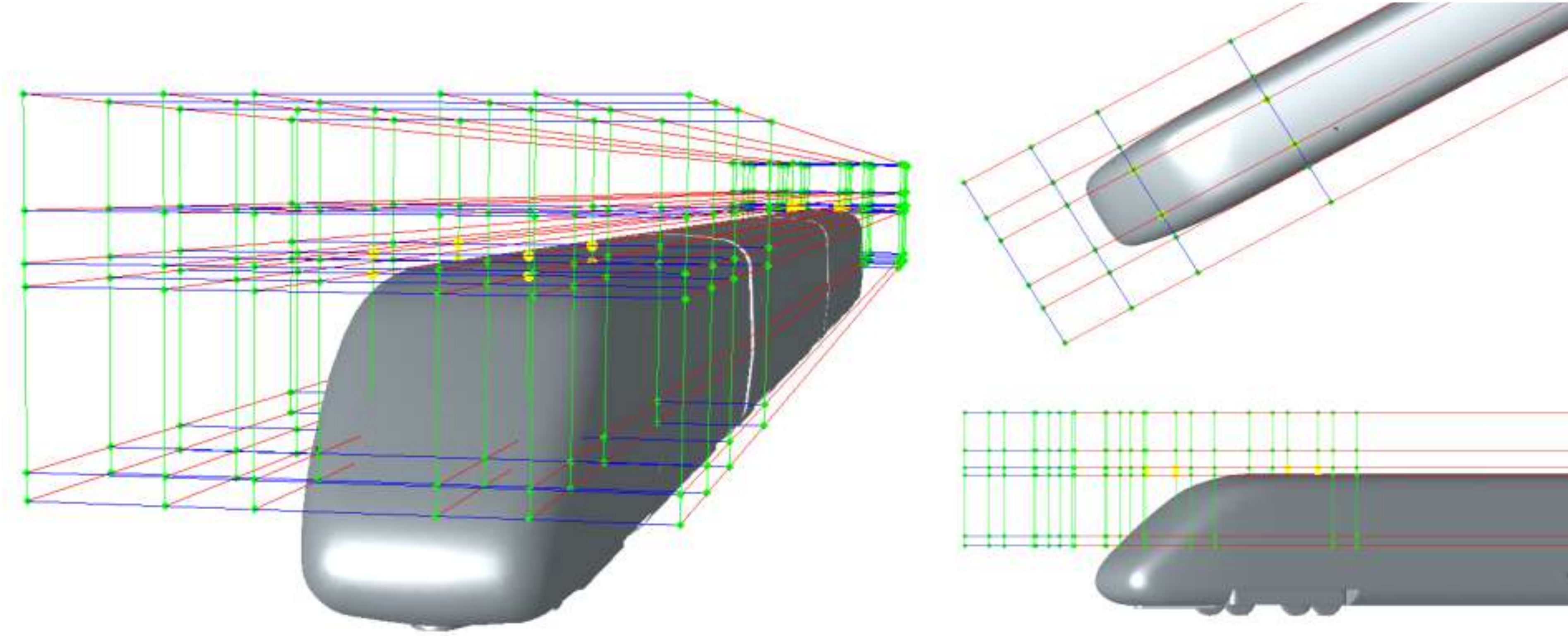


30°side wind
$U_\infty = 30$ m/s

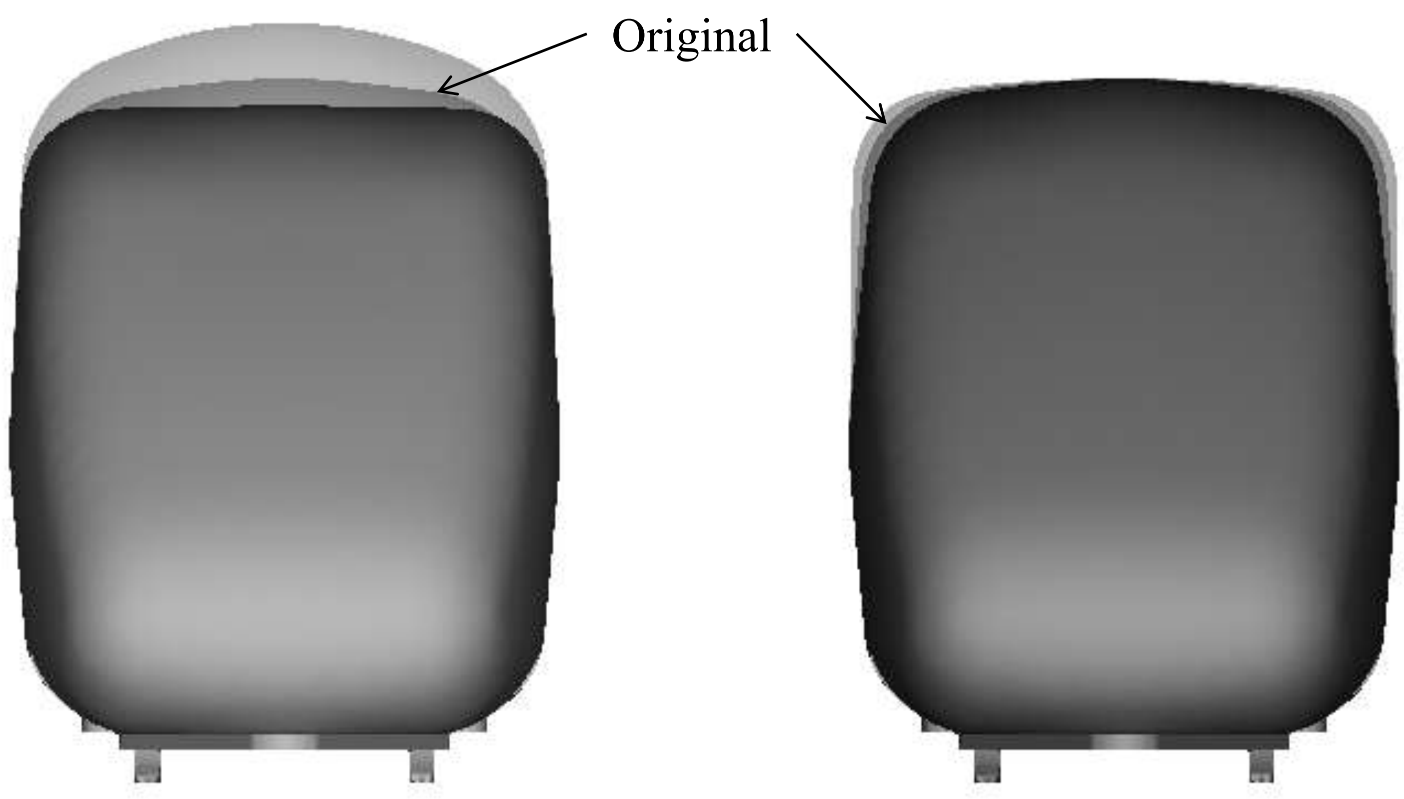




Mesh deformation in Sculptor

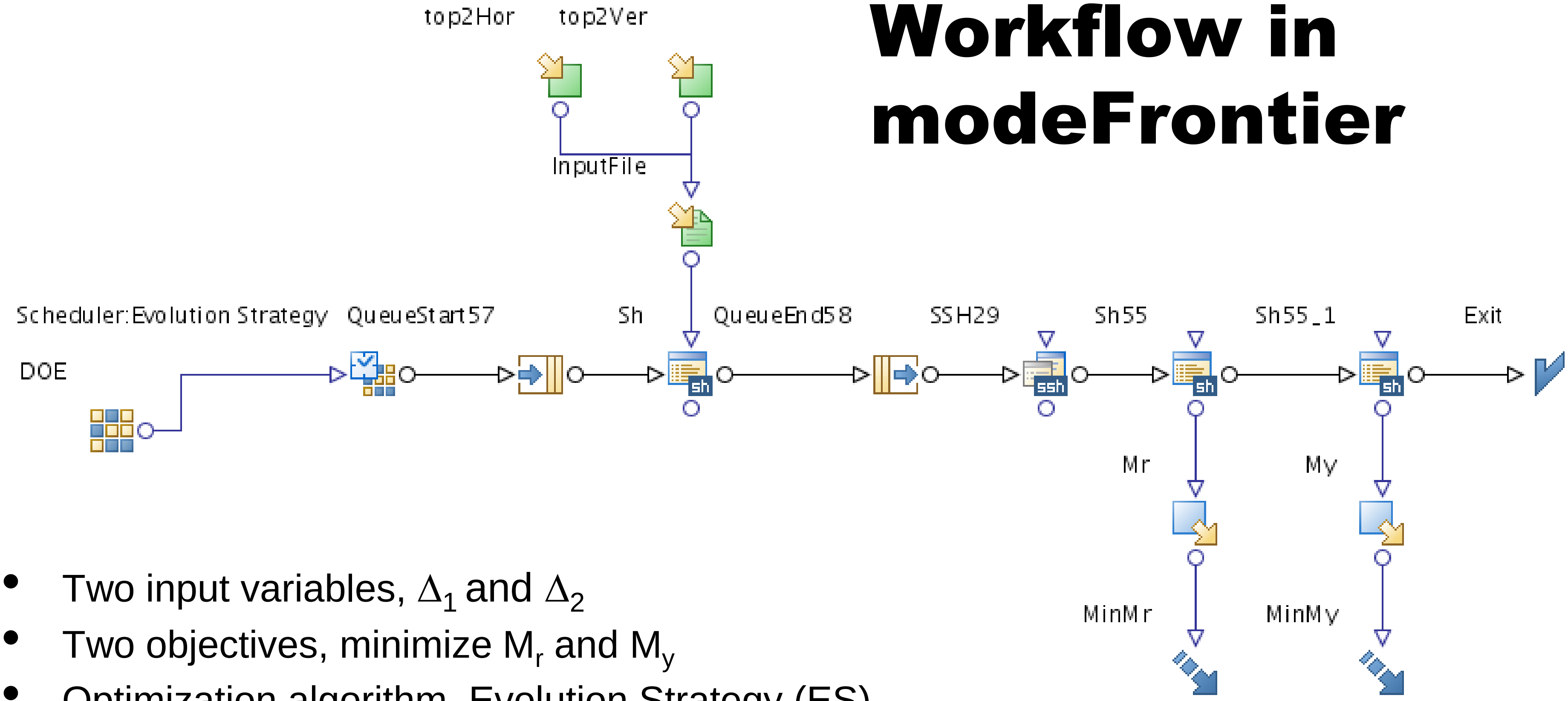


Creation of ASD volume



$\Delta_1 \in [-0.002, 0.004]$ $\Delta_2 \in [-0.004, 0.004]$

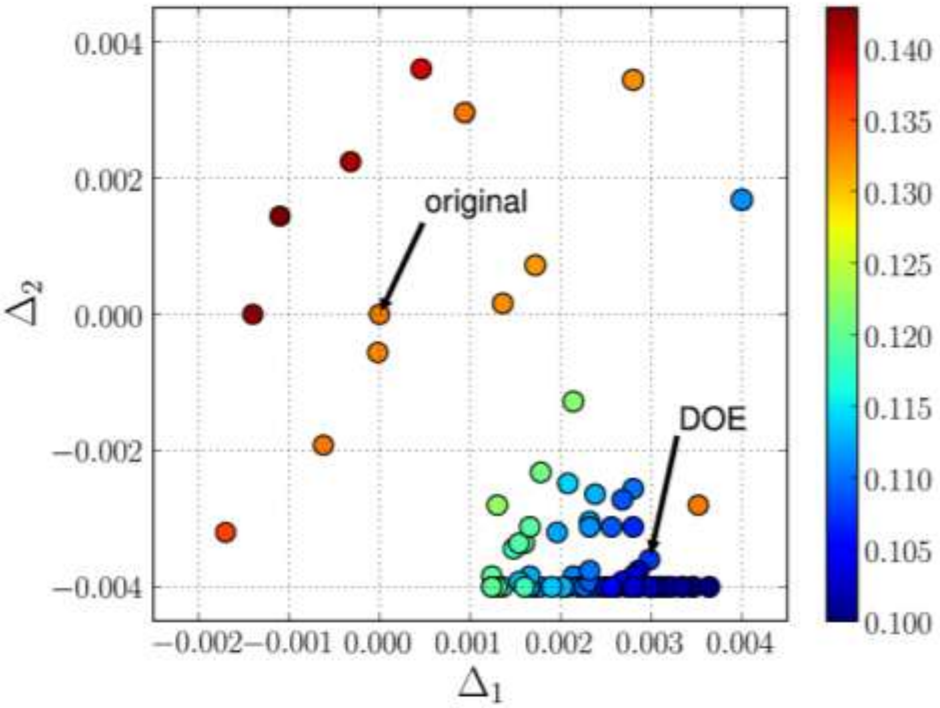
Workflow in modeFrontier

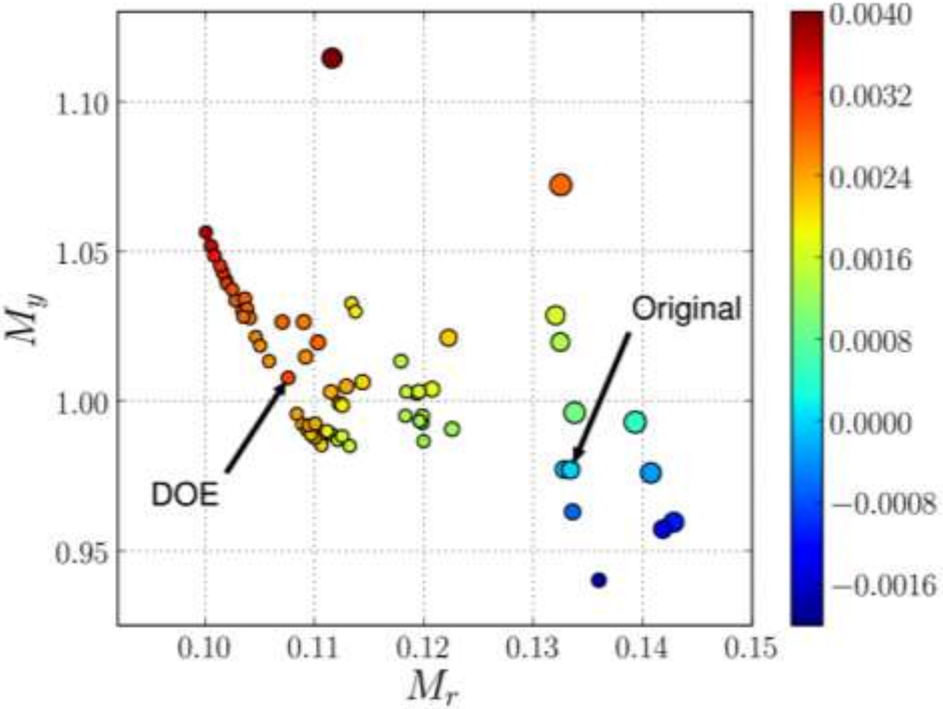


- Two input variables, Δ_1 and Δ_2
- Two objectives, minimize M_r and M_y
- Optimization algorithm, Evolution Strategy (ES)
- modeFrontier and Sculptor run locally
- AVL FIRE® runs on cluster
- Each design is restarted from original train

DOE Points	Concurrent Designs	Size of Generation	Generations	Simulation Time [h]	CPU´s	Total CPU Time [h]
16	8	16	5	5	48	18 000

Results

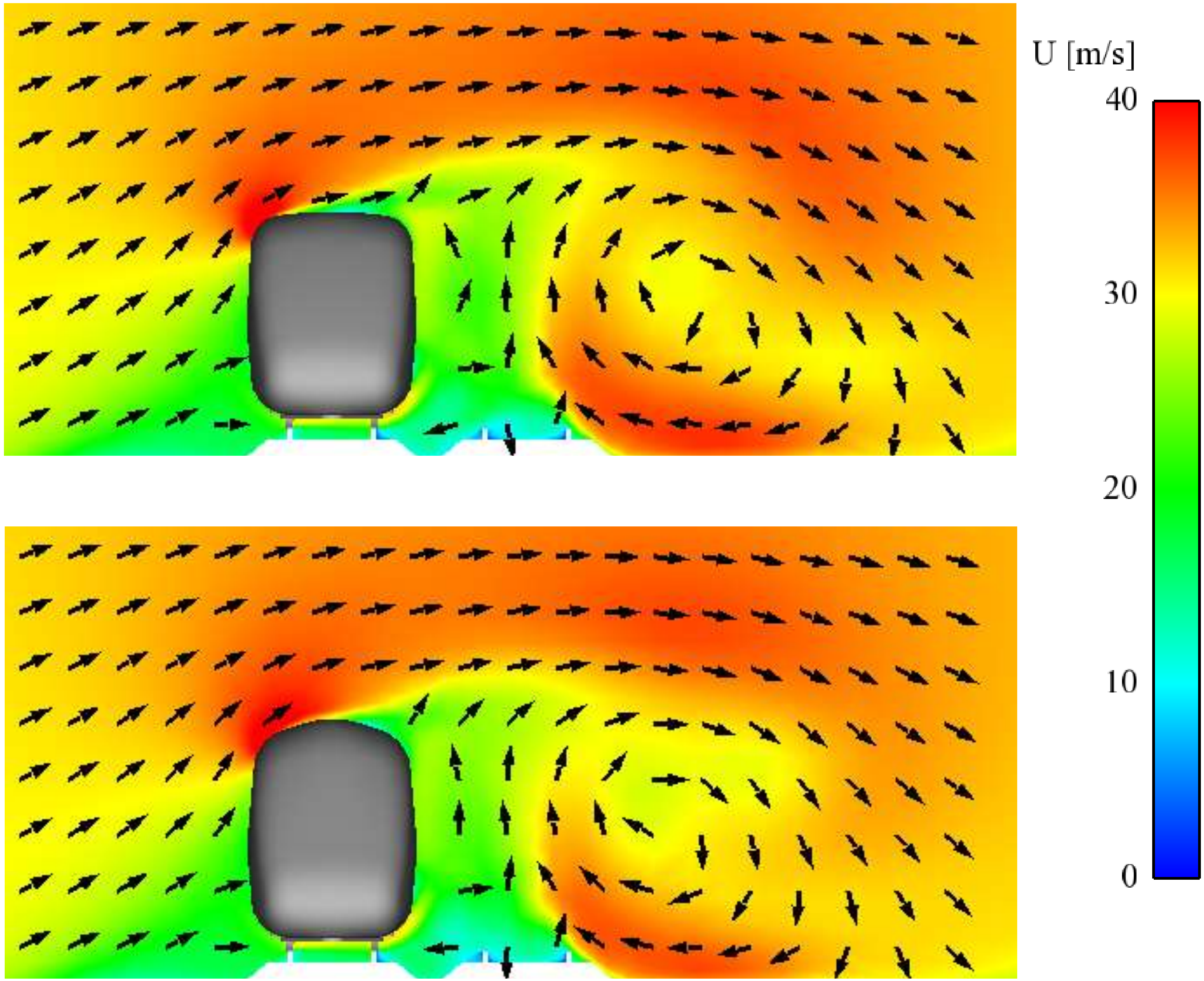




	Δ_1	Δ_2	My [Nm]	%	Mr [Nm]	%
Original			0.98		0.13	
DOE	0.00298	-0.0036	1.01	3.3	0.11	-21.3
ES	0.00364	-0.004	1.06	7.8	0.10	-33.4

Original

Optimized



The lessons learned and the impact of this research

- The new numerical technique is capable of studying different wind-gust-like situations.
- Examples of situations that we can study are:
  - Influence of atmospheric wind gusts on trains
  - Passing trains
  - Train passing a platform

- The Aerodynamic shape optimization algorithm is capable of multiobjective shape ptimization of trains. Better algorithms are needed as the computational effort limits number of design parameters.

The impact of this research

- We have been internationaly recognized for this research.
- Our crosswind work has led to cooperation project on wind gust influence on trains with Railway Technical Research Institute (RTRI) in Tokyo.
- Much of this research has been performed by involving BSc and MSc student This has íncreased interest of students in this research.
- Large number of scientific papers, MSc thesis, BSc thesis and popularscientific pblications.