The influence of mesh characteristics on OpenFOAM simulations of the DrivAer model

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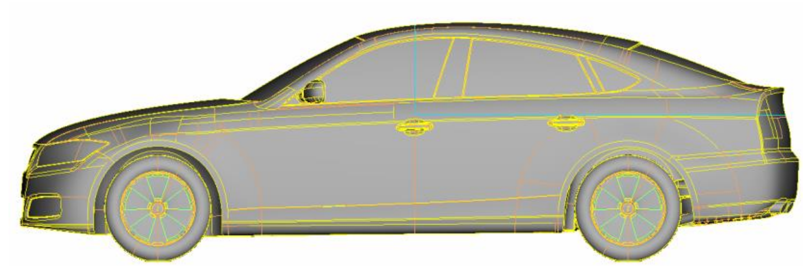
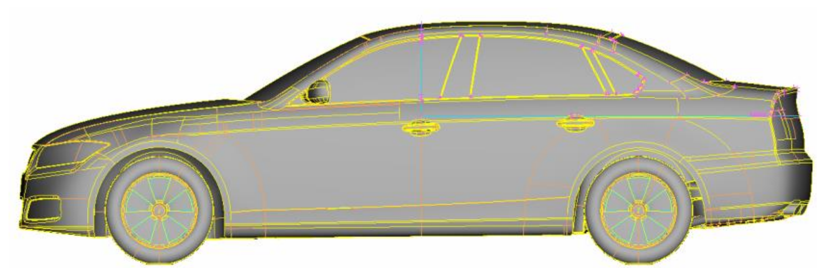
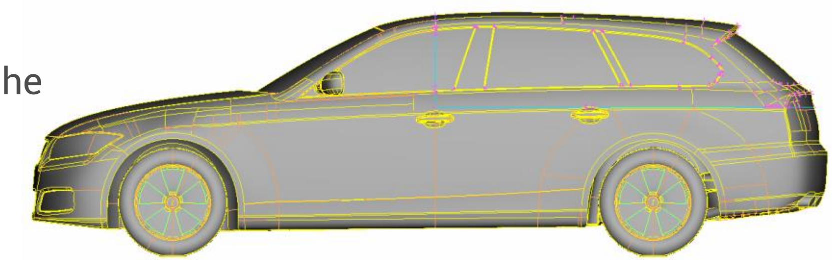
The DrivAer model of the Technical University of Munich

Experimental setup:
1:2.5 scale wind tunnel model
Re = 4.87×10^6
L = 1.84 m
U = 40 m/sec
Free stream turbulence = 0.4%







Acknowledgments to:
Institute of Fluid Mechanics and Aerodynamics of the Technical University of Munich
for providing the model geometries
in IGES and STEP formats

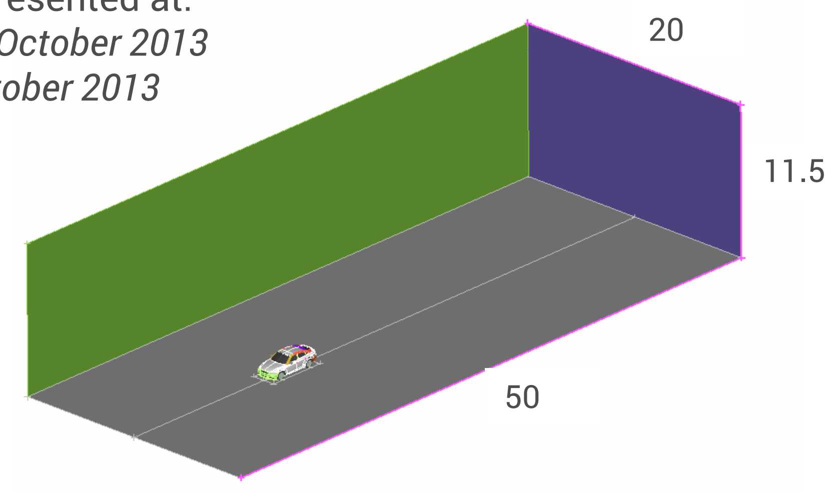
Reference

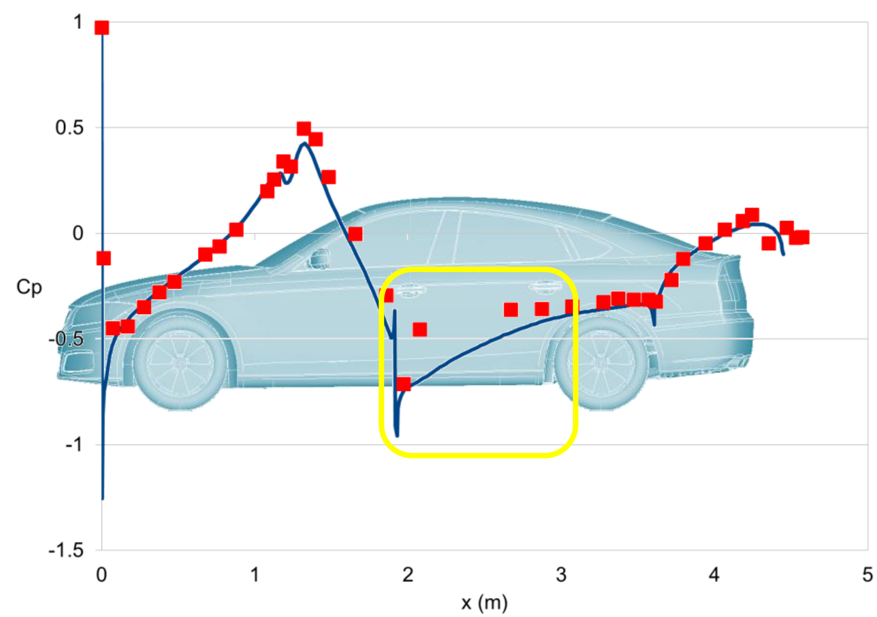
Heft Angelina (2014) “Aerodynamic Investigation of the Cooling Requirements of Electric Vehicles”, PhD Thesis, Technical University of Munich, ISBN 978-3-8439-1765-0

Previous related work of BETA CAE

Studies with Fluent and OpenFOAM simulations were presented at:
ANSYS Automotive Simulation Congress Group, Frankfurt, October 2013
International Open Source CFD Conference, Hambourg, October 2013

Model was scaled up to full size L = 4.612 m
Domain size 50 x 20 x 11.5 m
blockage ratio= 1%
domain sides set to symmetry
Steady State RANS simulations
Re = 4.87×10^6
Turbulence model: k-omega SST
Cases with and without moving ground simulation with MRF modeling of rotating wheels

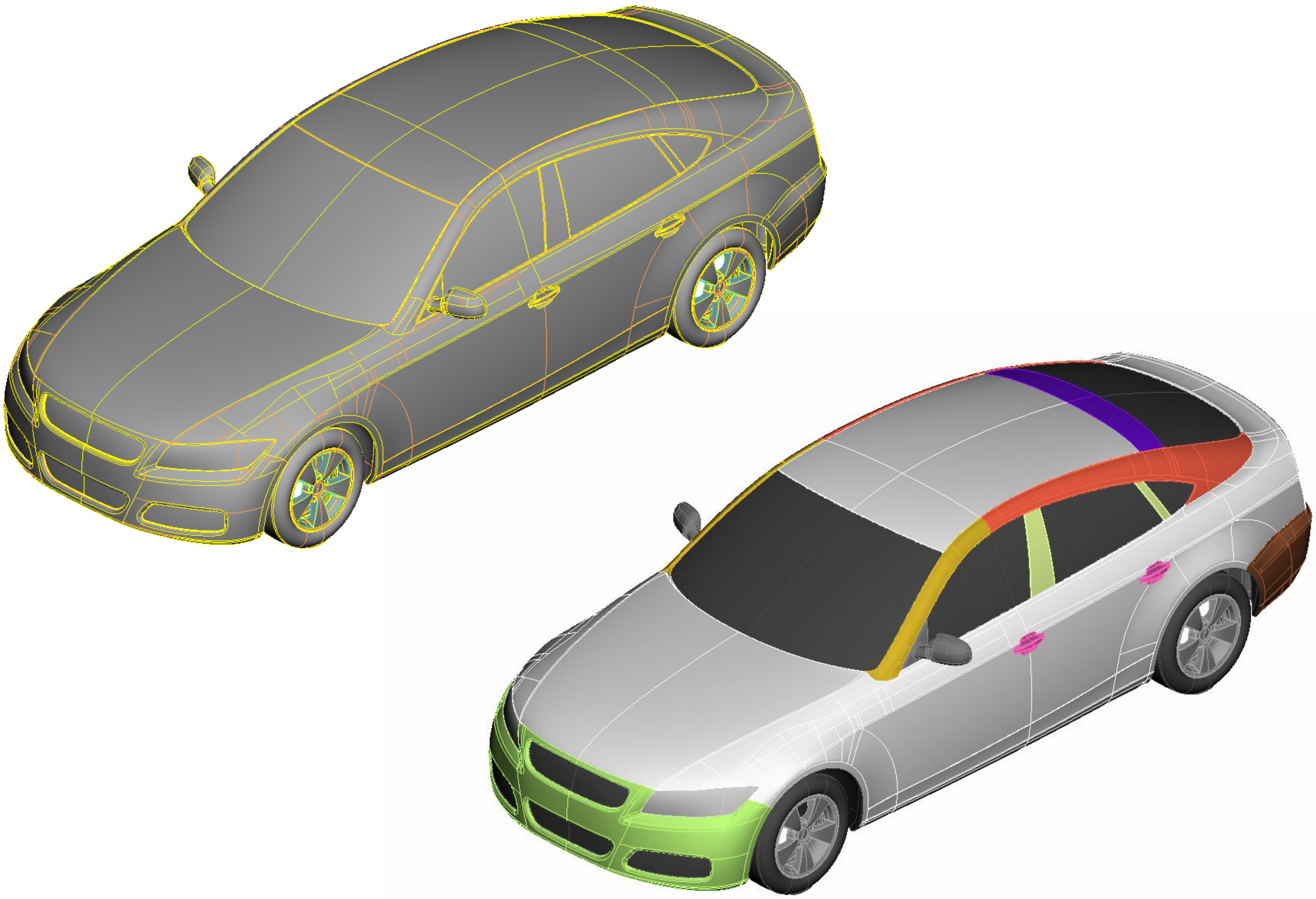




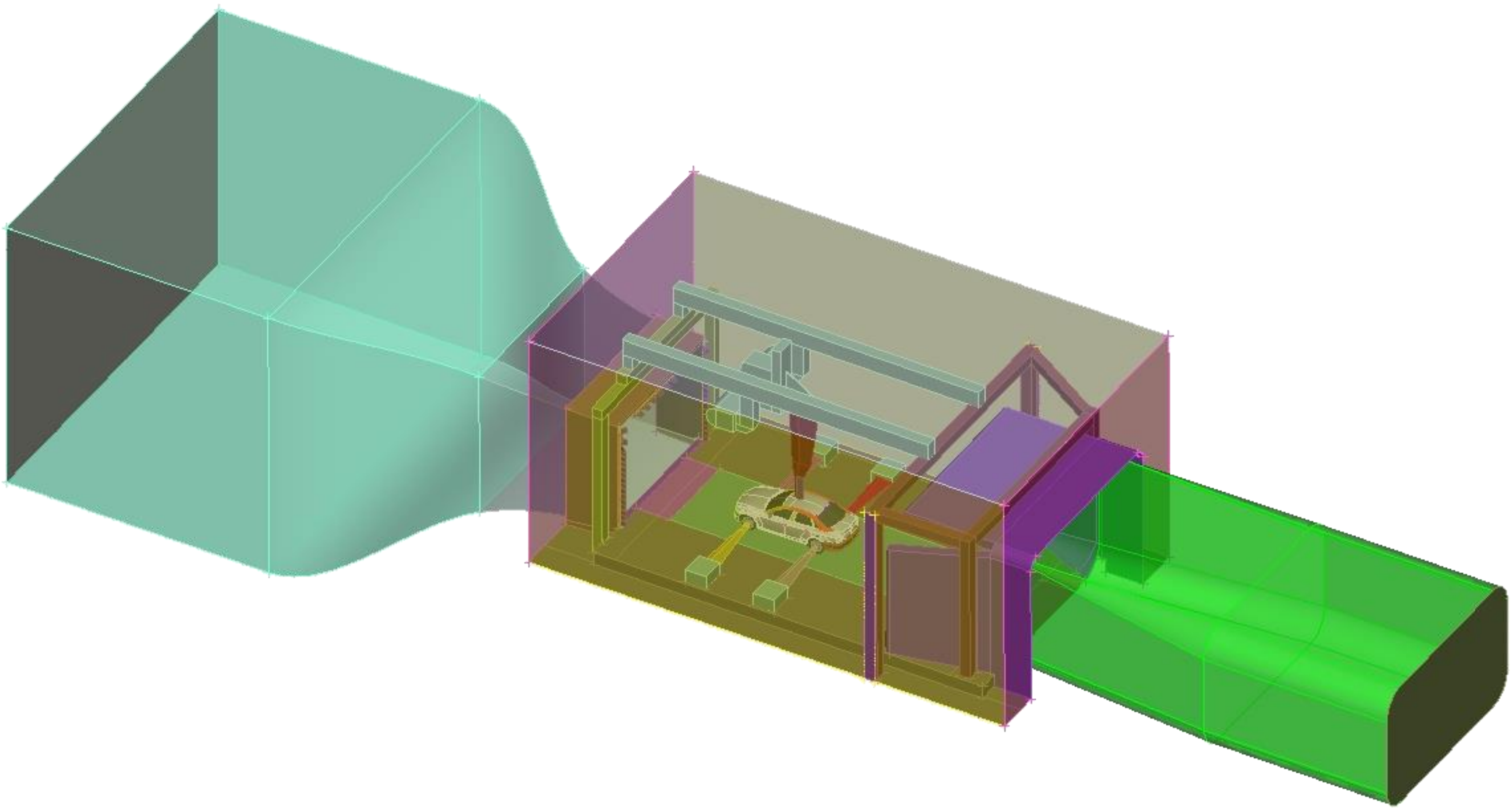
Presence of model support seems to decelerate the flow locally

Geometry preparation: STEP file input and property assignment

Geometries that included detailed underbody and mirrors were selected

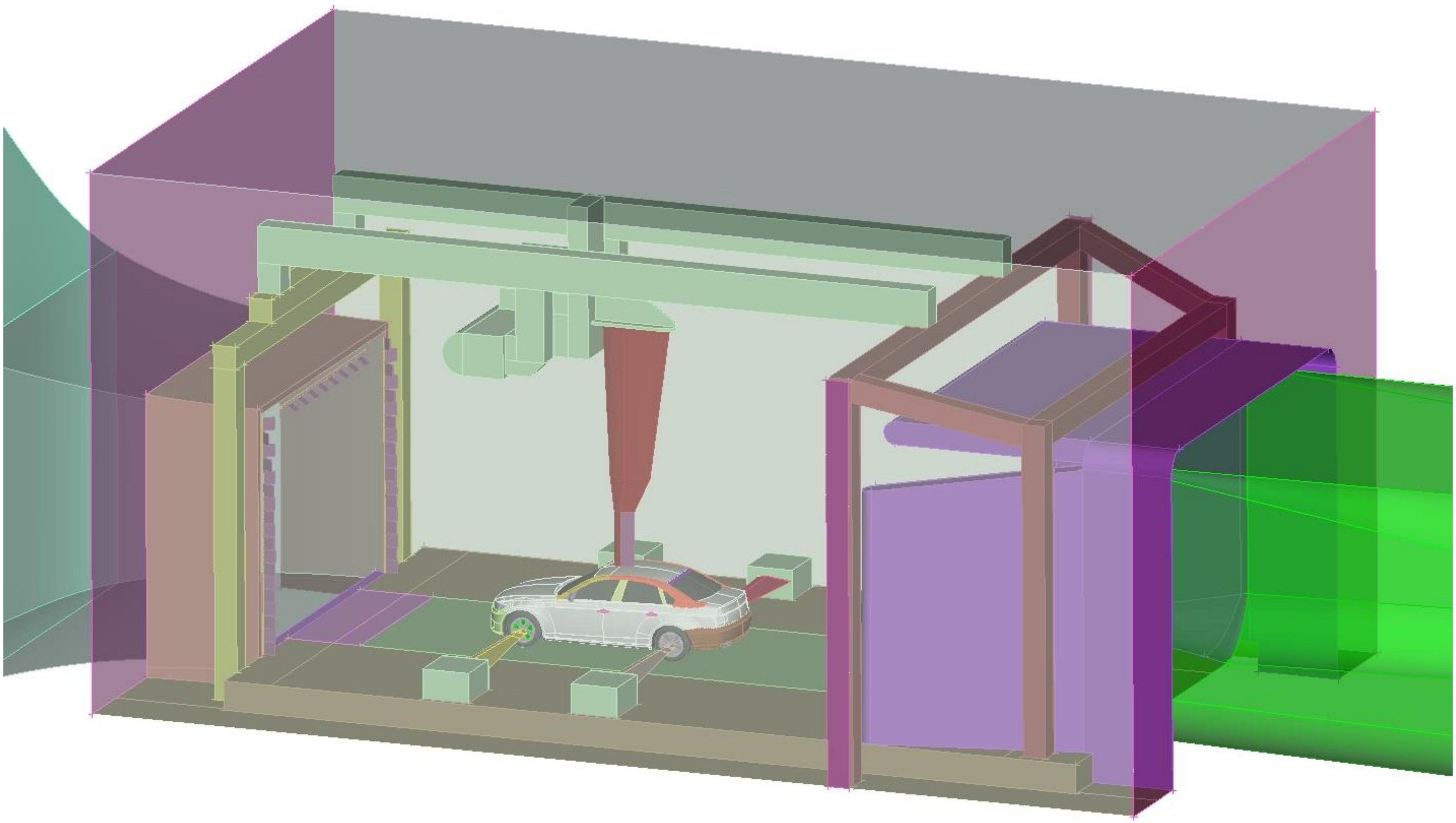


Geometry preparation: construction of wind tunnel geometry



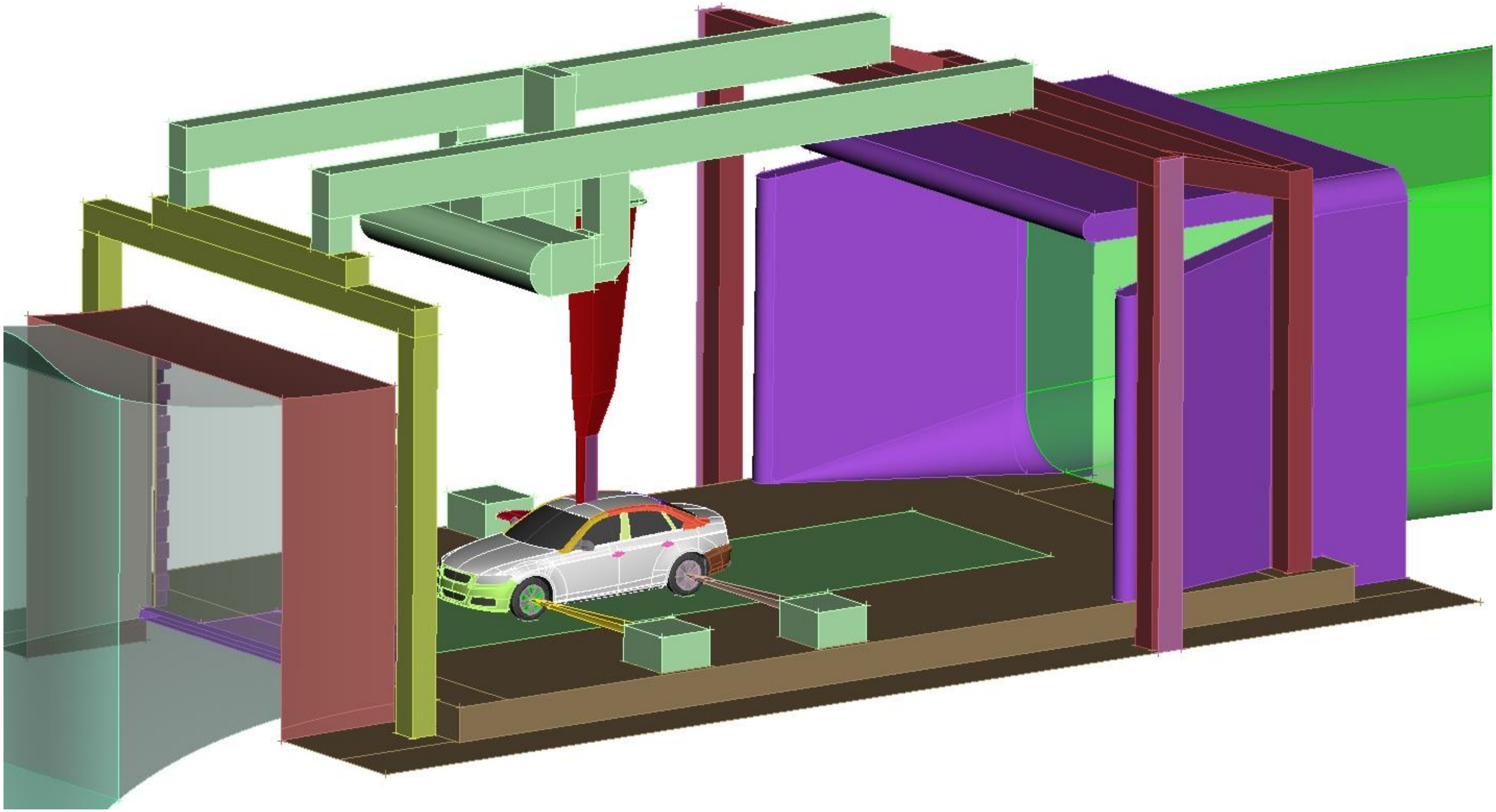
Geometry preparation: construction of wind tunnel geometry

Blockage ratio ≈ 8%

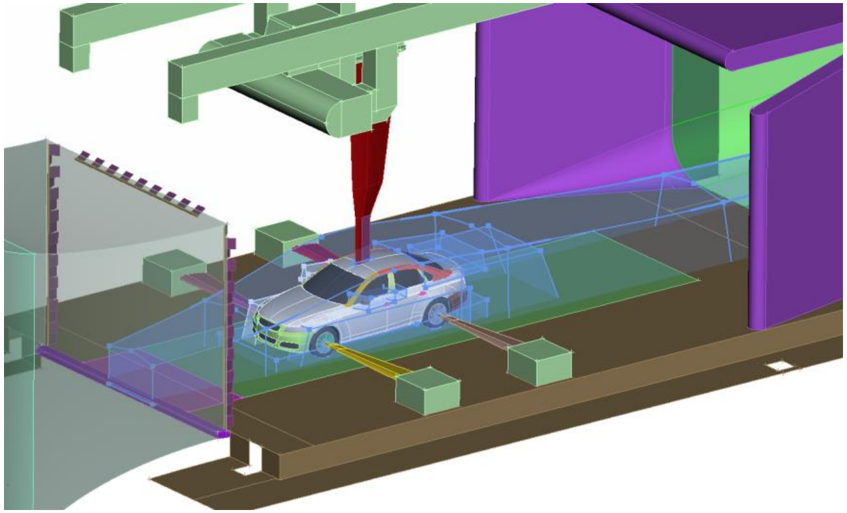


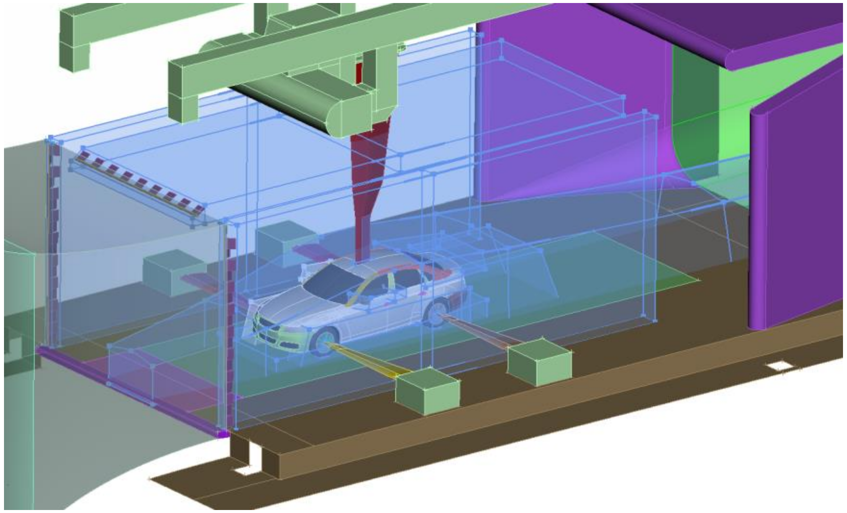
Geometry preparation: construction of wind tunnel geometry

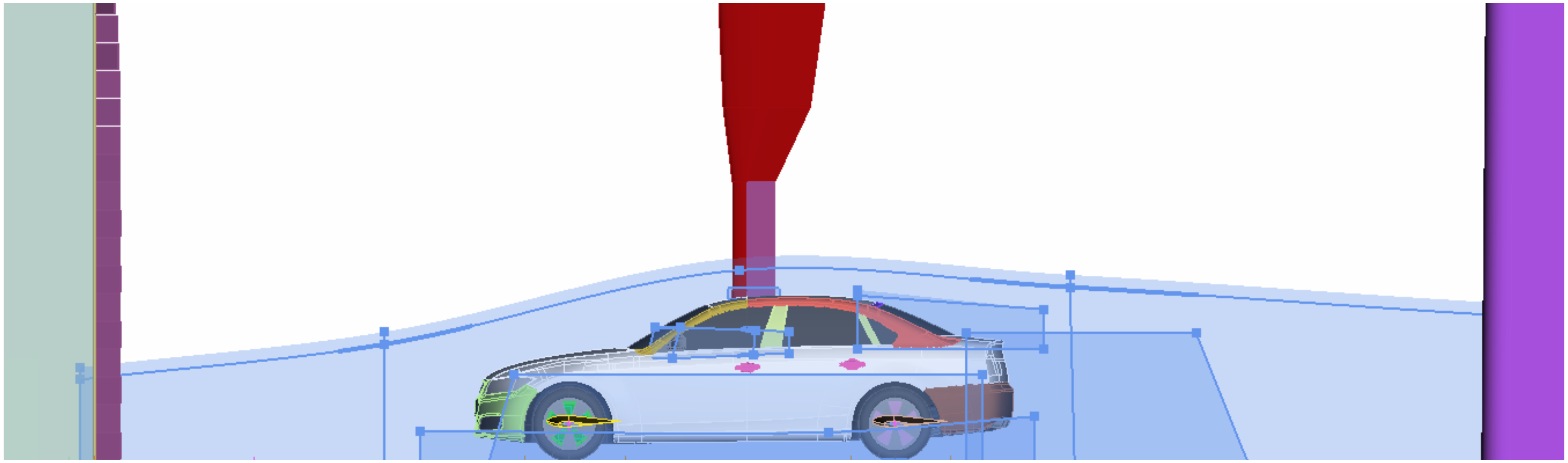
Blockage ratio ≈ 8%



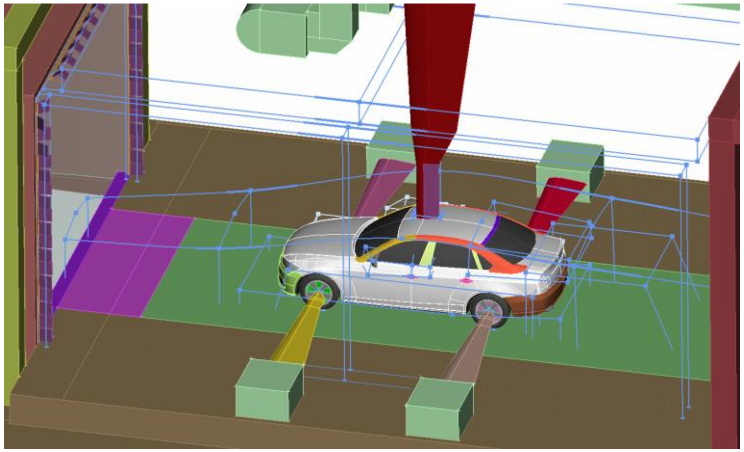
Flexible Size Boxes controlling mesh refinement aligned to the flow



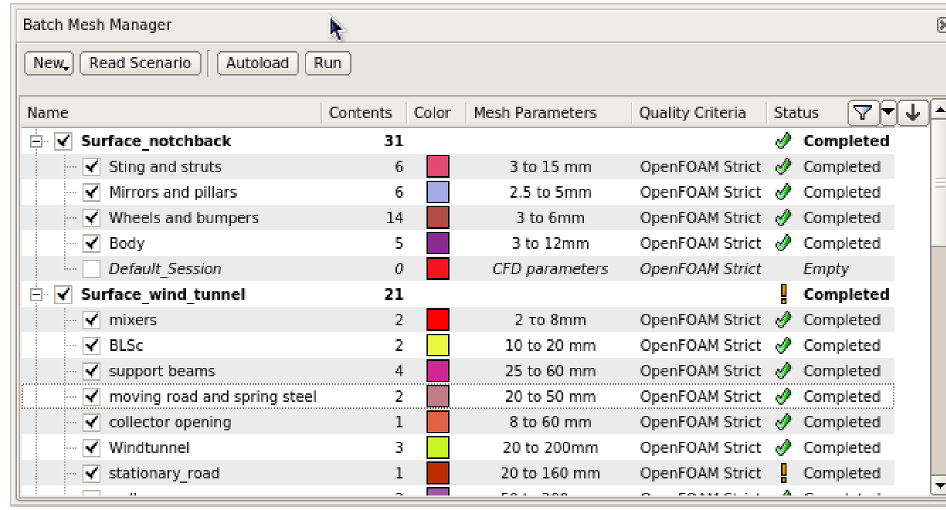




Batch Mesh tool setup: automation and consistency in meshing



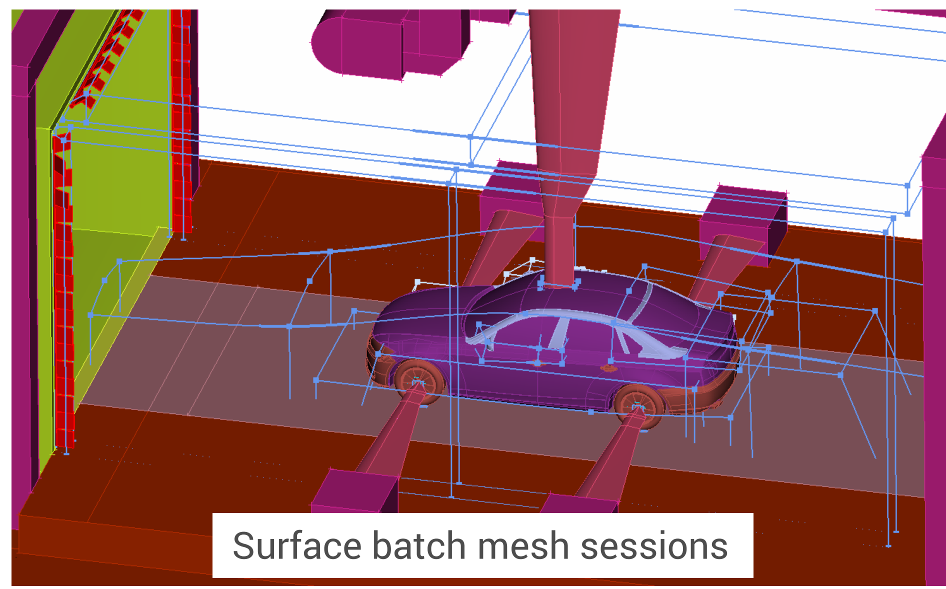
Model Properties (OpenFOAM BCs)



Batch Mesh Manager

New | Read Scenario | Autoload | Run

Name	Contents	Color	Mesh Parameters	Quality Criteria	Status
Surface_notchback	**31**				**Completed**
Sting and struts	6		3 to 15 mm	OpenFOAM Strict	Completed
Mirrors and pillars	6		2.5 to 5mm	OpenFOAM Strict	Completed
Wheels and bumpers	14		3 to 6mm	OpenFOAM Strict	Completed
Body	5		3 to 12mm	OpenFOAM Strict	Completed
Default_Session	*0*		*CFD parameters*	*OpenFOAM Strict*	*Empty*
Surface_wind_tunnel	**21**				**Completed**
mixers	2		2 to 8mm	OpenFOAM Strict	Completed
BLSc	2		10 to 20 mm	OpenFOAM Strict	Completed
support beams	4		25 to 60 mm	OpenFOAM Strict	Completed
moving road and spring steel	2		20 to 50 mm	OpenFOAM Strict	Completed
collector opening	1		8 to 60 mm	OpenFOAM Strict	Completed
Windtunnel	3		20 to 200mm	OpenFOAM Strict	Completed
stationary_road	1		20 to 160 mm	OpenFOAM Strict	Completed

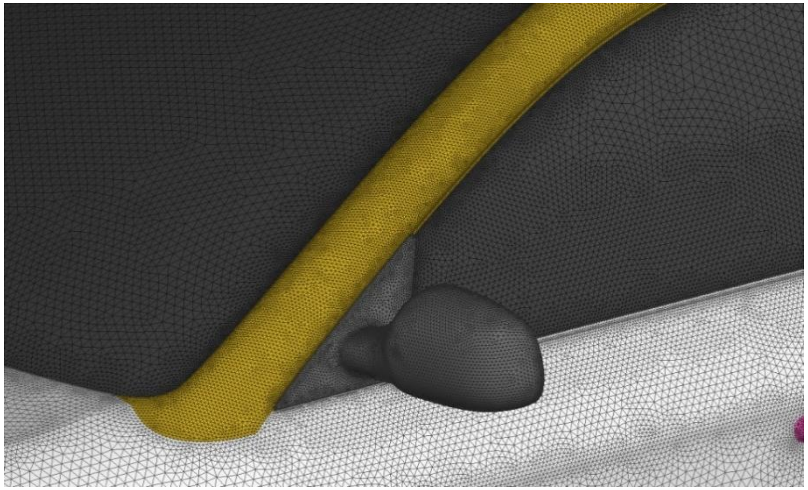


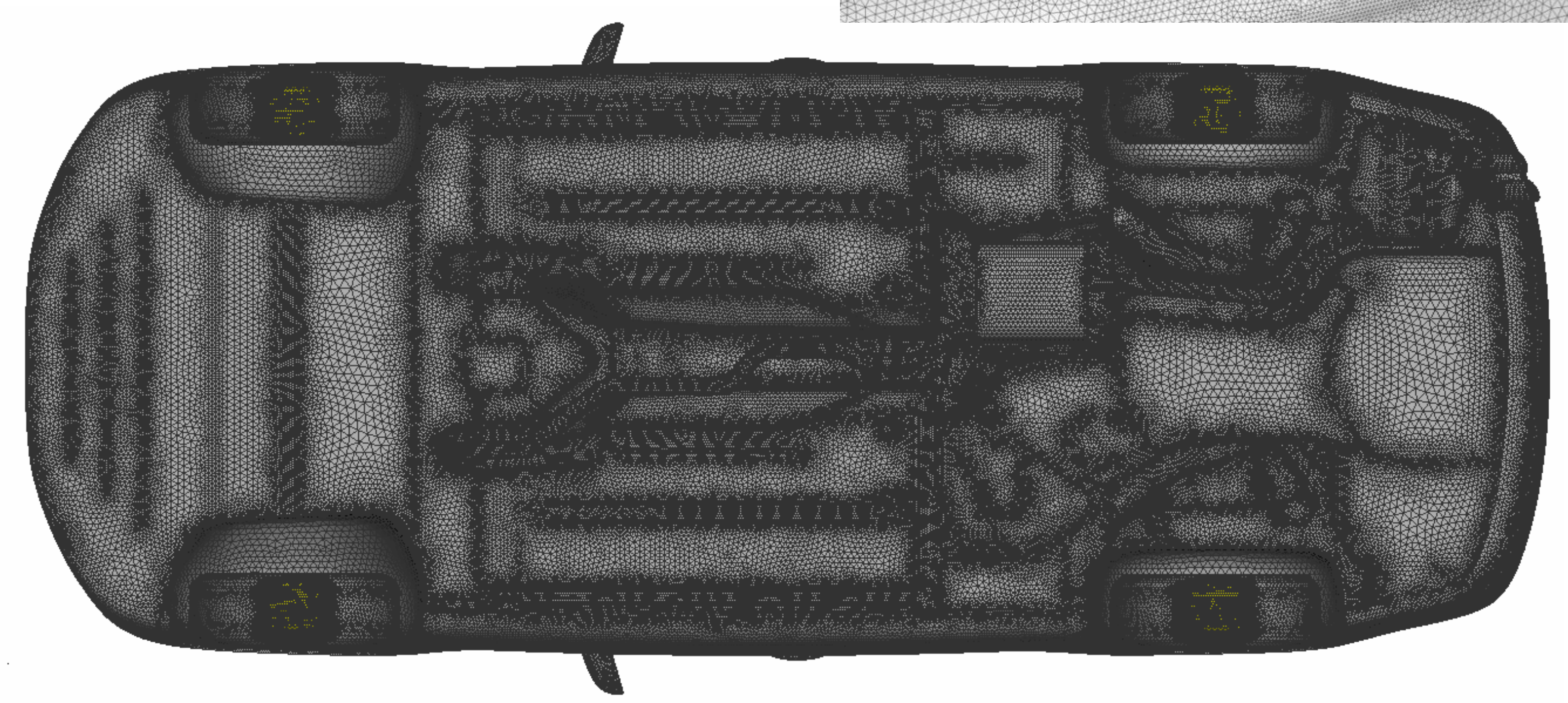
Surface batch mesh sessions

Batch Mesh provides:
- automation
- consistency
- mesh specs traceability

Batch mesh generated surface mesh

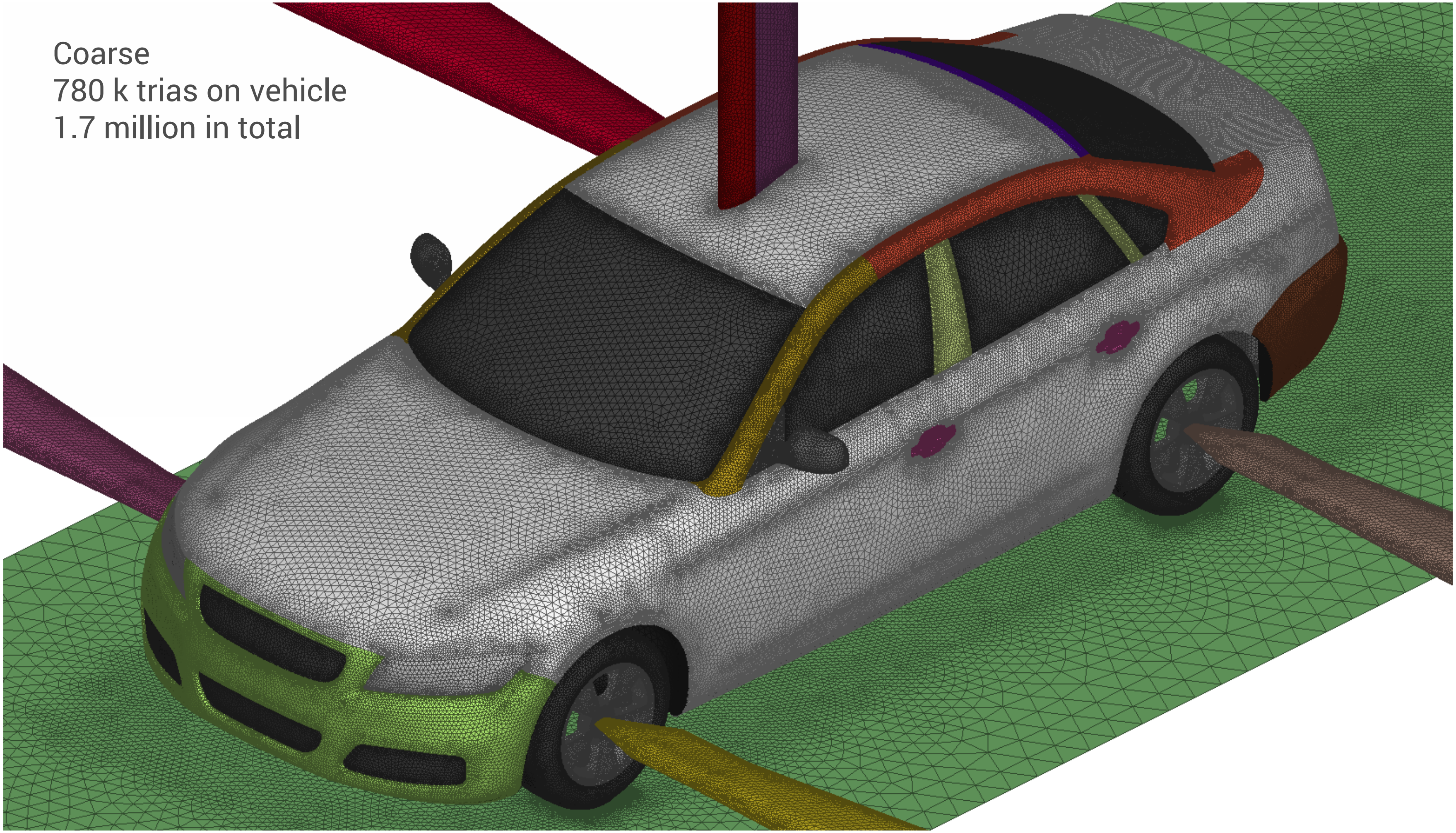
Automatic curvature and sharp edge refinement, in combination with the use of Size Boxes ensure the efficient and accurate capturing of all details of the model.





Batch mesh generated surface mesh

Automatic generation of models with variable resolution using batch meshing



Batch mesh generated surface mesh

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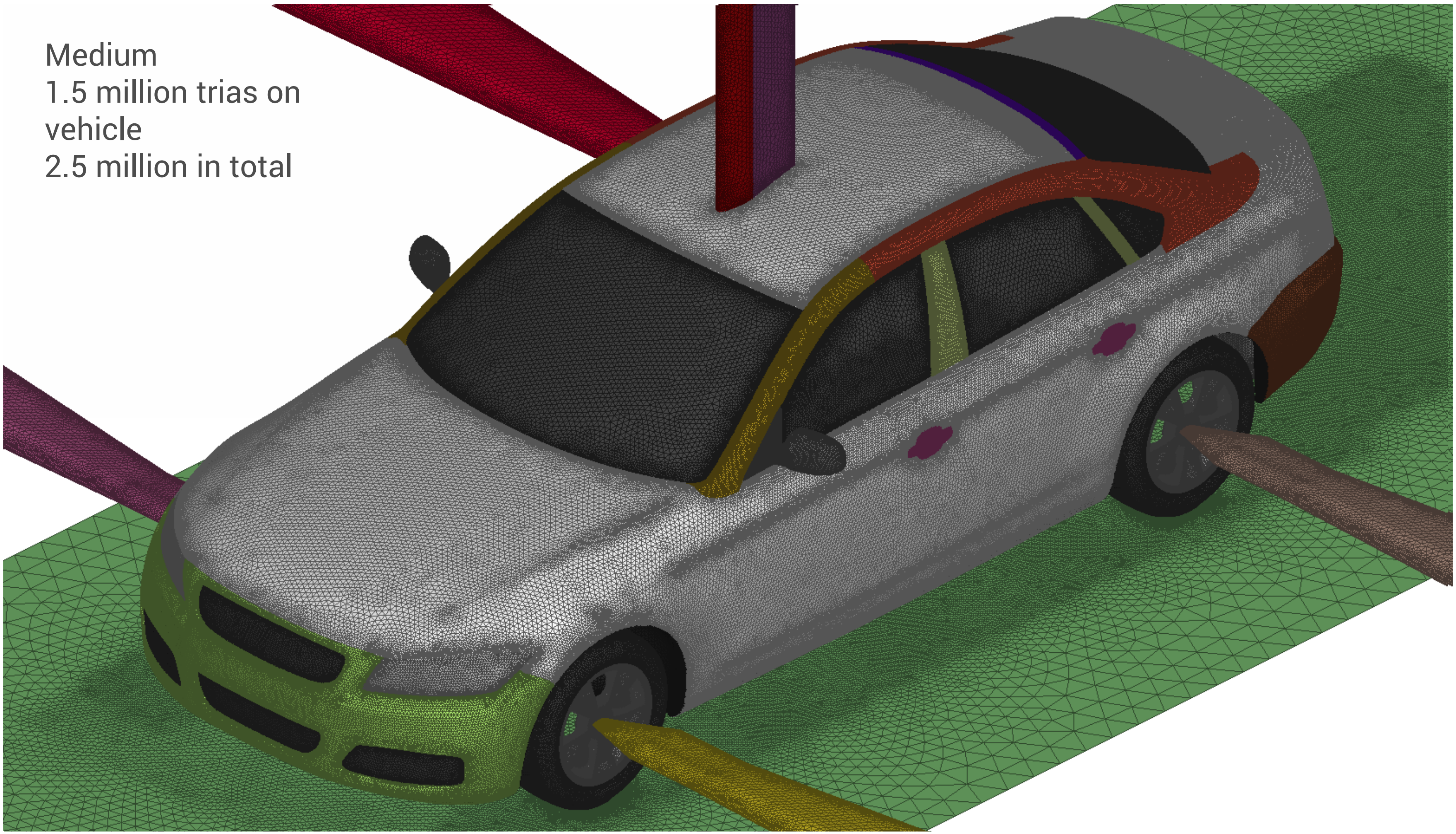
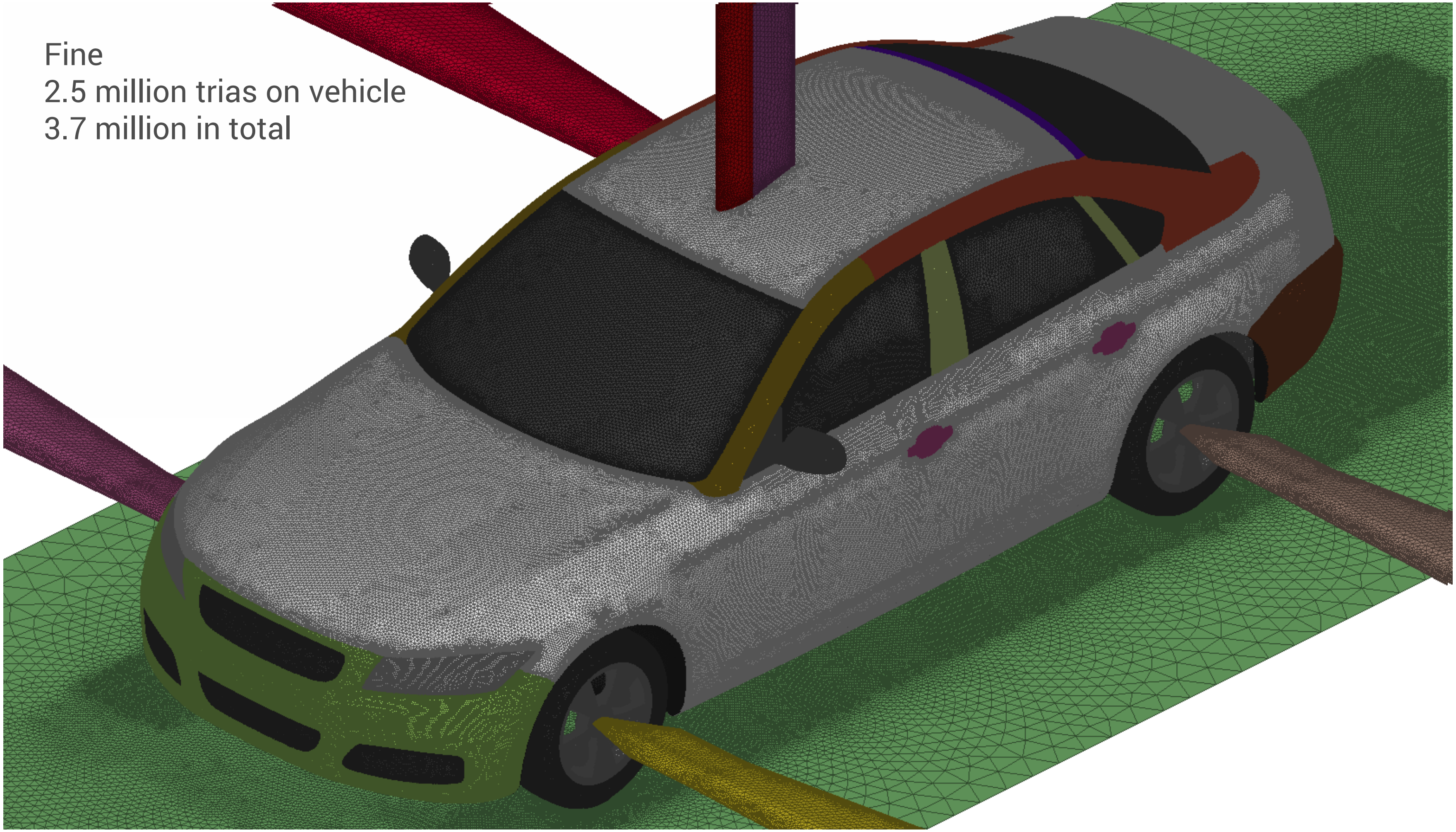


Batch mesh generated surface mesh

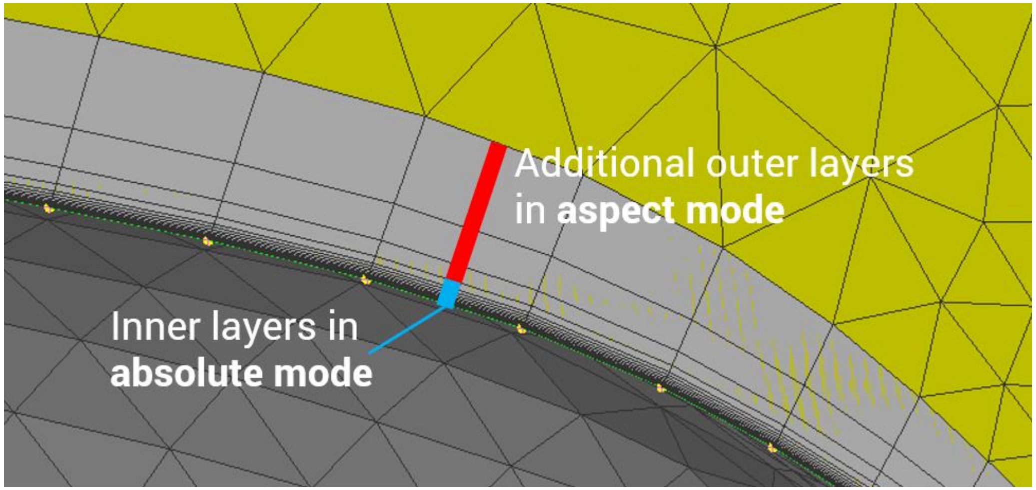
Automatic generation of models with variable resolution using batch meshing

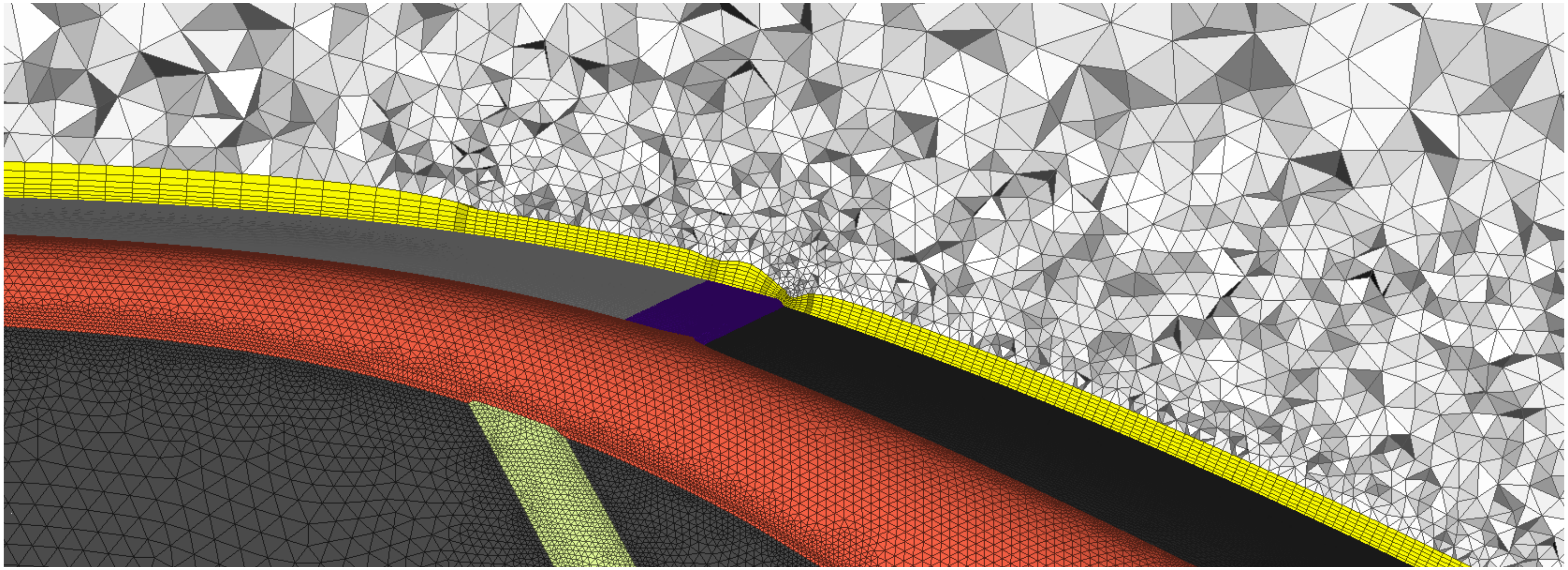


Boundary layer generation

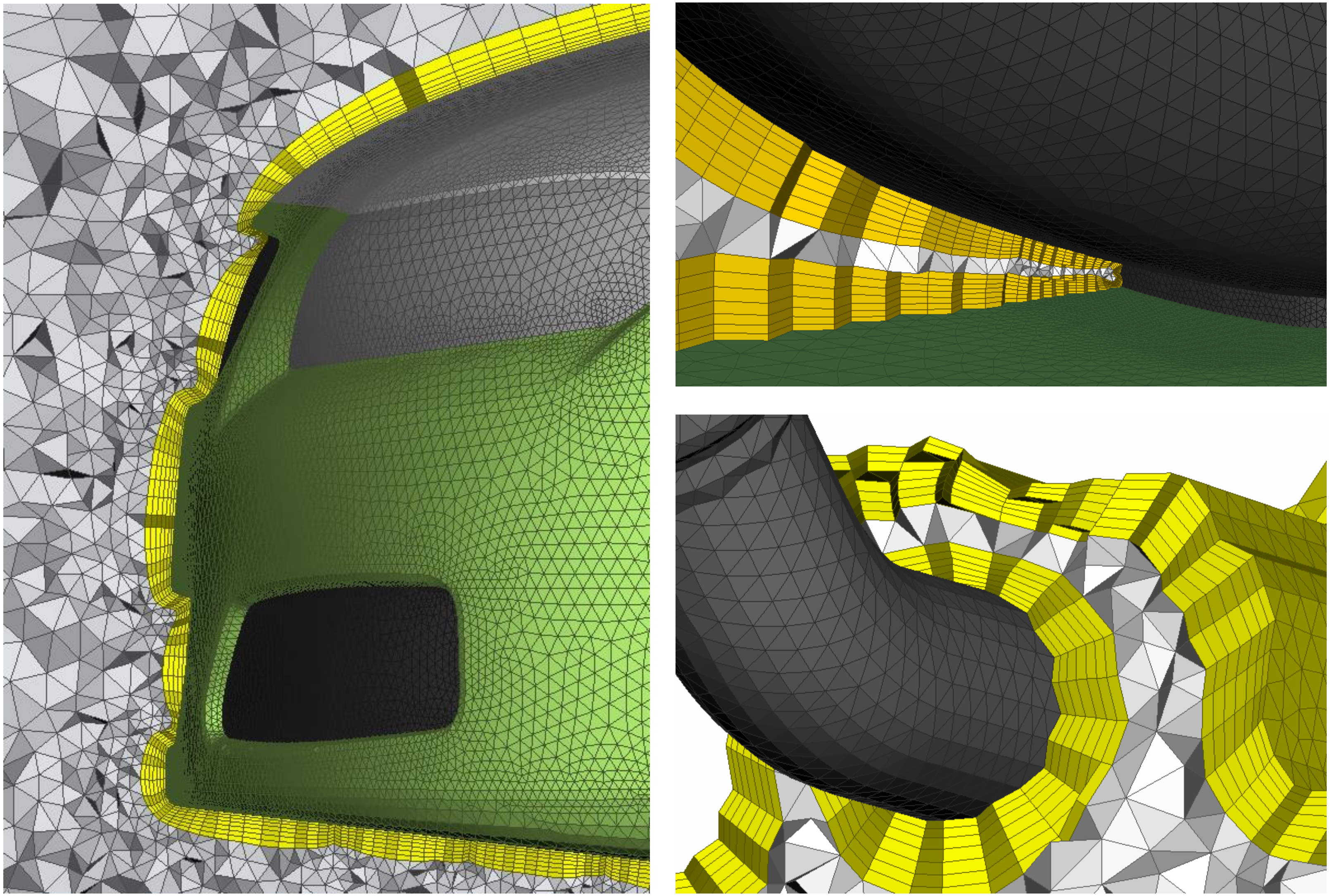
First height 0.8 mm
Growth rate = 1.2
4 layers (absolute mode)
+ 3 layers (aspect mode)
Last aspect ratio: 0.4
(40% of the base length)

Total layer height ≈ 10-12 mm

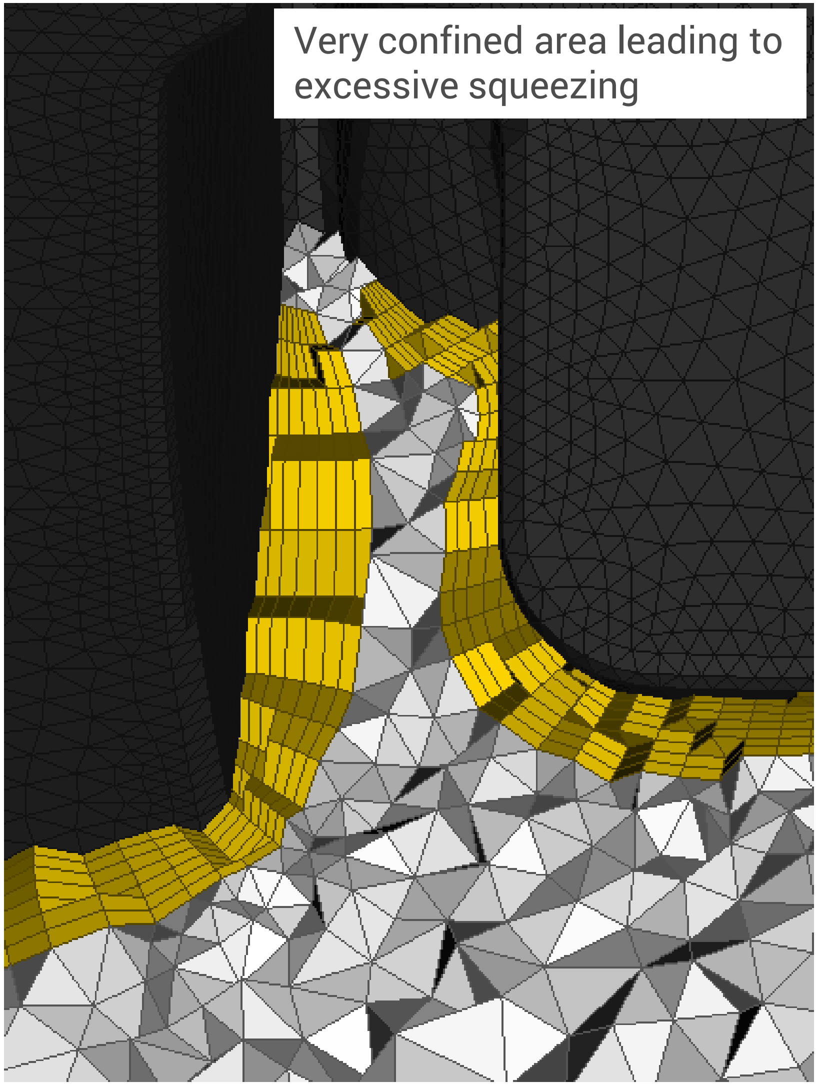


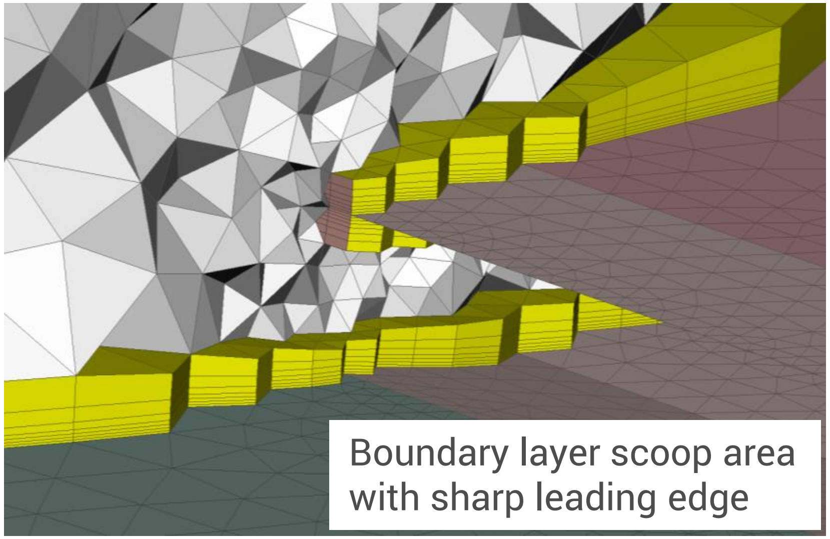


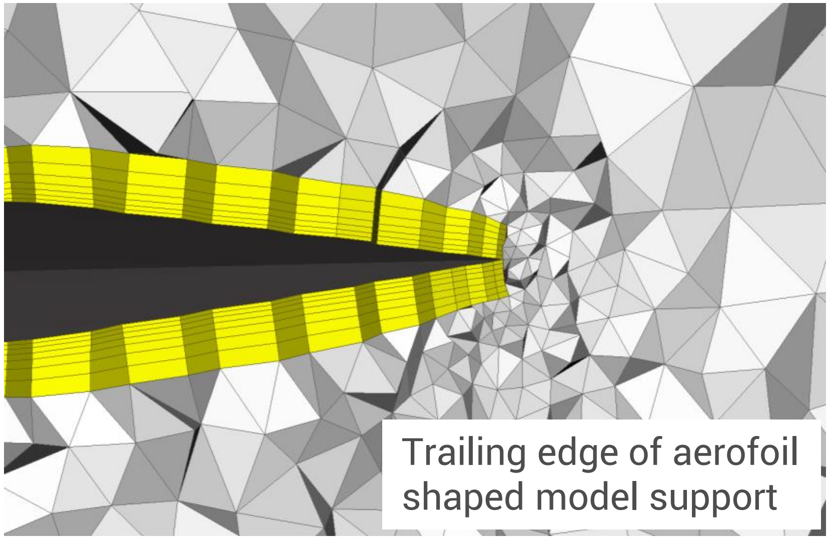
Boundary layer generation : local squeezing at proximities



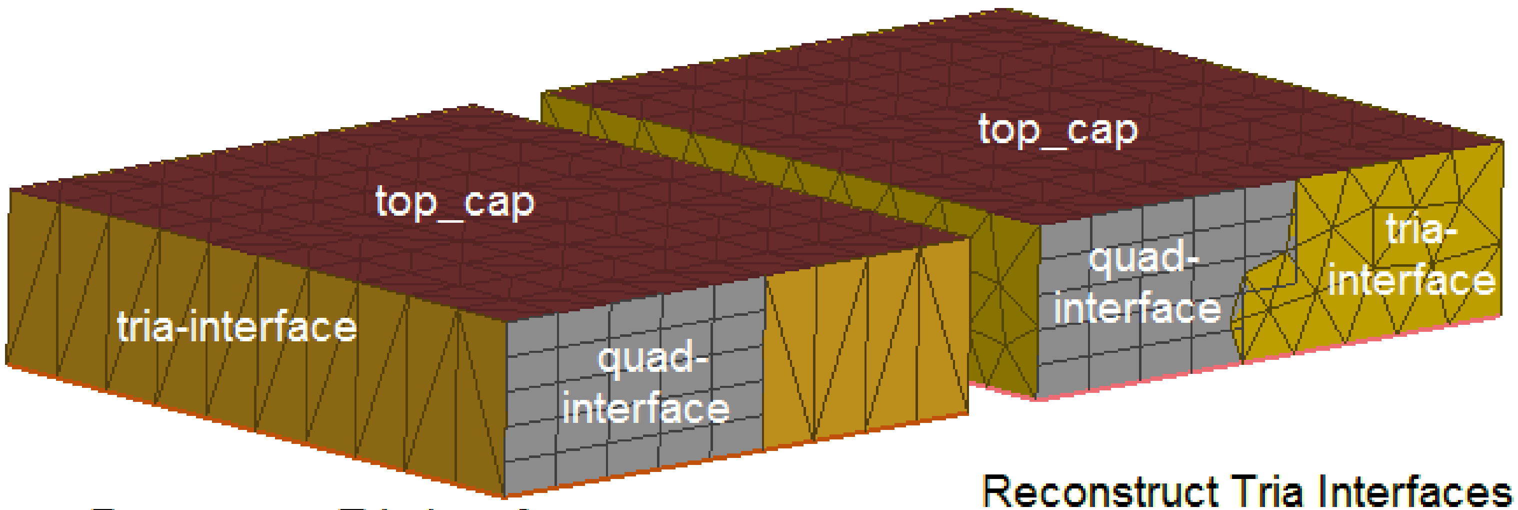
Boundary layer generation: local exclusion of layers at problematic areas







Boundary layer generation: local exclusion of layers at problematic areas

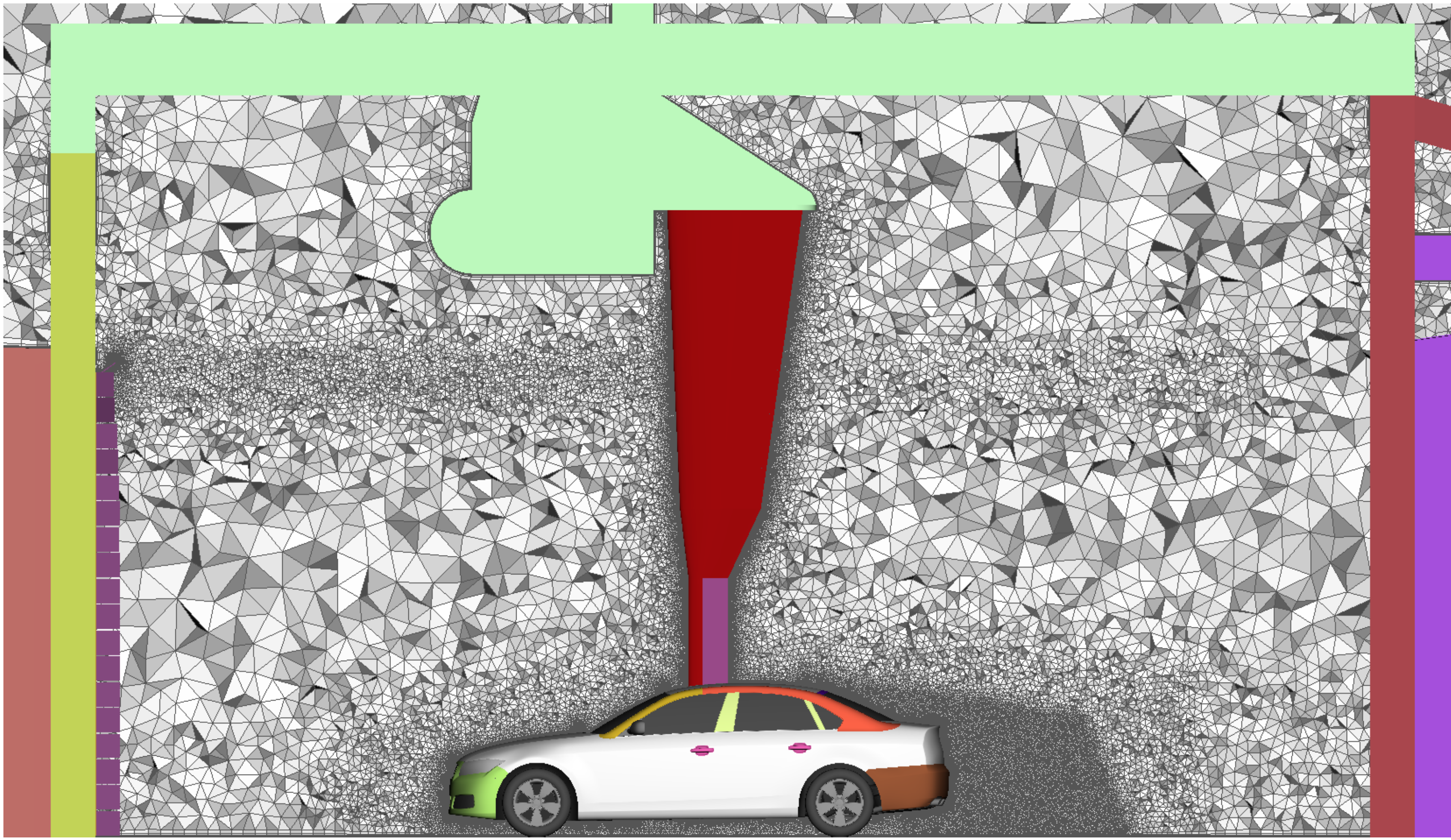


Reconstruct Tria Interfaces
(de-activated)

Reconstruct Tria Interfaces
(activated)

Batch mesh generated volume mesh

Automatic generation of layers and volume mesh for all variants and mesh densities (15 combinations). Image below of medium size mesh with layers (50 million cells) generated in under 40 minutes (including mesh quality fix).



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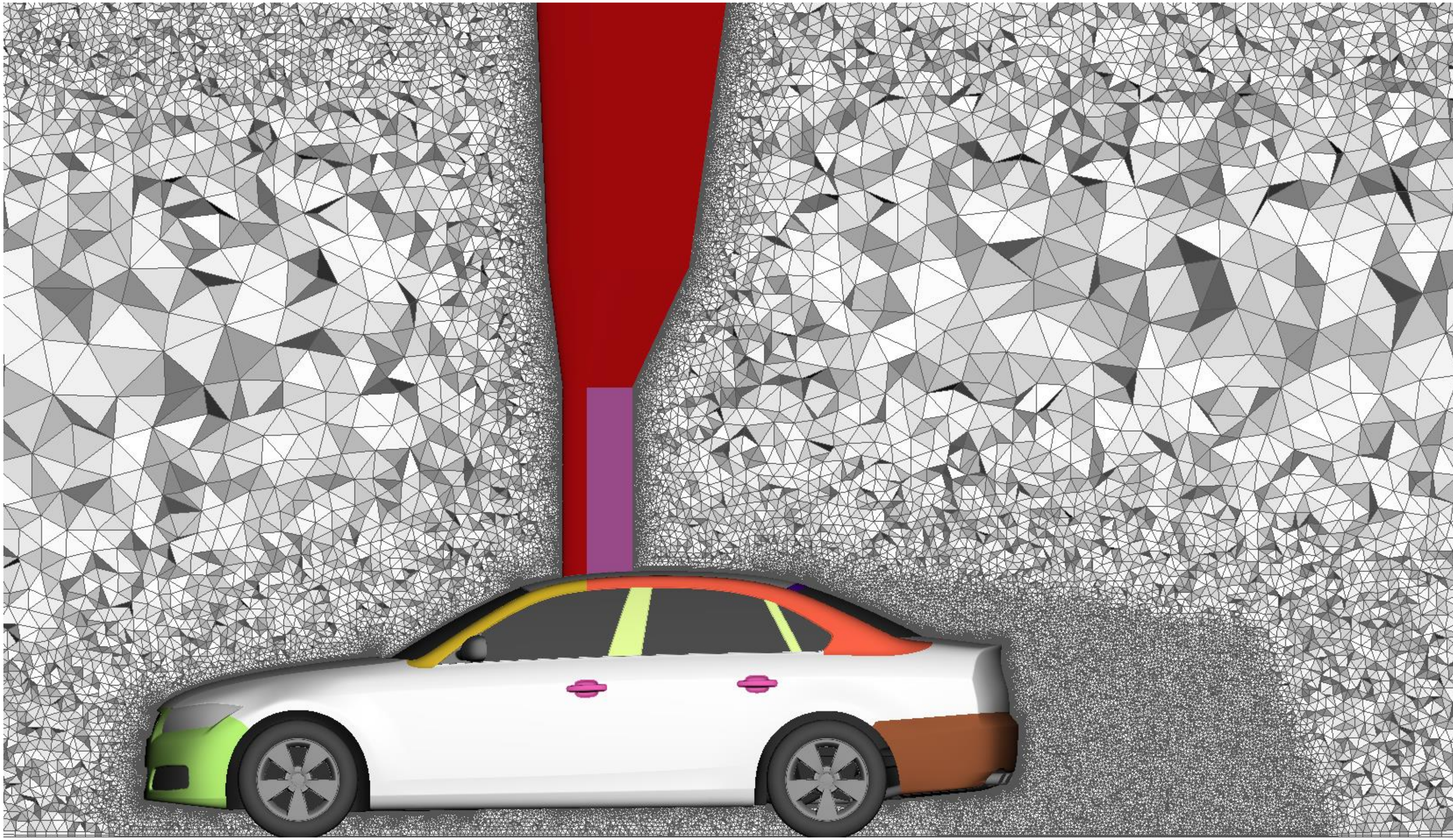
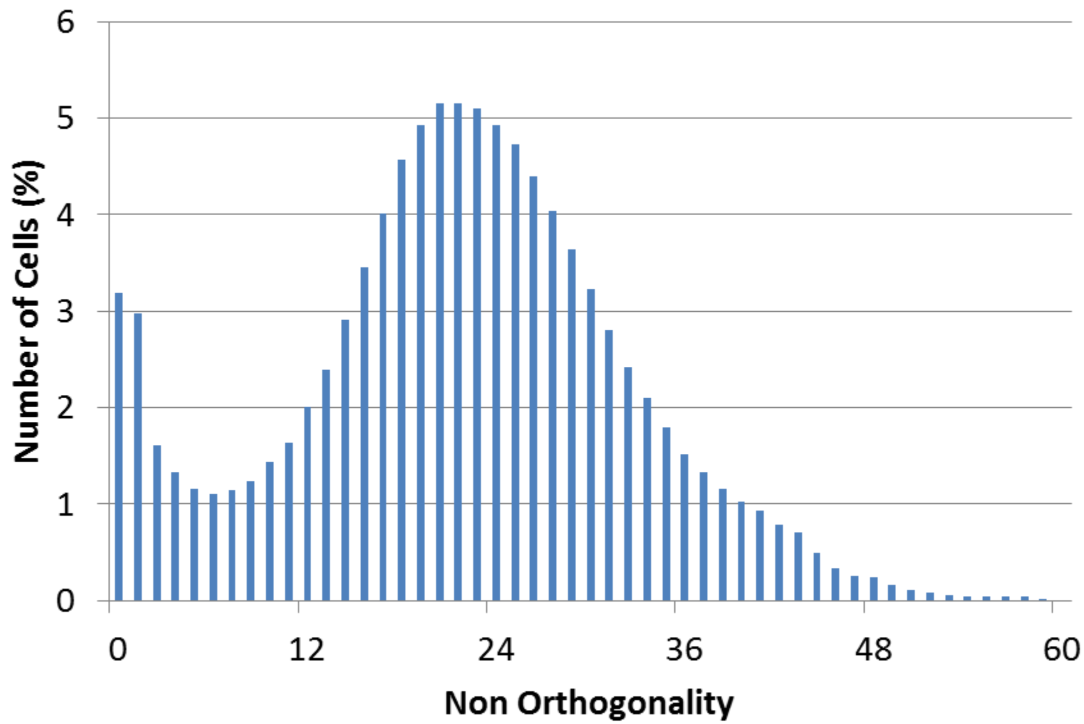
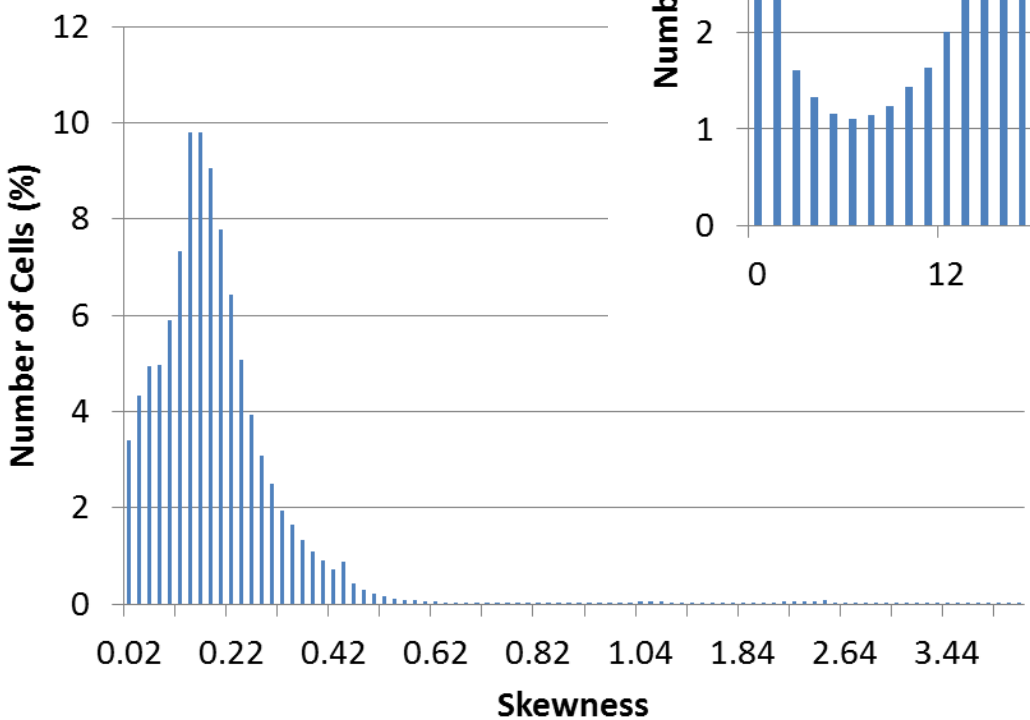


Indicative mesh quality statistics: notchback tetra medium with layers



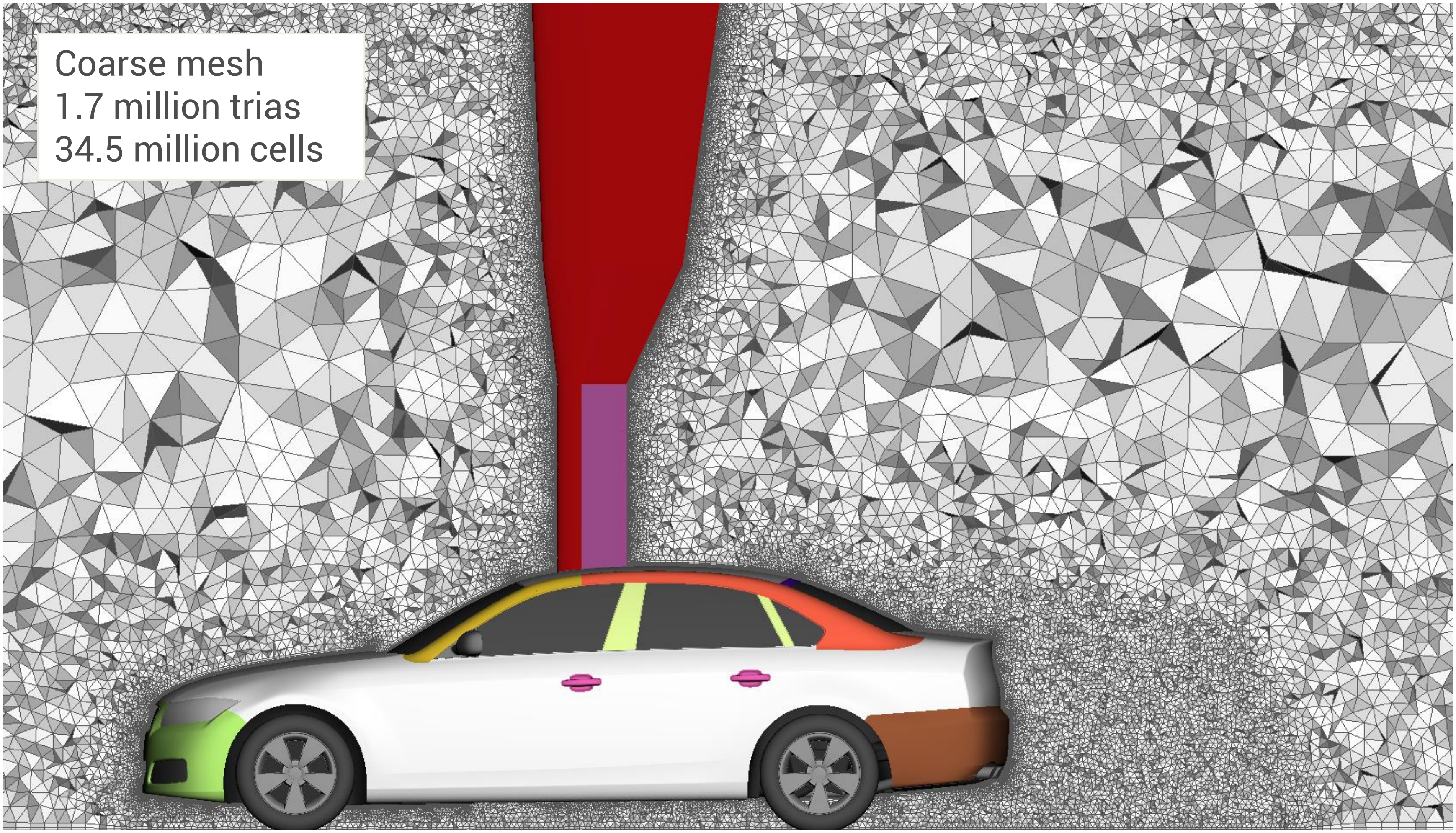


Max Non orthogonality = 59.99

Maximum skewness = 3.99

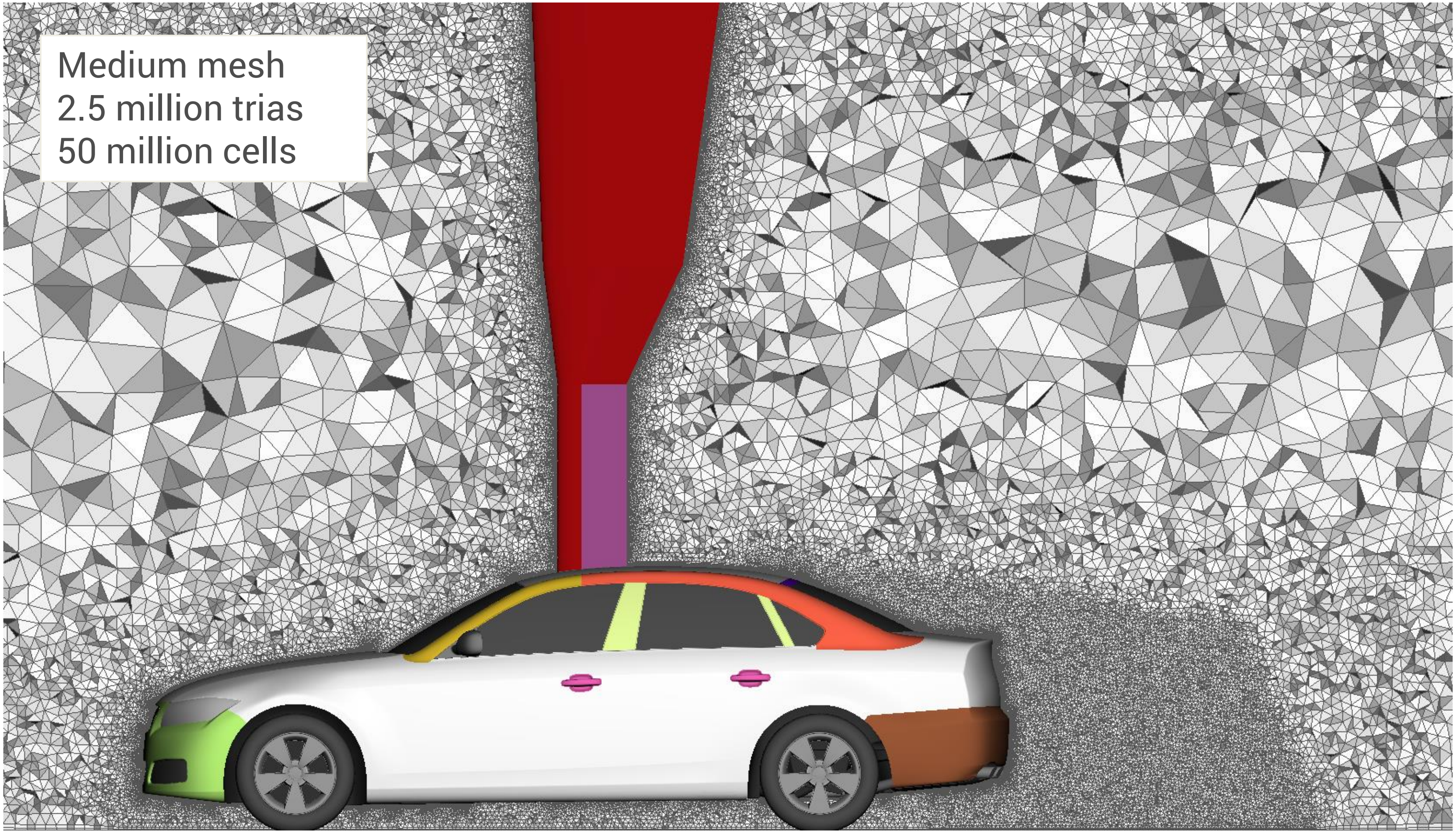
Mesh refinement study for tetra with layers case

Automatic generation of models with variable resolution using batch meshing



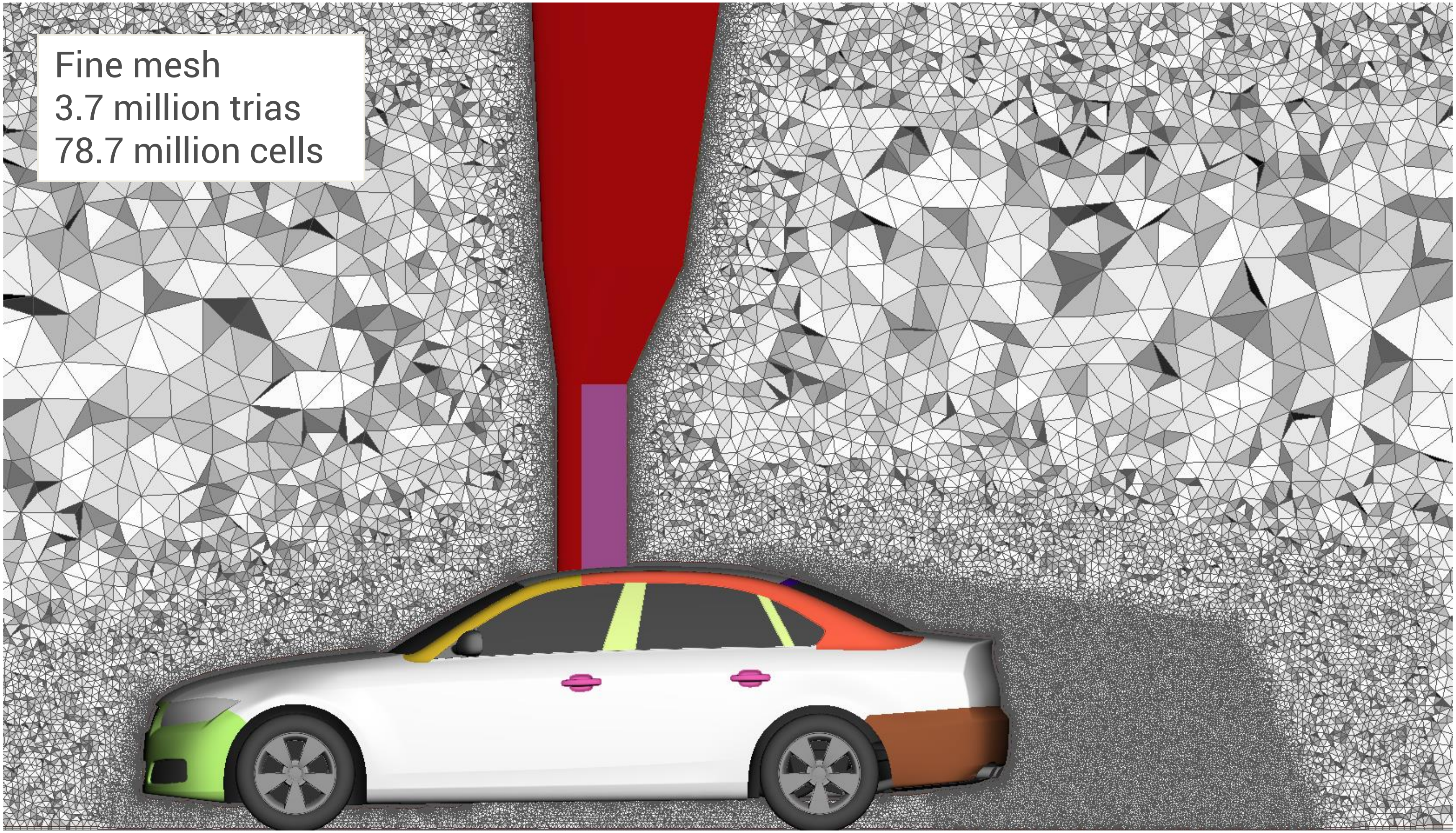
Mesh refinement study for tetra with layers case

Automatic generation of models with variable resolution using batch meshing



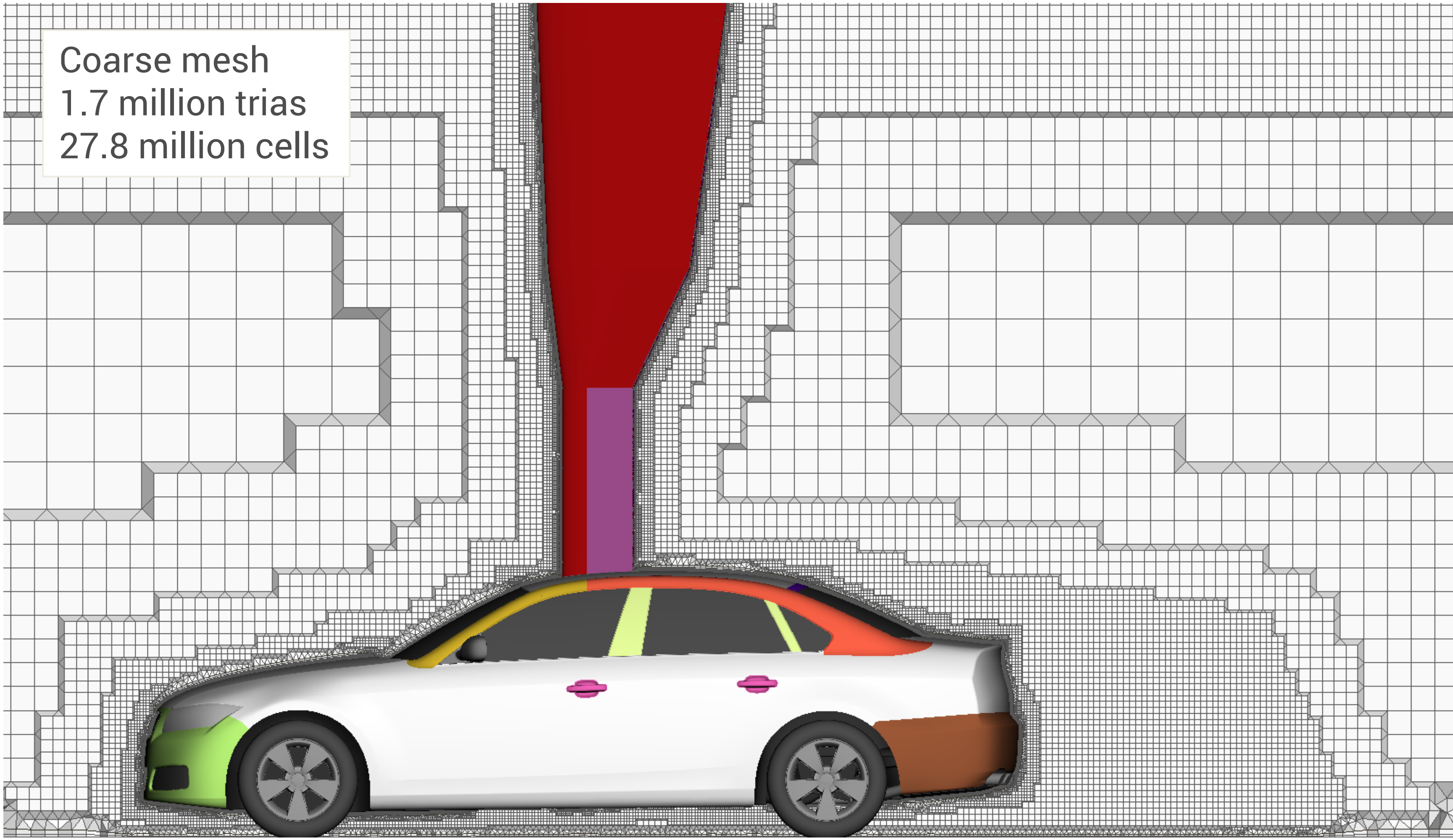
Mesh refinement study for tetra with layers case

Automatic generation of models with variable resolution using batch meshing



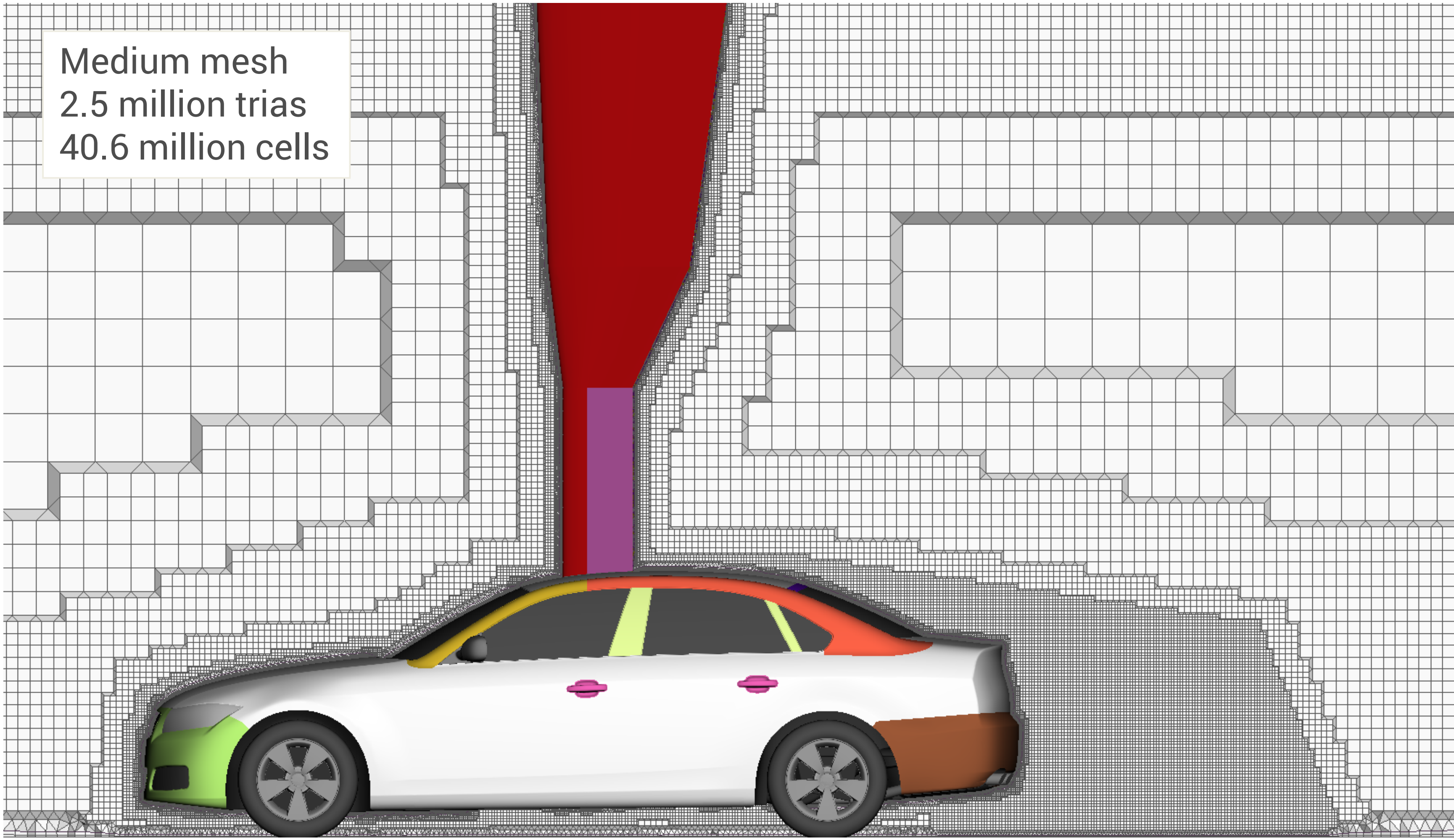
Mesh refinement study for HexaInterior with layers case

Automatic generation of models with variable resolution using batch meshing



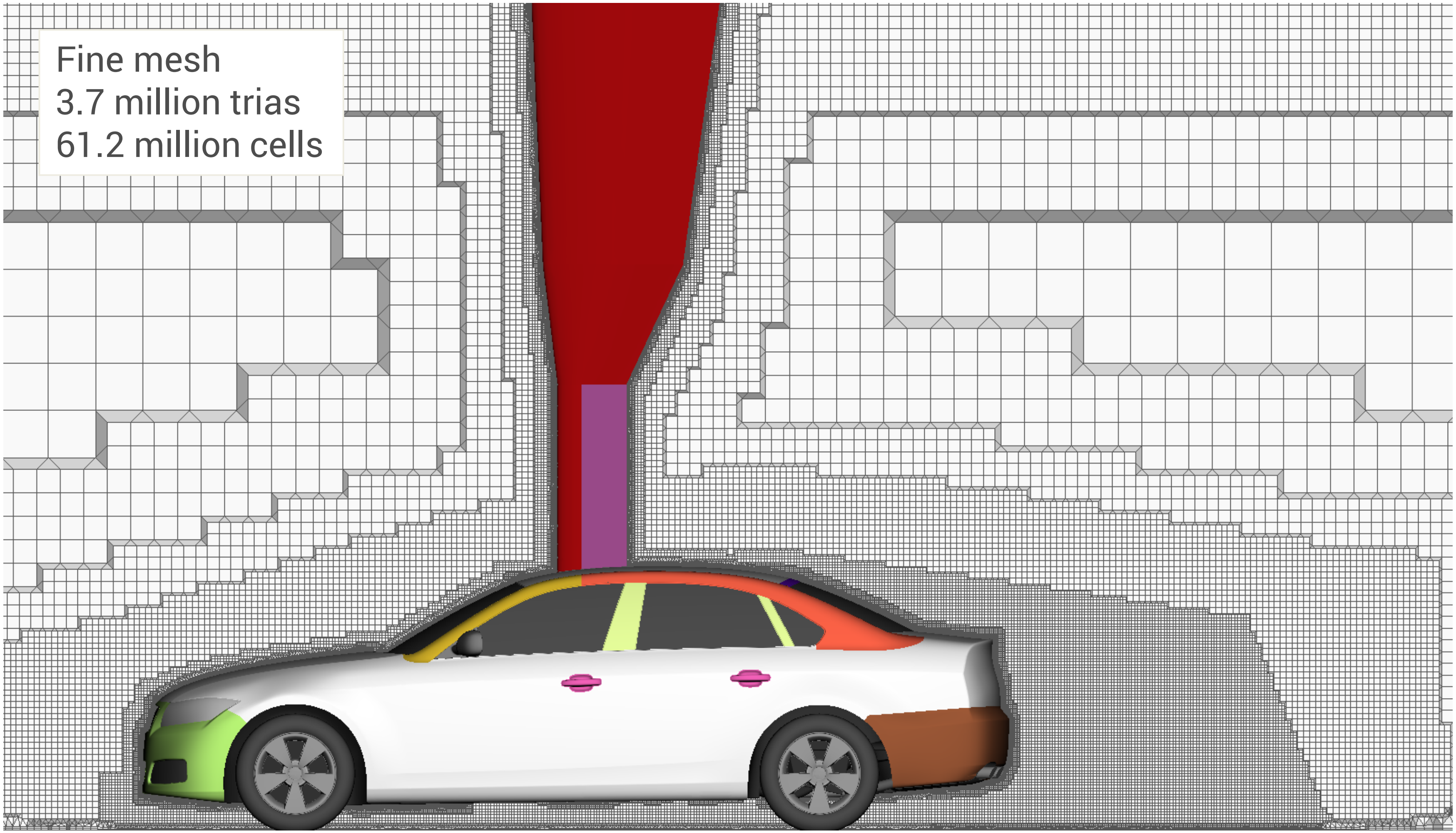
Mesh refinement study for HexaInterior with layers case

Automatic generation of models with variable resolution using batch meshing



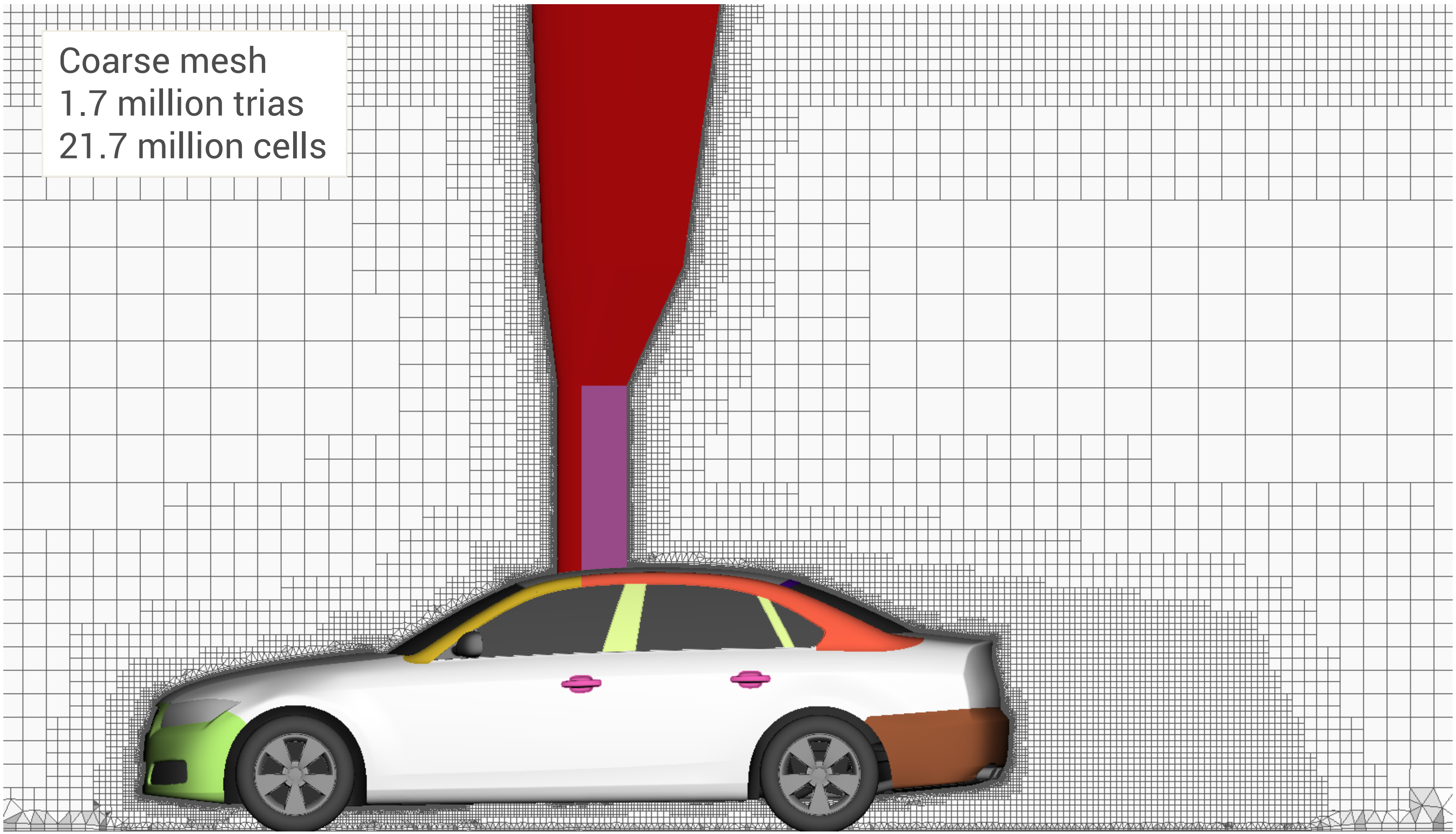
Mesh refinement study for HexaInterior with layers case

Automatic generation of models with variable resolution using batch meshing



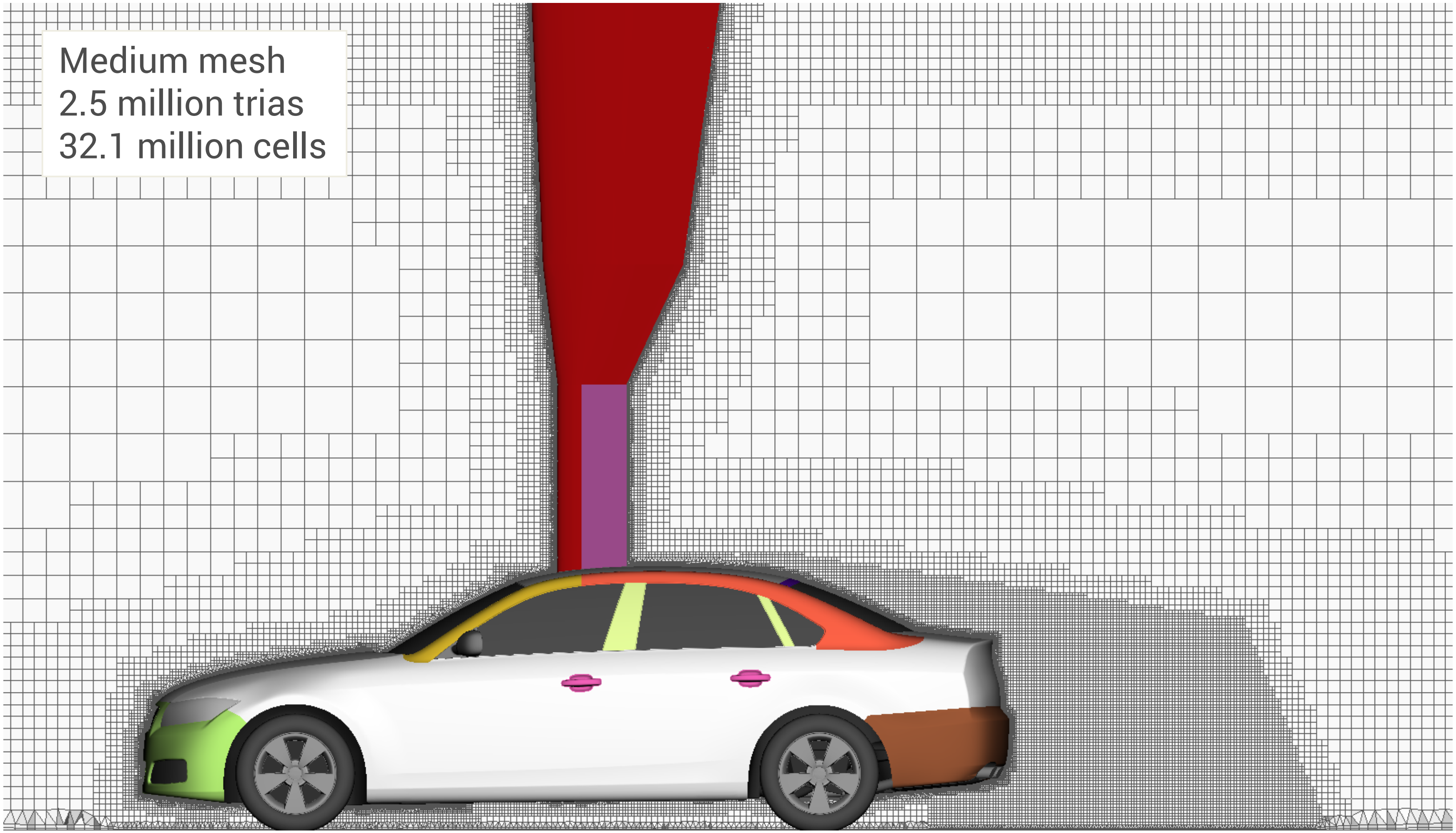
Mesh refinement study for HexaPoly with layers case

Automatic generation of models with variable resolution using batch meshing



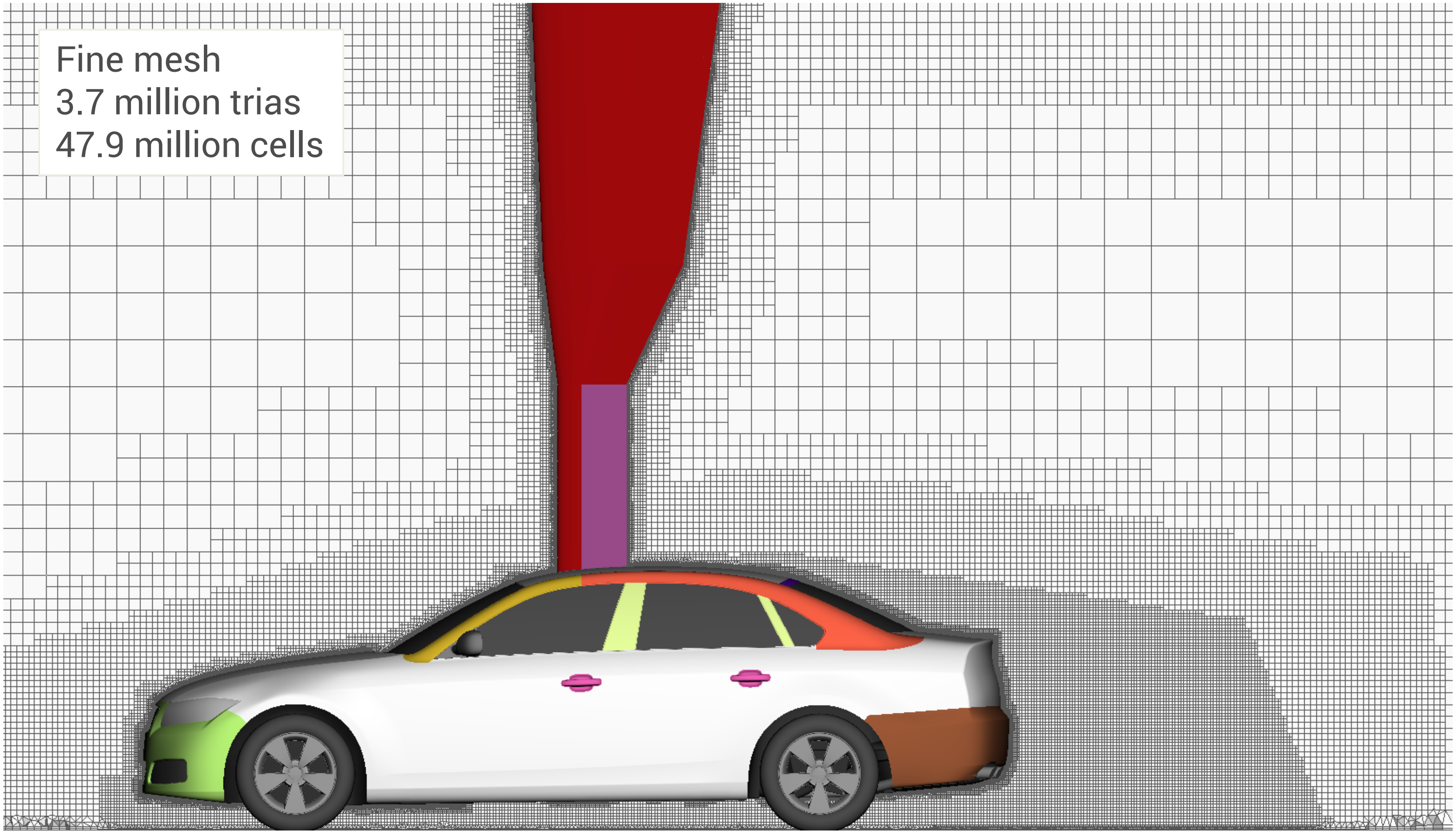
Mesh refinement study for HexaPoly with layers case

Automatic generation of models with variable resolution using batch meshing

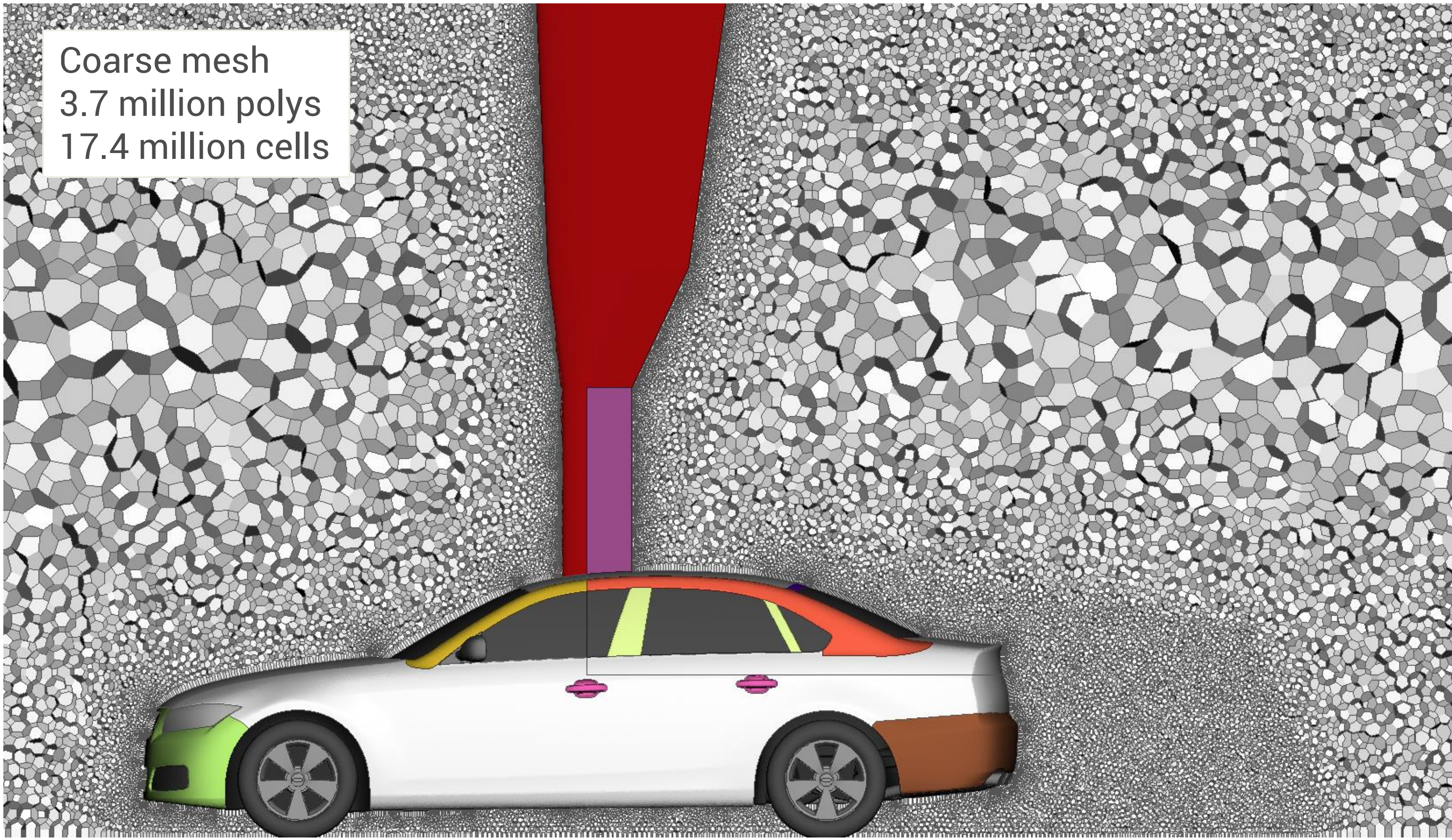


Mesh refinement study for HexaPoly with layers case

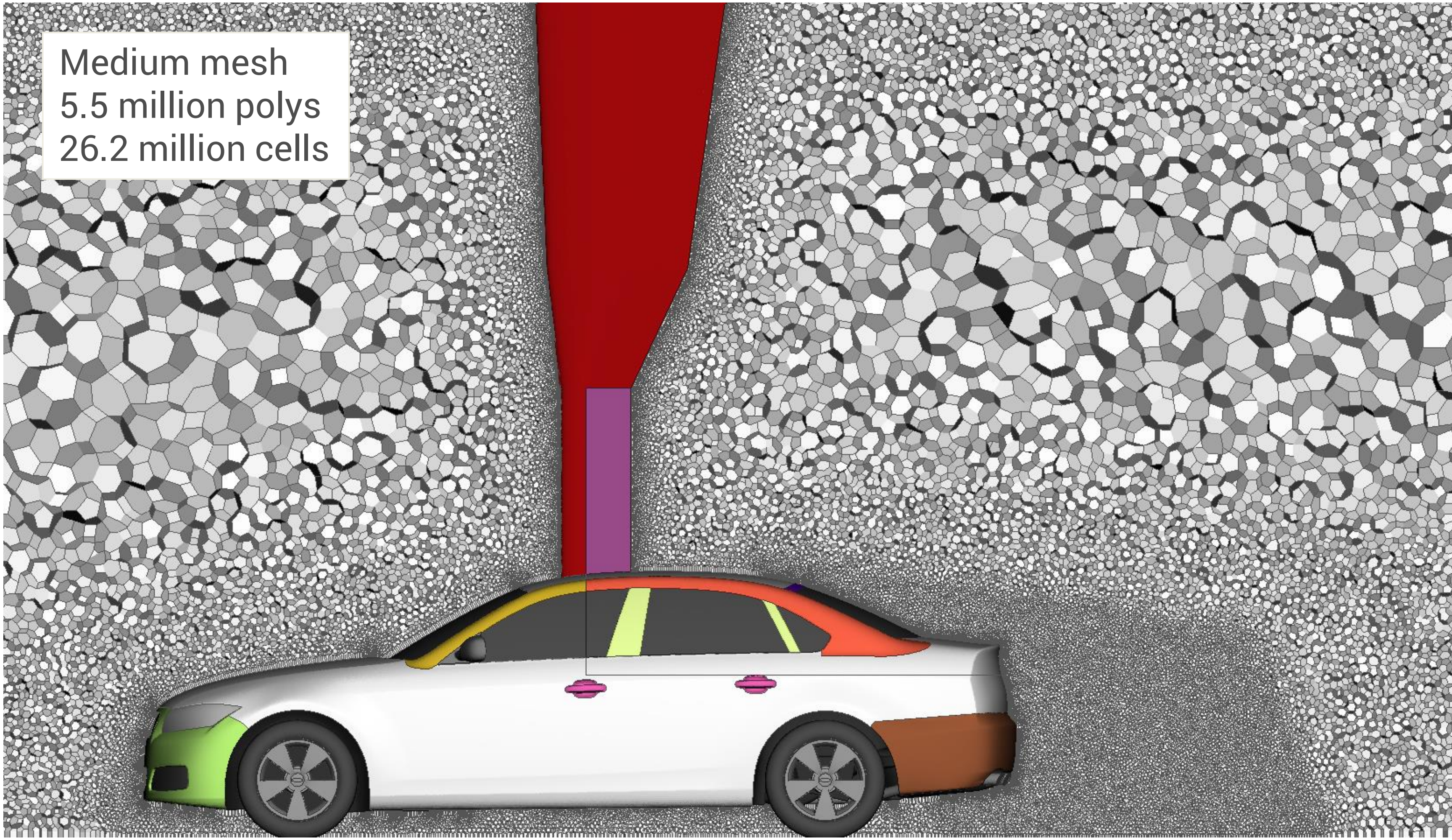
Automatic generation of models with variable resolution using batch meshing



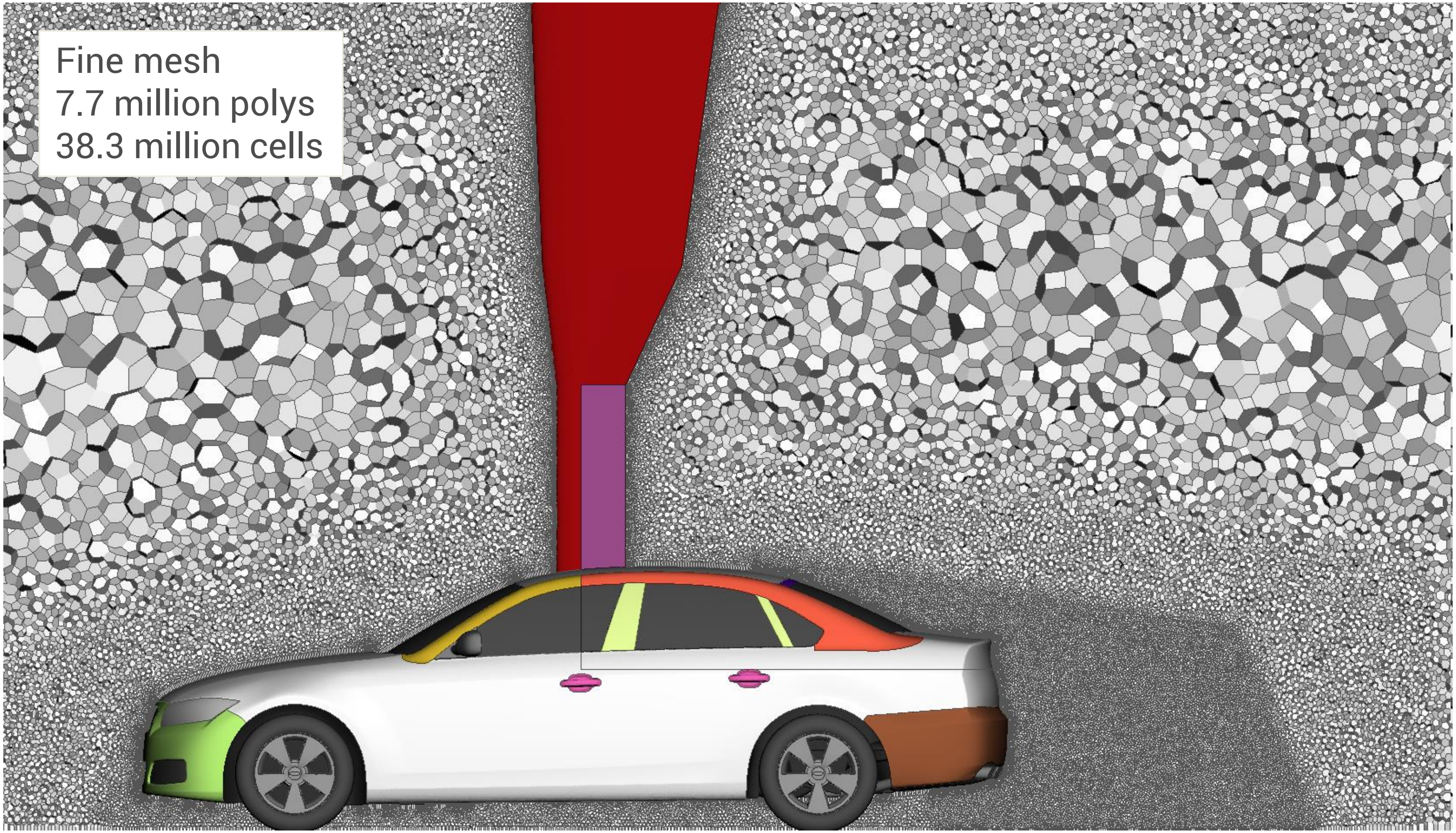
Generation of Polyhedral mesh through hybrid mesh conversion



Generation of Polyhedral mesh through hybrid mesh conversion

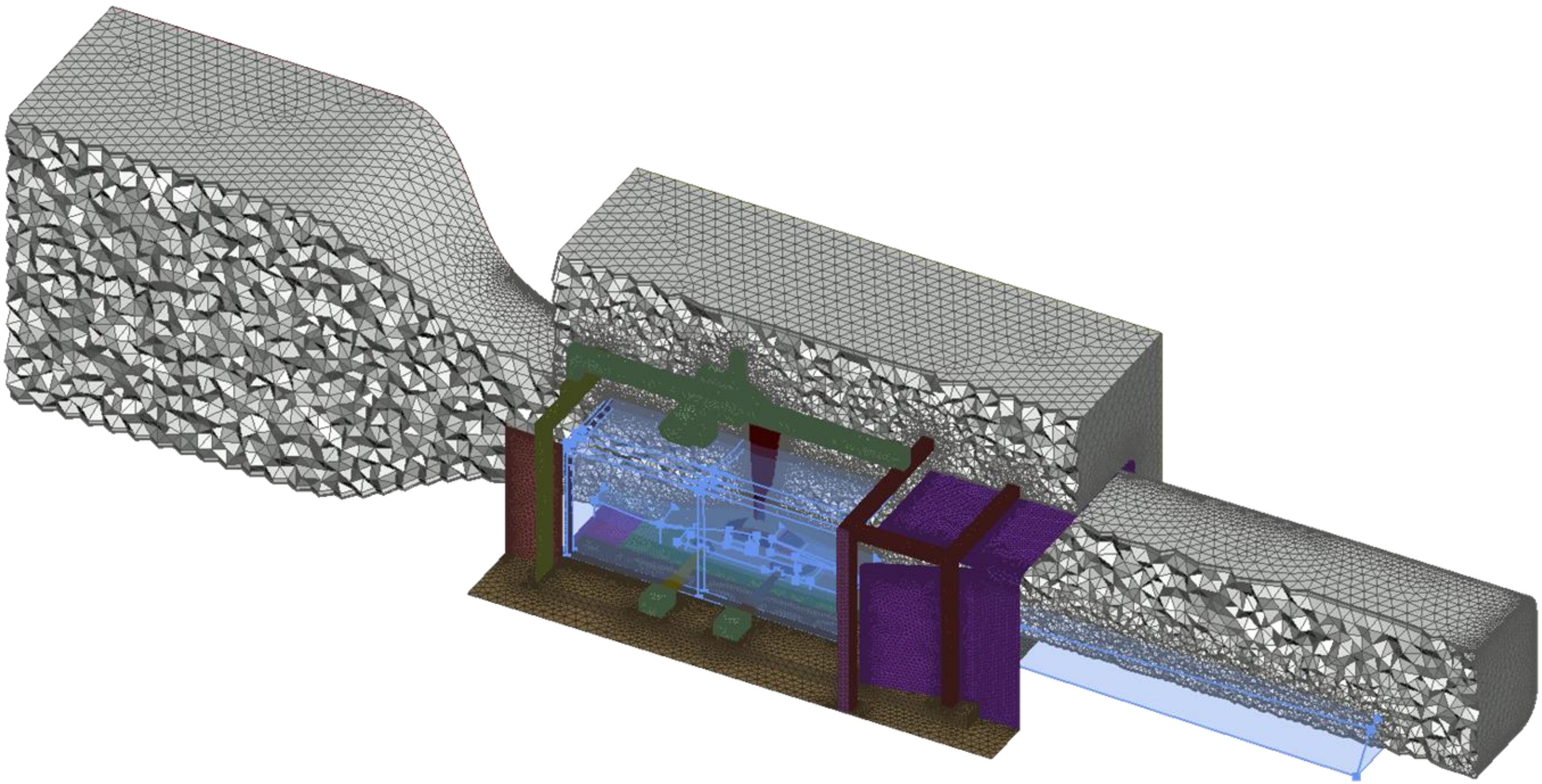


Generation of Polyhedral mesh through hybrid mesh conversion

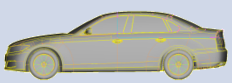
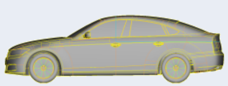
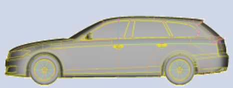


Overview of final volume mesh

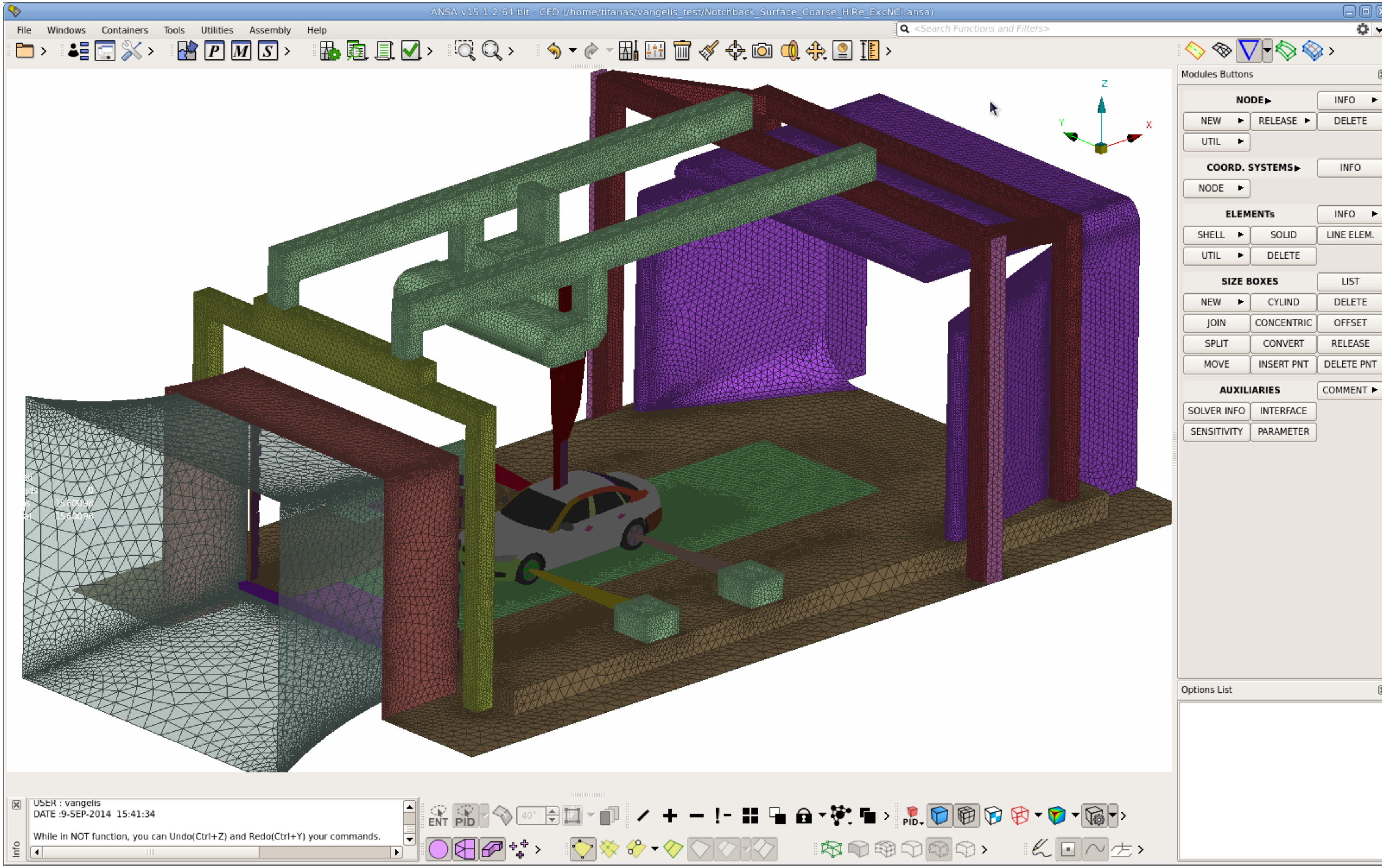
Medium tetra model



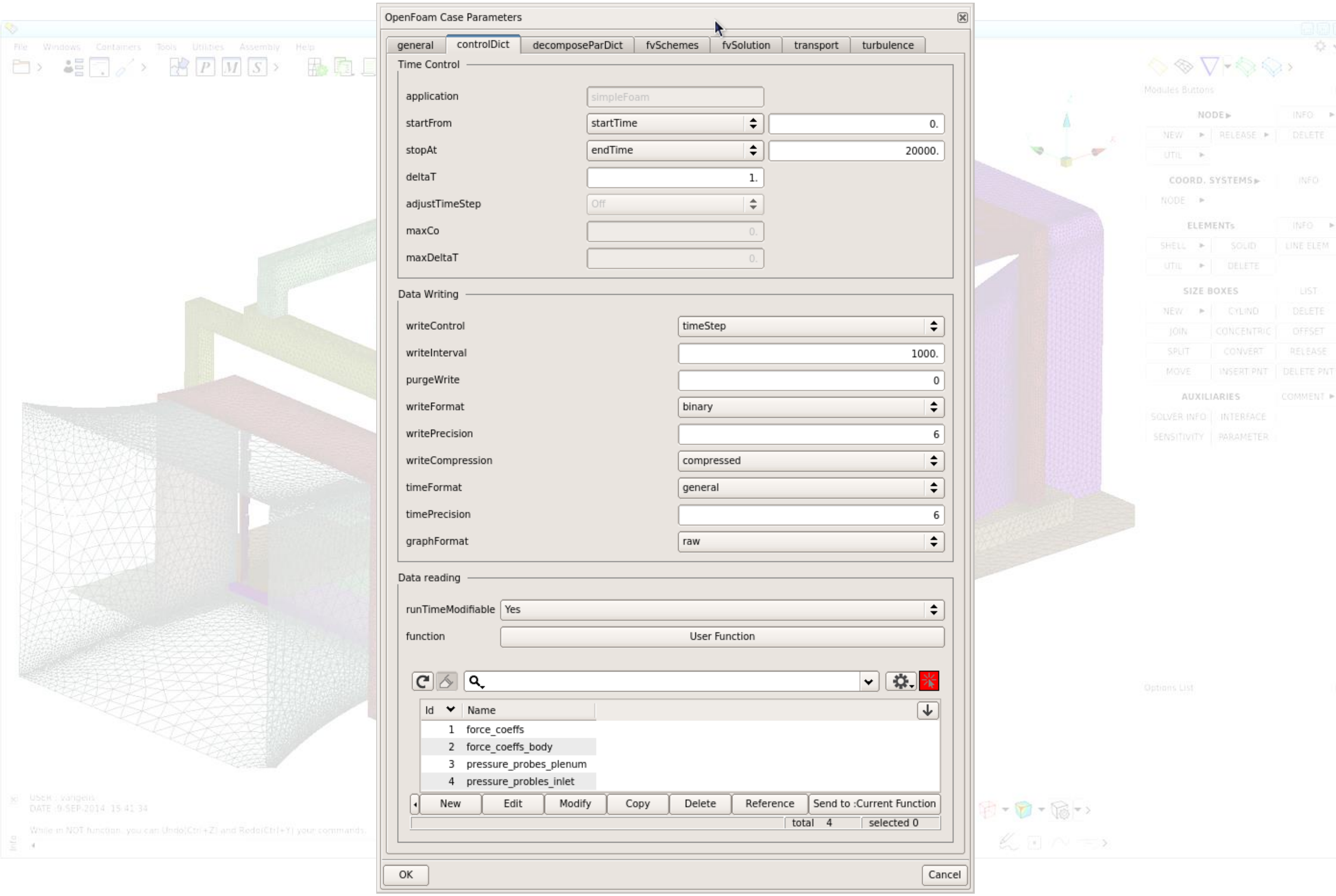
Summary of mesh models for different variants

		Coarse	Medium	Fine
Notchback 	Open domain	-	Tetra (30.6 million)	-
	Wind tunnel	Tetra (34.5 million)	Tetra (50 million)	Tetra (78.7 million)
		Hexa Interior (27.8 million)	Hexa Interior (40.6 million)	Hexa Interior (61.2 million)
		Hexa Poly (21.7 million)	Hexa Poly (32.1 million)	Tetra (47.9 million)
		Polyhedral (17.4 million)	Polyhedral (26.2 million)	Polyhedral (38.3 million)
Fastback 		-	Tetra (50.1 million)	-
Estate 		-	Tetra (51.6 million)	-

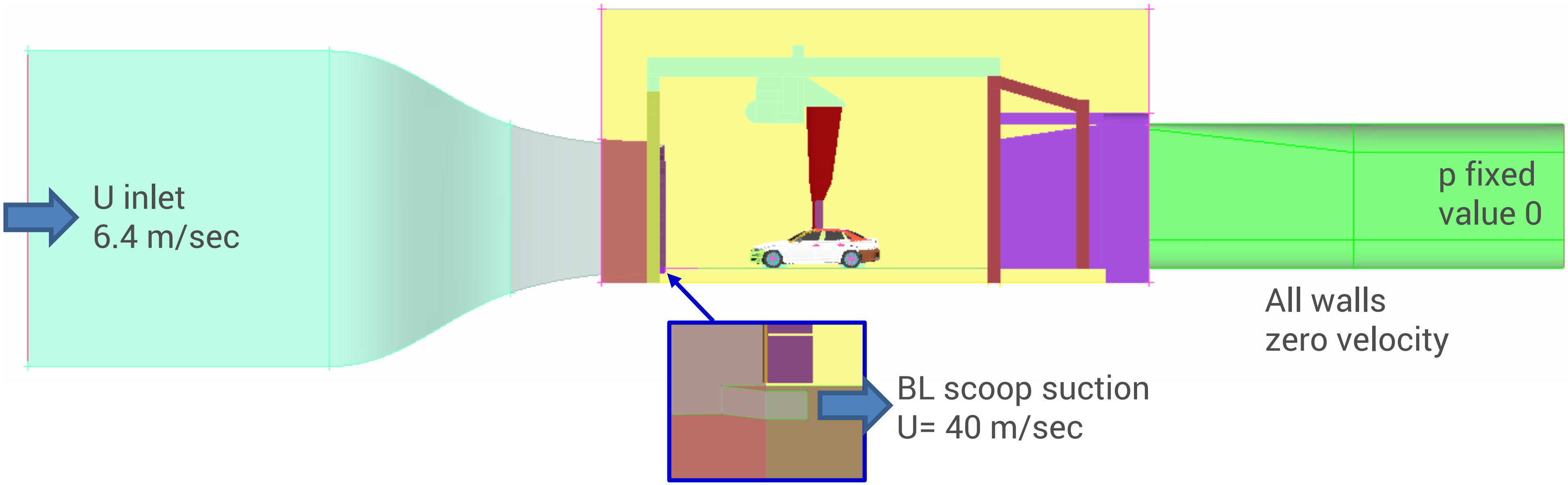
Setting up the OpenFOAM case in ANSA



Setting up the OpenFOAM case in ANSA



OpenFOAM simulations: setup



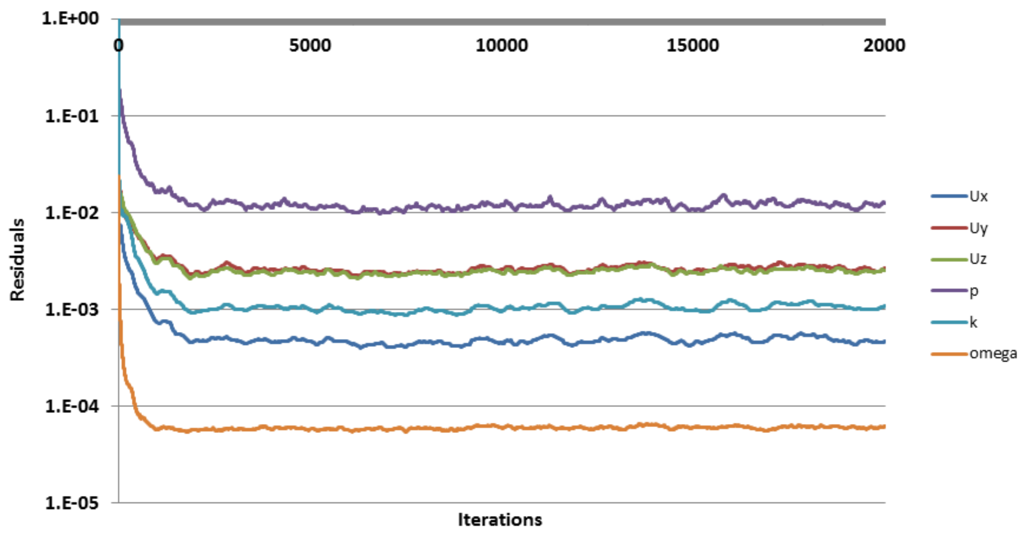
Numerical settings
LinearUpwind scheme for velocity
Upwind scheme for turbulence
GAMG solver for pressure, tolerance 10^{-10}, relTol 0.05
smoothSolver for velocity and turbulence, tolerance 10^{-10}, relTol 0.1

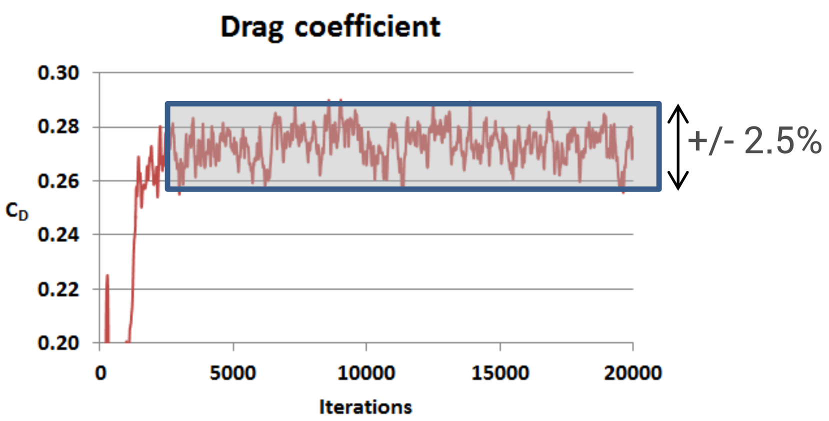
Steady State simulations
simpleFoam
Turbulence model: k-omega SST
Stationary ground
All runs initialized with potentialFoam

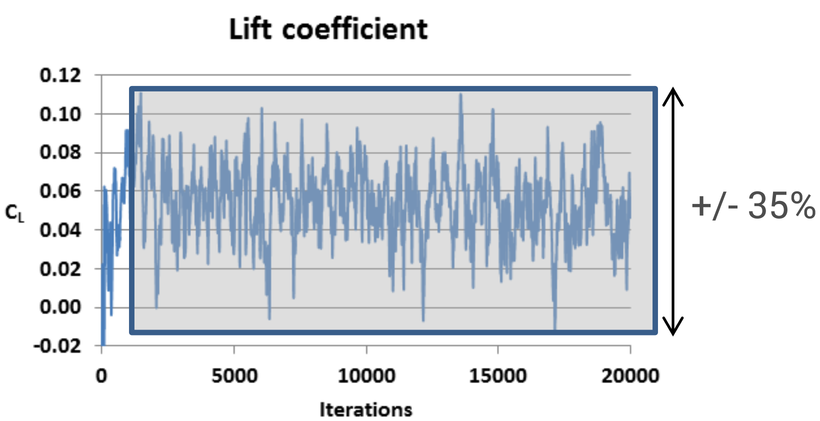
Transient simulation
pisoFoam
Time step 10^{-4} sec
Run for 3.5 sec real time
Turbulence model: IDDES Spalart Almaras for near wall
Run starting from converged steady state solution

OpenFOAM simulations: Steady state simpleFoam convergence

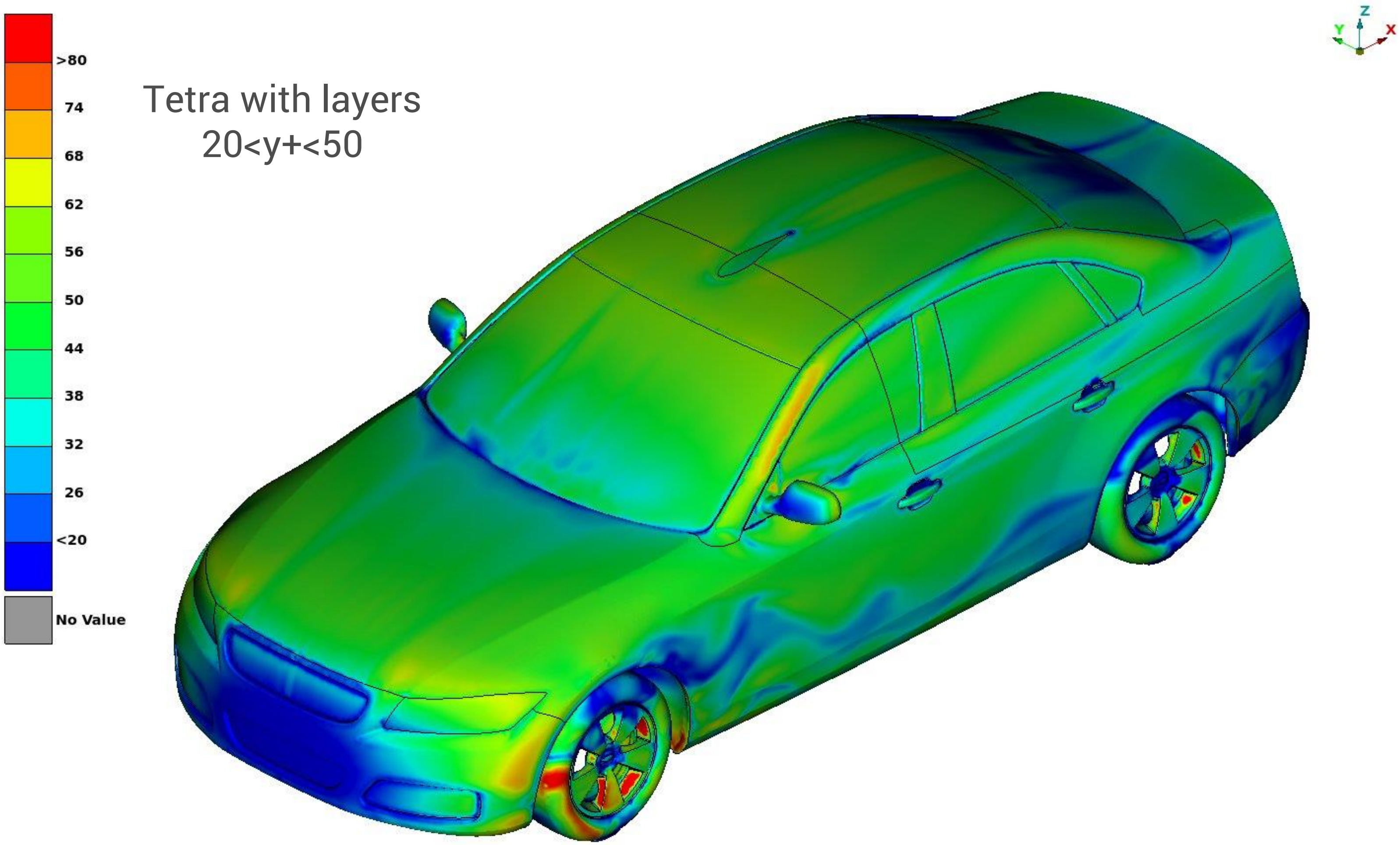
Indicative convergence history of residuals and drag and lift coefficients for Notchback TetraRapid medium model







Post-processing in META: y+ results

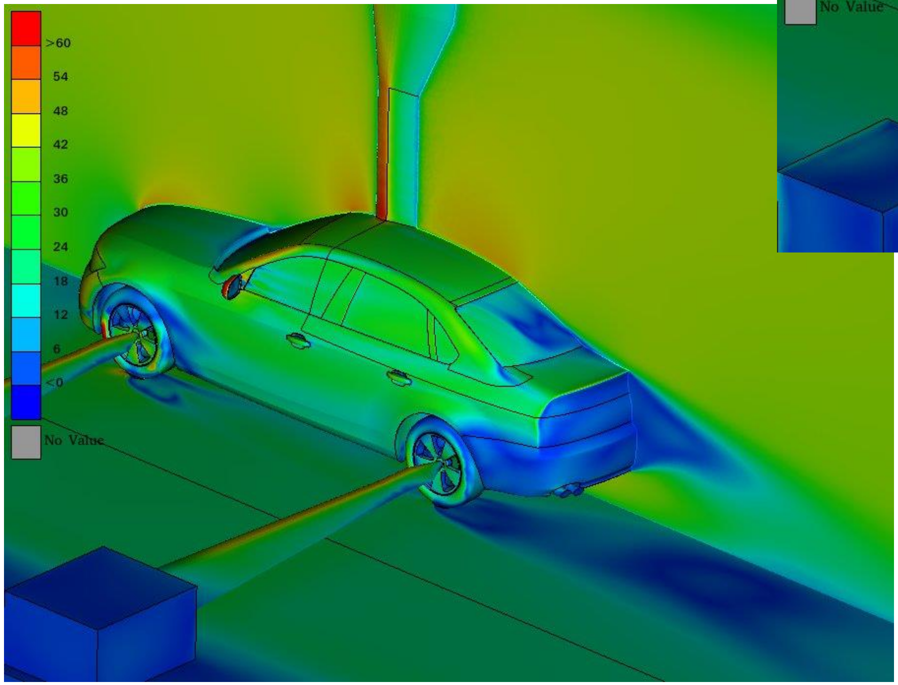


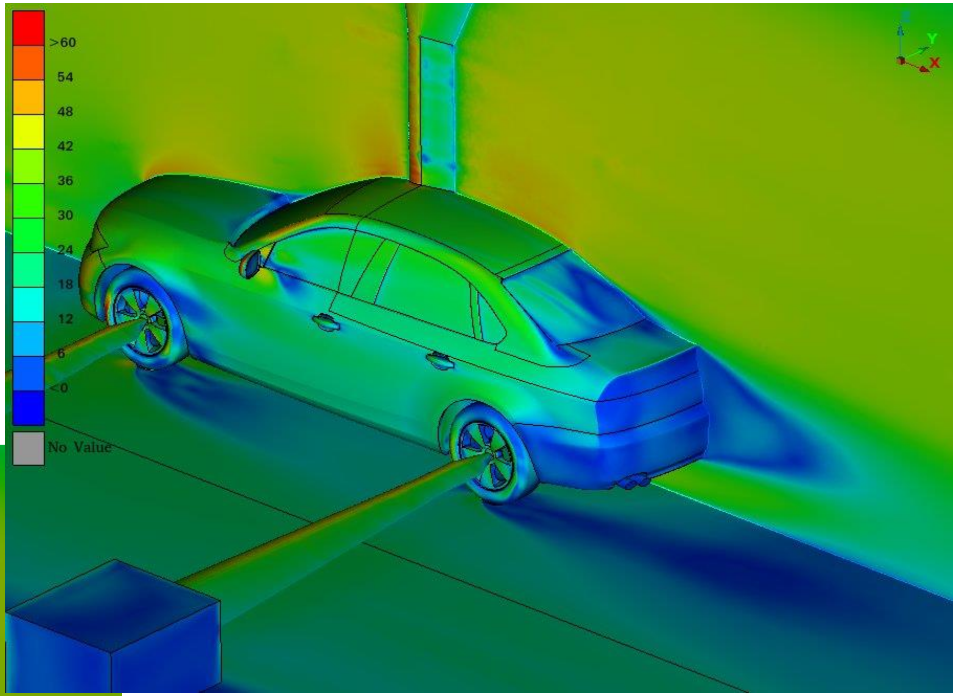
Post-processing was performed manually for one CFD run and then META run in batch mode for the other 14 simulations producing automatically the same images

Velocity field at symmetry plane of notchback

Tetra medium mesh

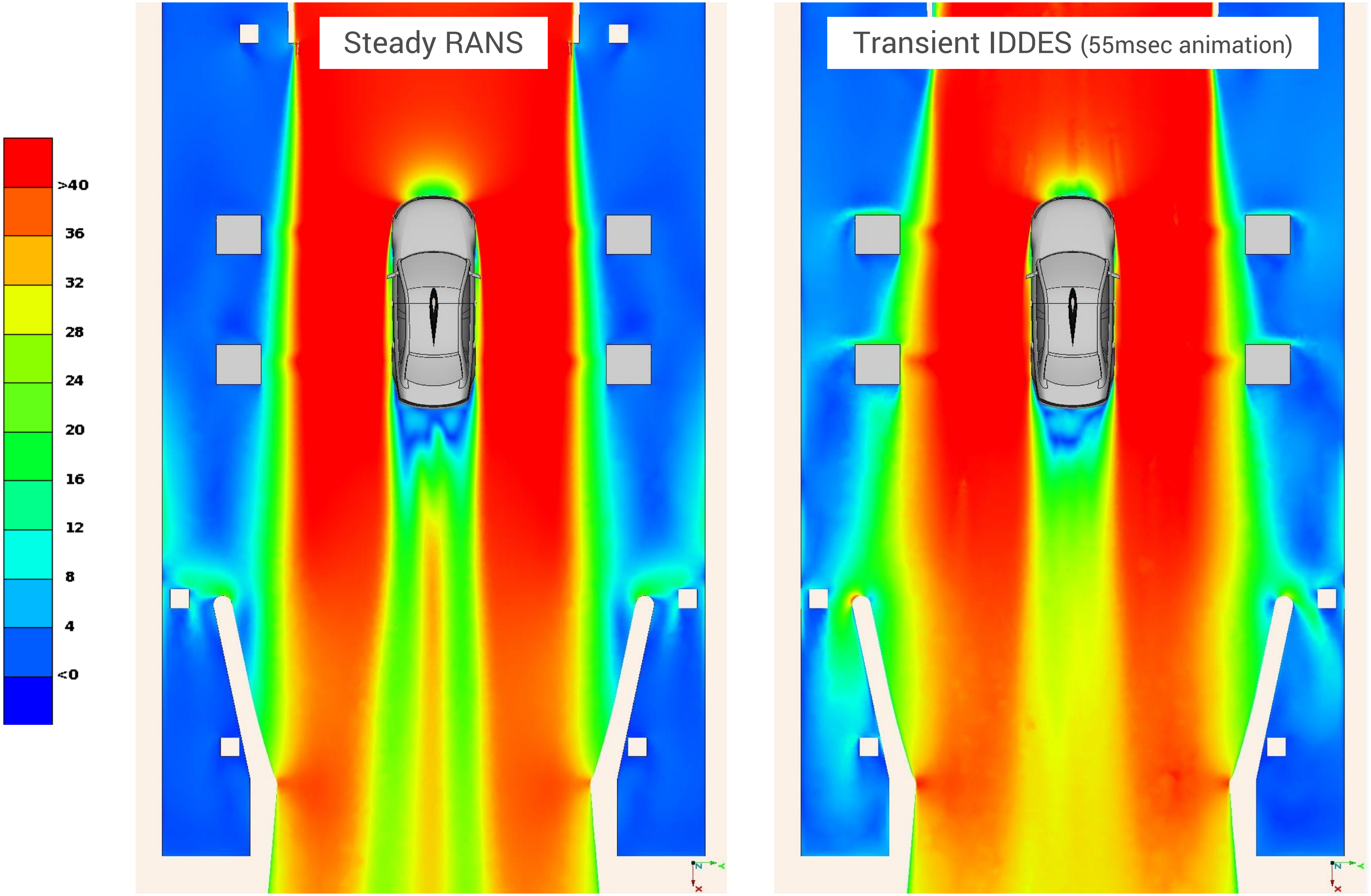
RANS





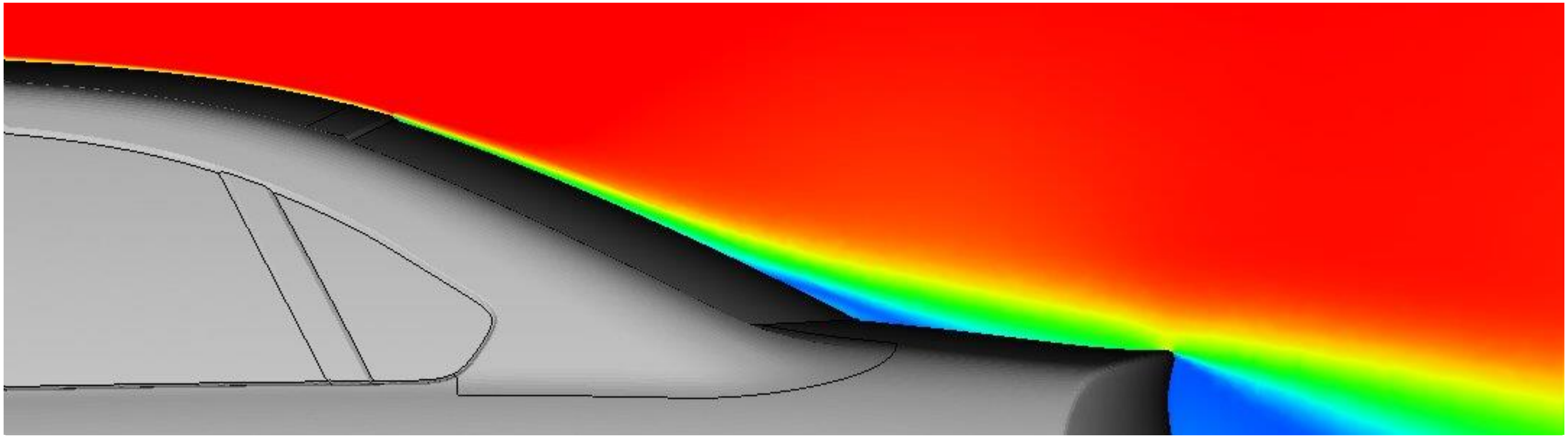
Transient IDDES (55msec animation)

Cut-plane of velocity magnitude

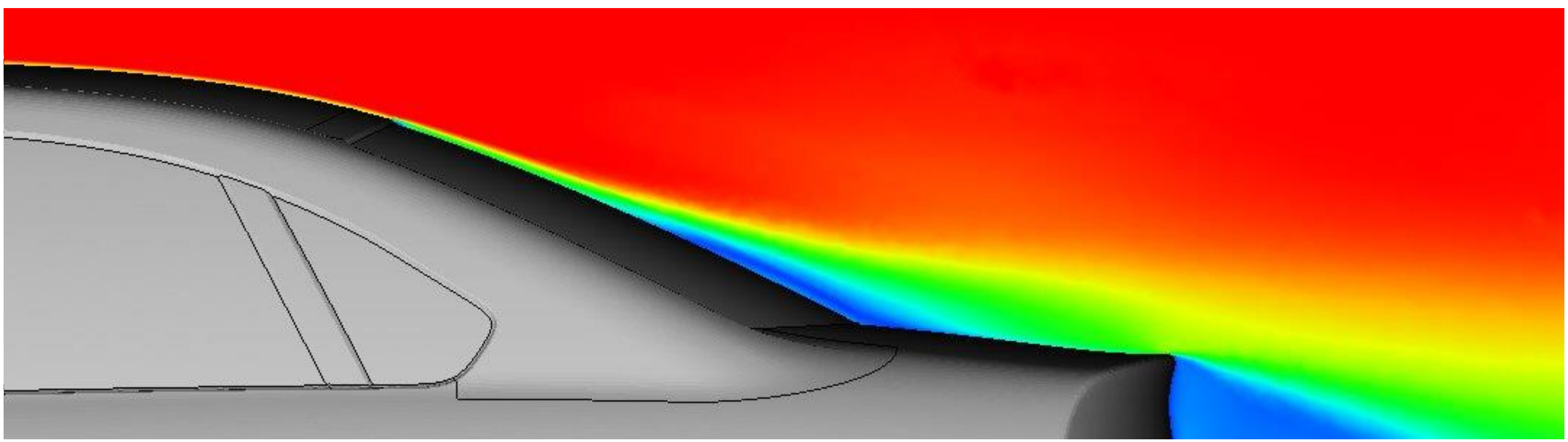


Velocity field at symmetry plane of notchback (tetra medium mesh)

RANS

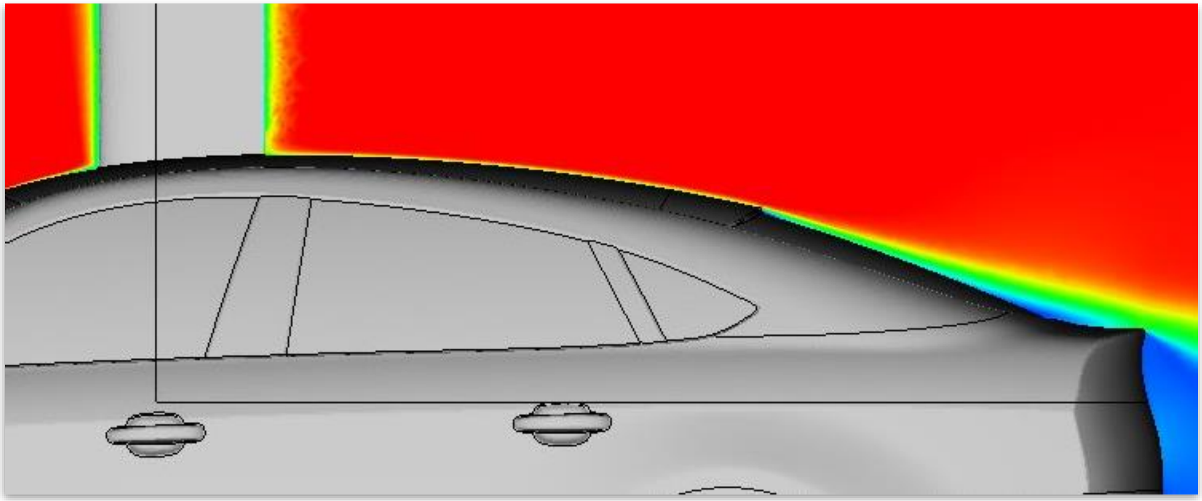


Transient IDDES (55 msec animation)

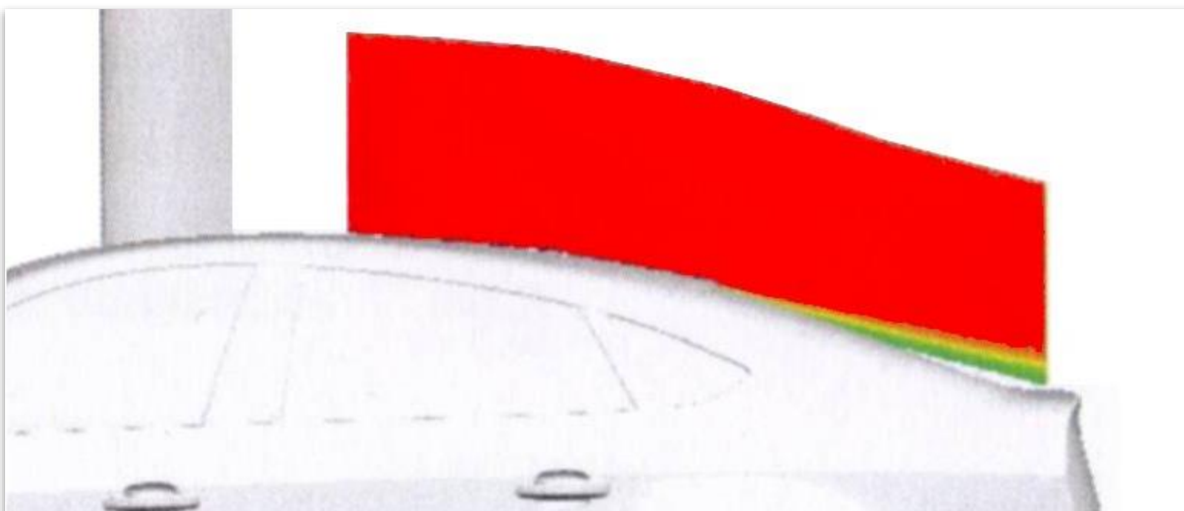


Velocity field at symmetry plane of fastback model

Averaged Velocity



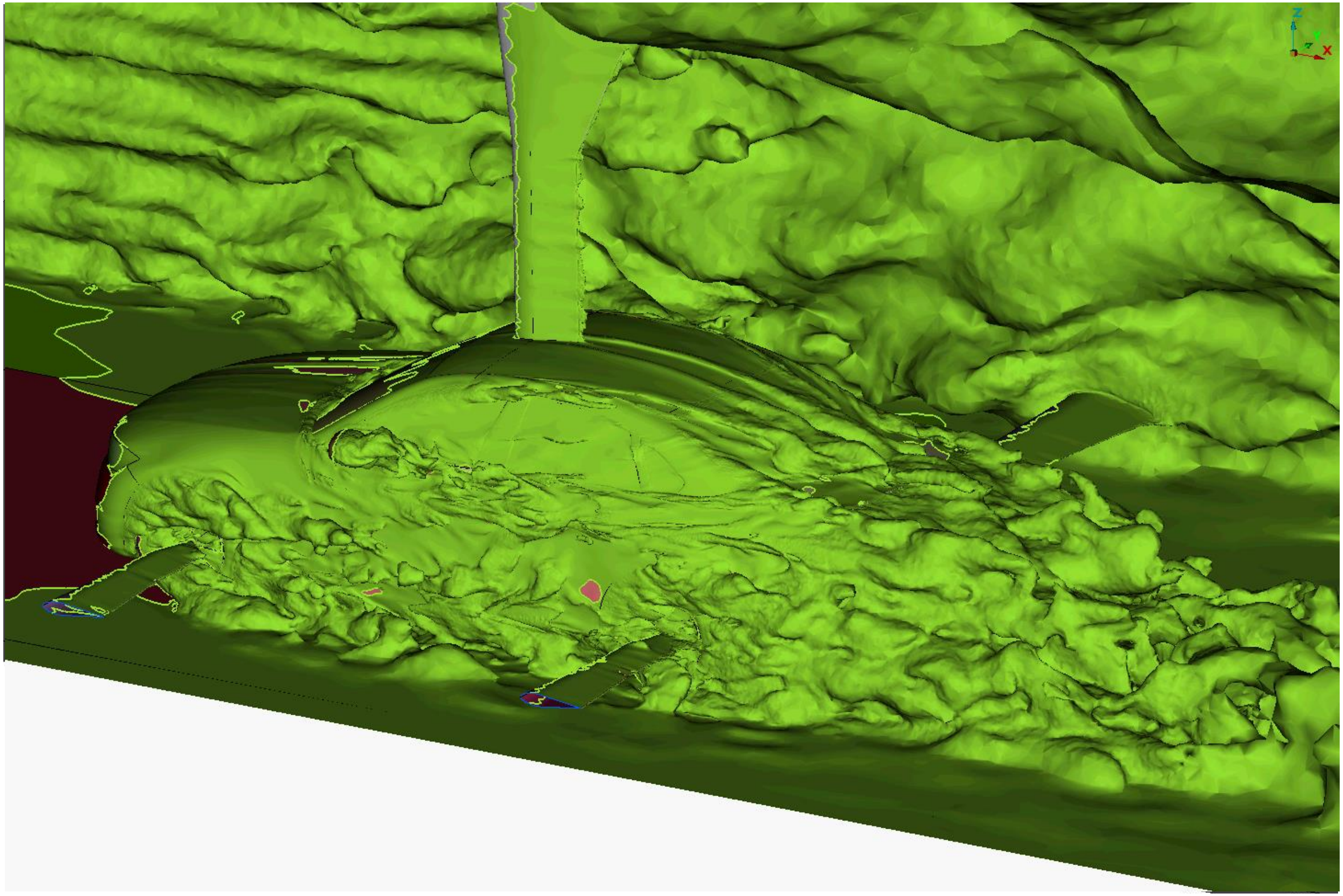
RANS k-omega SST
(Tetra Medium Mesh)



Experiment

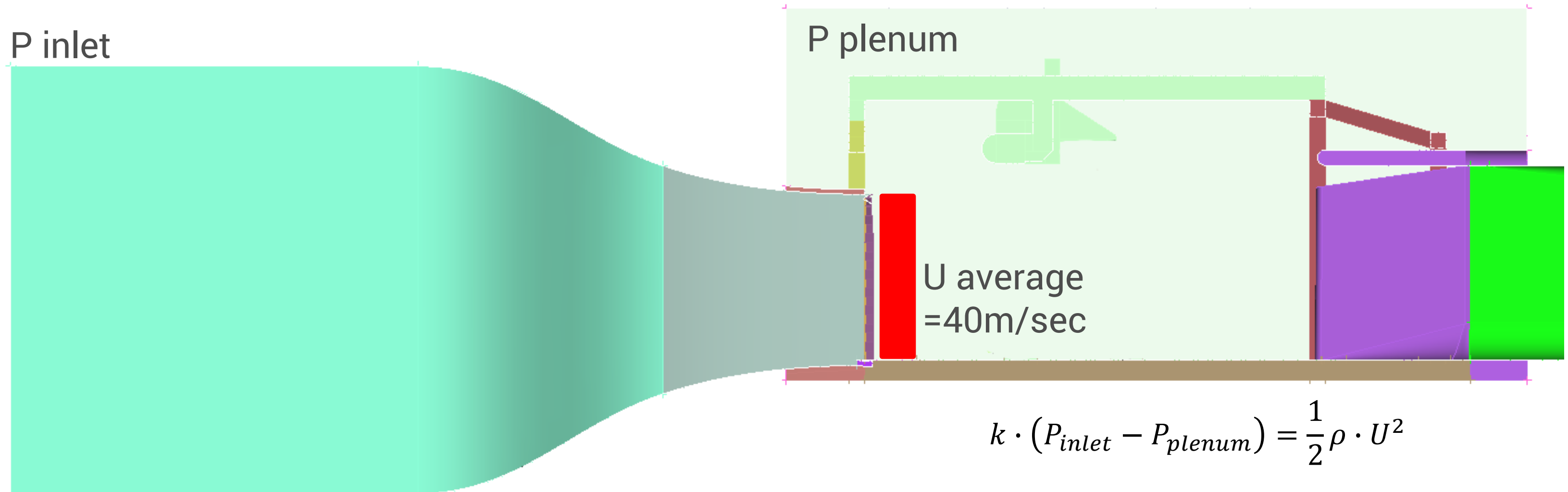
Pressure loss regions: iso-surface of total pressure = 0

Tetra medium mesh

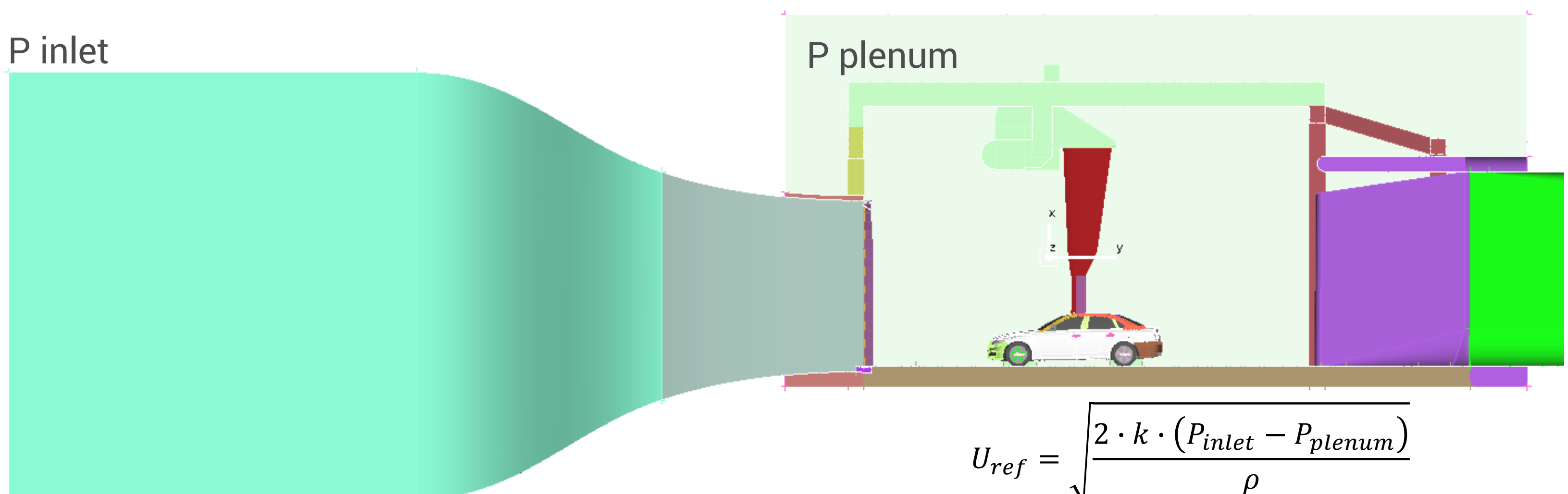


Open section wind tunnel corrections

Correction is applied on U_{ref} based on the Plenum Method described by B. Nijhof, G. Wickern SAE 2003-01-0428 and R. Kuenstner, K. Deutenbach, J. Vagt SAE 920344

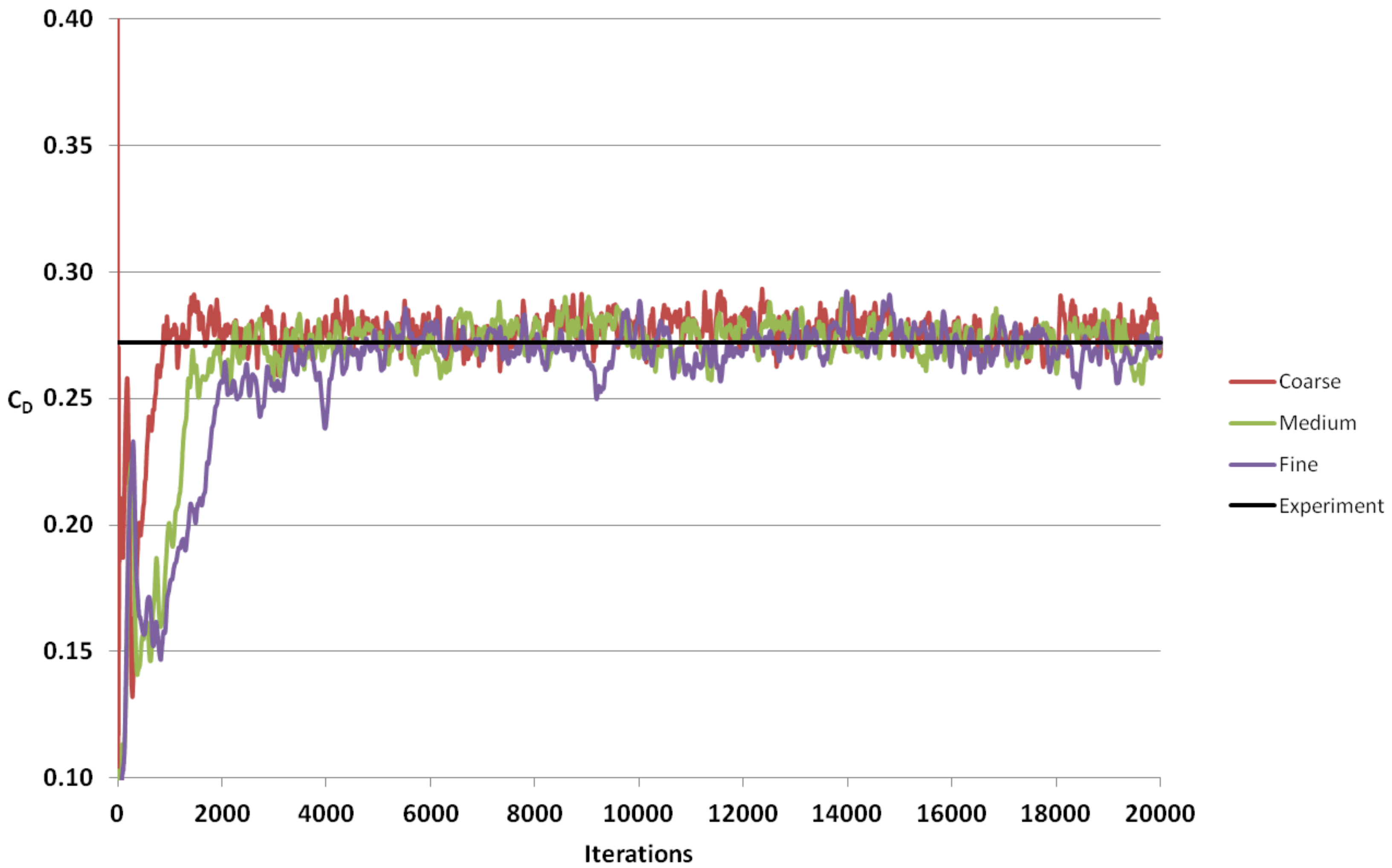


$$k \cdot \left(P_{inlet} - P_{plenum}\right) = \frac{1}{2} \rho \cdot U^2$$

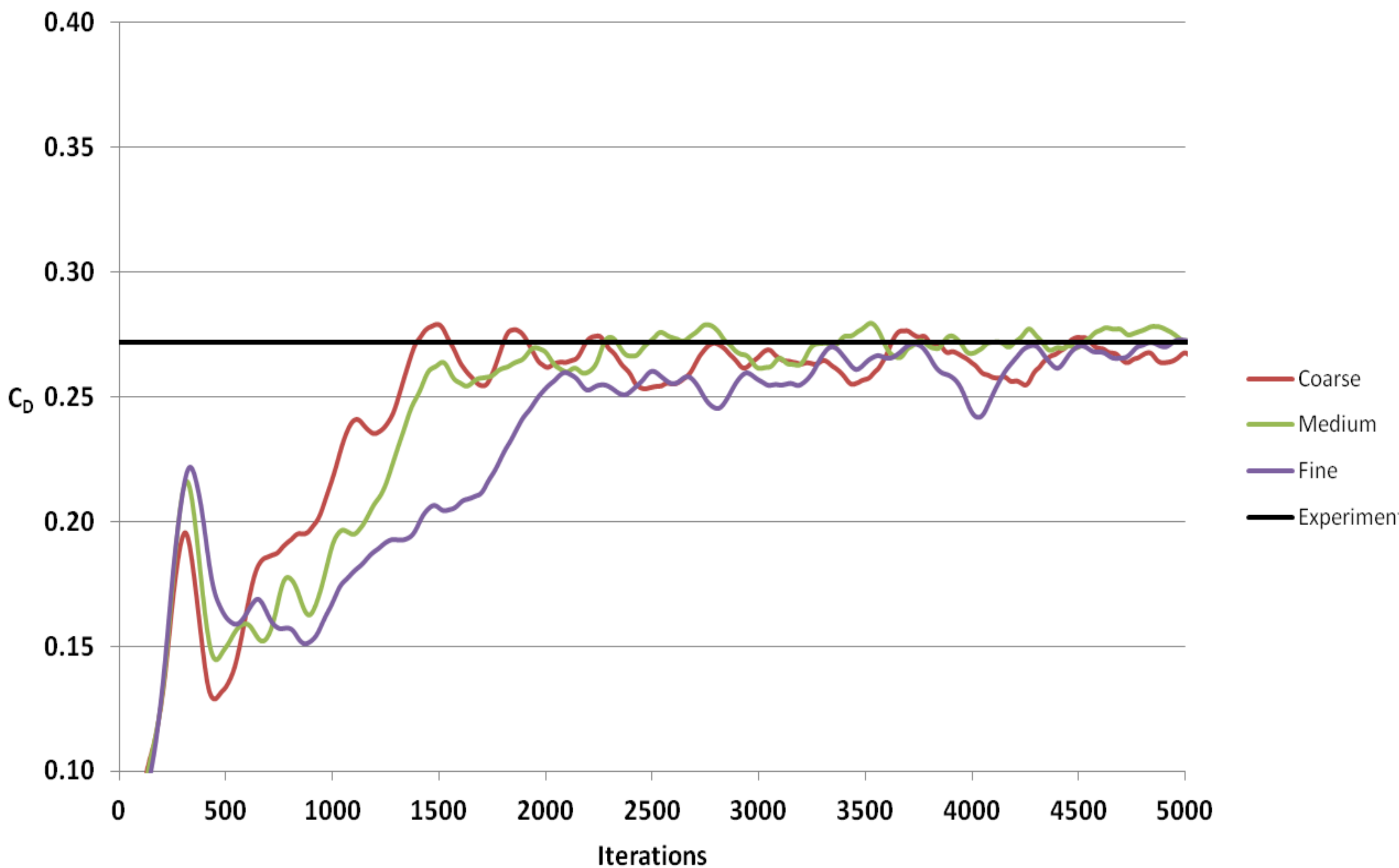


$$U_{ref} = \sqrt{\frac{2 \cdot k \cdot \left(P_{inlet} - P_{plenum}\right)}{\rho}}$$

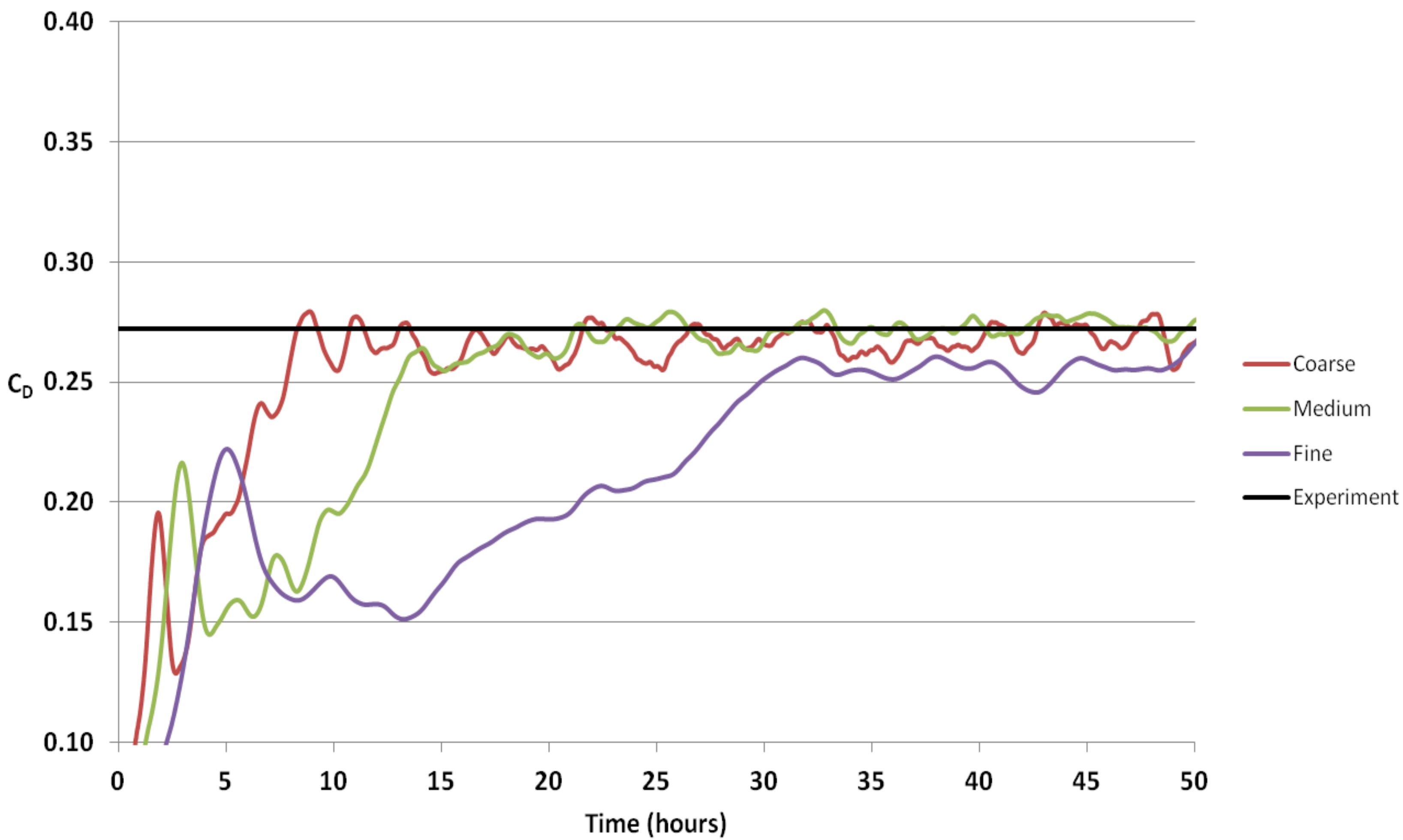
Convergence of drag coefficient: Tetra case - Notchback



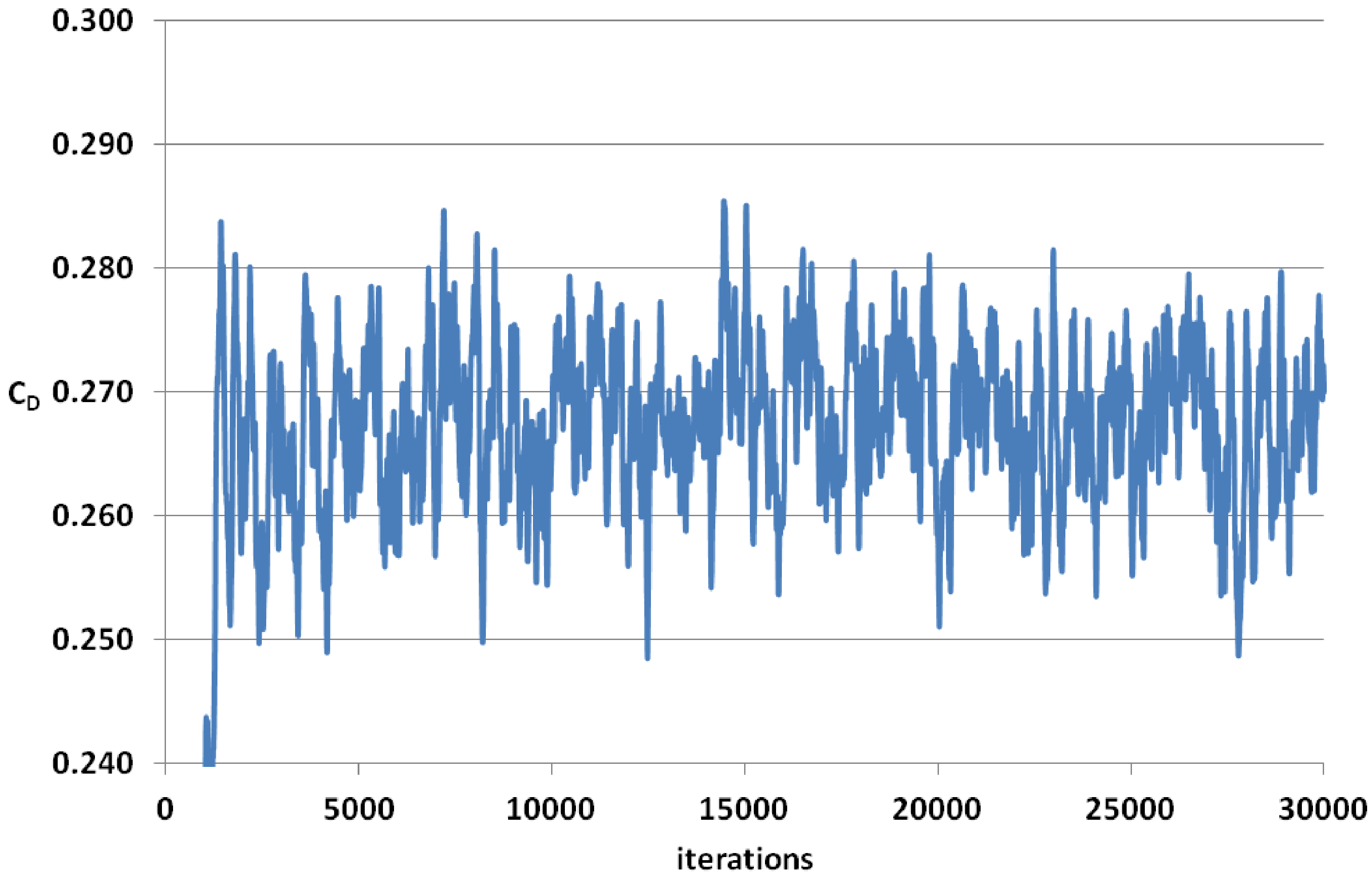
Convergence of drag coefficient: Tetra case - Notchback



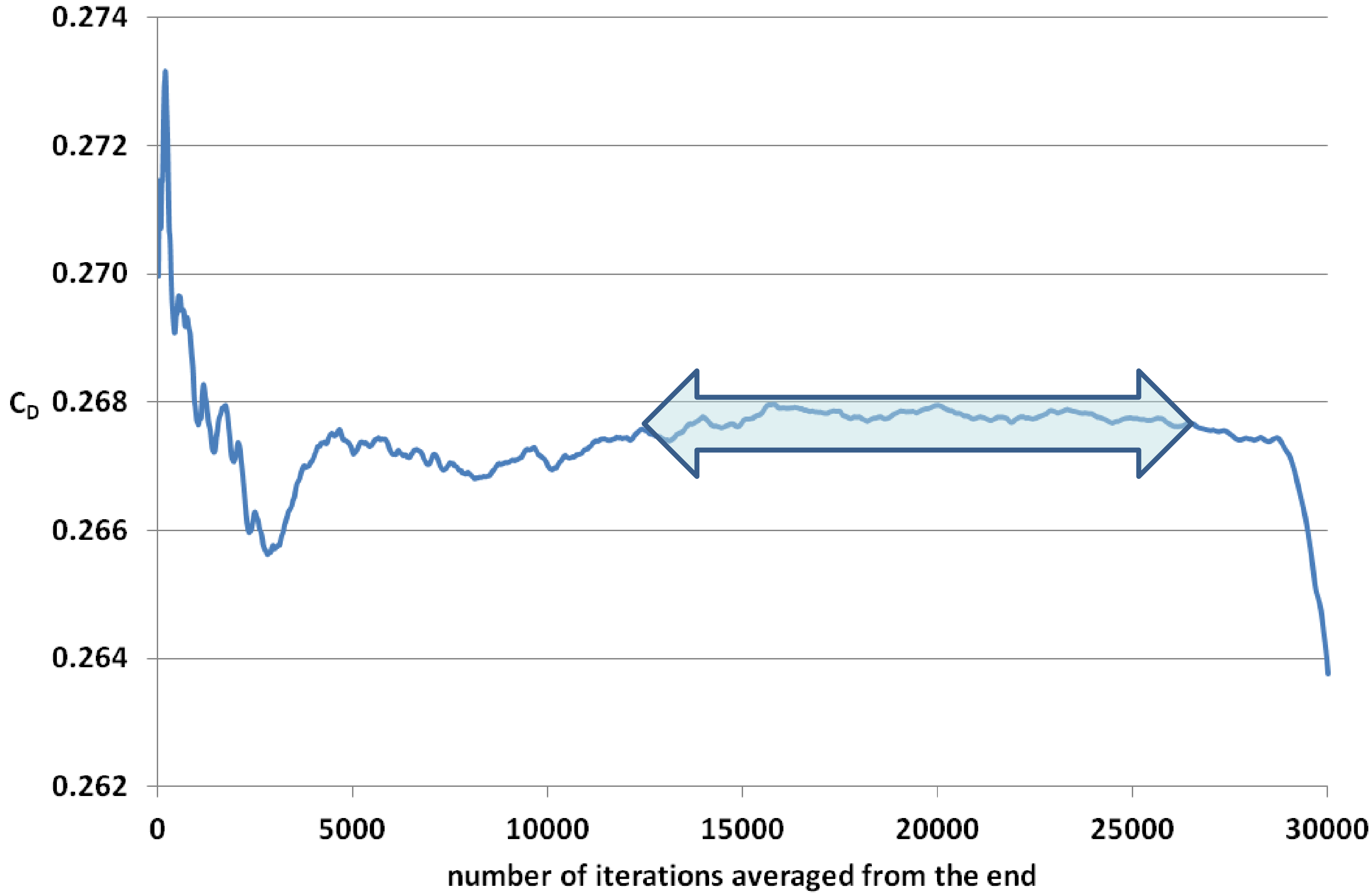
Convergence of drag coefficient: Tetra case - Notchback



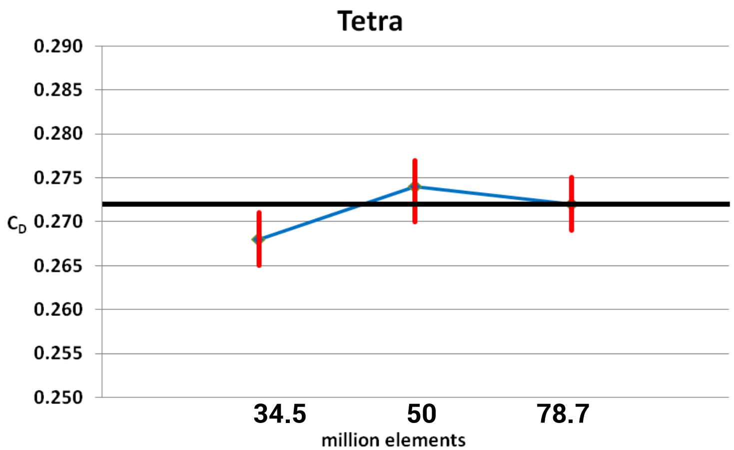
Averaging of fluctuating forces: Tetra medium mesh - Notchback

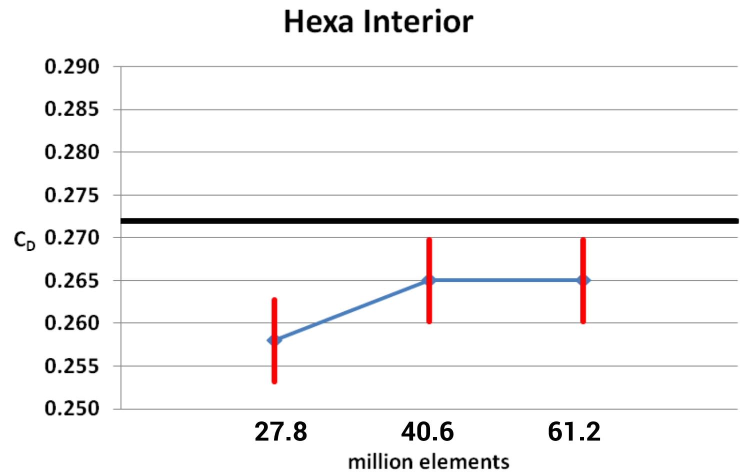


Averaging of fluctuating forces: Tetra medium mesh - Notchback

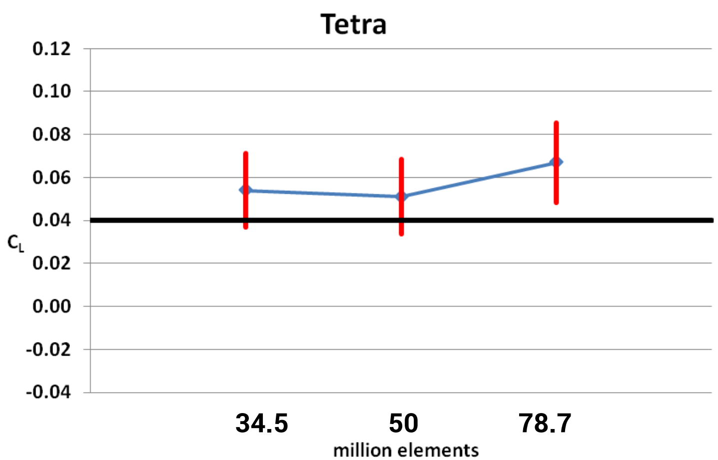


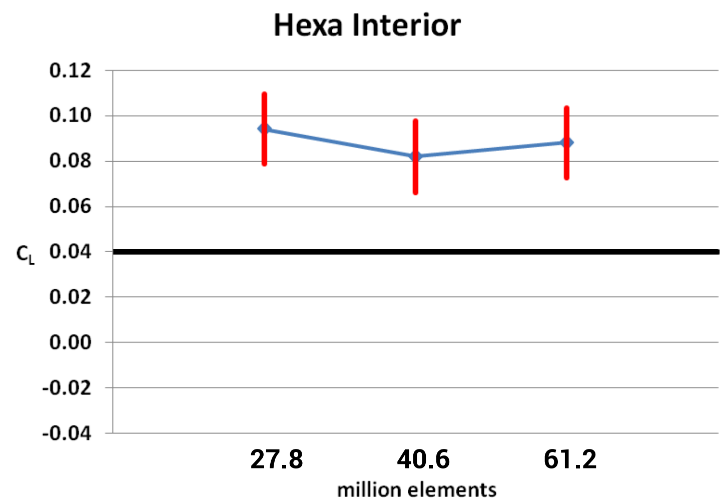
Sensitivity study of Tetra and Hexa Interior meshes: C_D & C_L convergence





Experimental C_D=0.272





Experimental C_L=0.04

Coefficients calculated based on notchback projected frontal area = 0.3475 m^2

Comparison with experimental C_D value of 0.272 for notchback model

	Run	Coarse	Medium	Fine
Open domain	RANS k-omega	-	Tetra 0.284 (+4%)	-
Wind tunnel	RANS k-omega	Tetra 0.268 (-1%)	Tetra 0.274 (+1%)	Tetra 0.272 (0%)
	RANS k-omega	HexaInt 0.258 (-5%)	HexaInt 0.265 (-3%)	HexaInt 0.265 (-3%)
	RANS k-omega	HexaPoly 0.258 (-5%)	HexaPoly 0.258 (-5%)	HexaPoly 0.265 (-3%)
	RANS k-omega	Polyhedral 0.284 (+4%)	Polyhedral 0.301 (+11%)	Polyhedral 0.283 (+4%)
	DES S-A	-	Tetra 0.281 (+3%)	-

Plenum method corrected values presented (correction can be as high as 15%)

Comparison with experimental C_L value of 0.04 for notchback model

	Run	Coarse	Medium	Fine
Open domain	RANS k-omega	-	Tetra 0.078 (+95%)	-
Wind tunnel	RANS k-omega	Tetra 0.054 (+35%)	Tetra 0.051 (+28%)	Tetra 0.067 (+68%)
	RANS k-omega	HexaInt 0.094 (+135%)	HexaInt 0.082 (+105%)	HexaInt 0.088 (+120%)
	RANS k-omega	HexaPoly 0.116 (+190%)	HexaPoly 0.087 (+118%)	HexaPoly 0.096 (+140%)
	RANS k-omega	Polyhedral 0.096 (+140%)	Polyhedral 0.133 (+233%)	Polyhedral 0.116 (+190%)
	DES S-A	-	Tetra 0.031 (-23%)	-

Plenum method corrected values presented (correction can be as high as 15%)

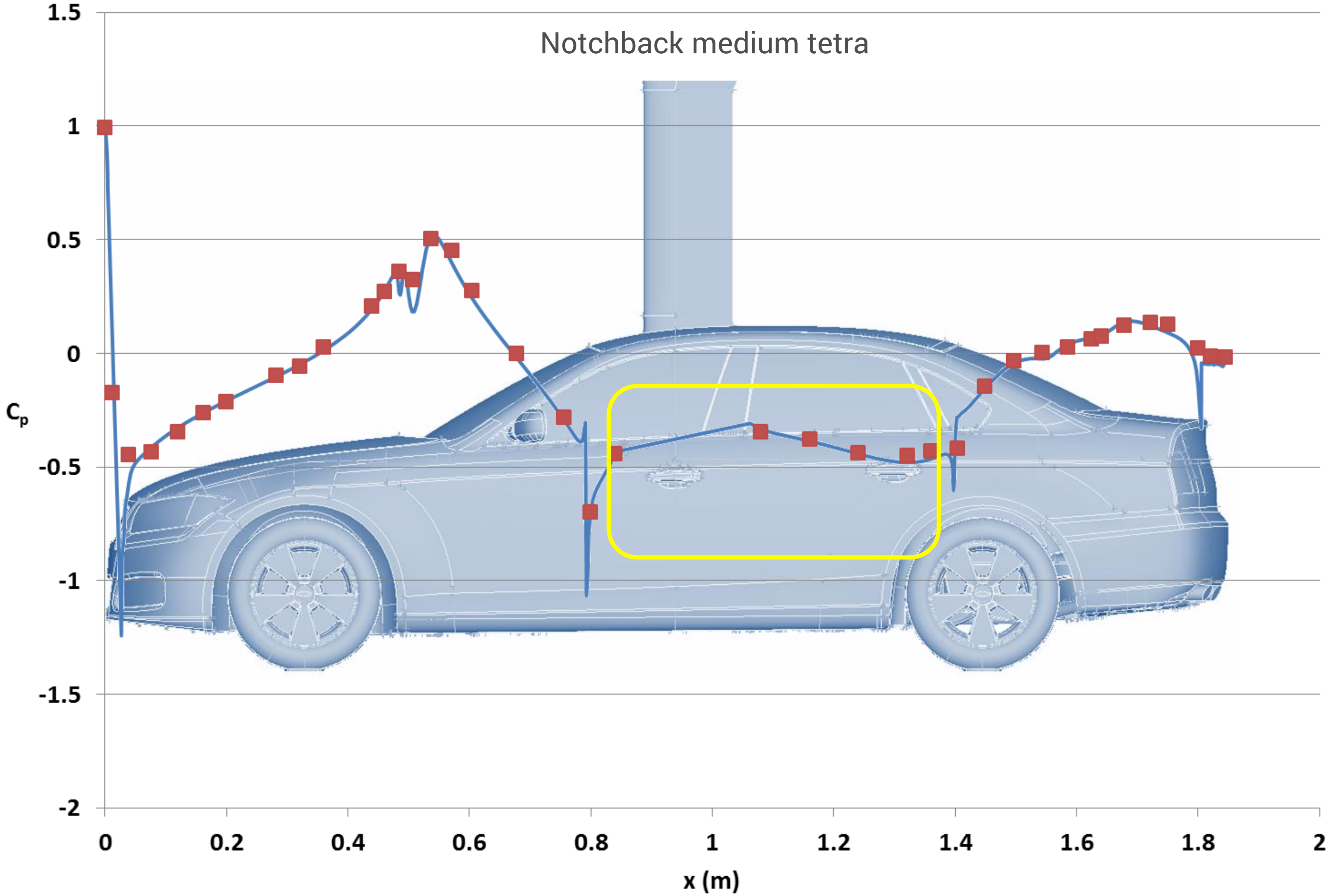
Summary of C_D and C_L values for three variants

Tetra medium mesh, RANS simulations

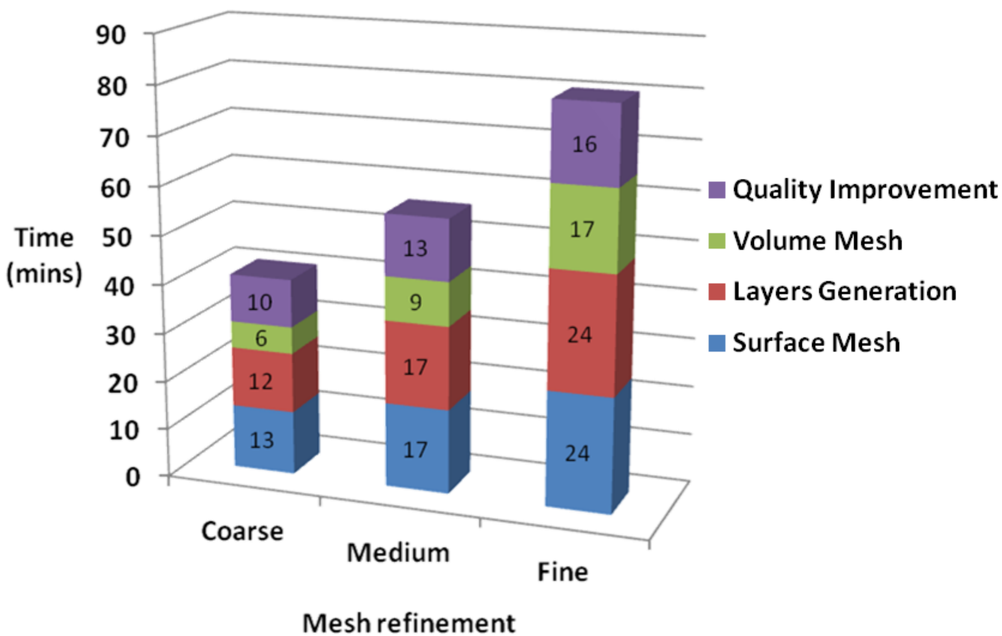
	C_D Experiment	C_D CFD	C_L Experiment	C_L CFD
Notchback	0.272	0.274 (+1%)	0.04	0.051 (+28%)
Fastback	0.274	0.271 (-1%)	0.05	0.058 (+16%)
Estate	0.314	0.279 (-11%)	-0.07	-0.050 (+29%)

Plenum method corrected values presented (correction can be as high as 15%)

Comparison with experiment: C_P along upper symmetry line



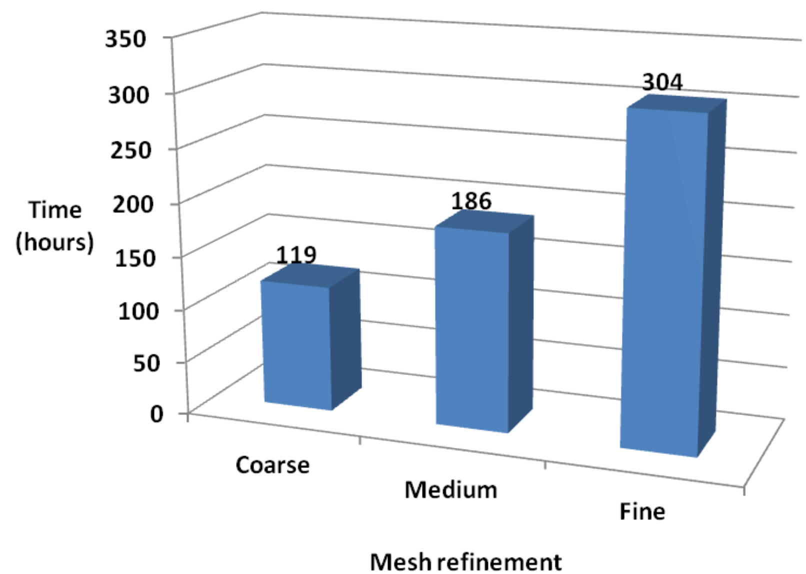
Pre-processing and simulation timing



Software used
ANSA v15.3.0 for pre-processing
OpenFOAM v2.3 for solving
META v15.3.0 for post-processing

We estimate gains up to 15% from ANSA-META latest version v17.1 (and soon v18) as well as mesh quality improvements

Simulation times for 20,000 iterations



Reported timing refers to single processor

Hardware used
6 Linux Centos 6.6 PCs
(each one with
40 cores Xeon CPU E5-2660 at 2.6GHz)
256 Gb RAM

Concluding remarks

- To extract more accurate conclusions from this and from future studies we need to have the exact experimental setup specifications, like, velocity correction method, k factor, reference pressure measurement and of course accurate geometry of the problem.
- The correction method for Open Test Section Wind Tunnels significantly affects the results.
- The addition of the wind tunnel to the simulation significantly improved the agreement of the results with the experiment.
- Interpretation of results is of utmost importance. Averaging of forces must be performed with great caution and should consider several thousands of iterations.
- Tetra mesh proved to be the most accurate (Spot-on drag coefficient prediction, 28% deviation for lift coefficient), while polyhedral meshes seem to deviate a lot.
- Mesh refinement study showed that acceptable mesh independence can be reached at medium size.
- **ANSA** and **META** pre and post-processing for OpenFOAM was demonstrated with key points like:
  - high quality automated surface and volume meshing allowing quick mesh alternatives;
  - fully automated post-processing for multiple simulation results.

stay connected

thank you!