The influence of mesh characteristics on external airflow CFD simulations of the DrivAer model

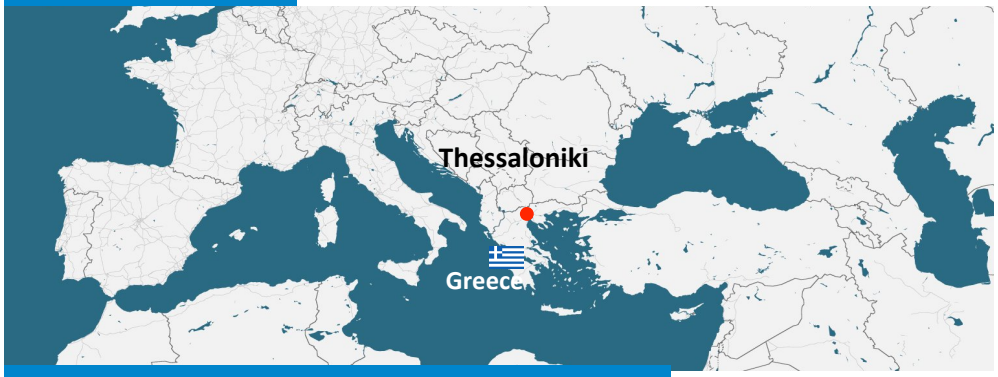
Grigoris Fotiadis, Vangelis Skaperdas, Aristotelis Iordanidis
BETA CAE Systems S.A.

Presented by:
Pravin Peddiraju
BETA CAE Systems USA, Inc.

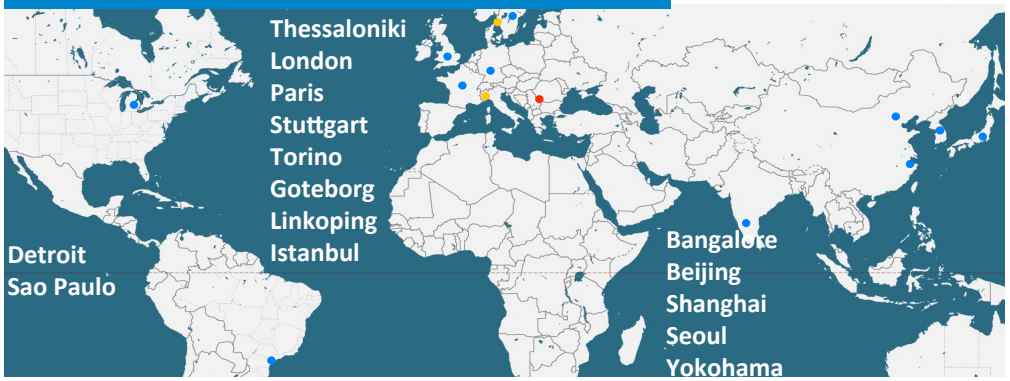
AMS Seminar Series, September 17, 2015, NASA Ames Research Center

Company

Head Office



Worldwide Sales and Services



βBETA CAE Systems SA



BETA



- Over 20 years experience in the CAE field
- Market leader in offering comprehensive CAE pre- and post-processing software
- 120 engineers in R&D & software dev; 120 engineers in software support

- Software sales, support and services in North America and Oceania
- In-house and On-site software training
- Software customization and Process automation

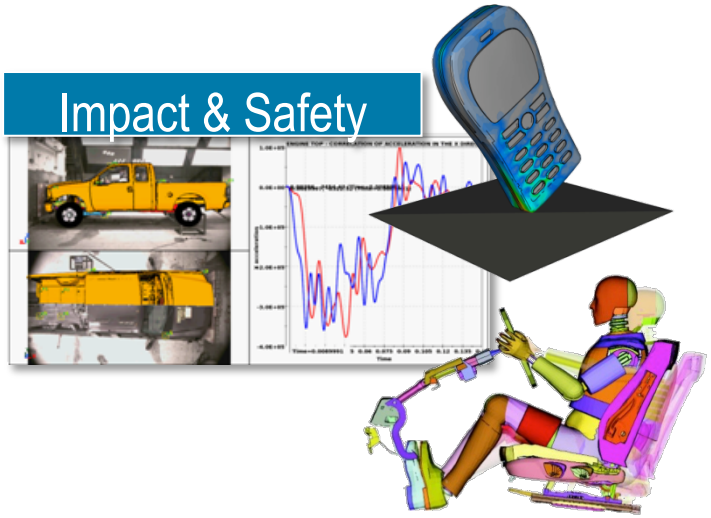
Pre- & Post- processing suite

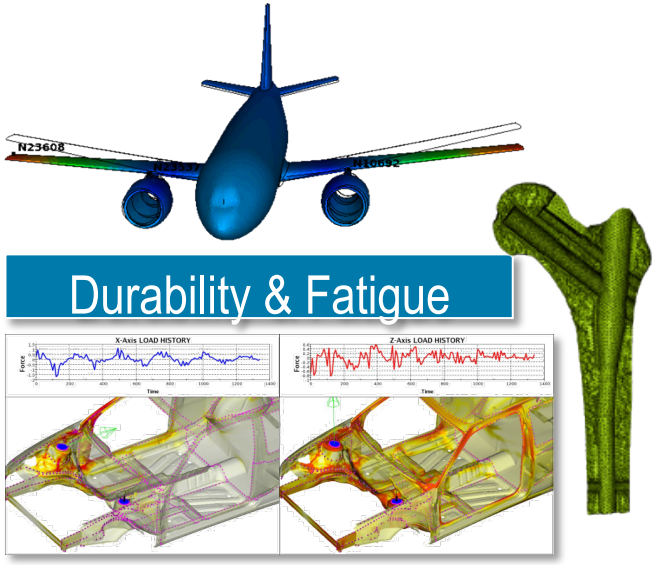
ANSA
μETA
PostProcessor

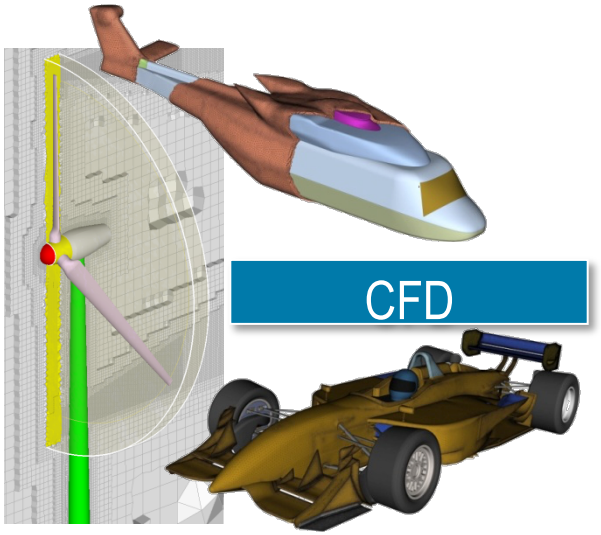
pioneering
software systems

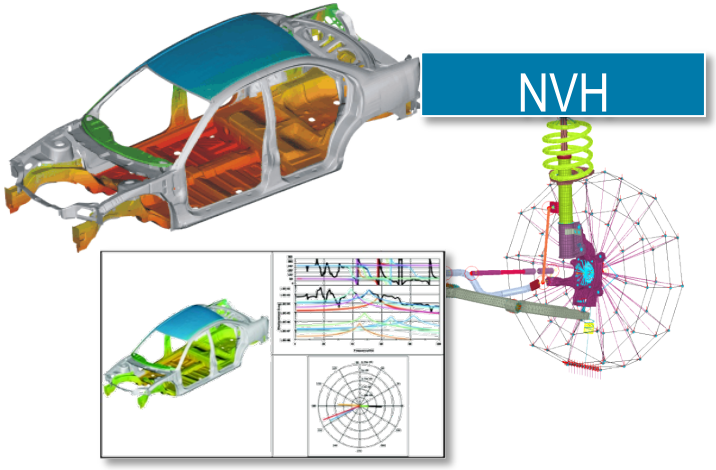
for multidisciplinary
pre- & post-processing

Multi-disciplinary solutions



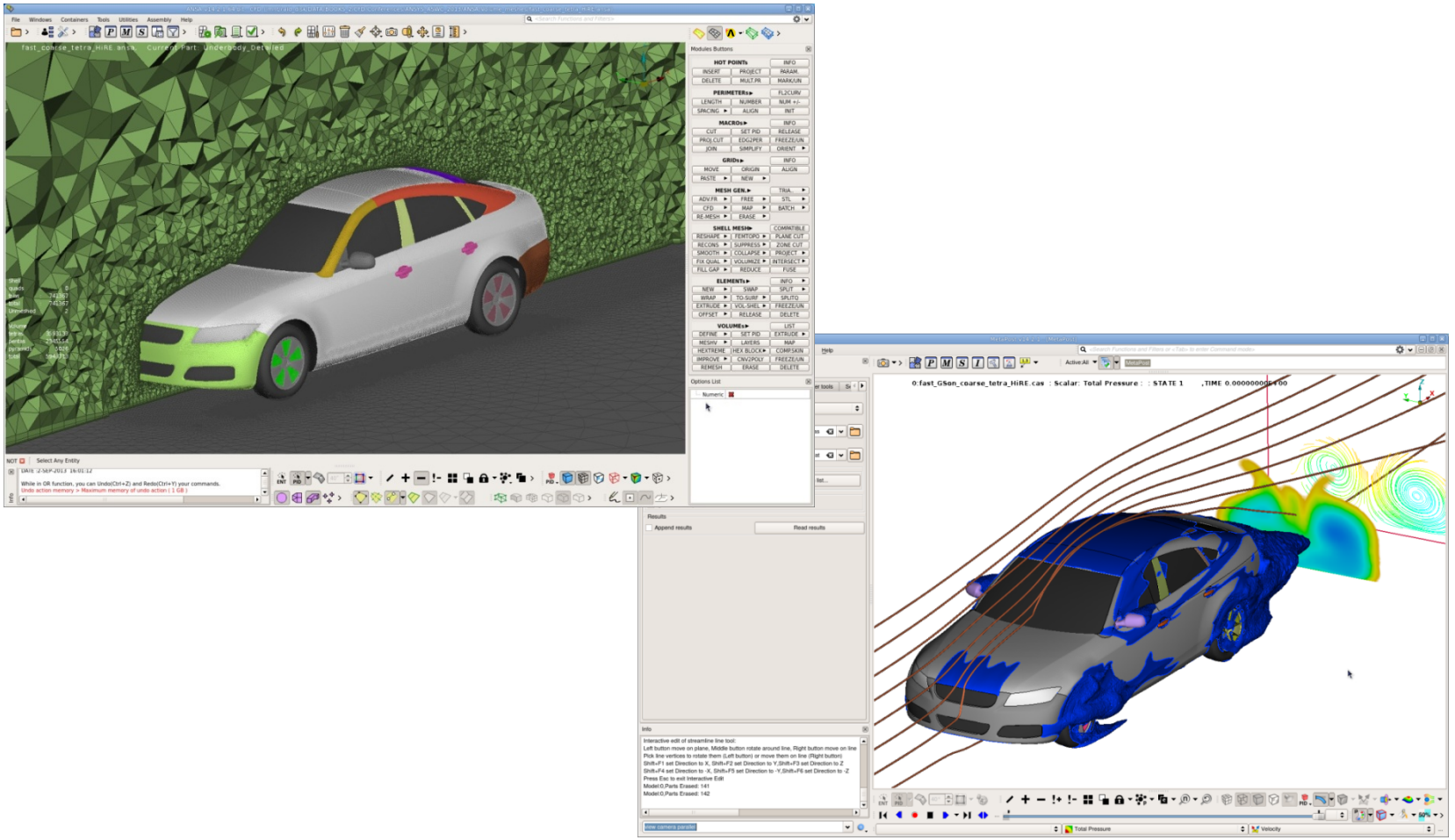






ANSA and META integration with CFD

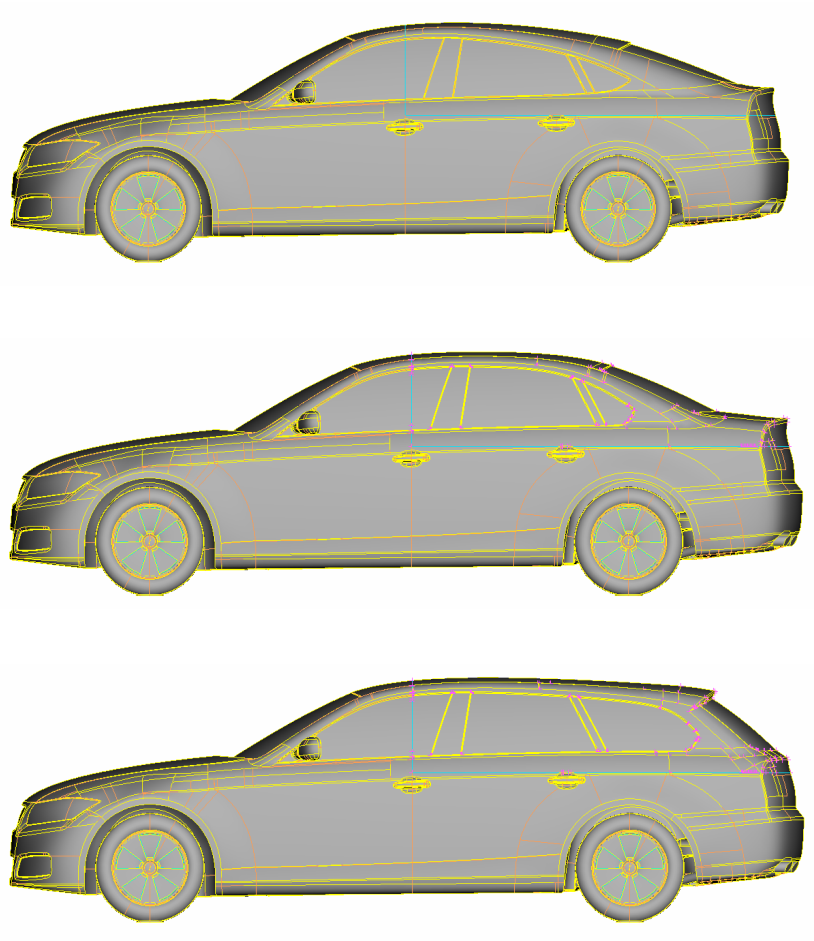
ANSA has been used in pre-processing for CFD since the mid 90s for geometry clean up and surface mesh generation. Currently, ANSA and META provide complete support for the most robust and high quality use of CFD in industrial scale and complexity simulations



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%





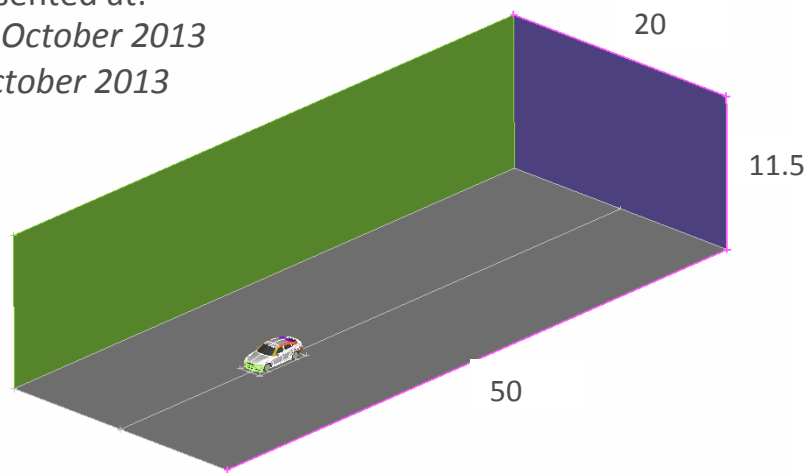
Acknowledgments to:
Institute of Fluid Mechanics and Aerodynamics of the Technical University of Munich
for providing the model geometries
in IGES and STEP formats

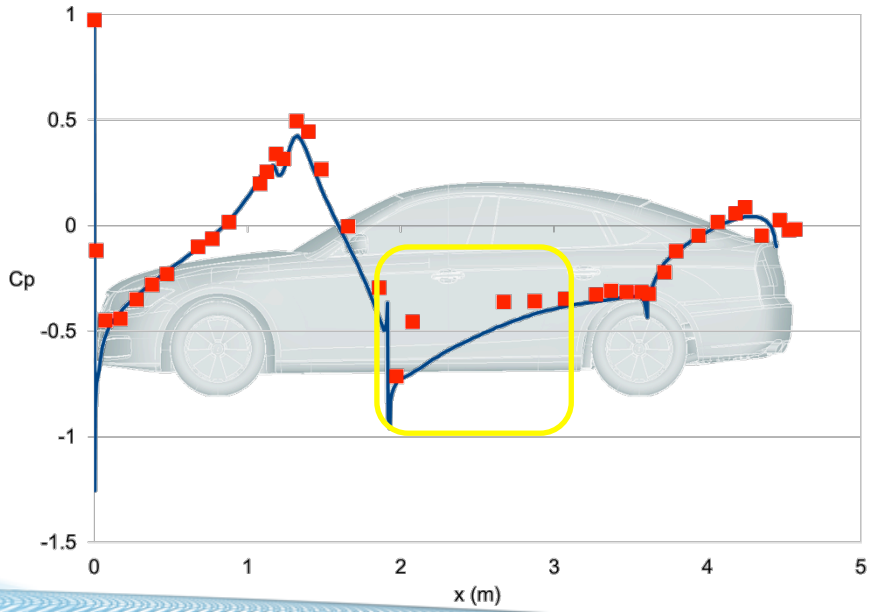
Reference
Heft Angelina (2014) “Aerodynamic Investigation of the Cooling Requirements of Electric Vehicles”, PhD Thesis, Technical University of Munich, ISBN 978-3-8439-1765-0

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

Software and hardware used

- ANSA v15.3.0 for pre-processing

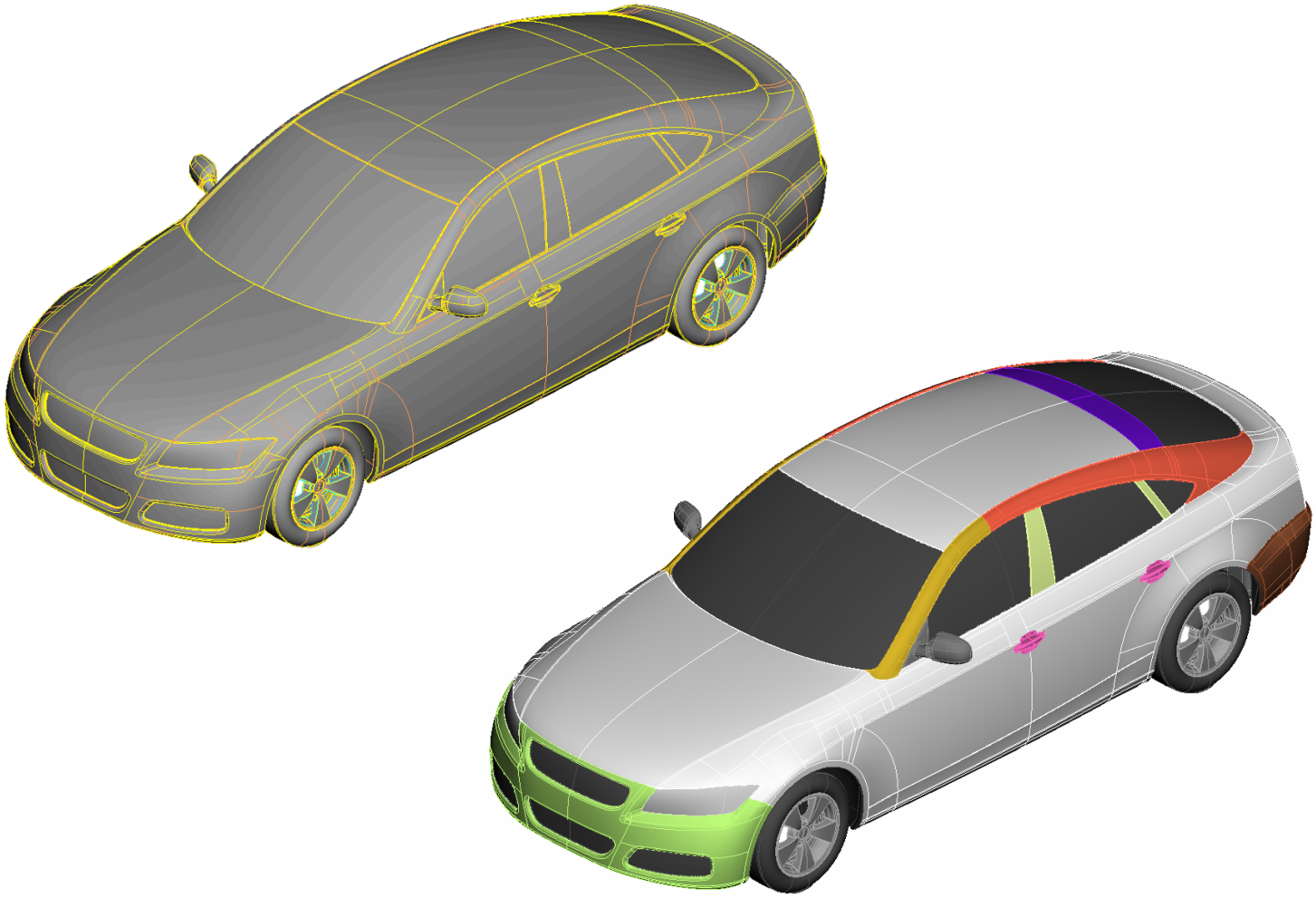
- OpenFOAM v2.3 for solving

- μETA v15.3.0 for post-processing

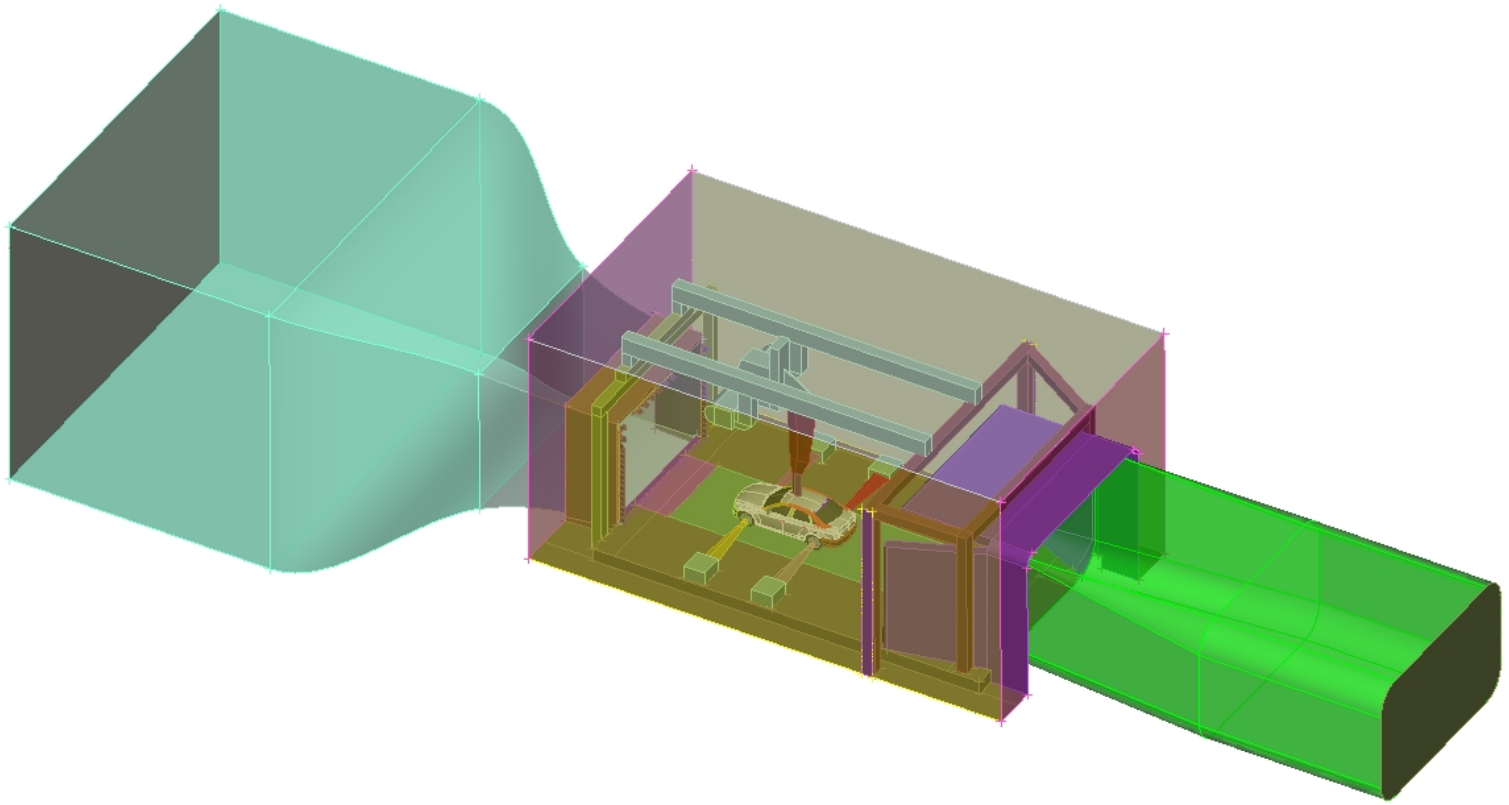
6 Linux Centos 6.6 PCs
Each one with
40 cores Xeon CPU E5-2660 at 2.6GHz
256 Gb RAM

Geometry preparation: STEP file input and property assignment

Geometries that included detailed underbody and mirrors were selected

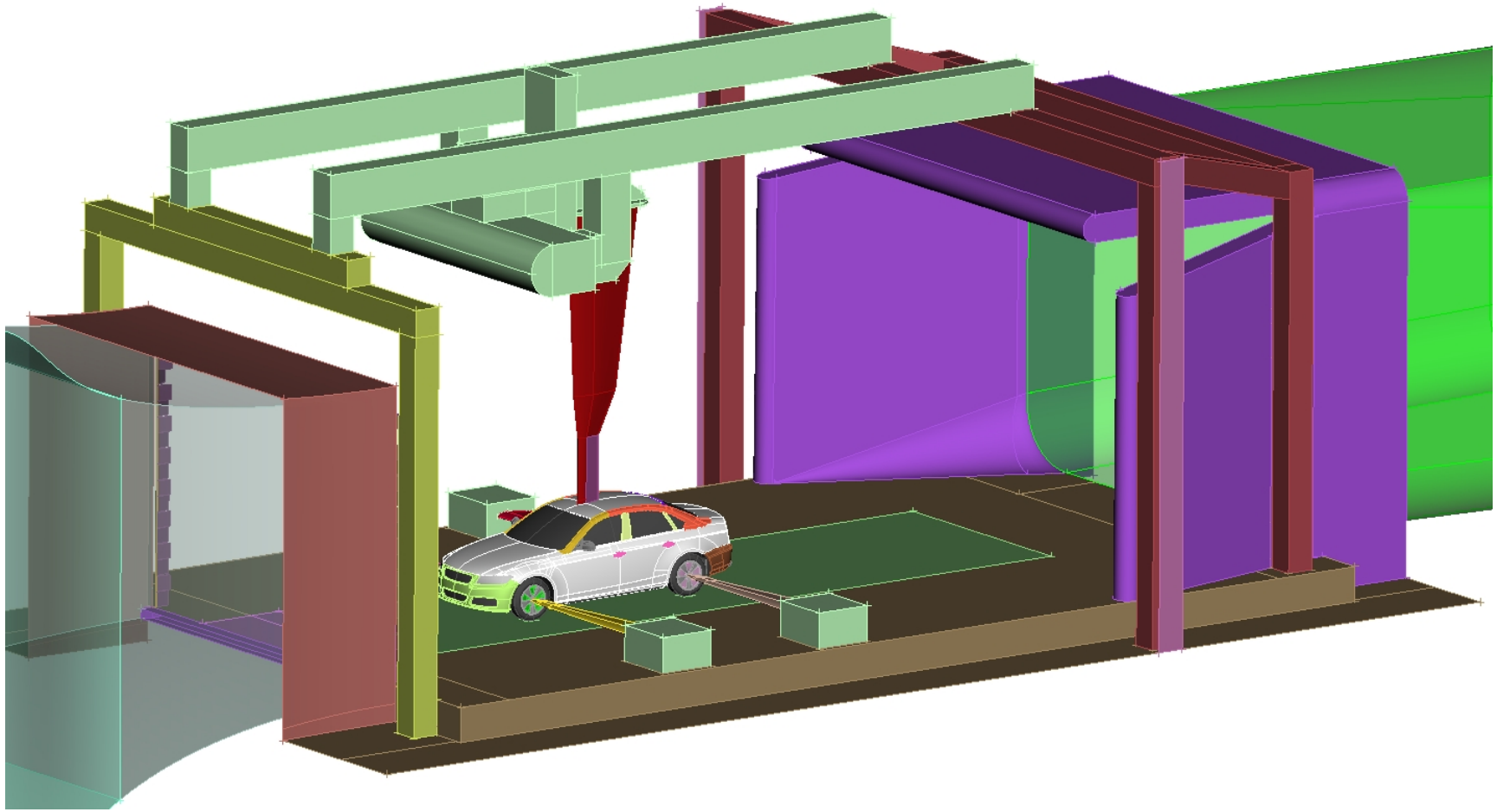


Geometry preparation: Construction of wind tunnel geometry



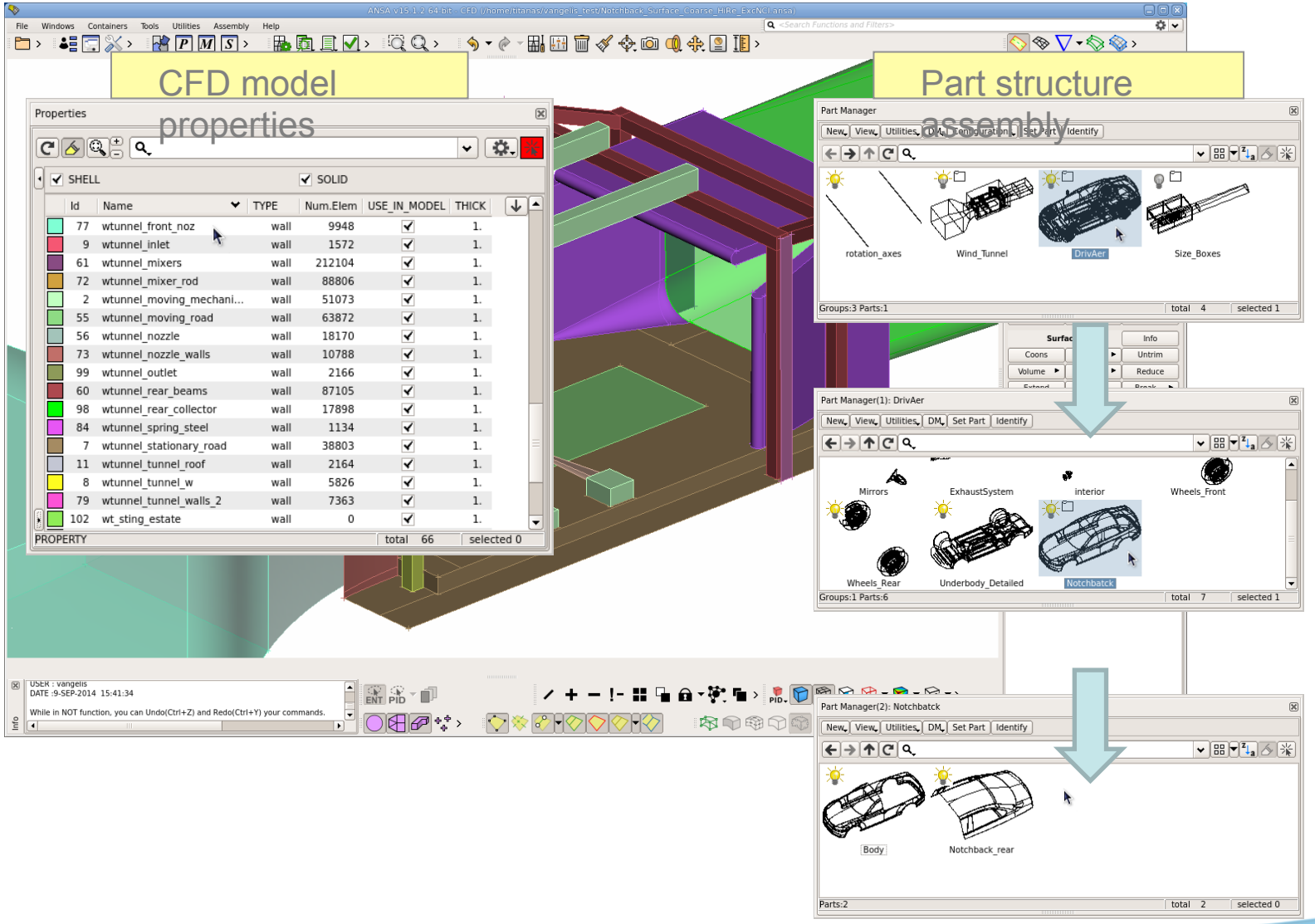
Geometry preparation: Construction of wind tunnel geometry

Blockage ratio ≈ 8%

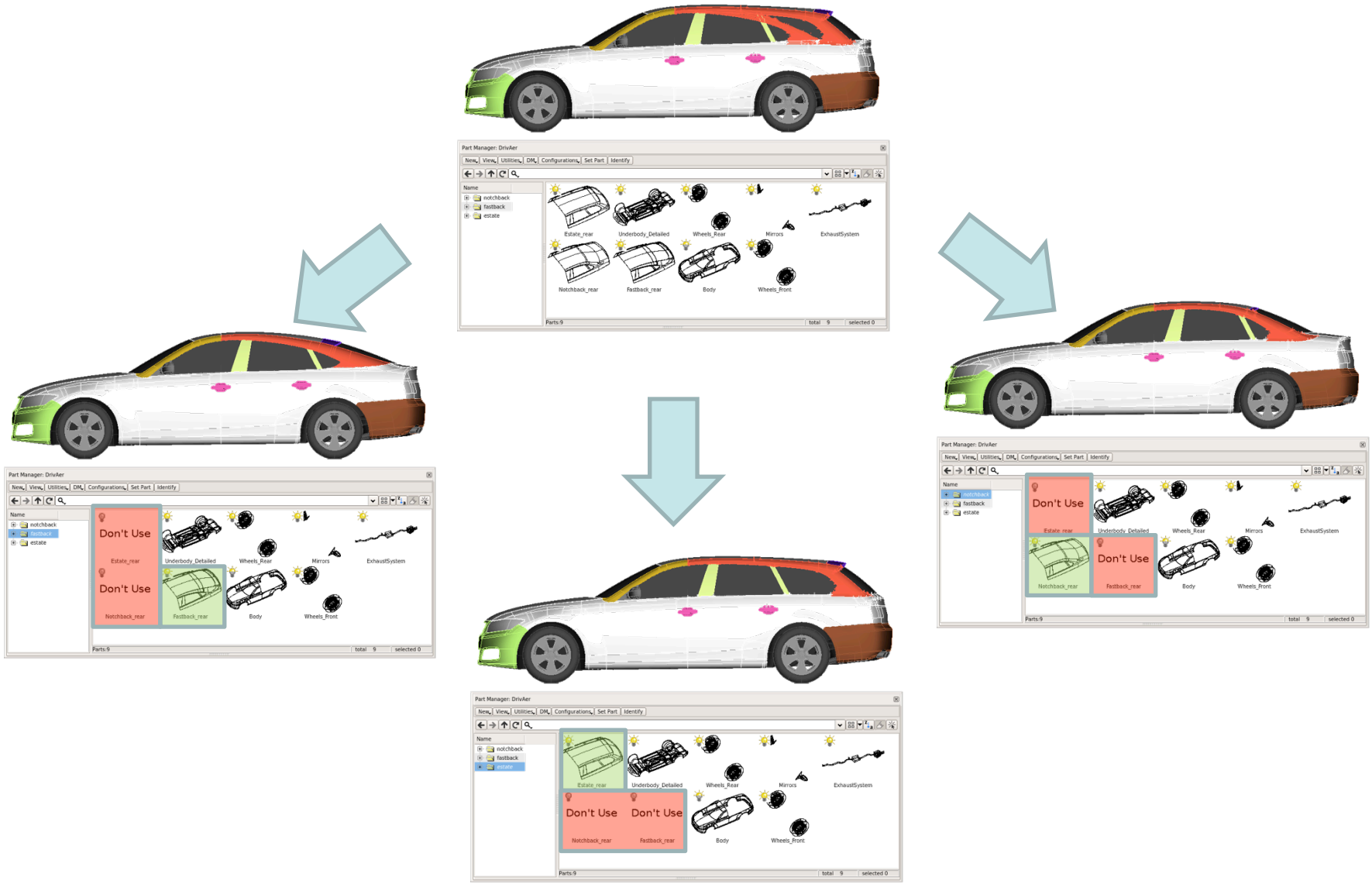


Model management in ANSA

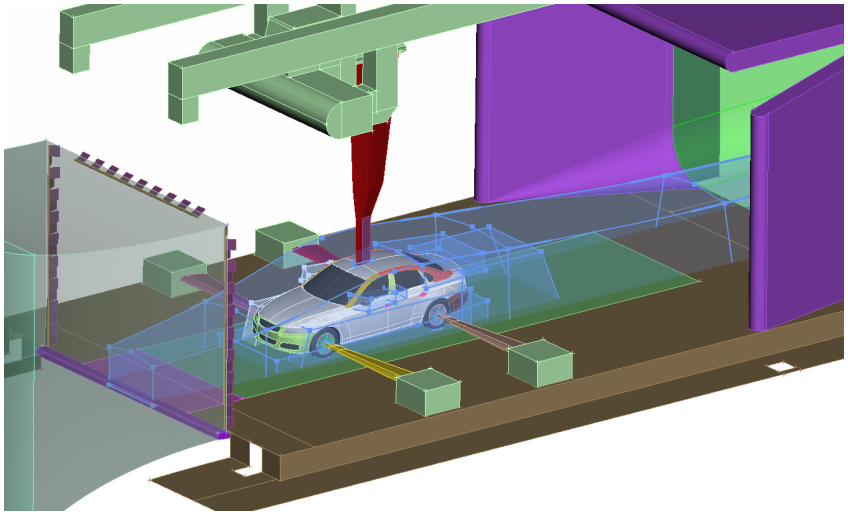
Managing CFD model properties while tracking Part and Property from PDM system

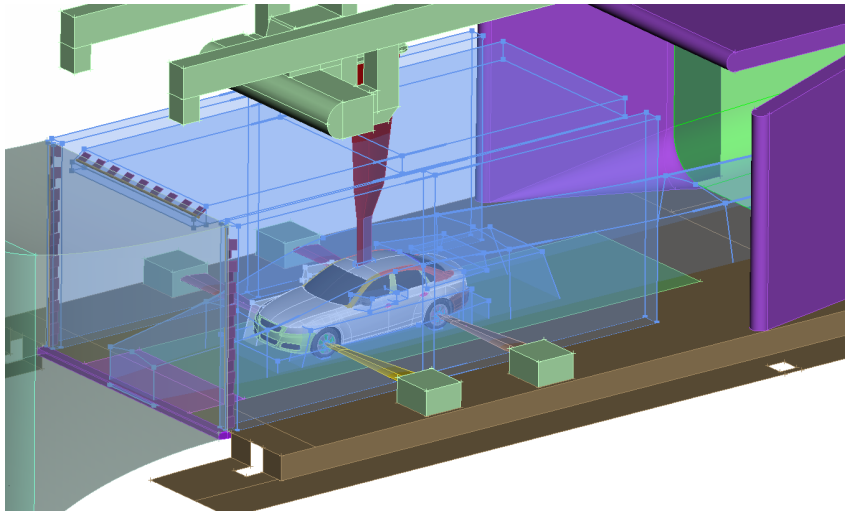


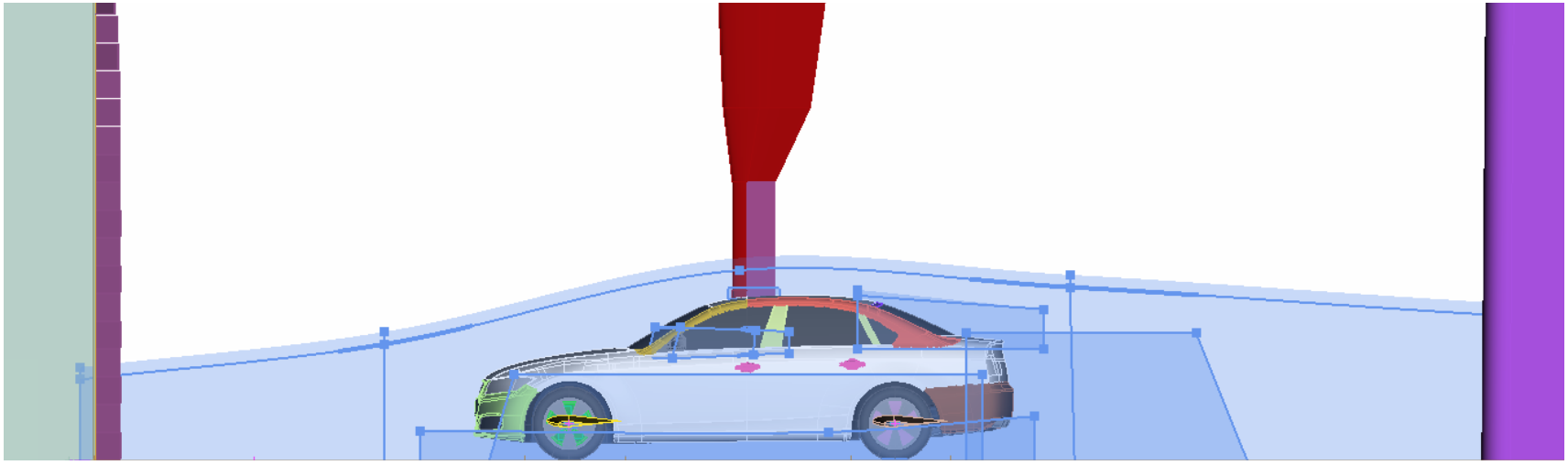
Configurations management in ANSA handling three variants in one file



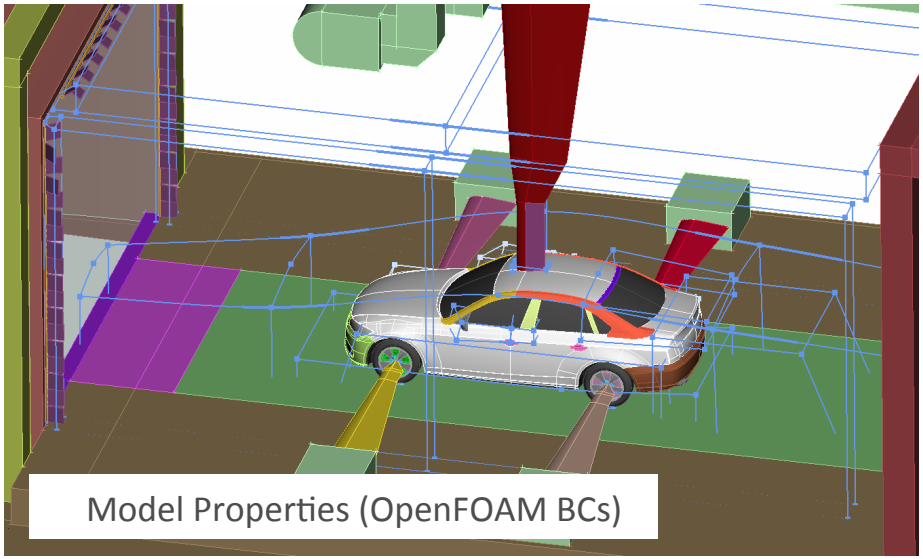
Flexible Size Boxes controlling mesh refinement aligned to the flow



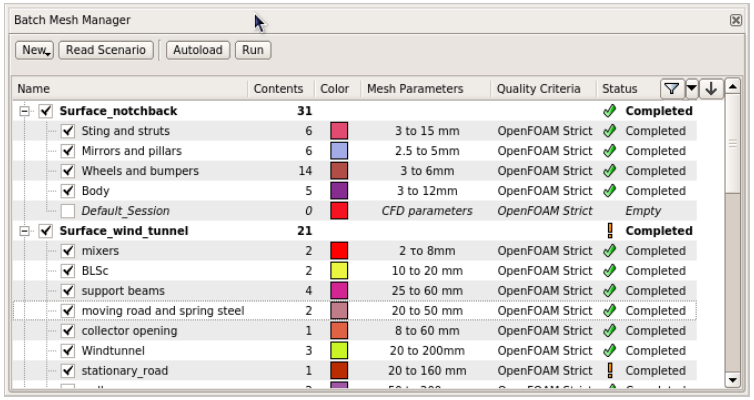




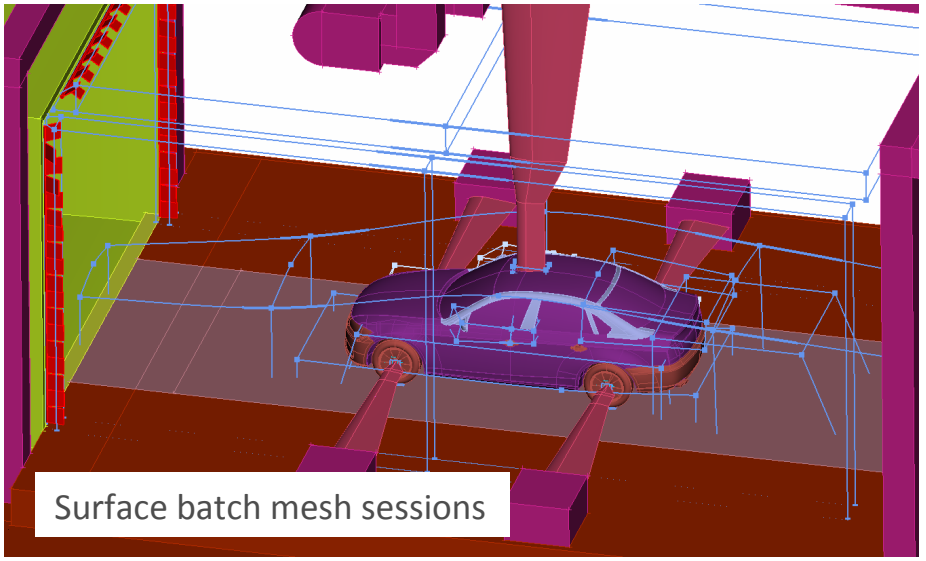
Batch Meshing setup: automation and consistency in meshing



Model Properties (OpenFOAM BCs)



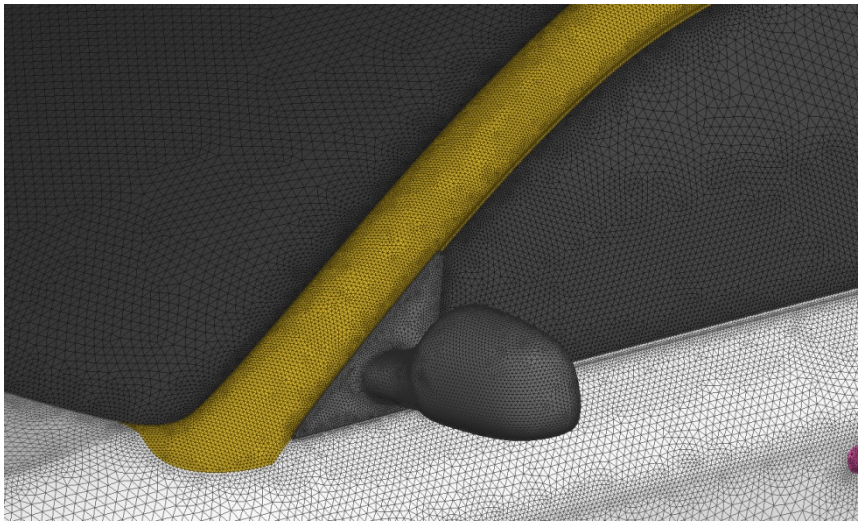
Batch Mesh provides:
- Automation
- Consistency
- Mesh spec traceability

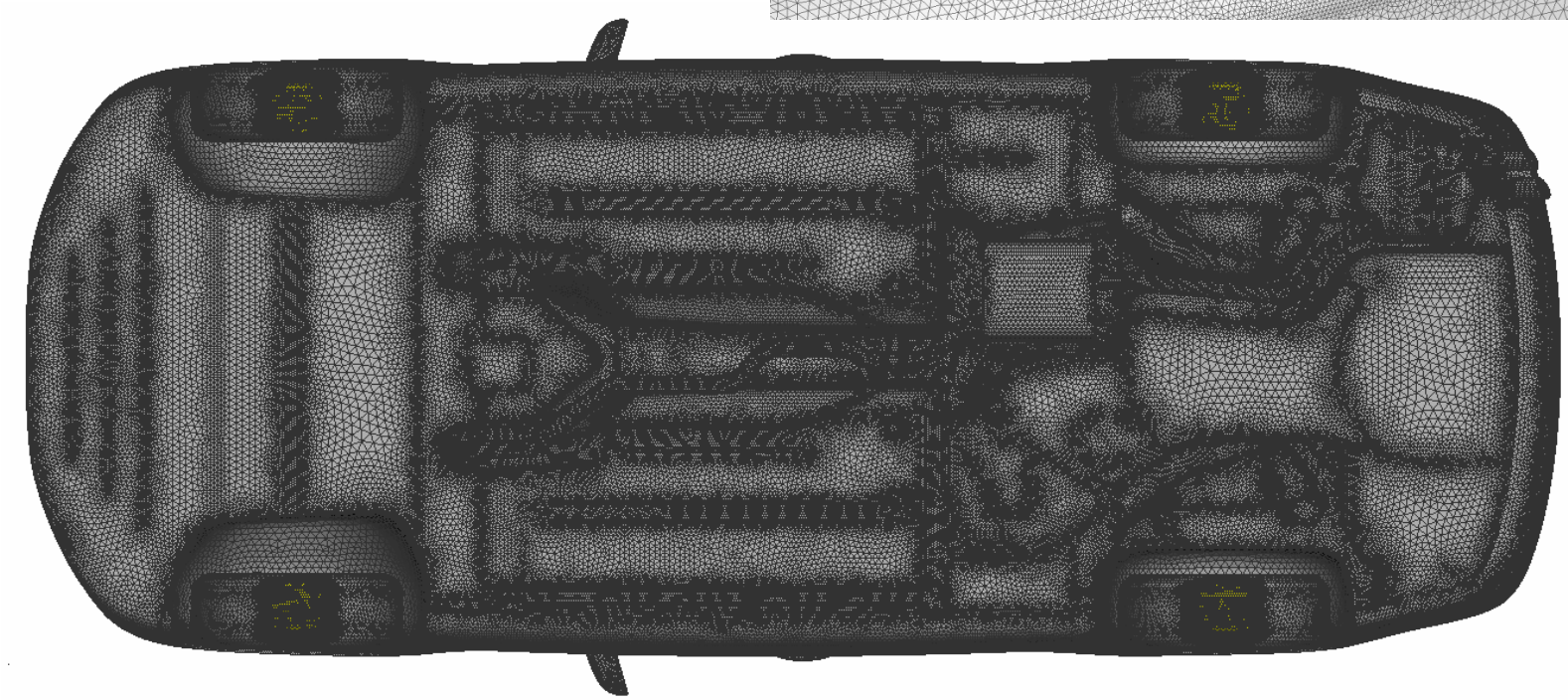


Surface batch mesh sessions

Batch mesh generated surface mesh

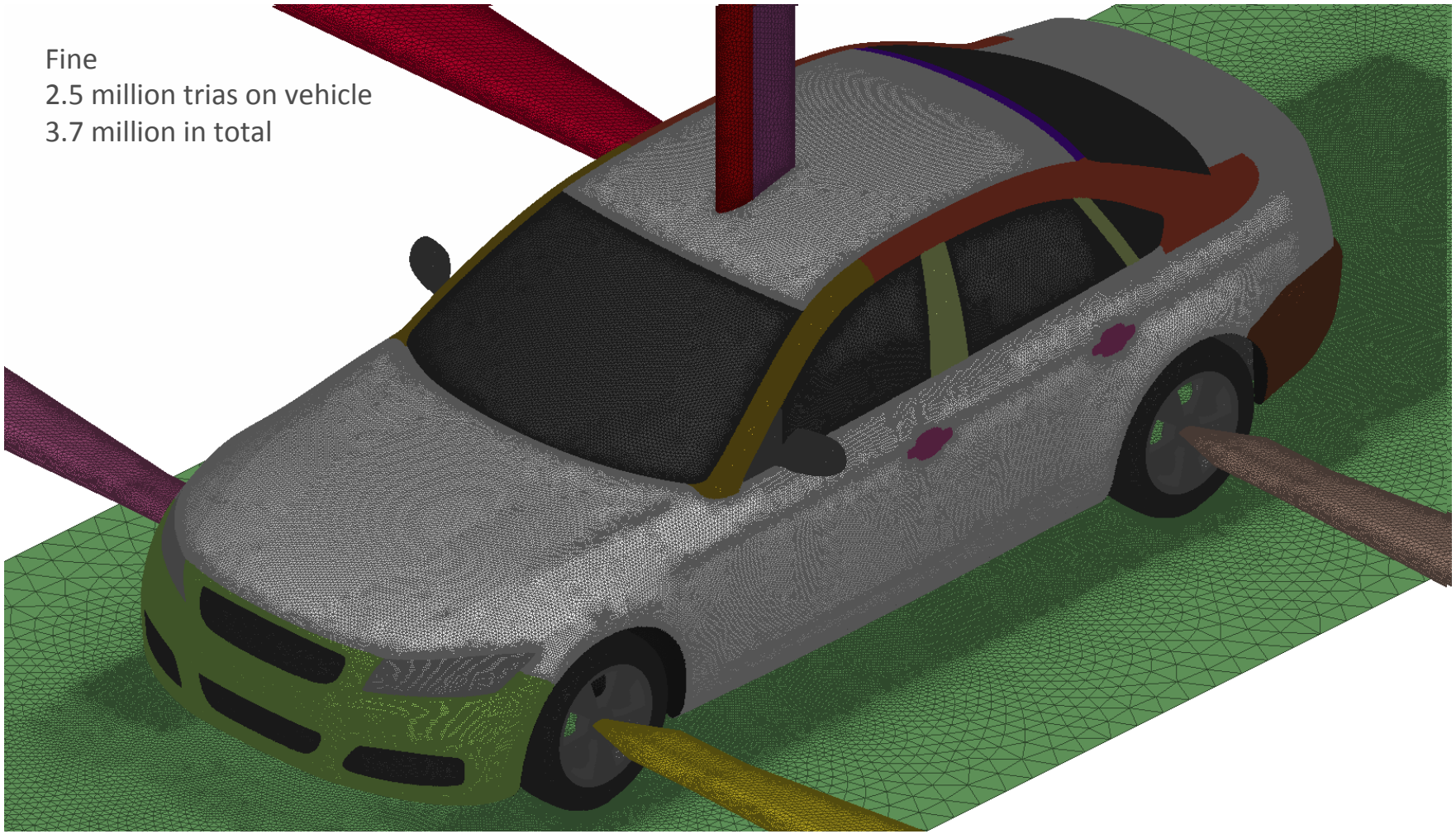
Automatic curvature and sharp edge refinement, in combination with the use of Size Boxes ensure the efficient and accurate capturing of all details of the model.
Quality according to Fluent skewness < 0.45





Batch mesh generated surface mesh

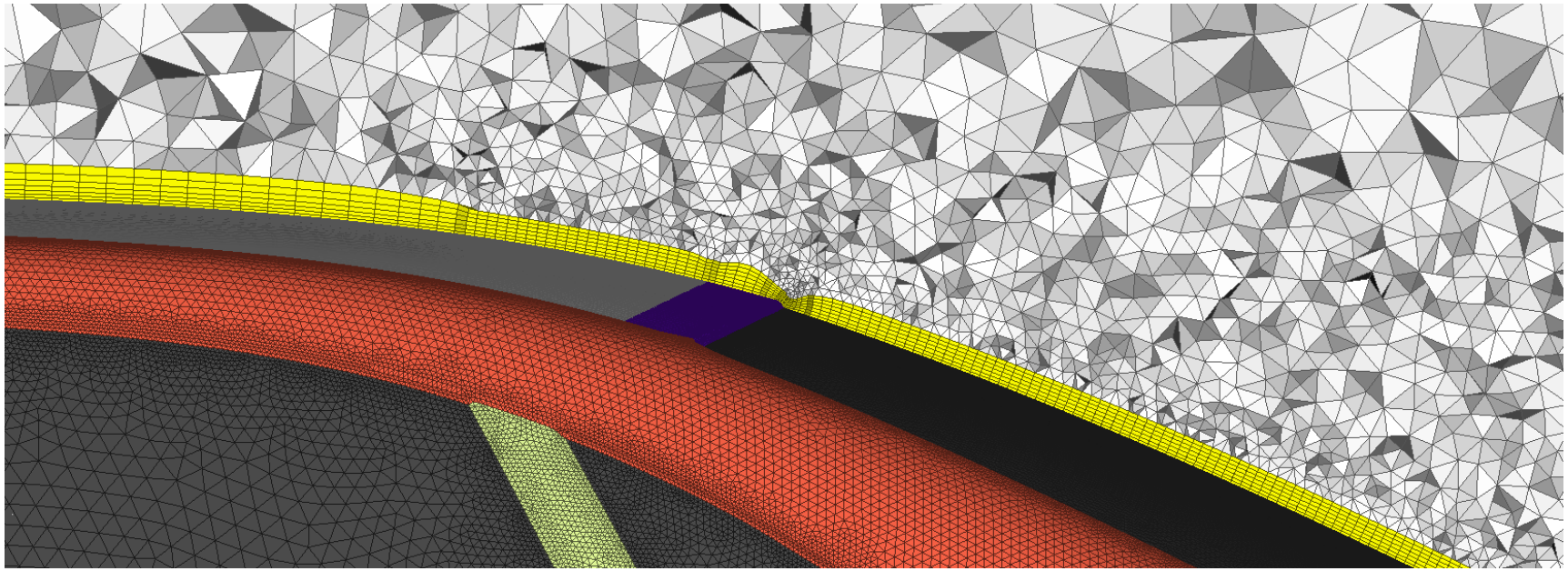
Automatic generation of models with variable resolution using batch meshing



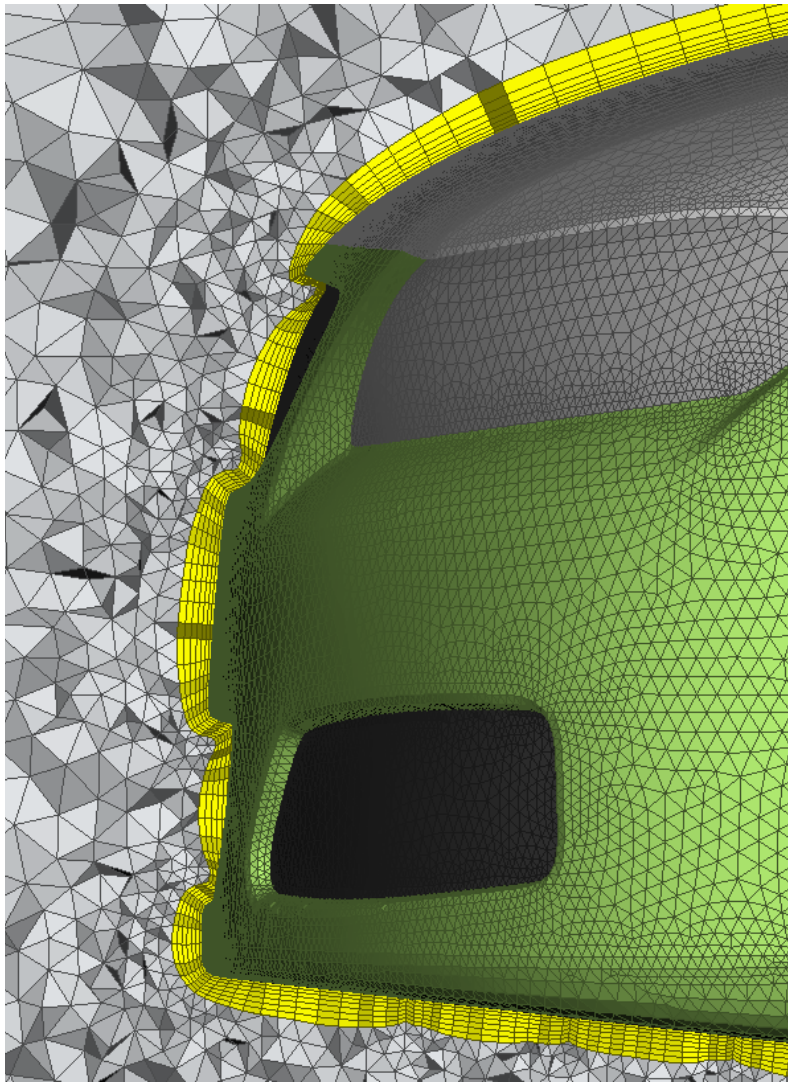
Boundary layer generation

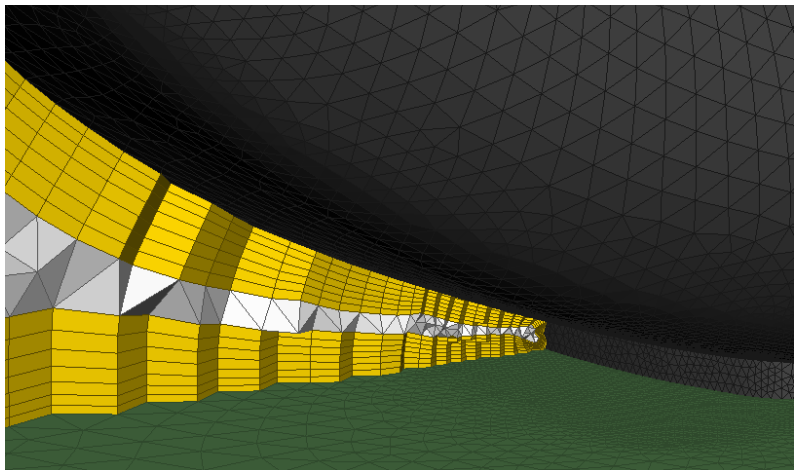
First height 0.8 mm
Growth rate = 1.2
4 layers
+3 layers in aspect mode
Last aspect ratio 40% of length

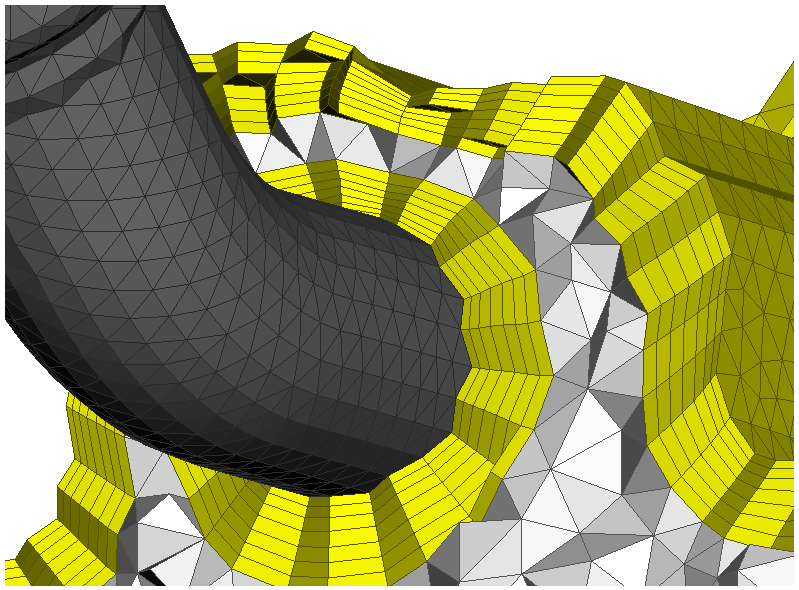
Total layer height ≈ 12 mm



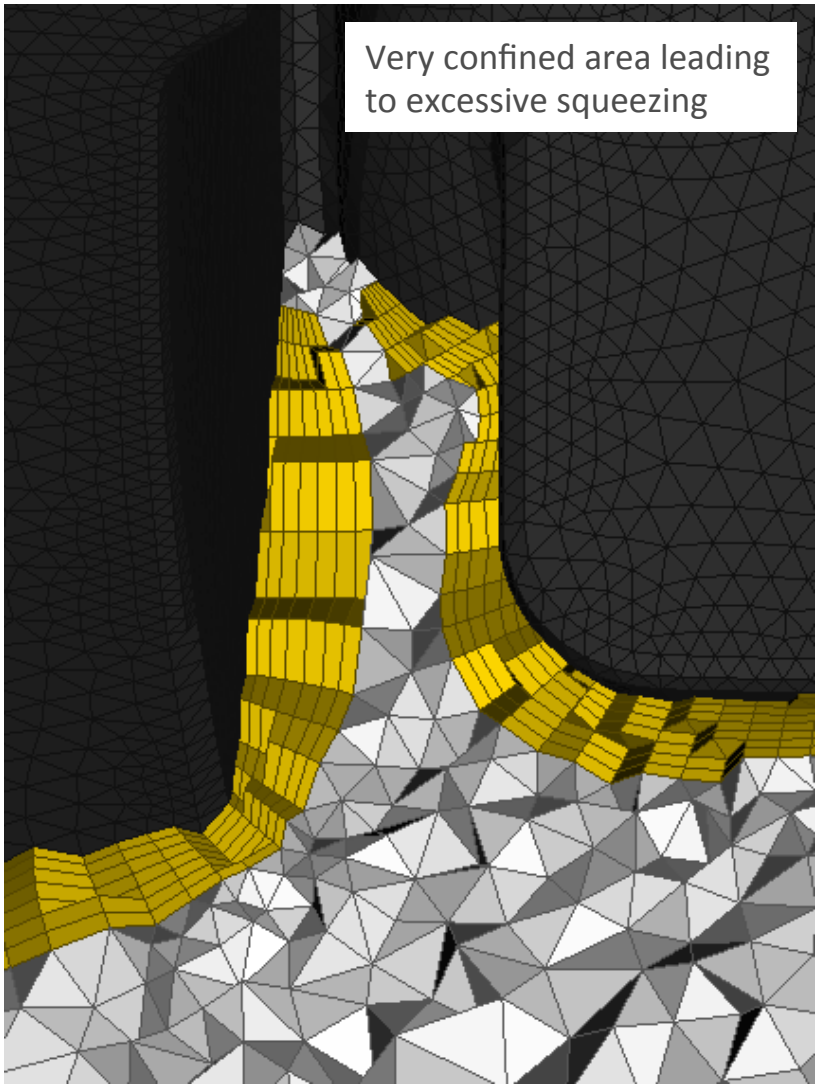
Boundary layer generation : local squeezing at proximities

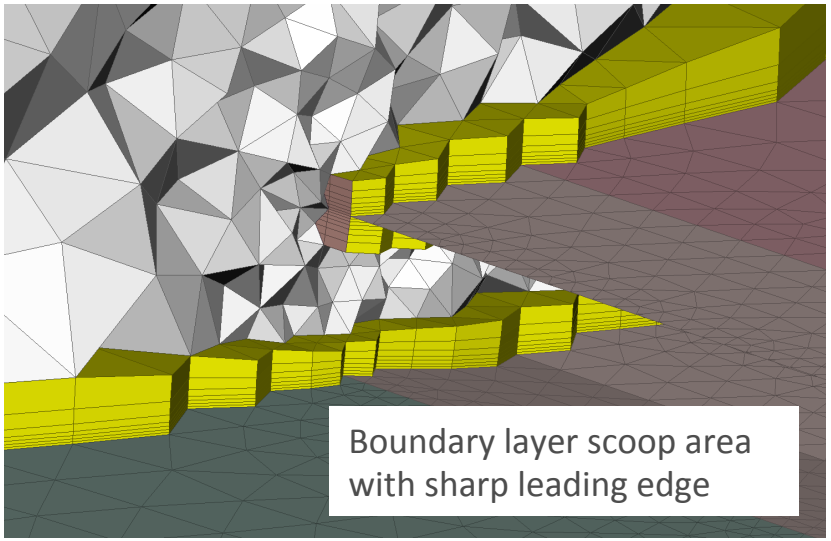


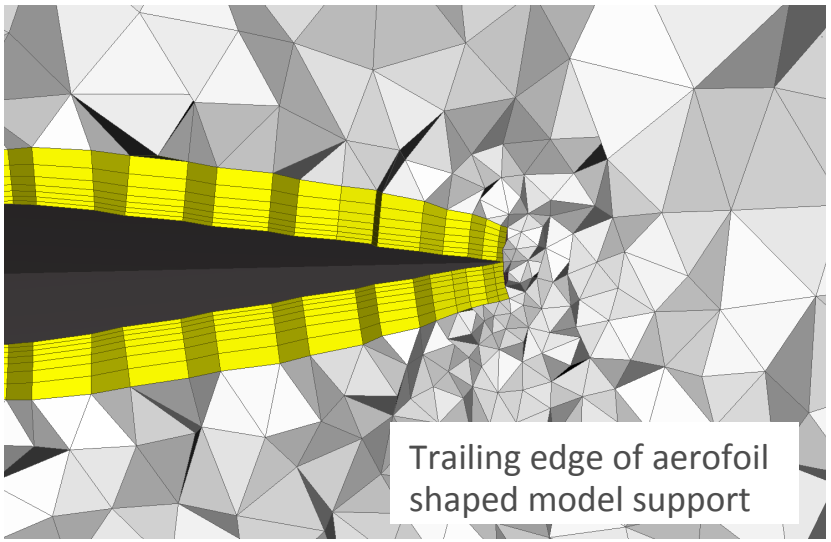




Boundary layer generation: local exclusion of layers at problematic areas

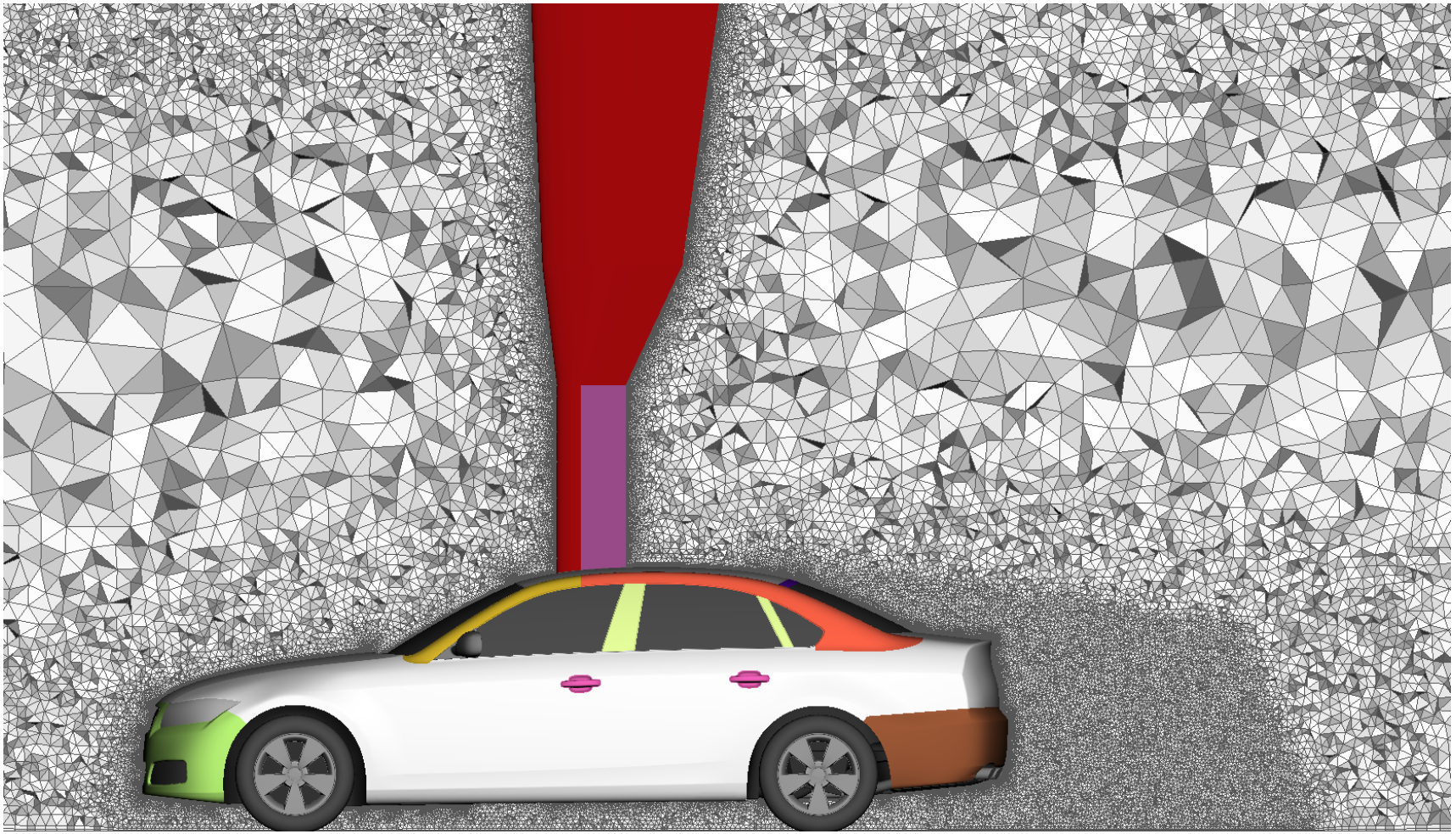




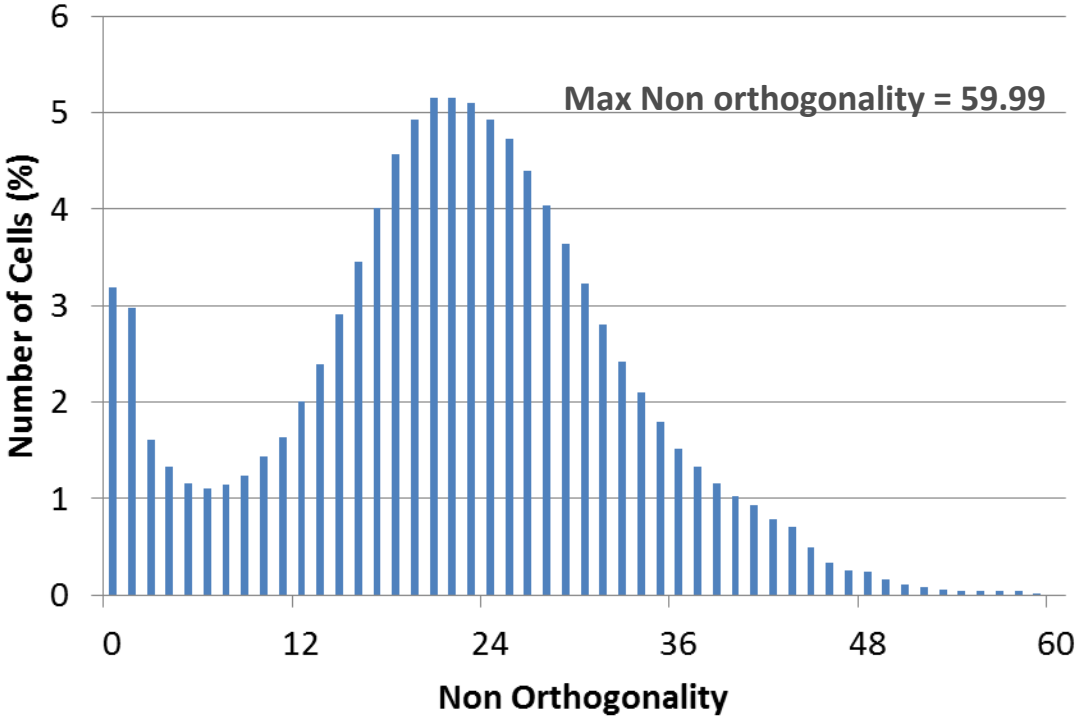


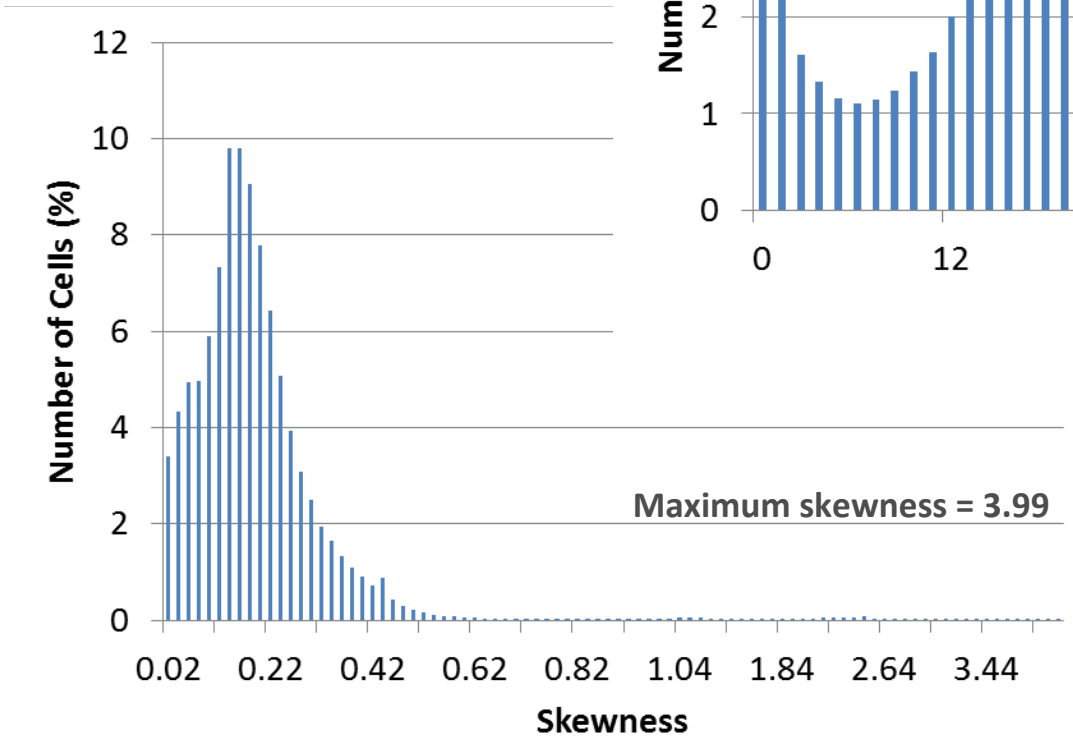
Batch mesh generated volume mesh

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 1 hour



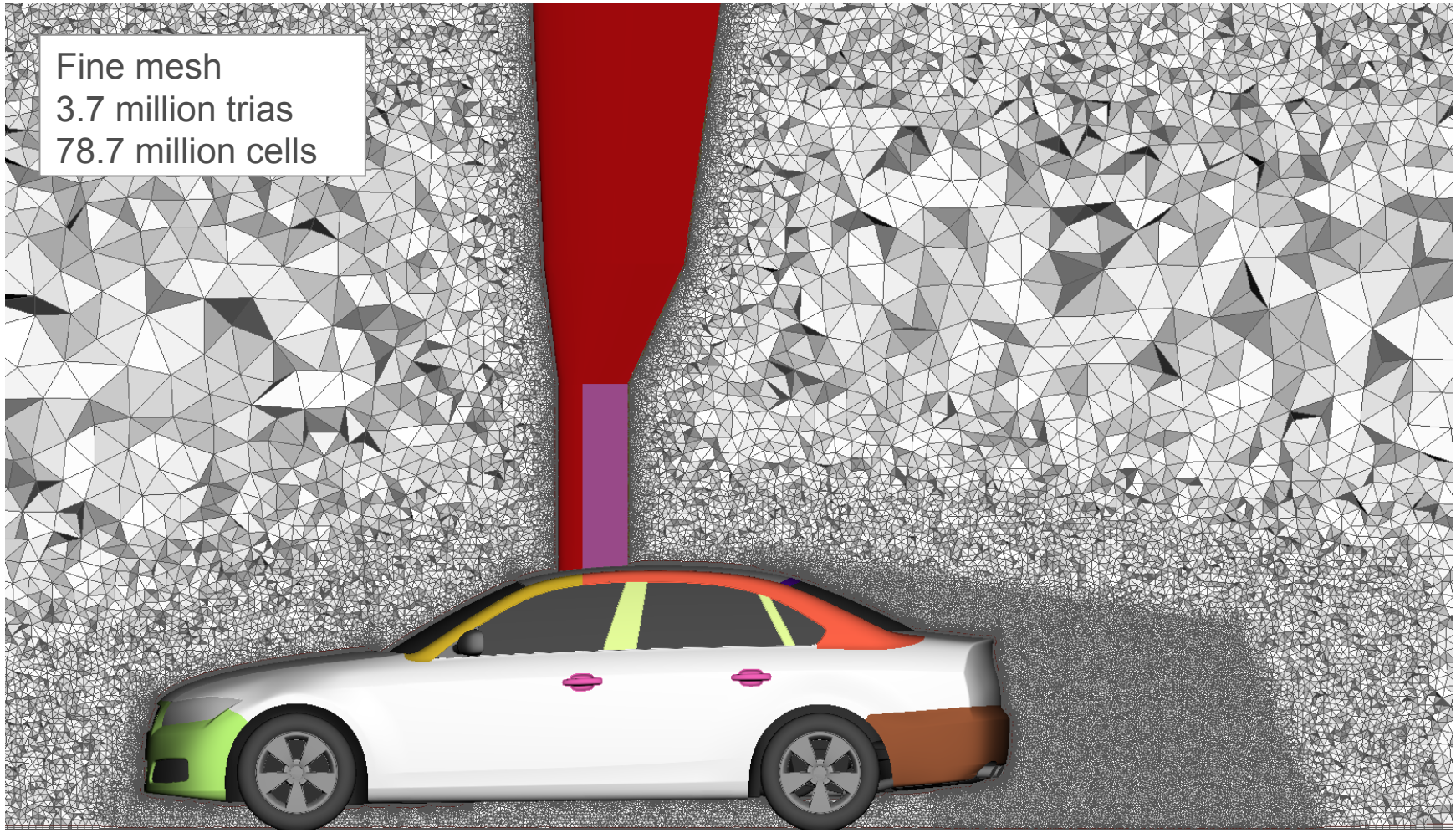
Indicative mesh quality statistics : Notchback tetra medium with layers





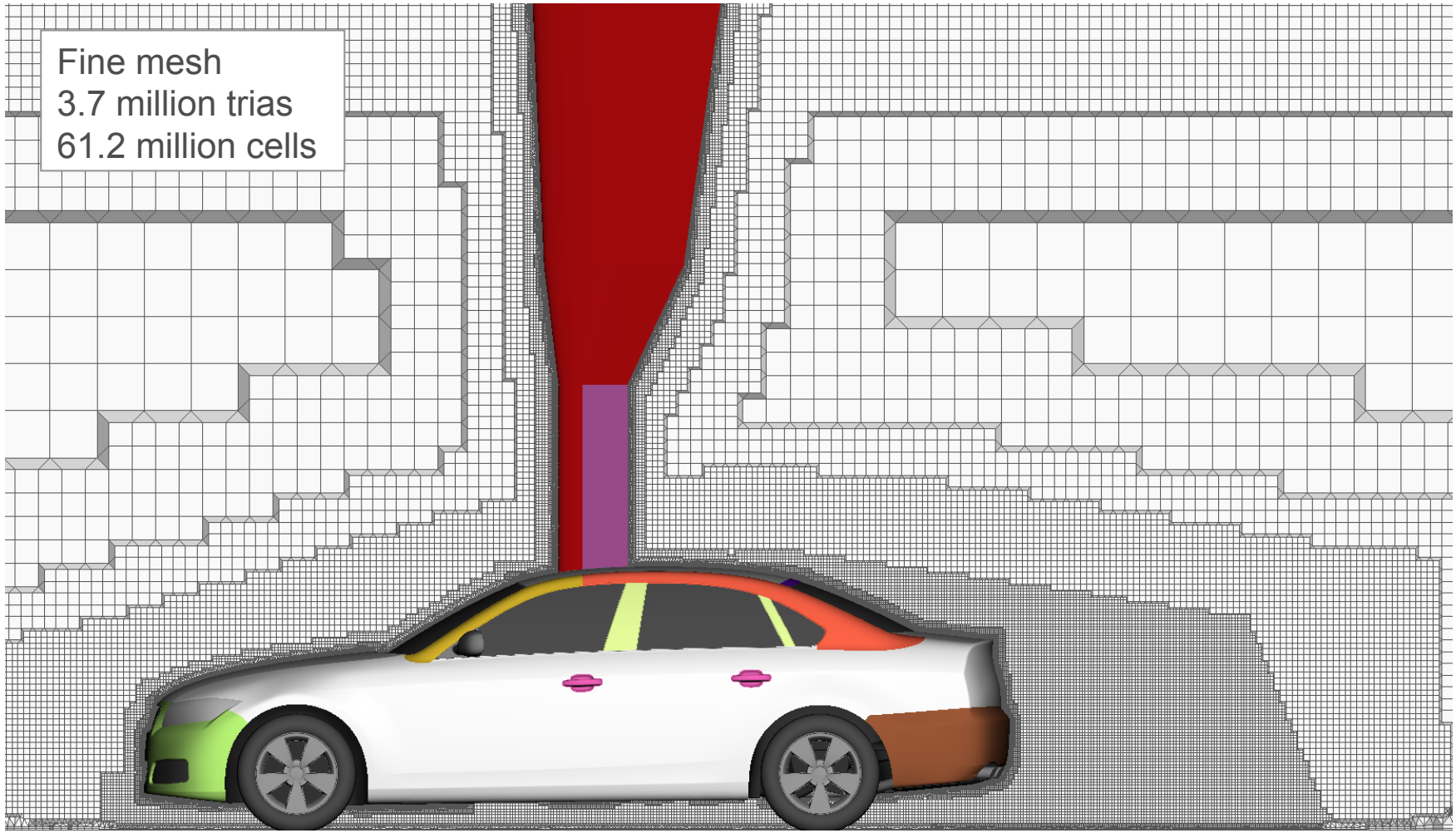
Mesh refinement study for tetra with layers case

Automatic generation of models with variable resolution using batch meshing



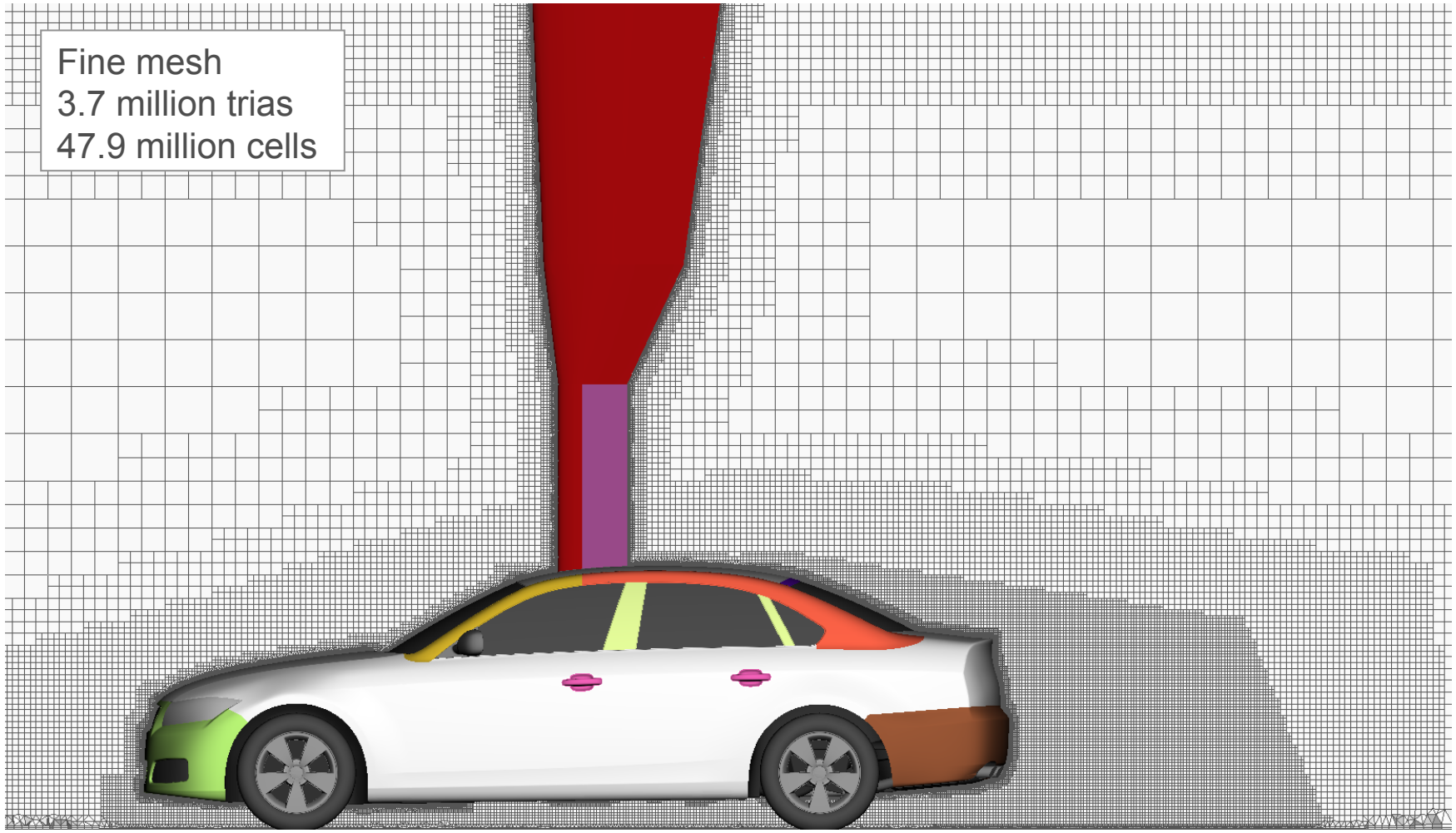
Mesh refinement study for HexaInterior with layers case

Automatic generation of models with variable resolution using batch meshing

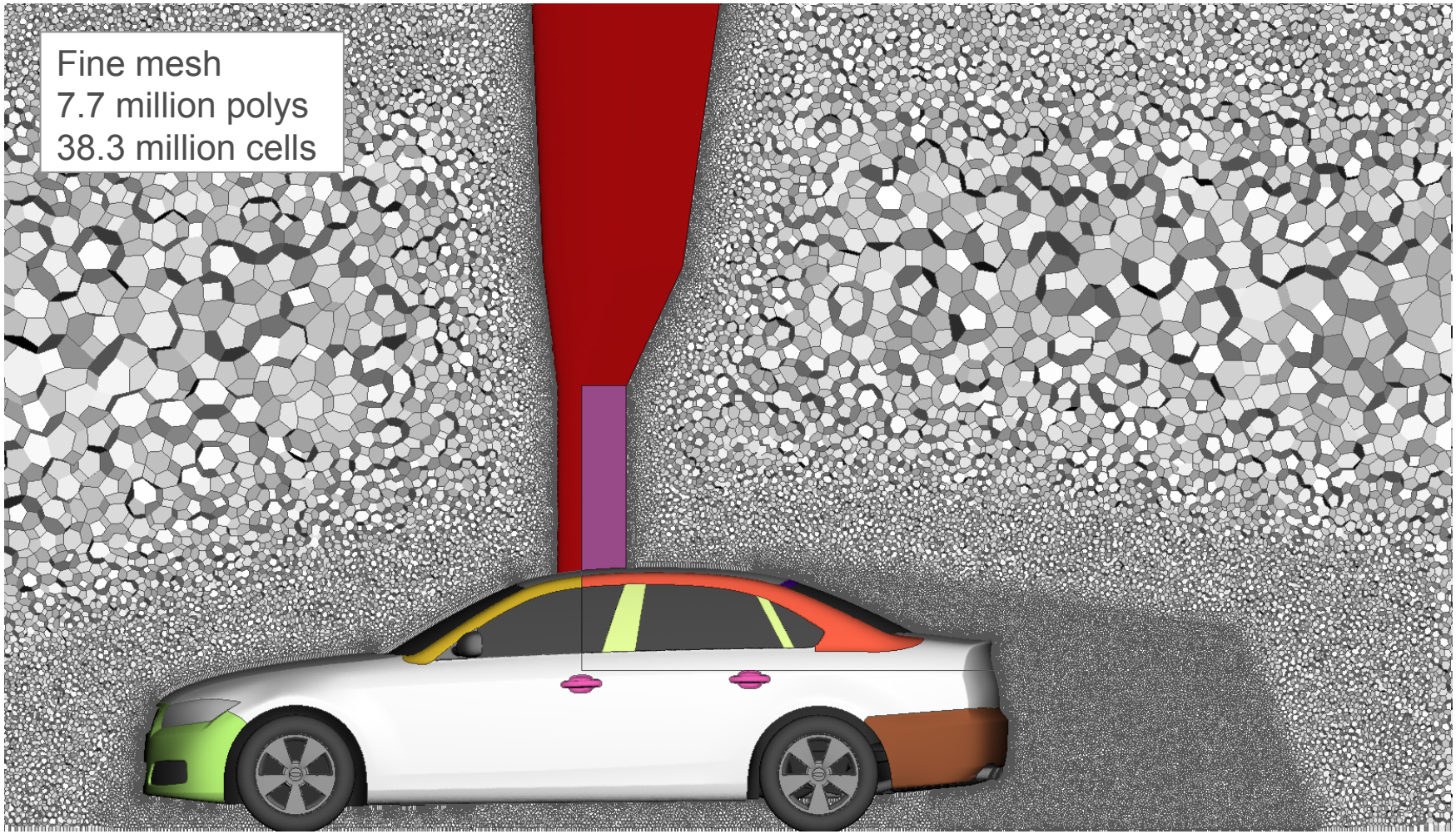


Mesh refinement study for HexaPoly with layers case

Automatic generation of models with variable resolution using batch meshing

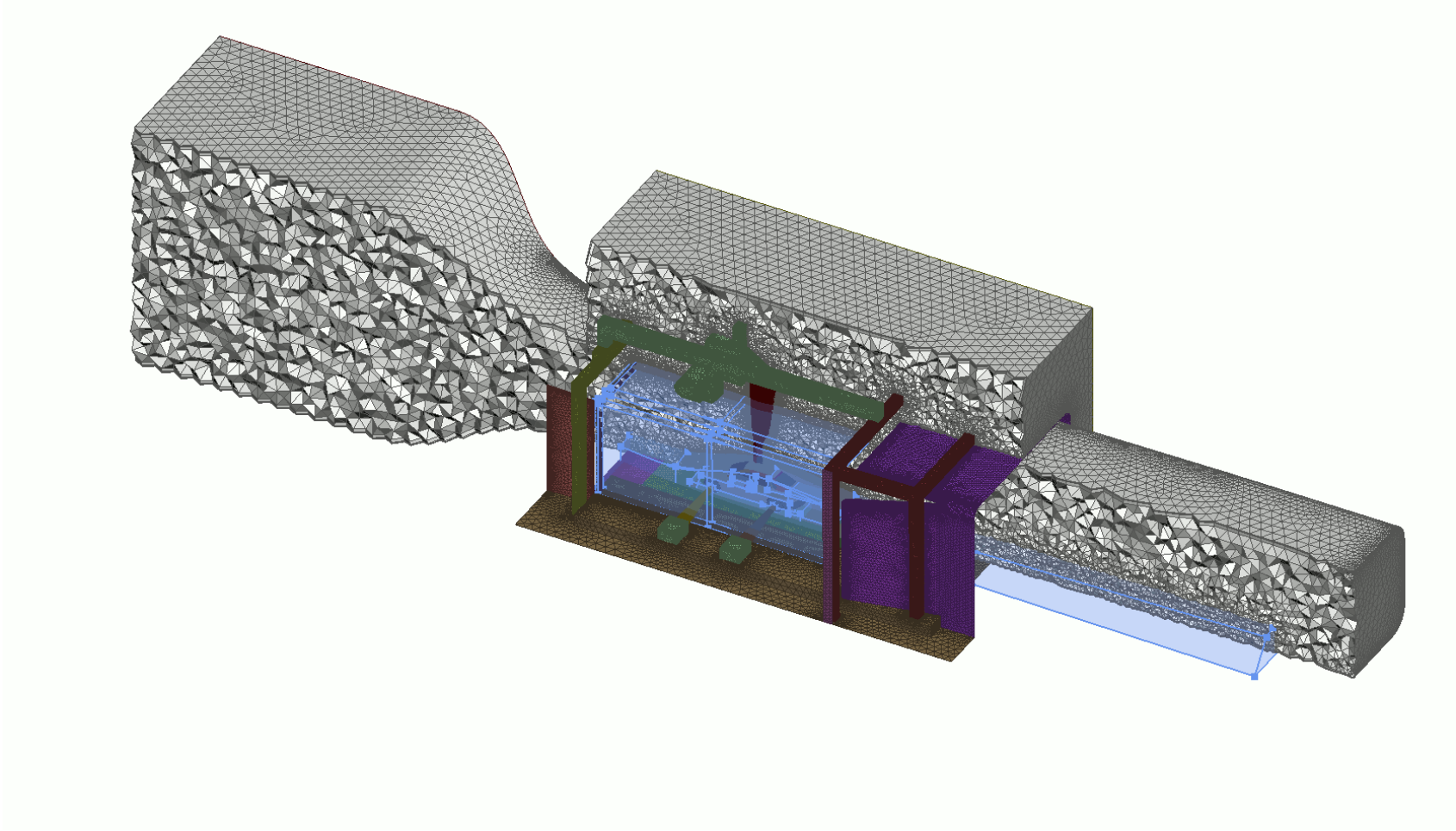


Generation of Polyhedral mesh from hybrid mesh conversion

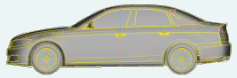


Overview of final volume mesh

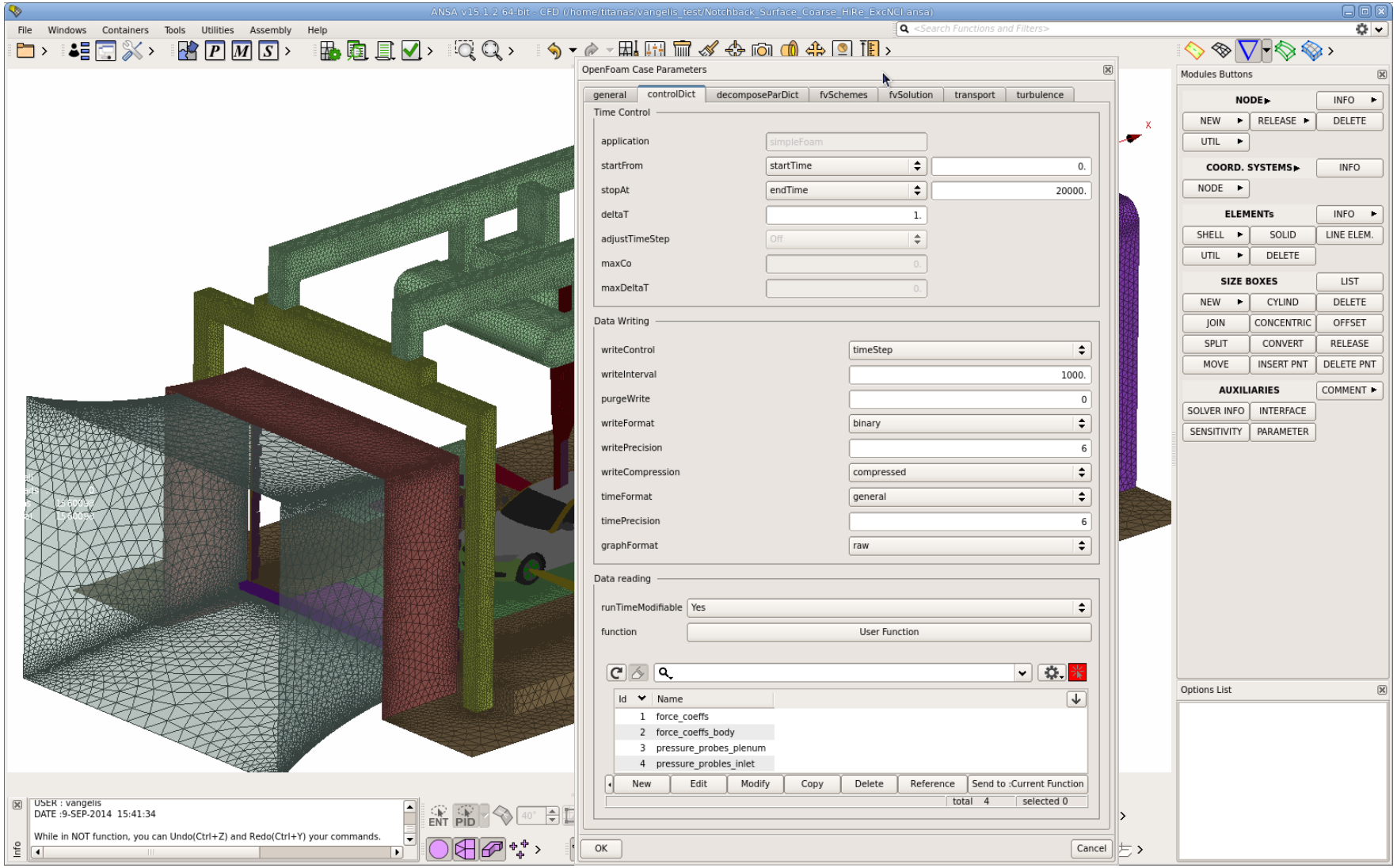
Medium tetra model



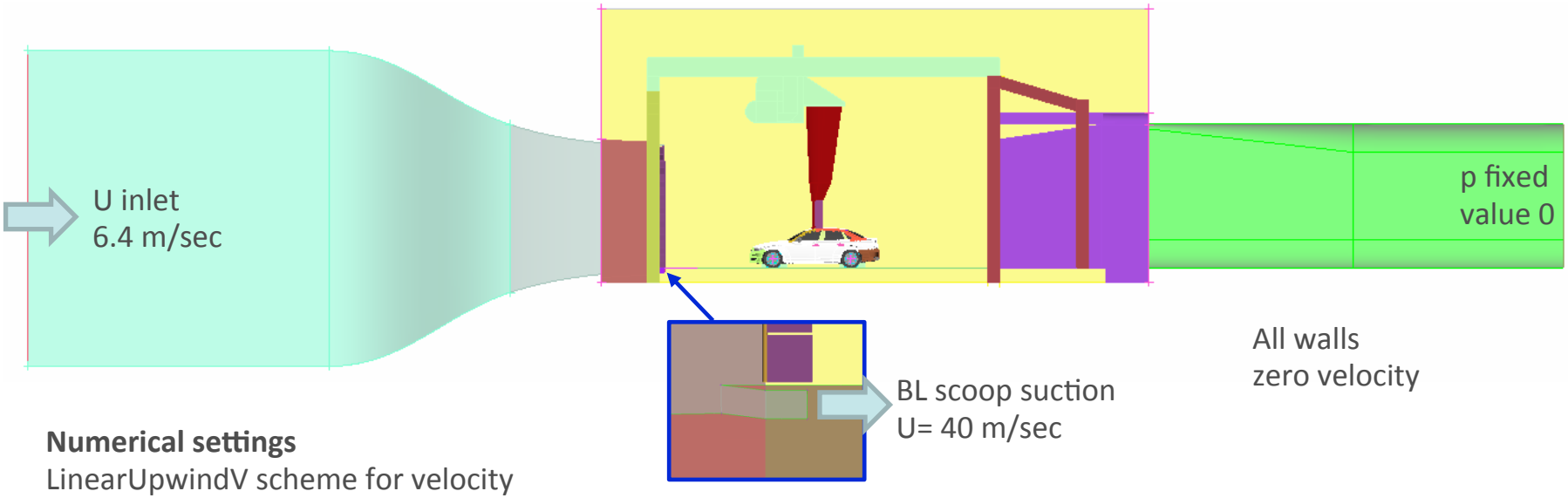
Summary of mesh models for different variants

		Coarse	Medium	Fine
Notchback 	Open Domain	-	Tetra (30.6 million)	-
	Windtunnel	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



OpenFOAM simulations: setup



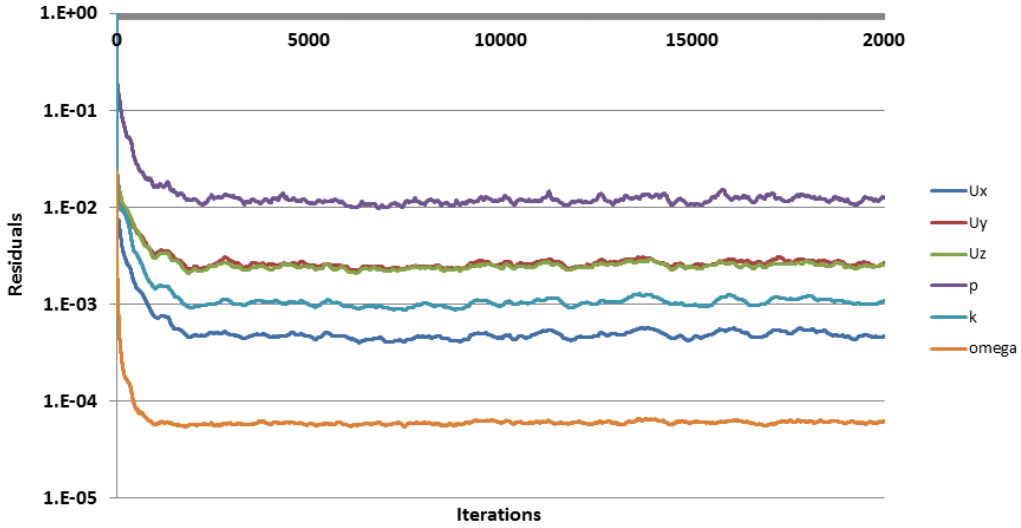
Numerical settings
LinearUpwindV scheme for velocity
Upwind scheme for turbulence
GAMG solver for pressure, tolerance 10^{-10}, relTol 0.05
smoothSolver for velocity and turbulence, tolerance 10^{-10}, relTol 0.1

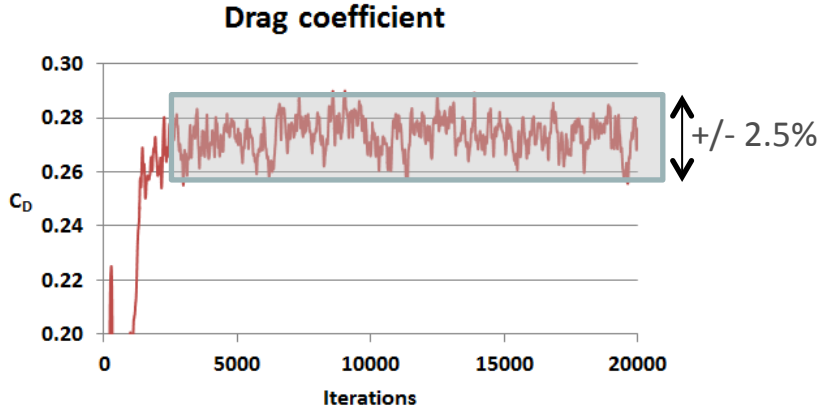
Steady State simulations
simpleFoam
Turbulence model: k-omega SST
Stationary ground
All runs started from potentialFoam initialization

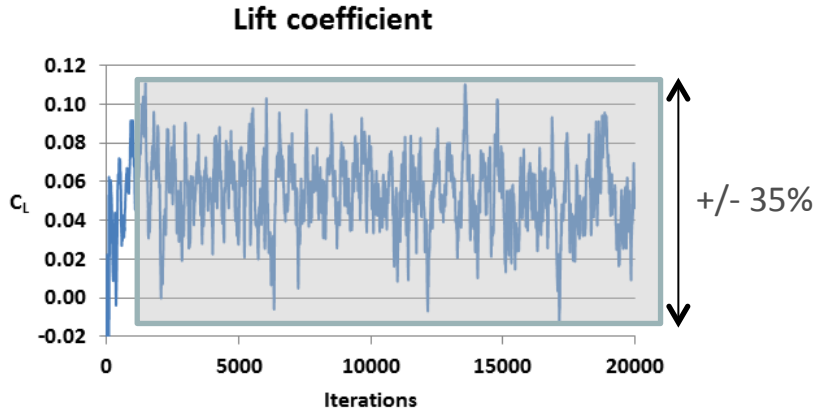
Transient simulation
pisoFoam
time step 10^{-4} sec
run for 3.5 sec real time
Turbulence model: IDDES Spalart Almaras model for near wall
Run starting from converged steady state solution

OpenFOAM simulations: Steady state simpleFoam convergence

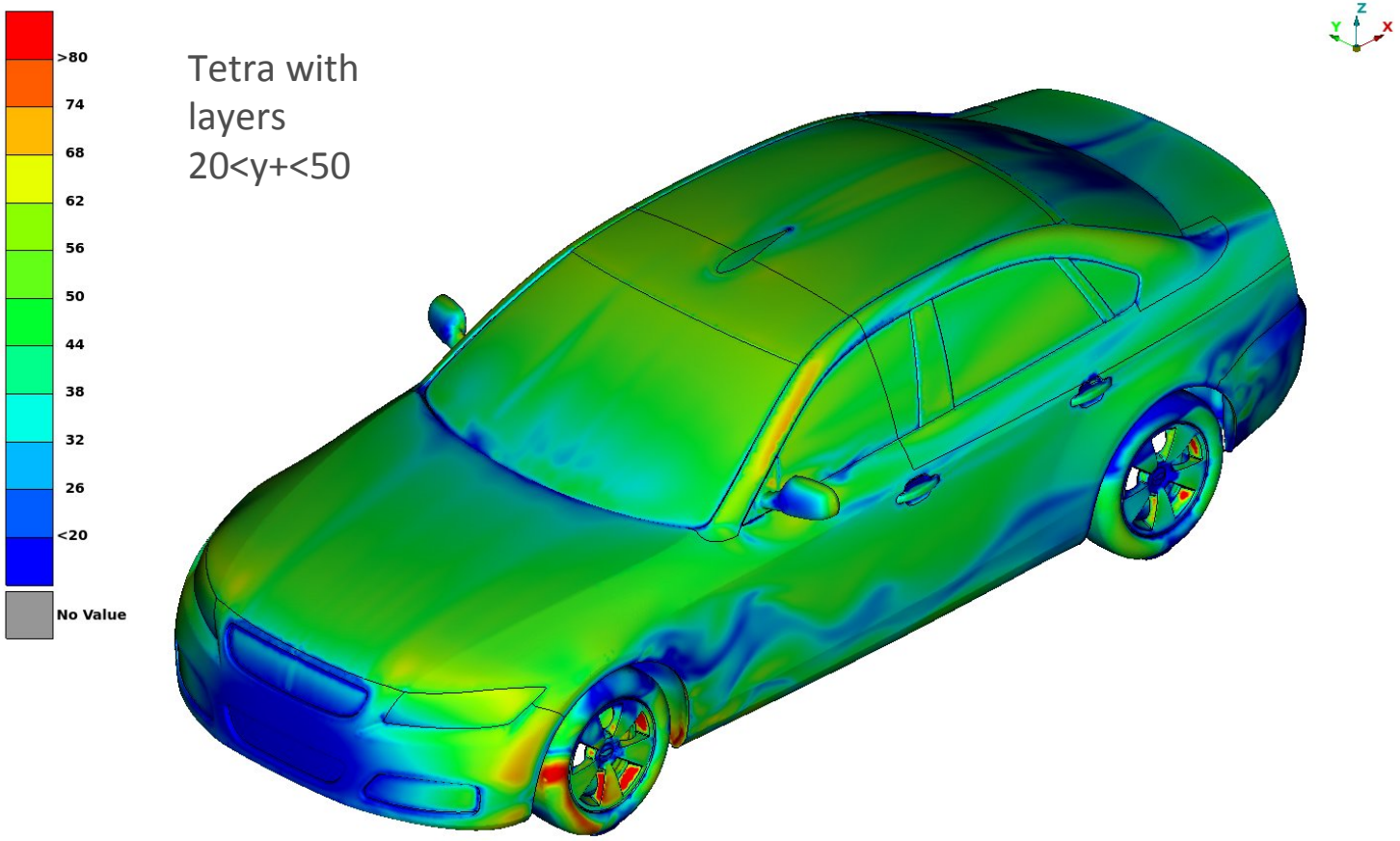
Indicative convergence history of residuals and drag and lift coefficients for Notchback TetraRapid medium model







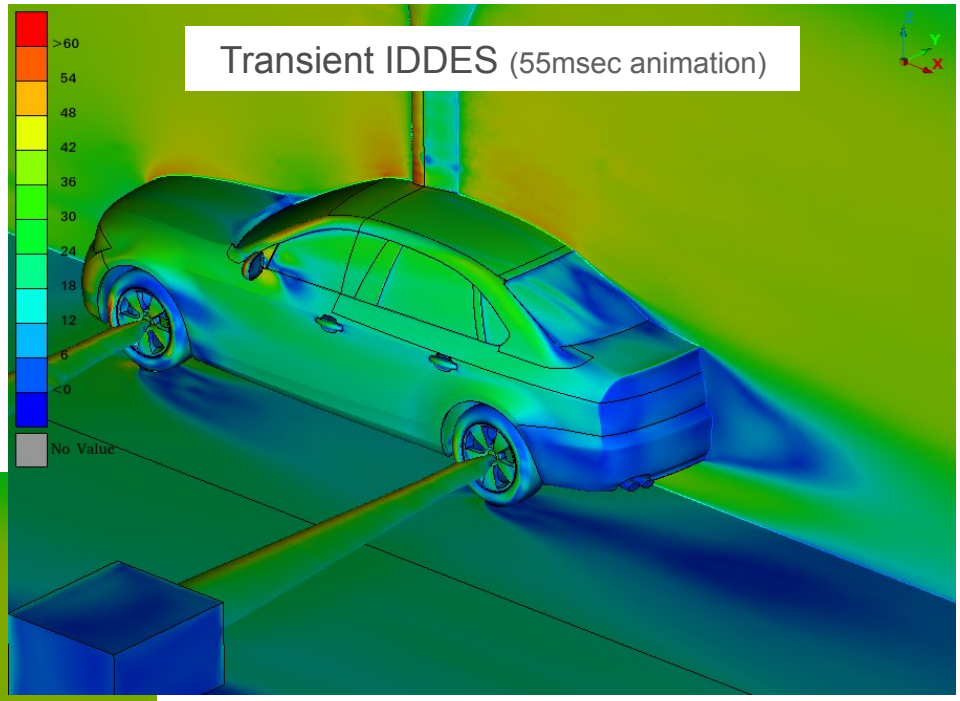
Post-processing in μETA: y+ results

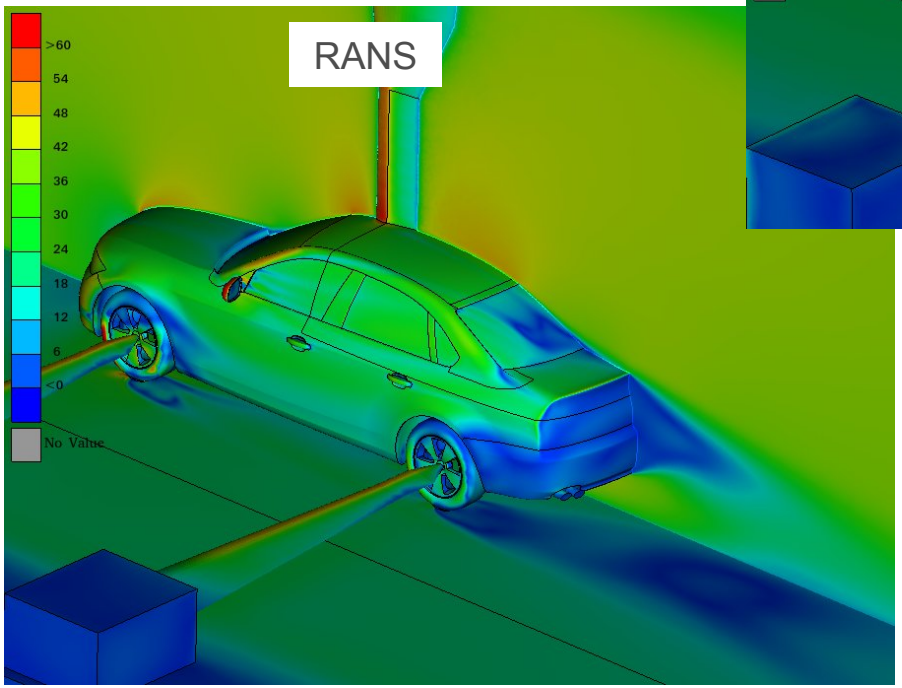


Post-processing was performed manually for one CFD run and then META run in batch mode for the other 14 simulations producing automatically the same images

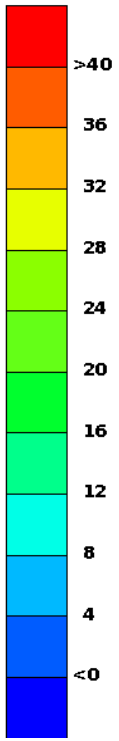
Velocity field at symmetry plane of notchback

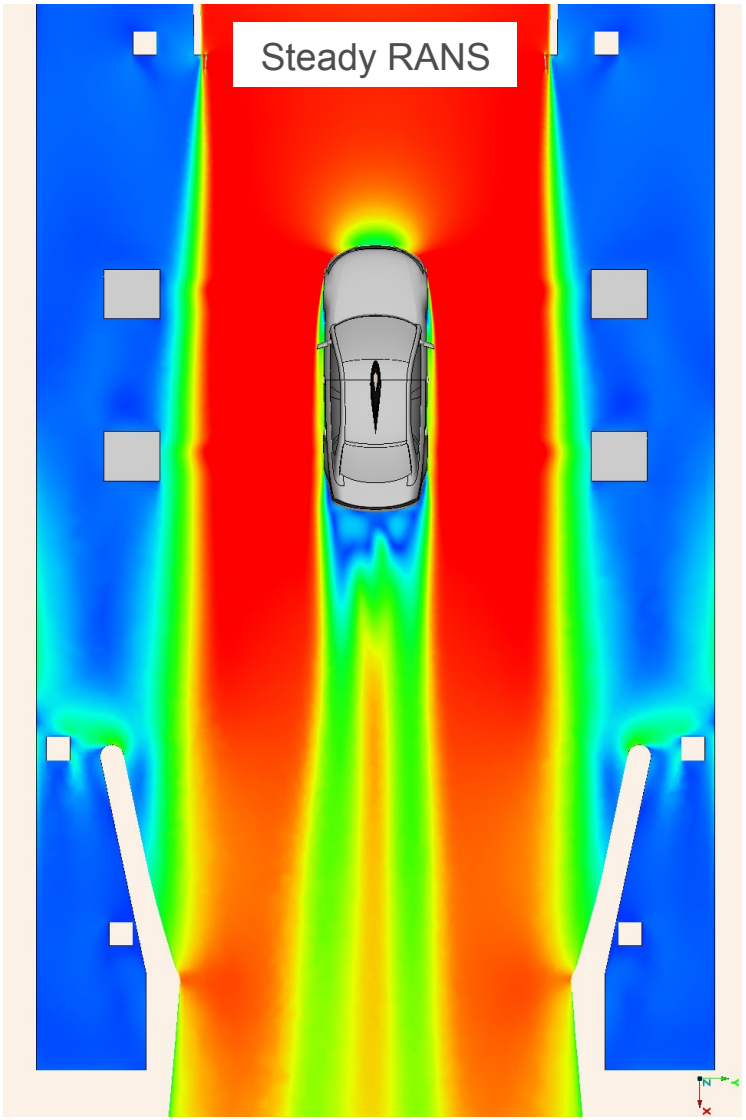
Tetra medium mesh

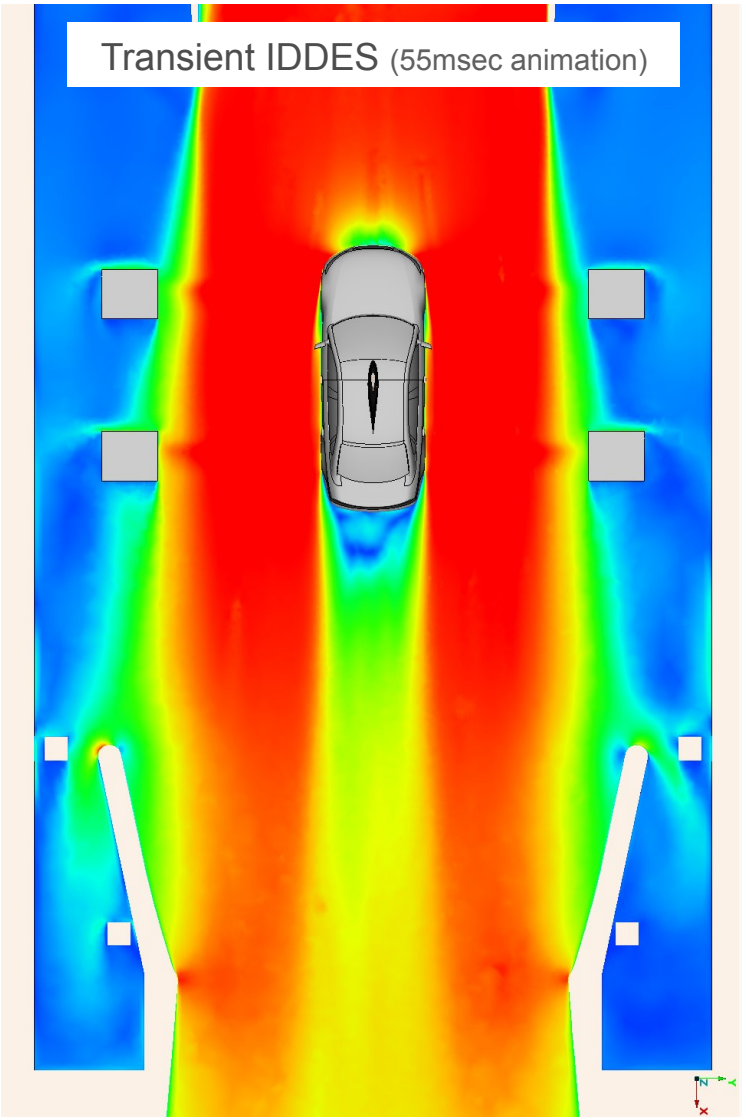




Cut-plane of velocity magnitude

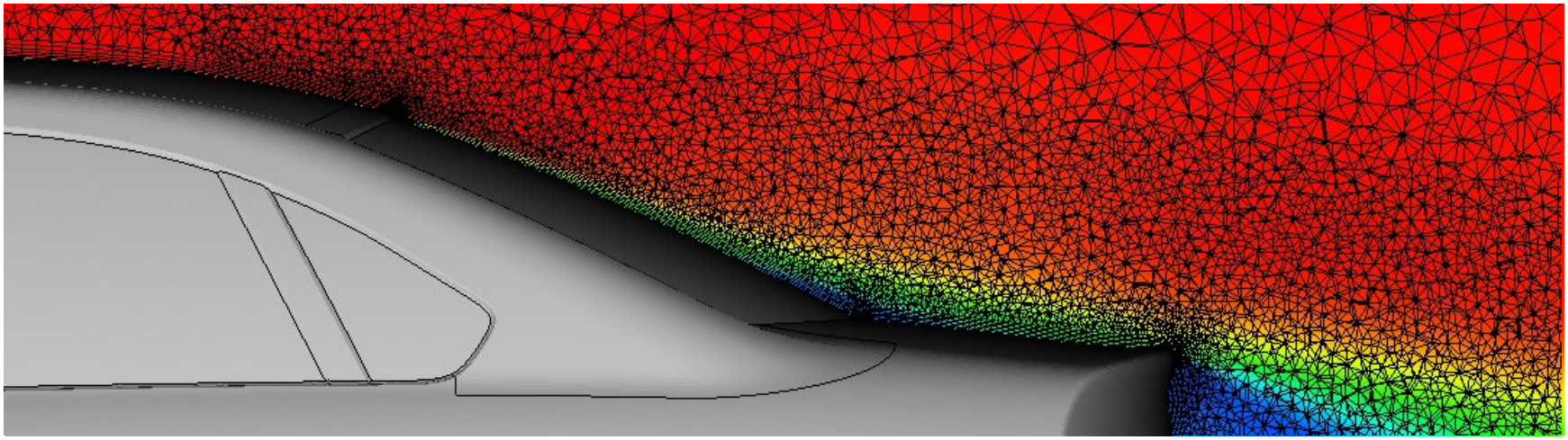




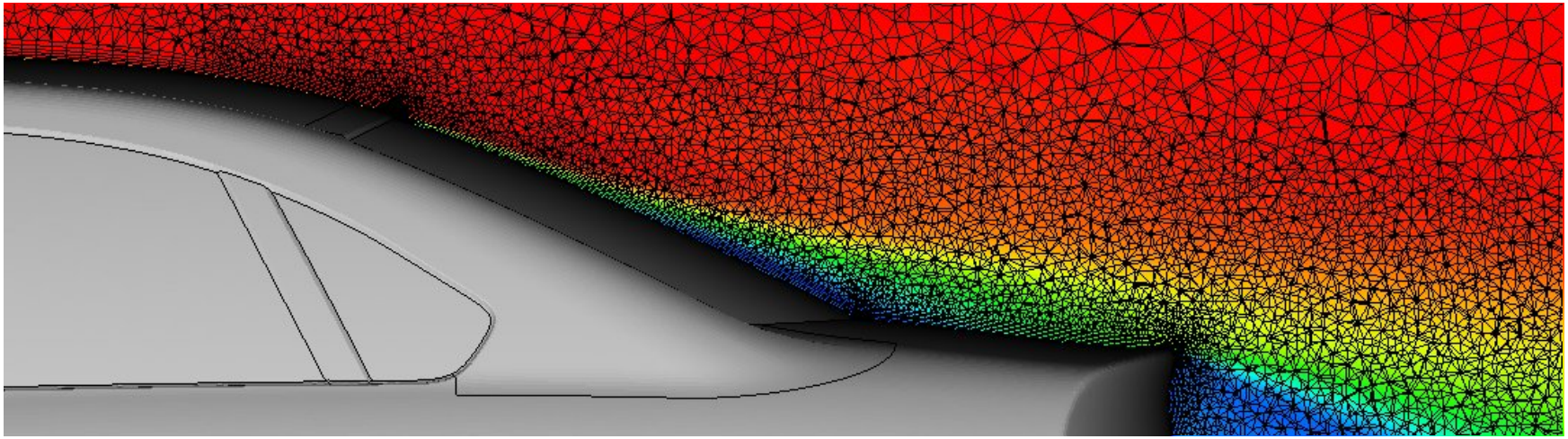


Velocity field at symmetry plane of notchback (tetra medium mesh)

RANS

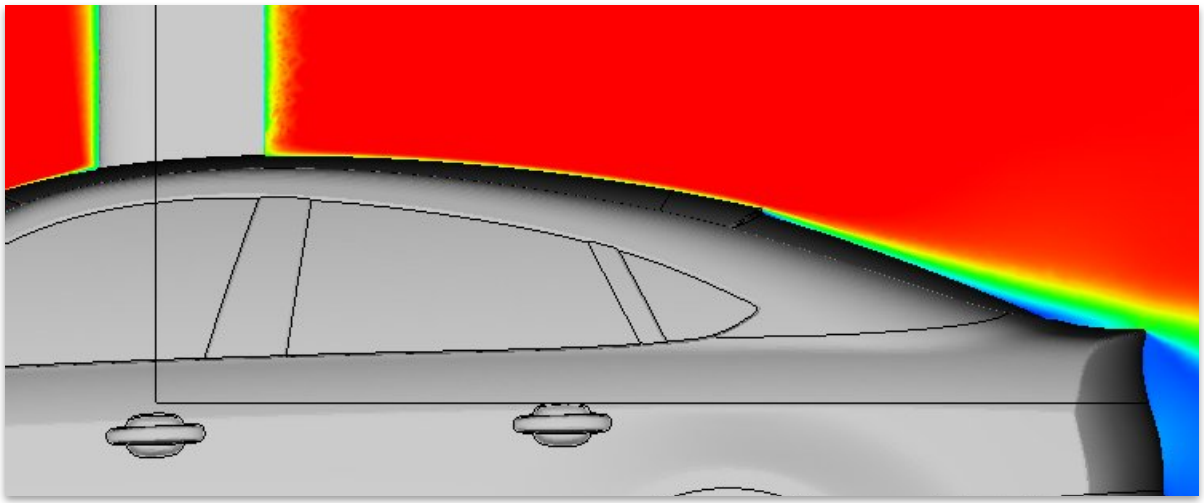


Transient IDDES (55 msec animation)

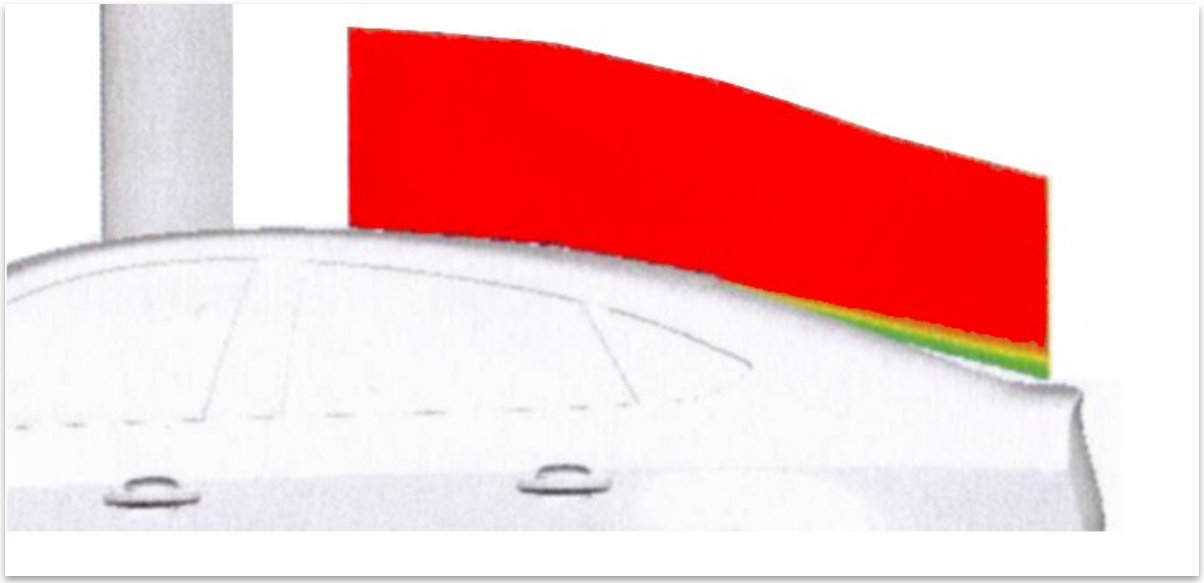


Velocity field at symmetry plane of fastback model

Averaged Velocity



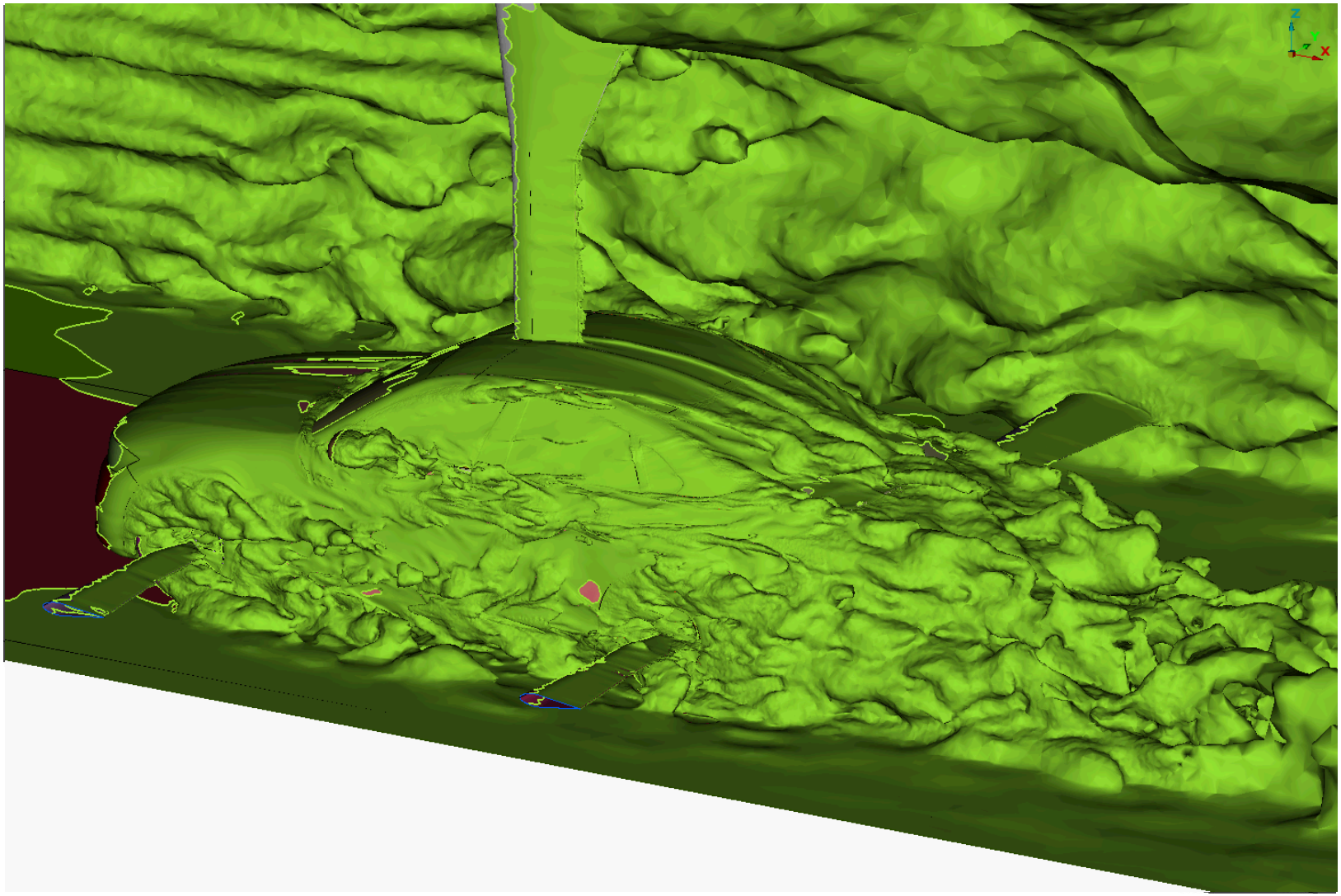
RANS k-omega SST
(Tetra Medium Mesh)



Experiment

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

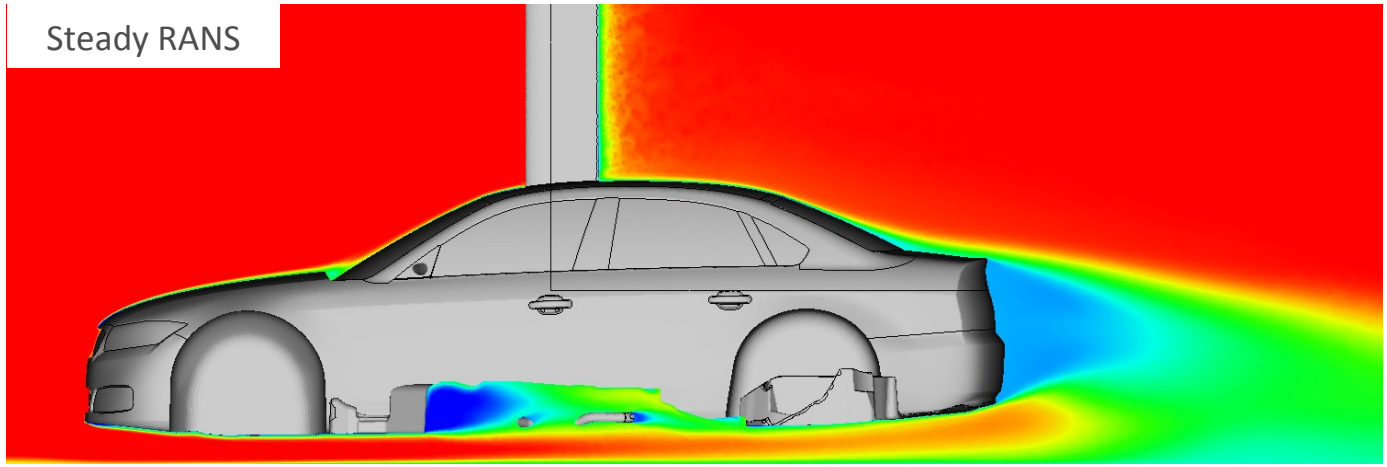
Tetra medium mesh



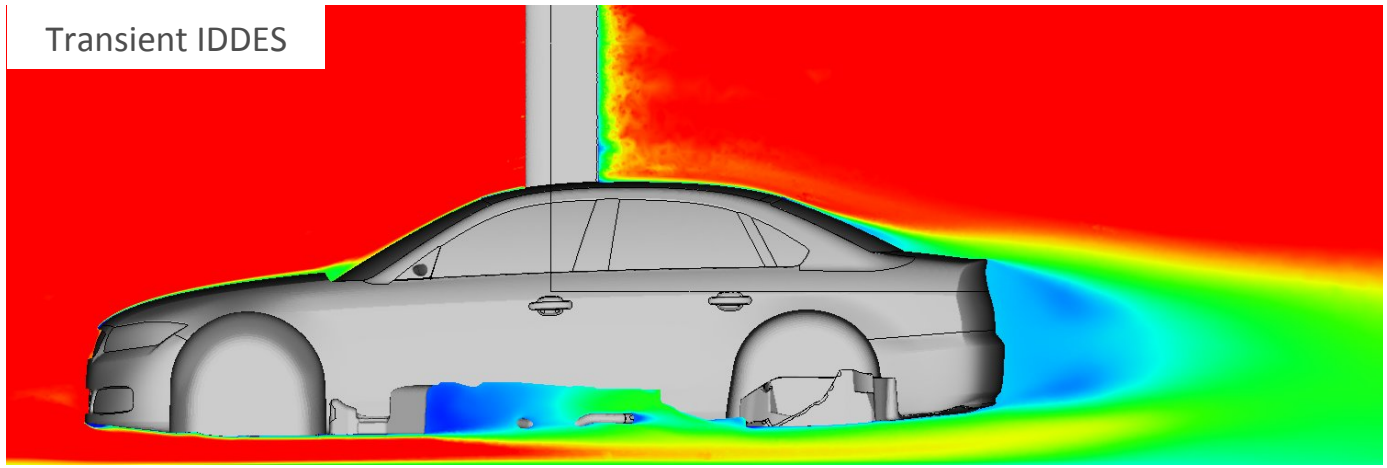
Pressure loss regions: Total pressure at symmetry plane of notchback

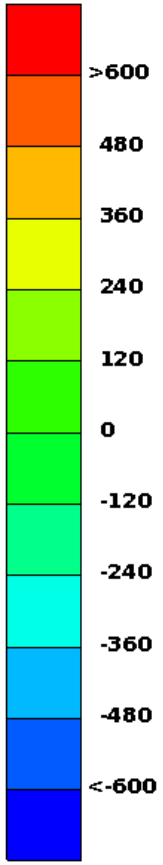
Tetra medium mesh – Iteration / Time averaged values

Steady RANS



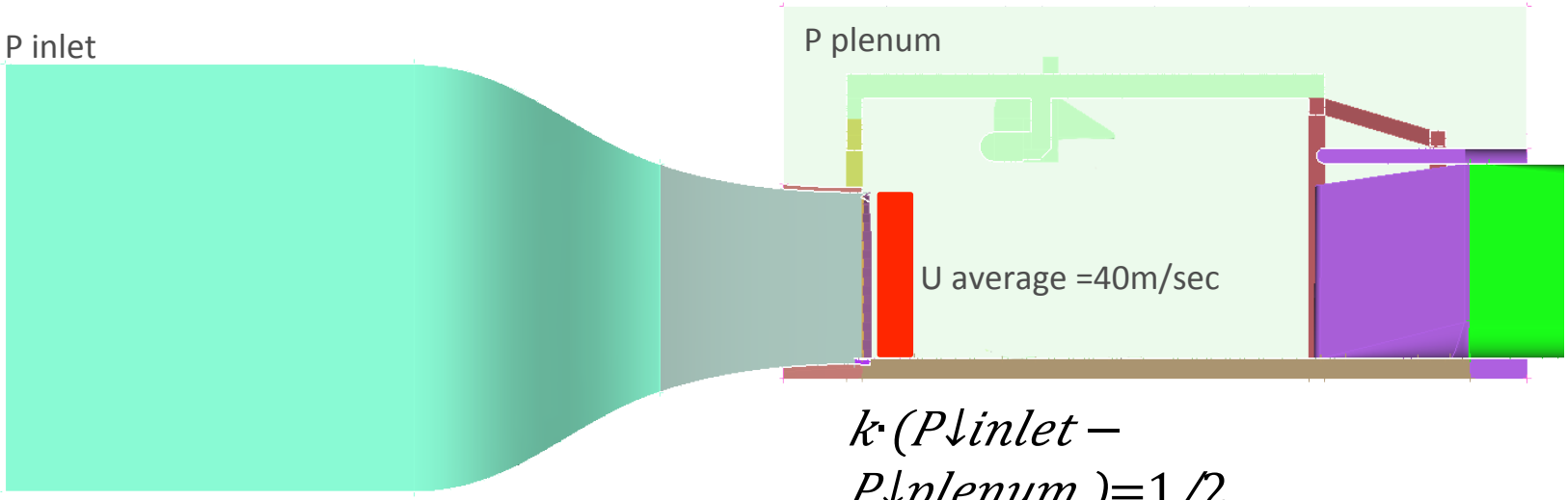
Transient IDDES



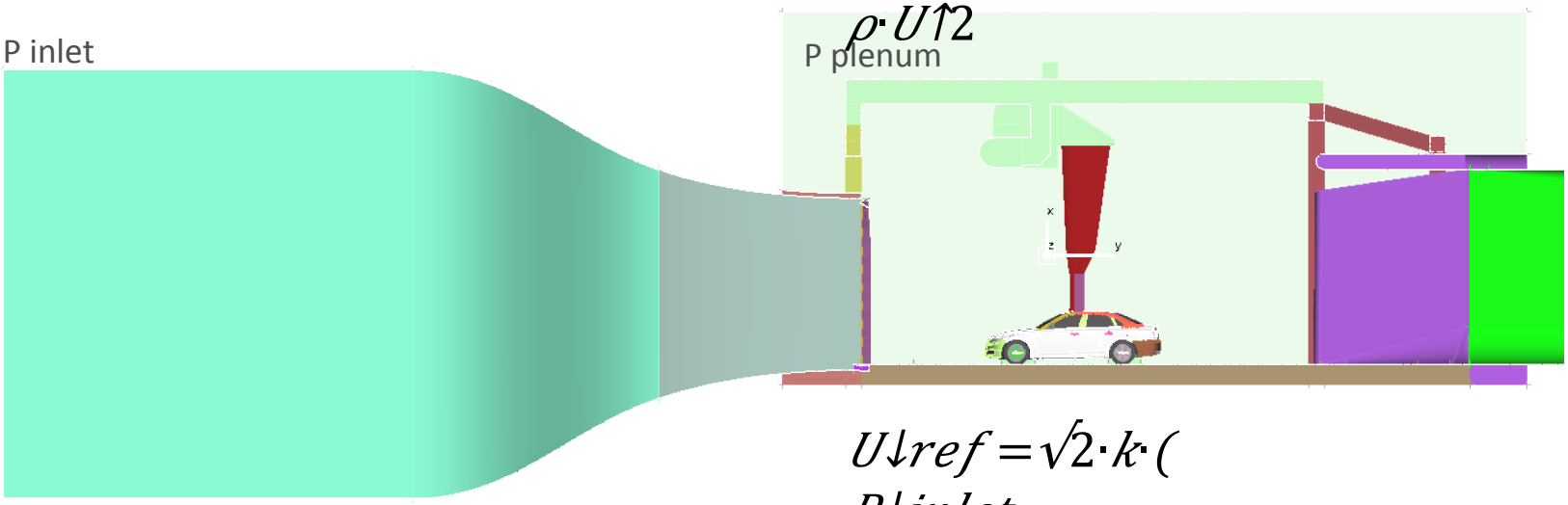


Open section wind tunnel corrections

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

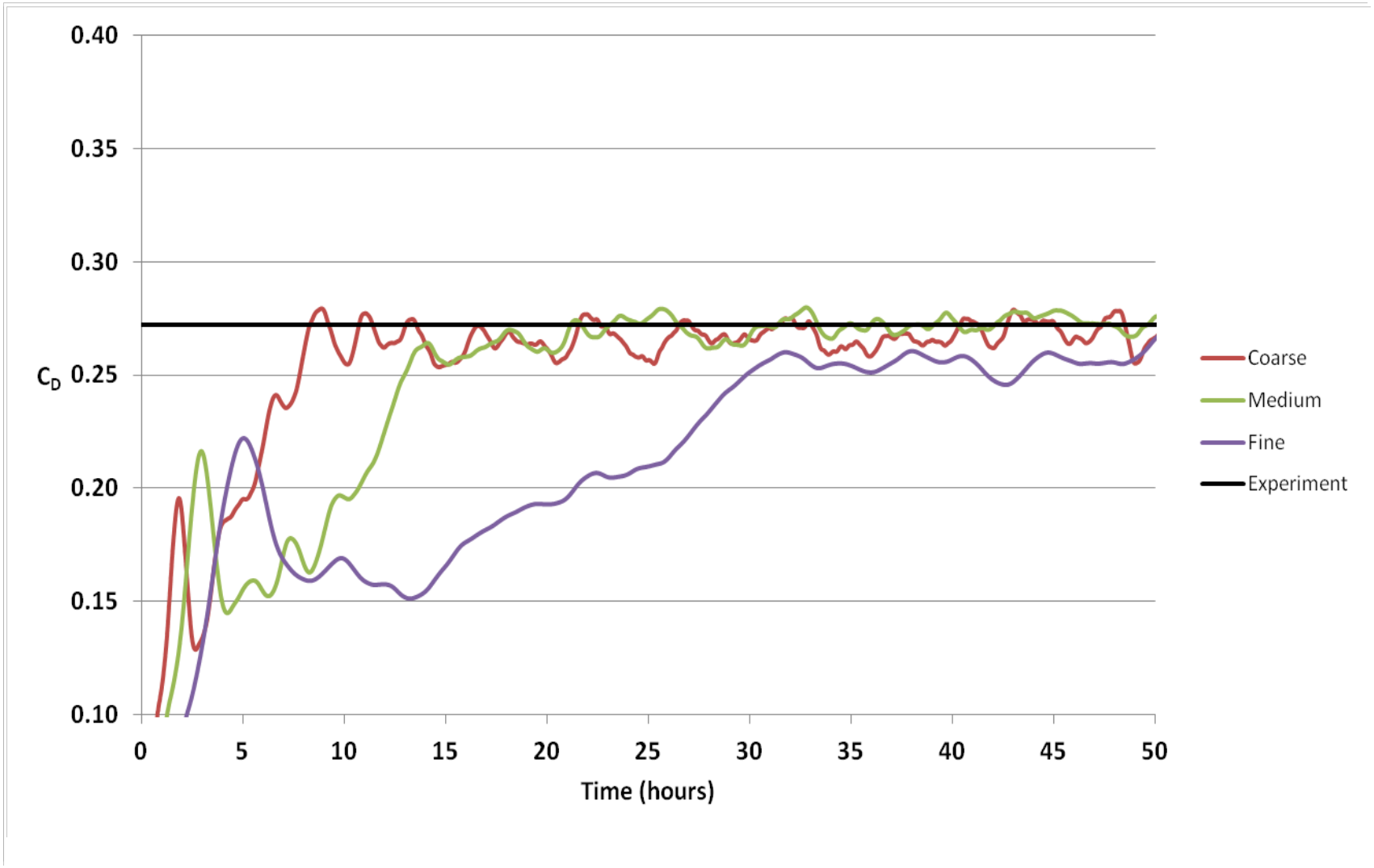


$$k \cdot (P\downarrow inlet - P\downarrow plenum) = 1/2 \rho \cdot U\uparrow 2$$

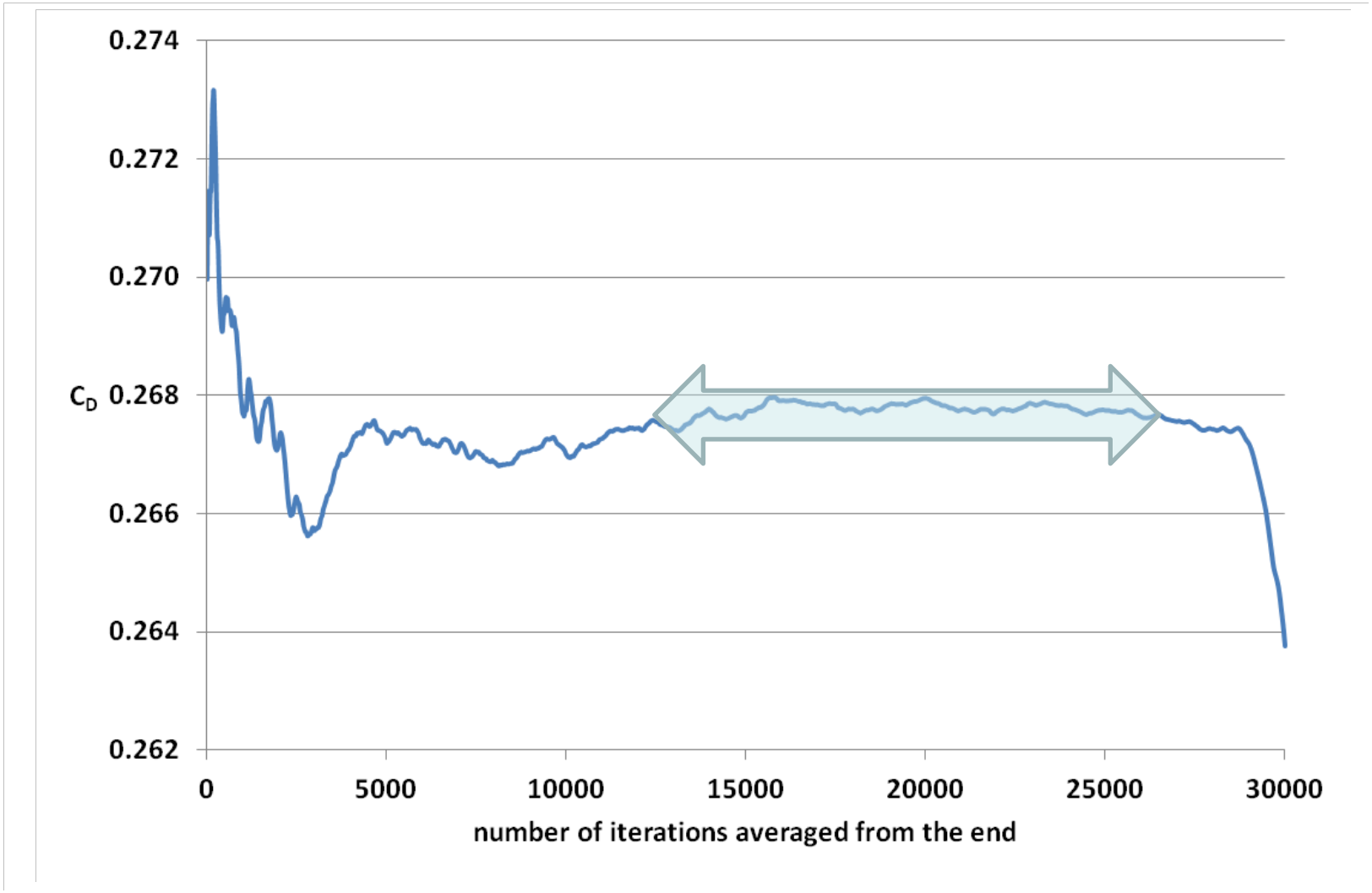


$$U\downarrow ref = \sqrt{2} \cdot k \cdot (P\downarrow inlet - P\downarrow plenum)/\rho$$

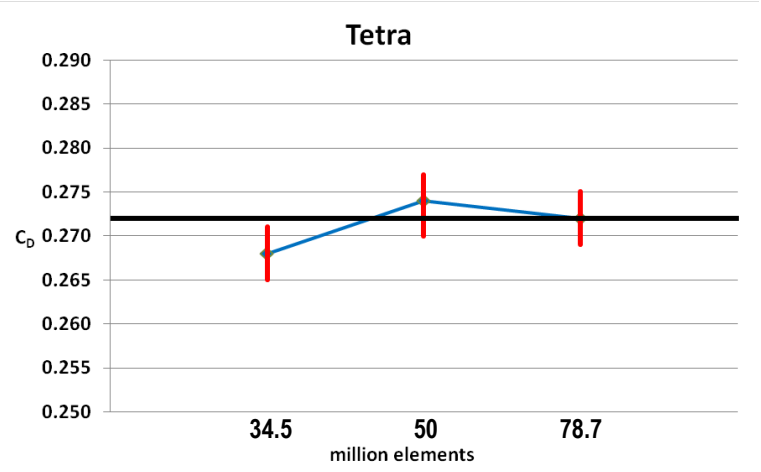
Convergence of Drag Coefficient: Tetra case - Notchback



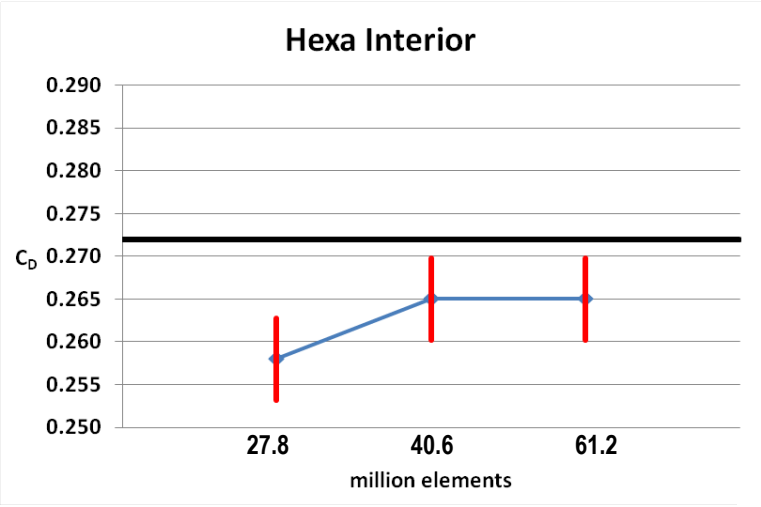
Averaging of fluctuating forces: Tetra medium mesh - Notchback

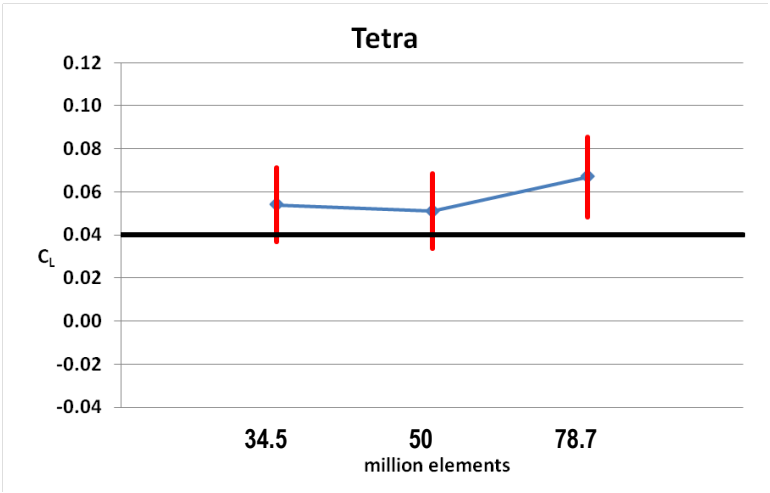


Mesh refinement study for Tetra and Hexa Interior meshes: C_D & C_L convergence

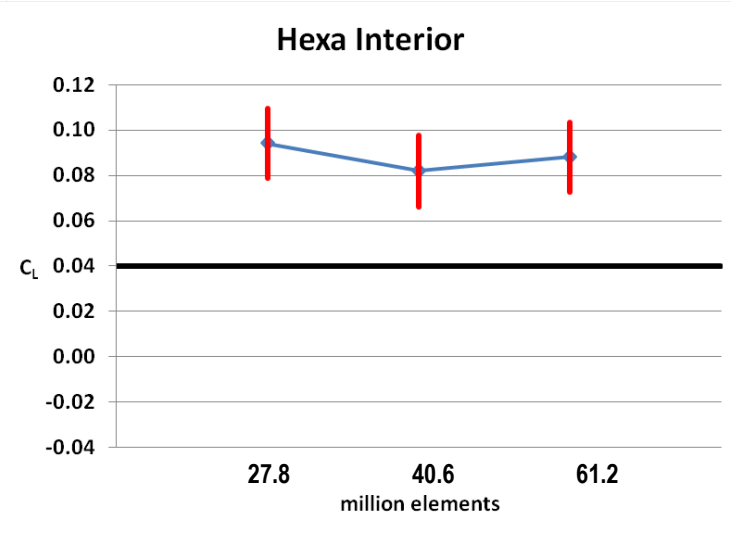


Experimental
C_D=0.272





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	Hexa Int 0.258 (-5%)	Hexa Int 0.265 (-3%)	Hexa Int 0.265 (-3%)
	RANS k-omega	Hexa Poly 0.258 (-5%)	Hexa Poly 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	Hexa Int 0.094 (+135%)	Hexa Int 0.082 (+105%)	Hexa Int 0.088 (+120%)
	RANS k-omega	Hexa Poly 0.116 (+190%)	Hexa Poly 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%)

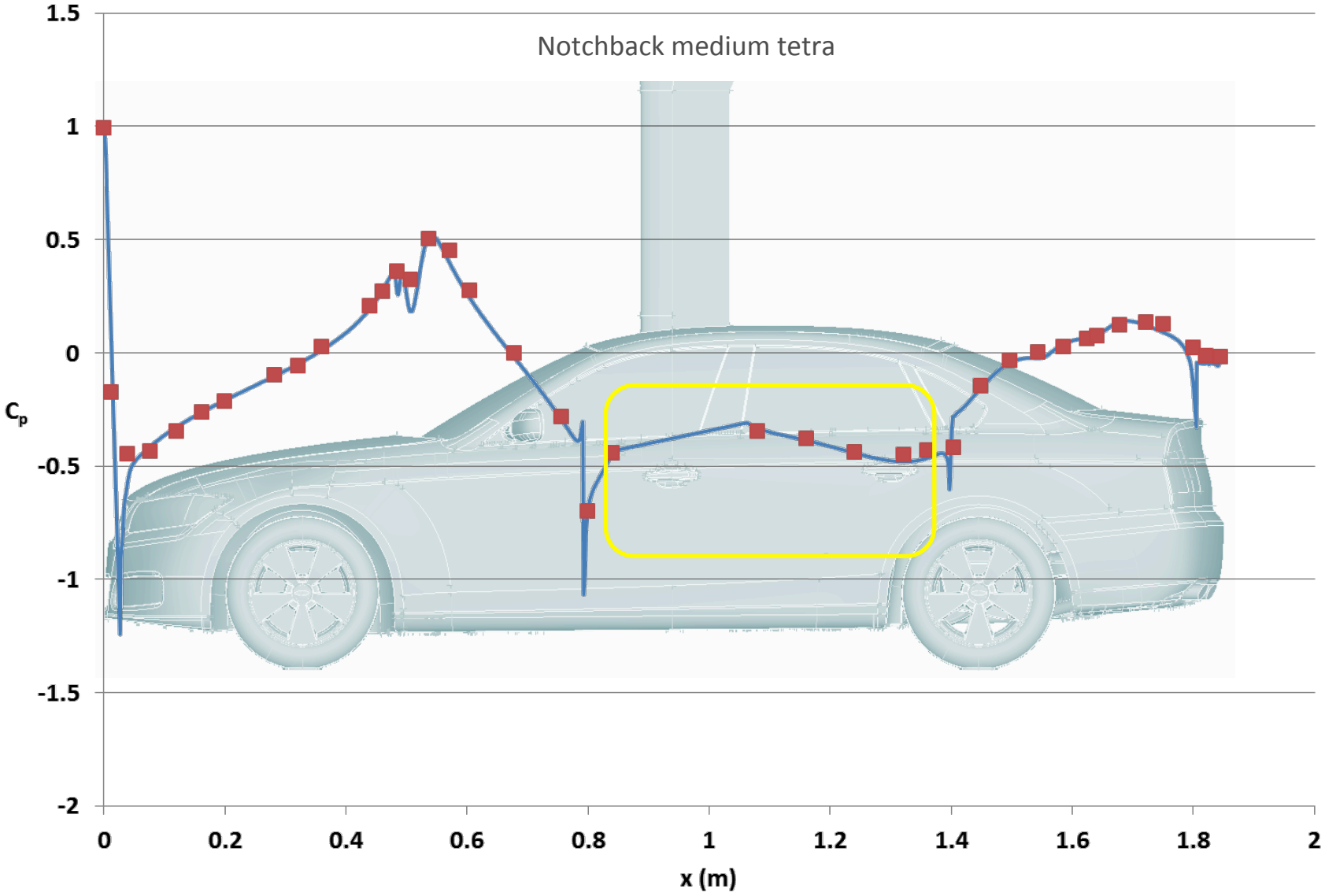
Summary of C_D and C_L values for three variants

Tetra medium meshes RANS simulations

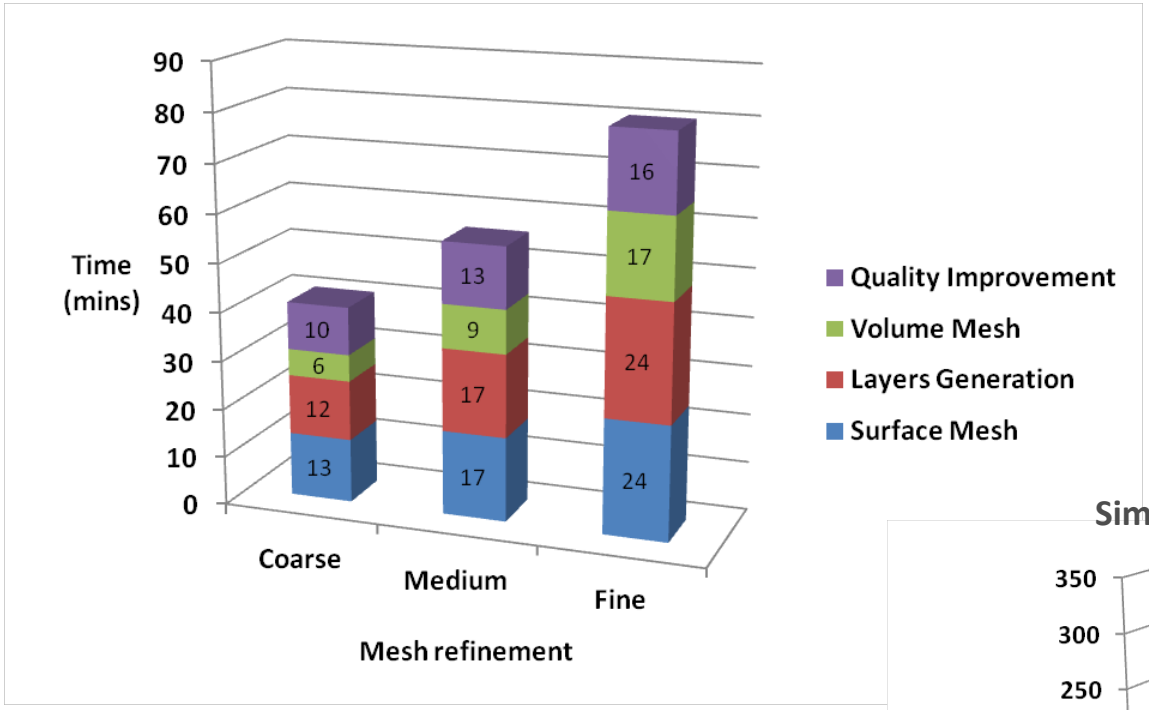
	C_D Experiment	C_D CFD	C_L Experiment	C_L CFD
Notchback	0.272	0.274 (+1%)	0.04	0.050 (+25%)
Fastback	0.274	0.271 (-1%)	0.05	0.058 (+16%)
Estate	0.314	0.279 (-11%)	-0.07	-0.050 (+29%)

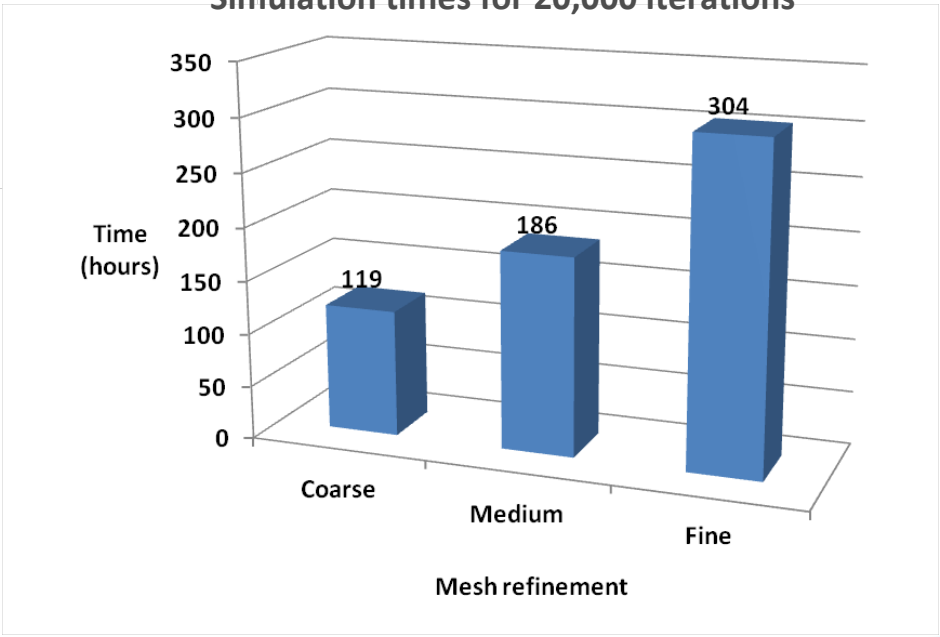
Plenum method corrected values presented (correction can be as high as 15%)

Comparison with experiment: C_P along upper symmetry line



Pre-processing and Simulation Times





Concluding remarks

- In order 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 μETA 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

Thank you

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