THE INFLUENCE OF MESH CHARACTERISTICS ON OPENFOAM SIMULATIONS OF THE DRIVAER MODEL

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

KEYWORDS –
ANSA, μETA, meshing, pre-processing, post-processing, CFD, OpenFOAM, automotive aerodynamics

ABSTRACT –
In this study external aerodynamics CFD simulations are performed using OpenFOAM on the three variants of the DrivAer model, a realistic geometry with details representative of current automotive designs. A thorough examination of the effect of different meshes on the solution convergence and accuracy is performed. These meshes differ in terms of generation process and time involved, their density and their quality. Different meshing approaches are followed using the pre-processor ANSA, ranging from standard hybrid penta and tetra meshes to hexa dominant and polyhedral ones. Other factors considered are the steady or transient approaches, as well as the importance of including the wind tunnel in the simulations to exactly match CFD and experimental results. All post-processing steps are performed in μETA fully automatically in order to identify the differences in the above simulations. Conclusions are derived with respect to the importance of the mesh, and the optimum pre-processing strategy that ensures robust automation as well as high fidelity CFD simulations with OpenFOAM.

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

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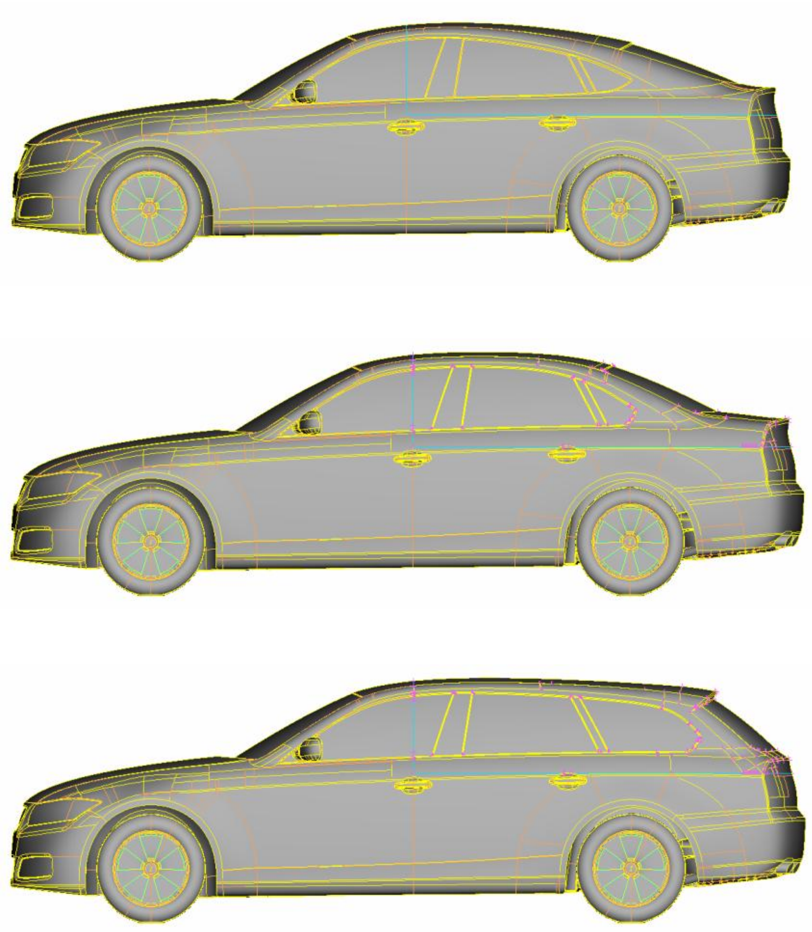
The DrivAer model of the Technical University of Munich

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%

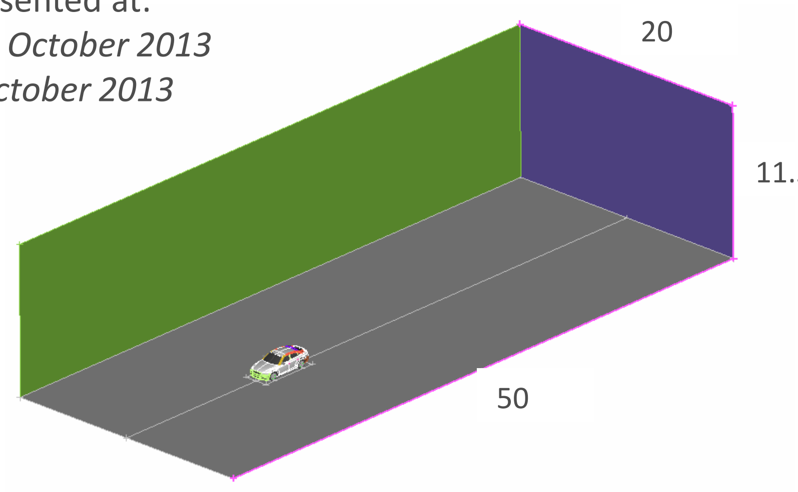


Acknowledgments to:
Institute of Fluid Mechanics and Aerodynamics of the Technical University of Munich
for providing the model geometries
in IGES and STEP formats

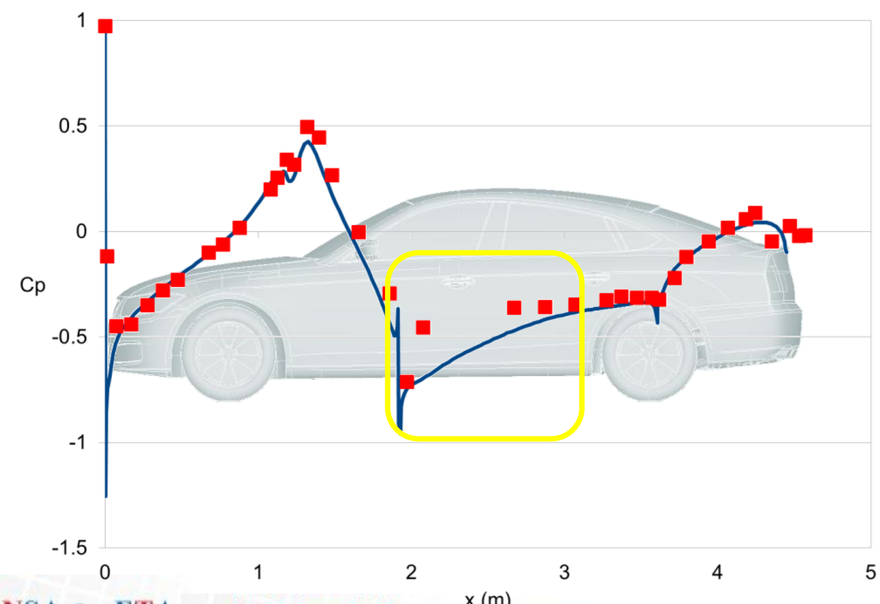
Reference
Heft Angelina (2014) “Aerodynamic Investigation of the Cooling Requirements of Electric Vehicles”, PhD Thesis, Technical University of Munich, ISBN 978-3-8439-1765-0

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

Software and hardware used

- ANSA v15.3.0 for pre-processing

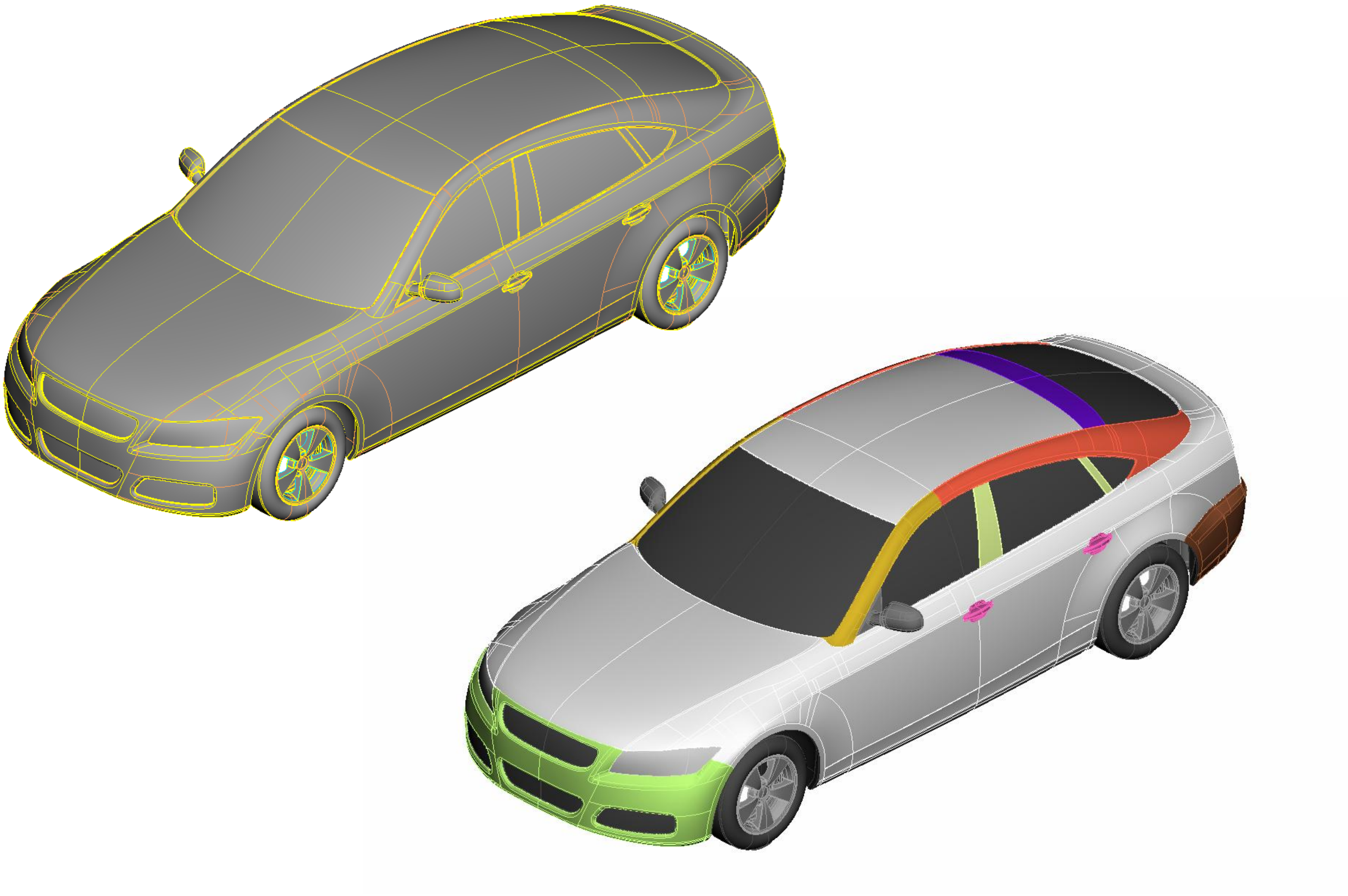
- OpenFOAM v2.3 for solving

- μETA v15.3.0 for post-processing

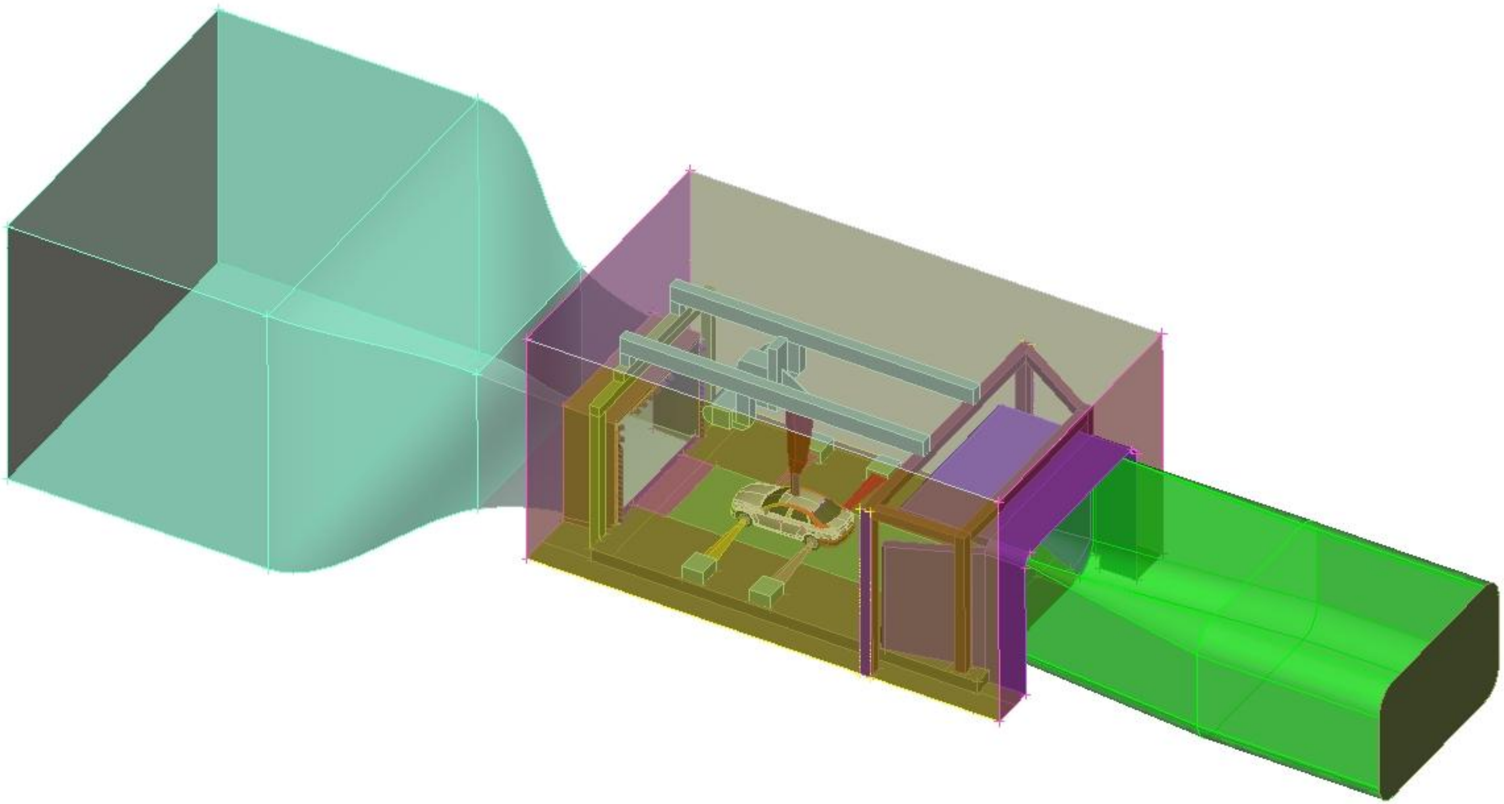
6 Linux Centos 6.6 PCs
Each one with
40 cores Xeon CPU E5-2660 at 2.6GHz
256 Gb RAM

Geometry preparation: STEP file input and property assignment

Geometries that included detailed underbody and mirrors were selected

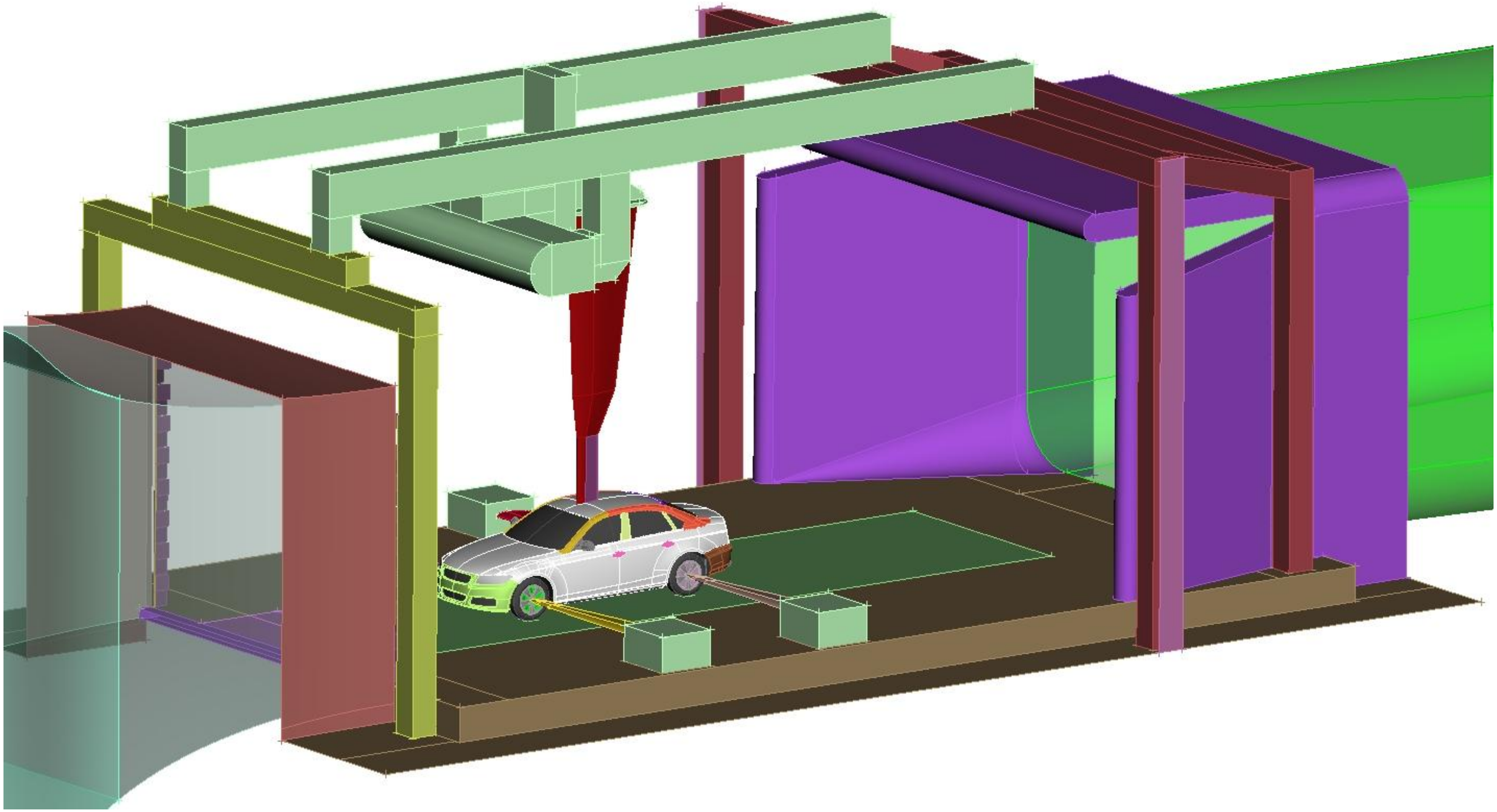


Geometry preparation: Construction of wind tunnel geometry

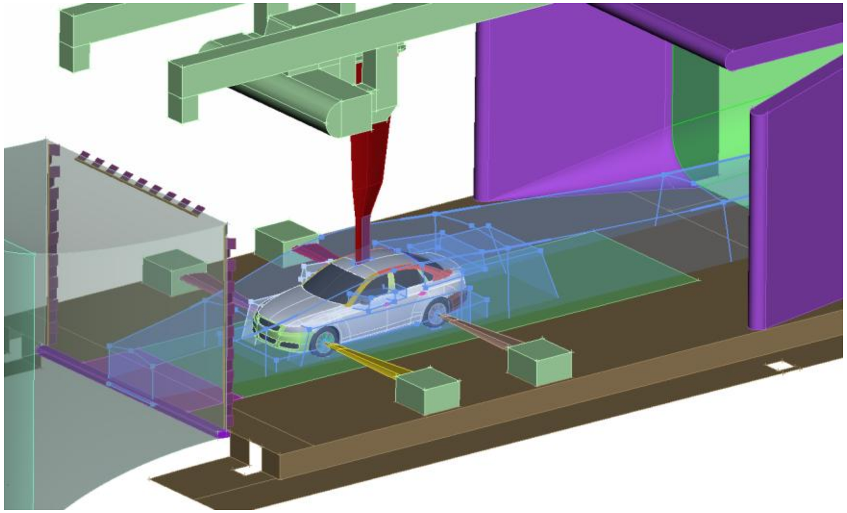


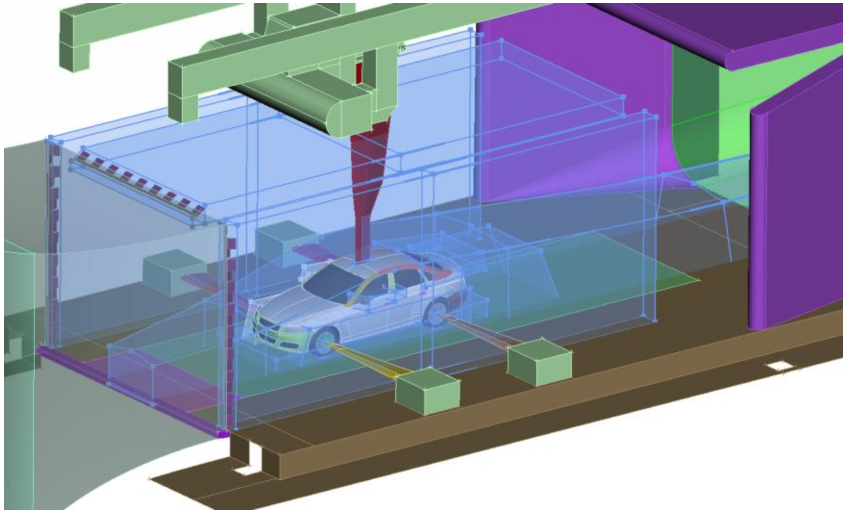
Geometry preparation: Construction of wind tunnel geometry

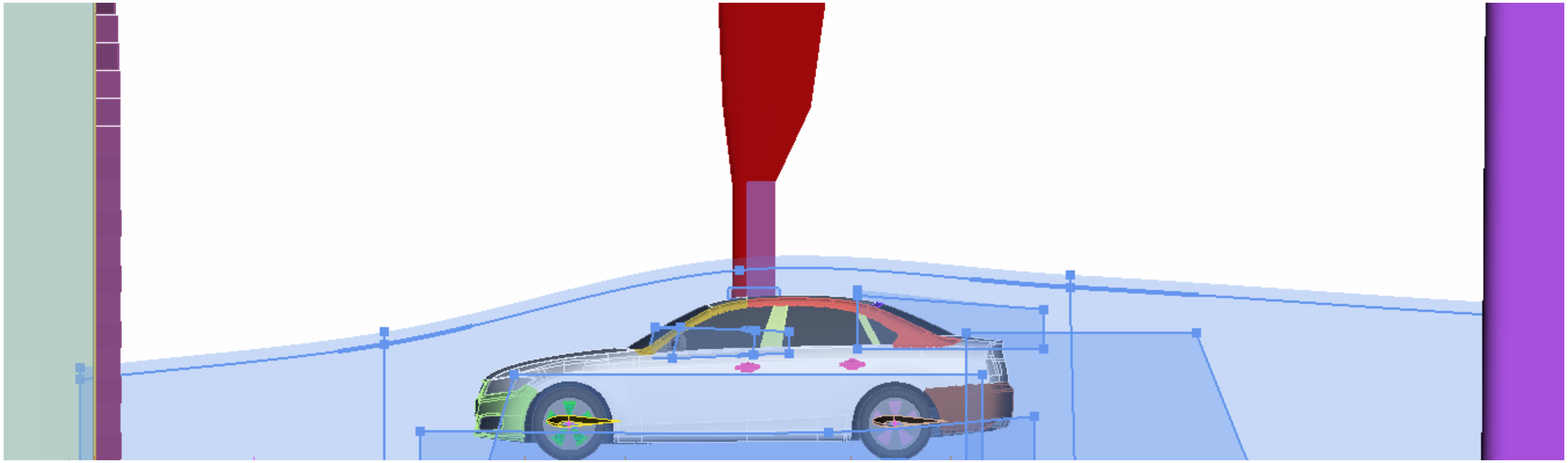
Blockage ratio ≈ 8%



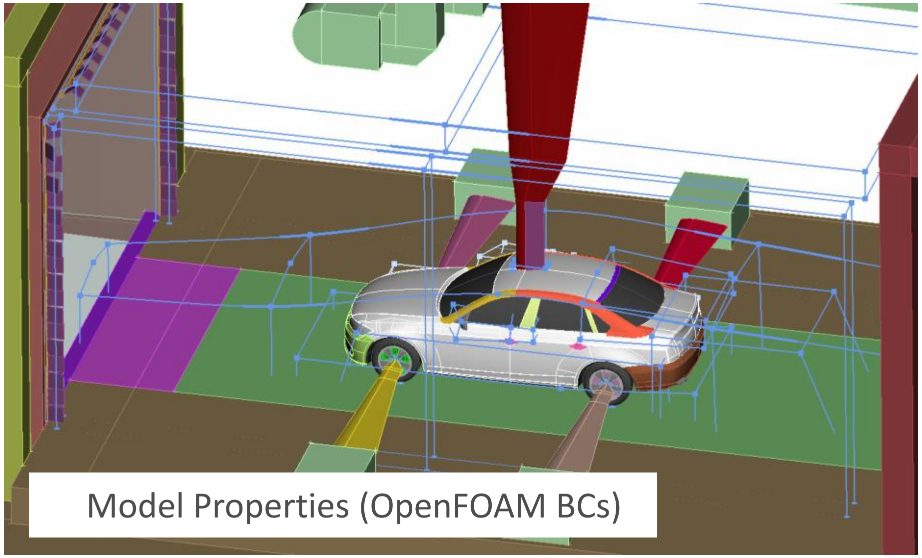
Flexible Size Boxes controlling mesh refinement aligned to the flow

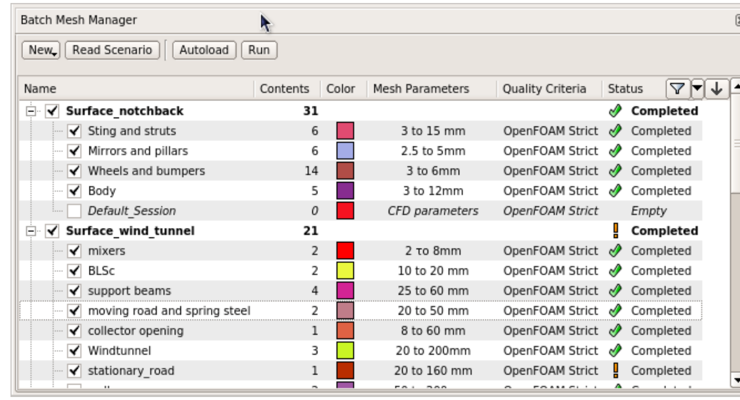




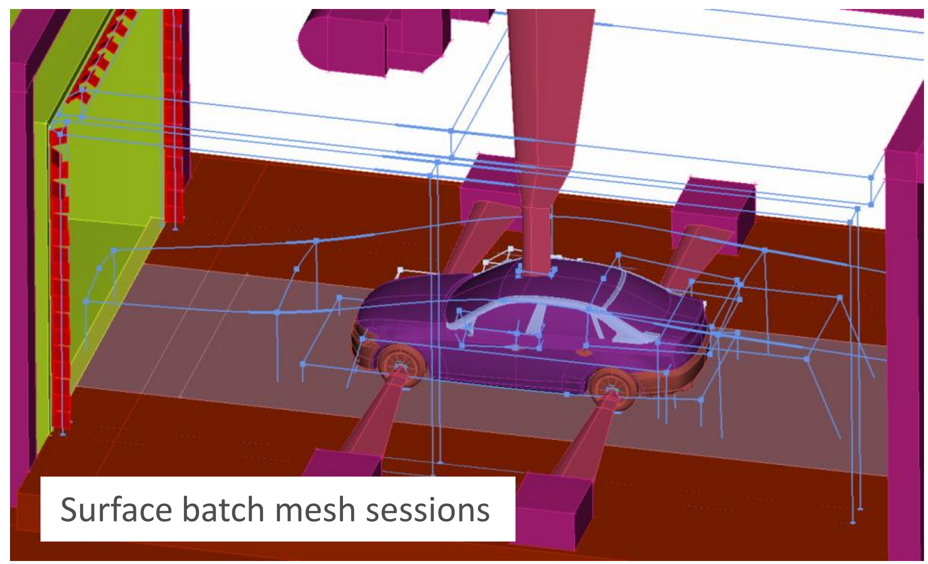


Batch Meshing setup: automation and consistency in meshing


Model Properties (OpenFOAM BCs)

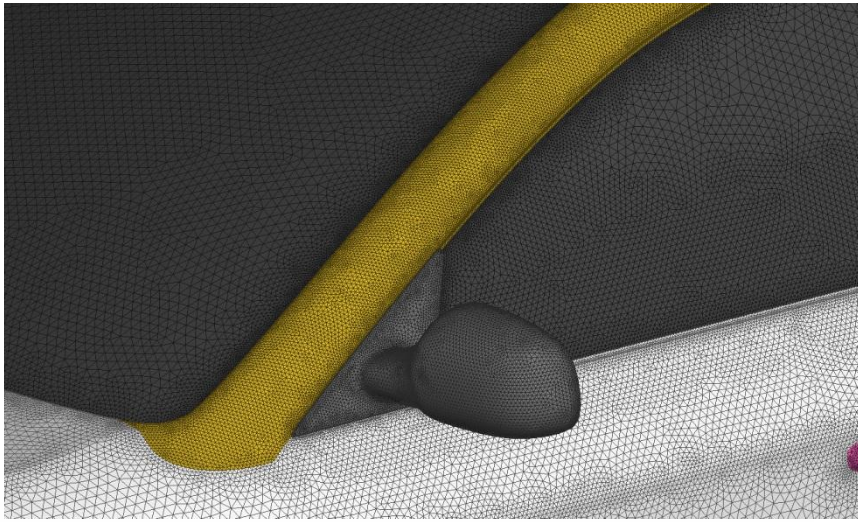


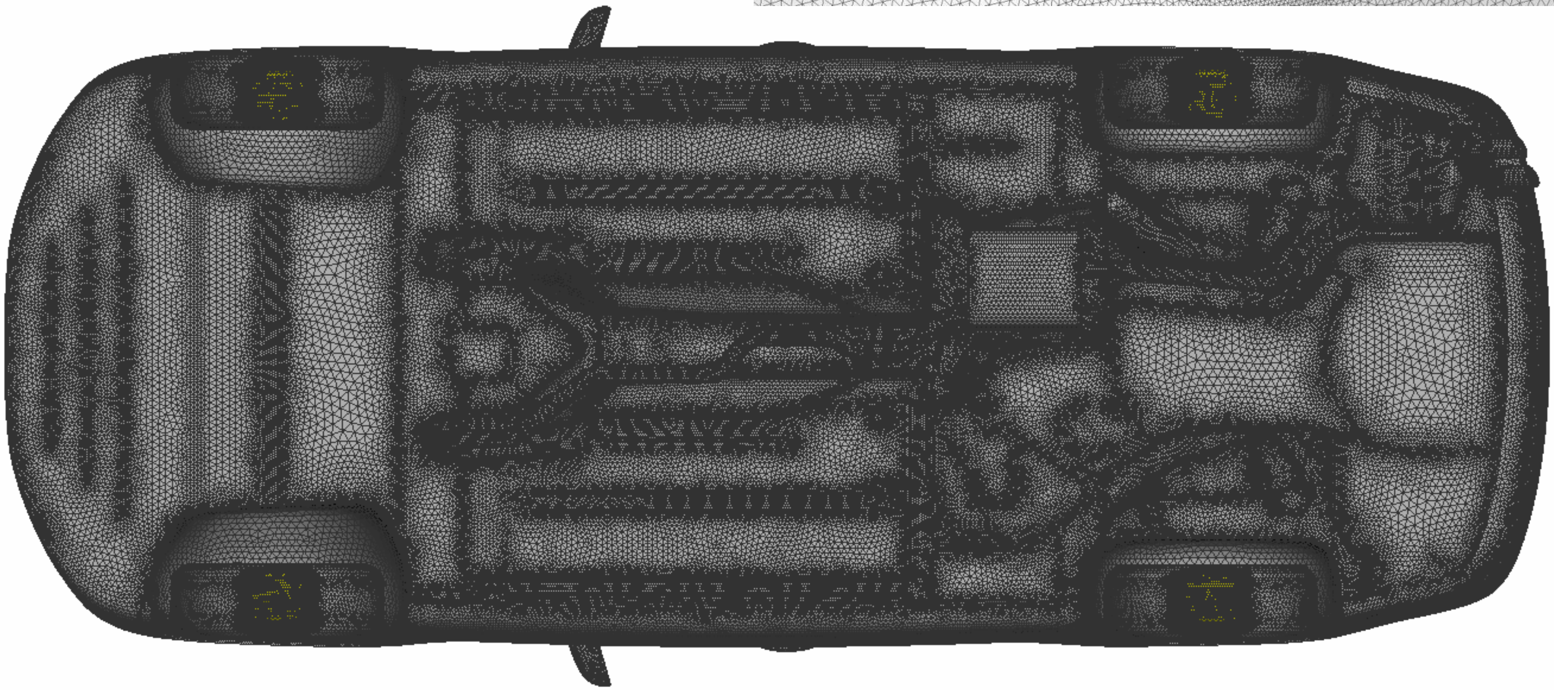
Batch Mesh provides:
- Automation
- Consistency
- Mesh spec traceability


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

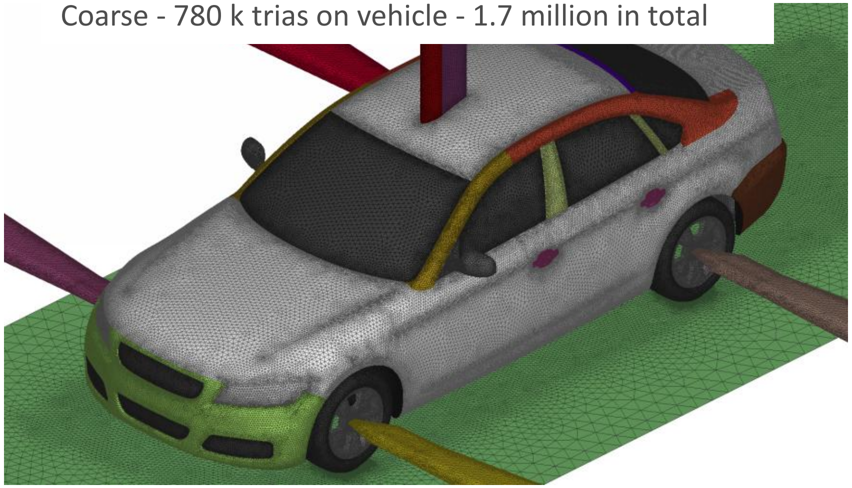




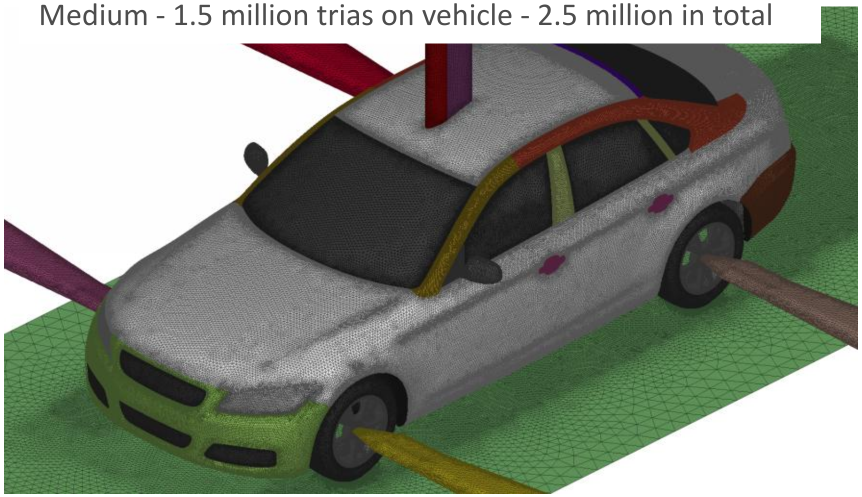
Batch mesh generated surface mesh

Automatic generation of models with variable resolution using batch meshing

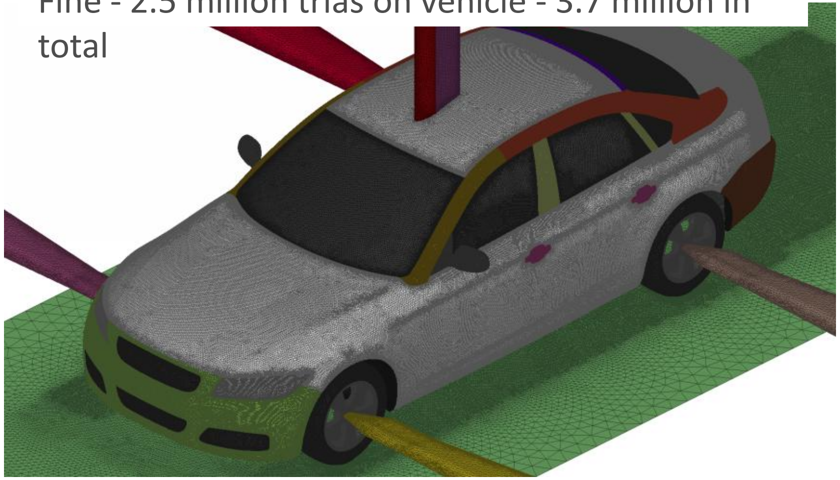
Coarse - 780 k trias on vehicle - 1.7 million in total



Medium - 1.5 million trias on vehicle - 2.5 million in total



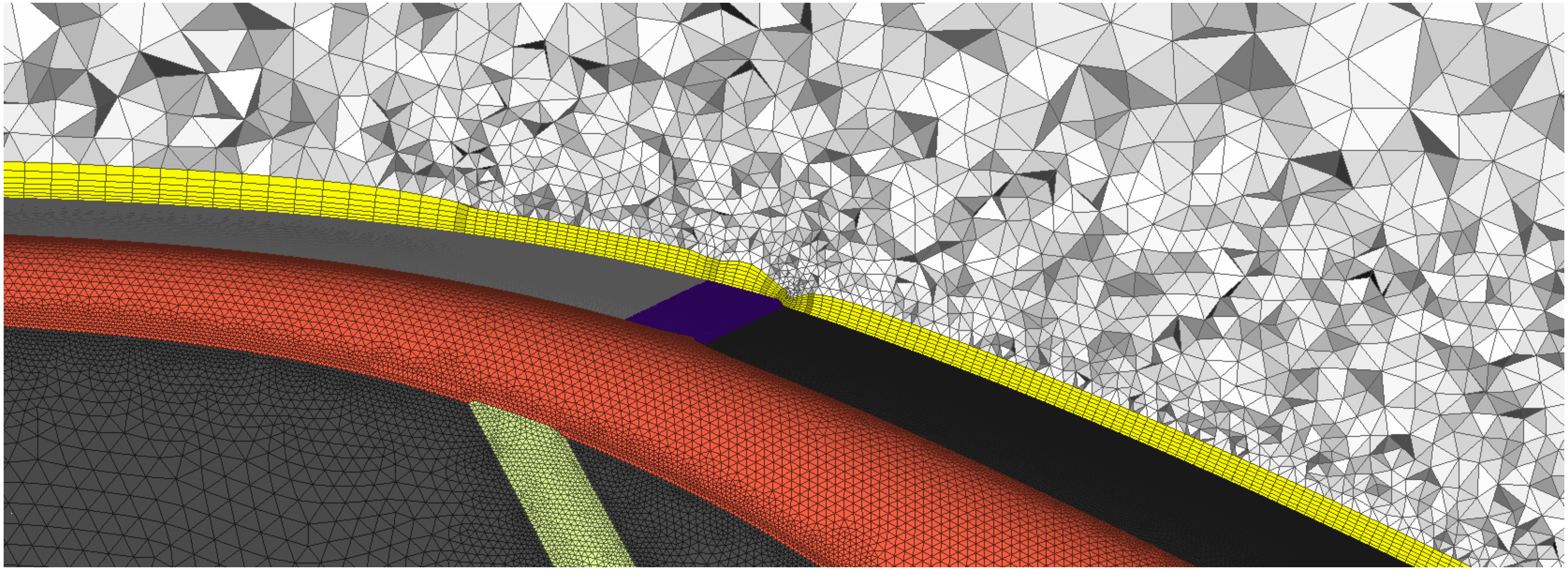
Fine - 2.5 million trias on vehicle - 3.7 million in total



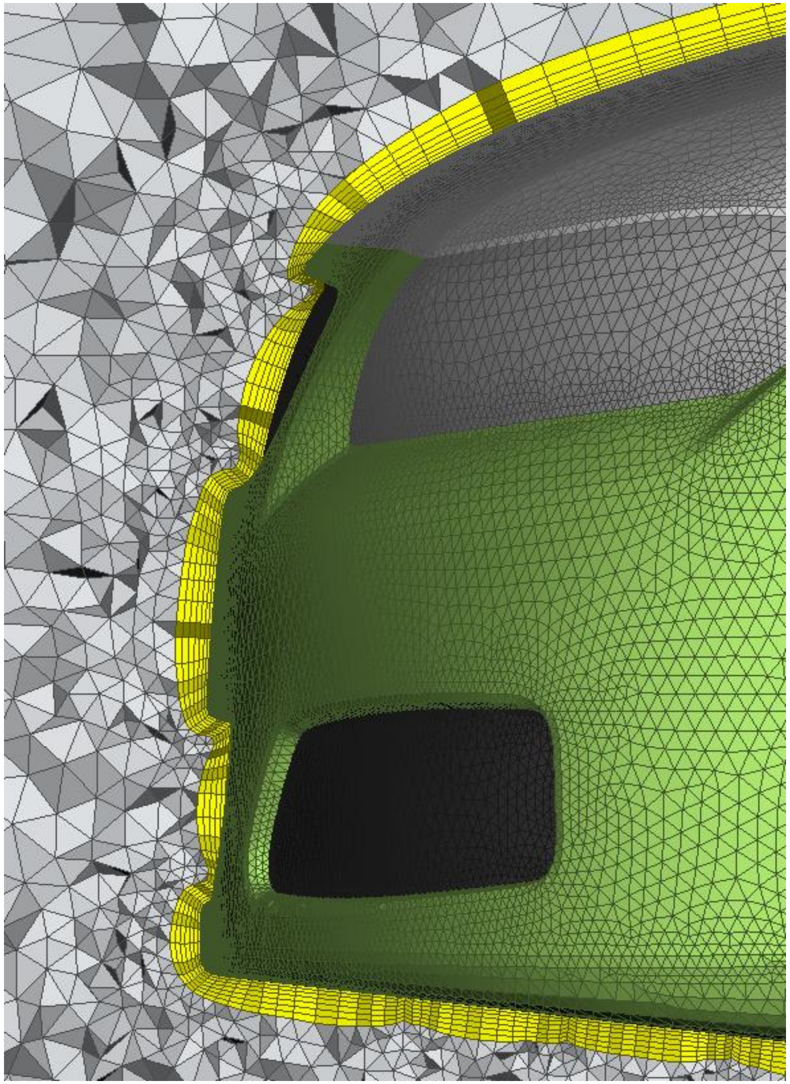
Boundary layer generation

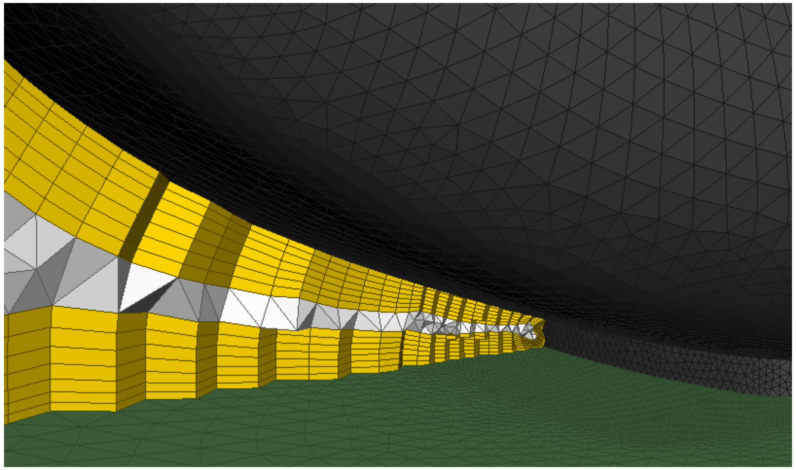
First height 0.8 mm
Growth rate = 1.2
4 layers
+3 layers in aspect mode
Last aspect ratio 40% of length

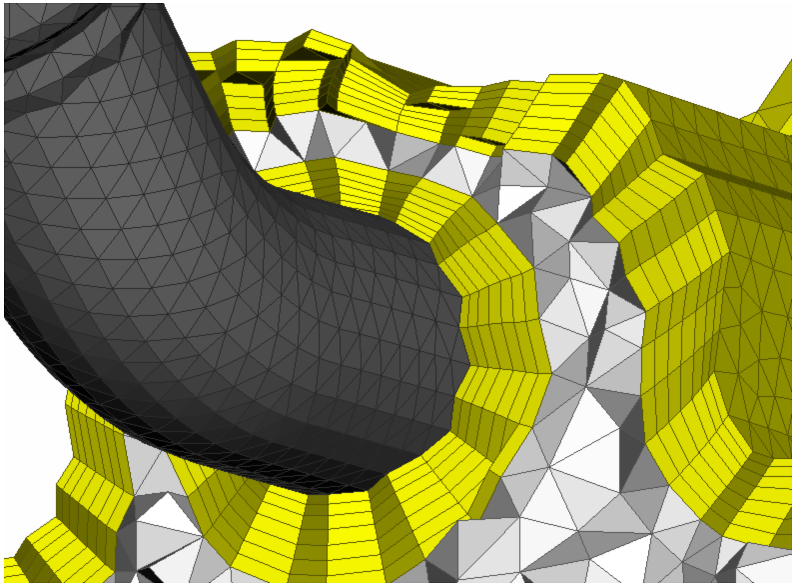
Total layer height ≈ 12 mm



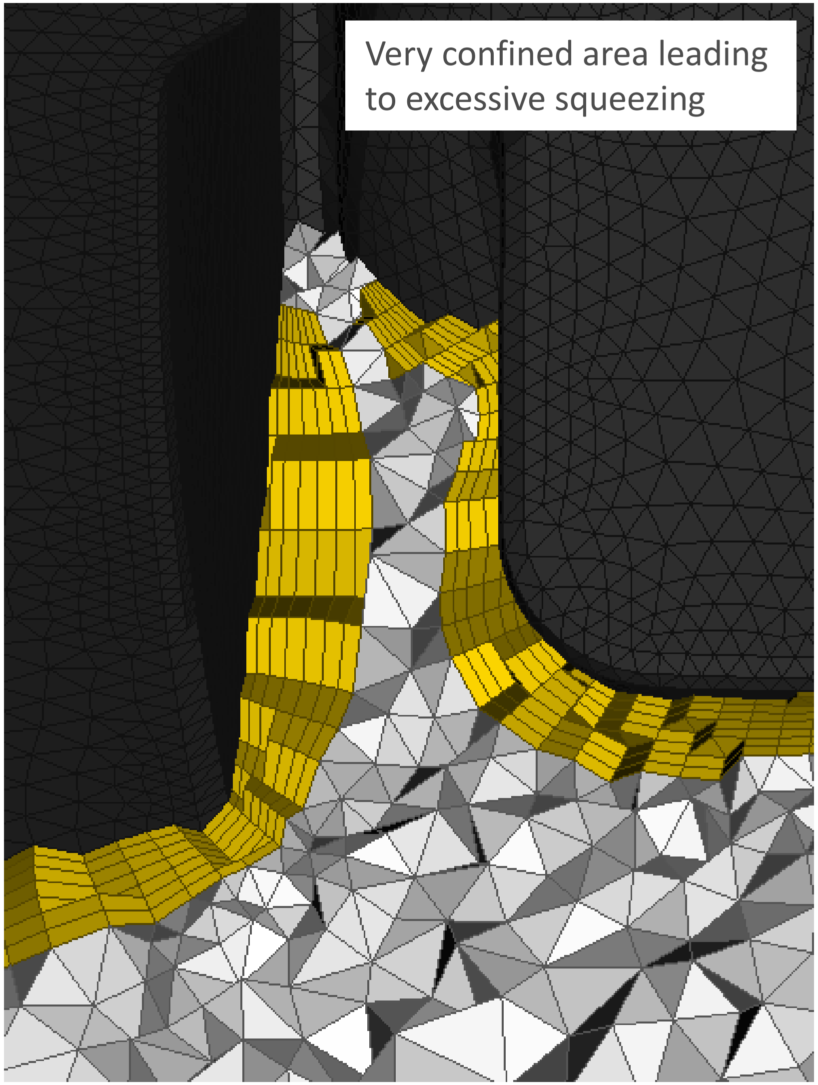
Boundary layer generation : local squeezing at proximities

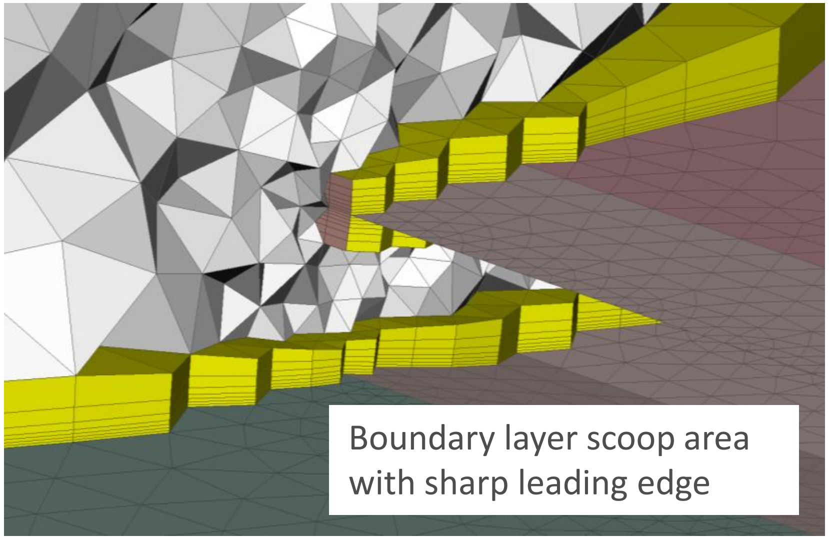


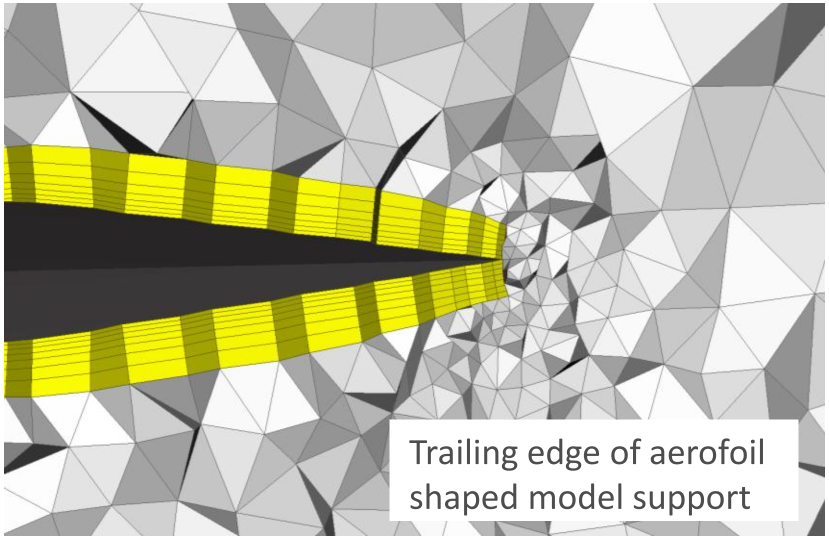




Boundary layer generation: local exclusion of layers at problematic areas

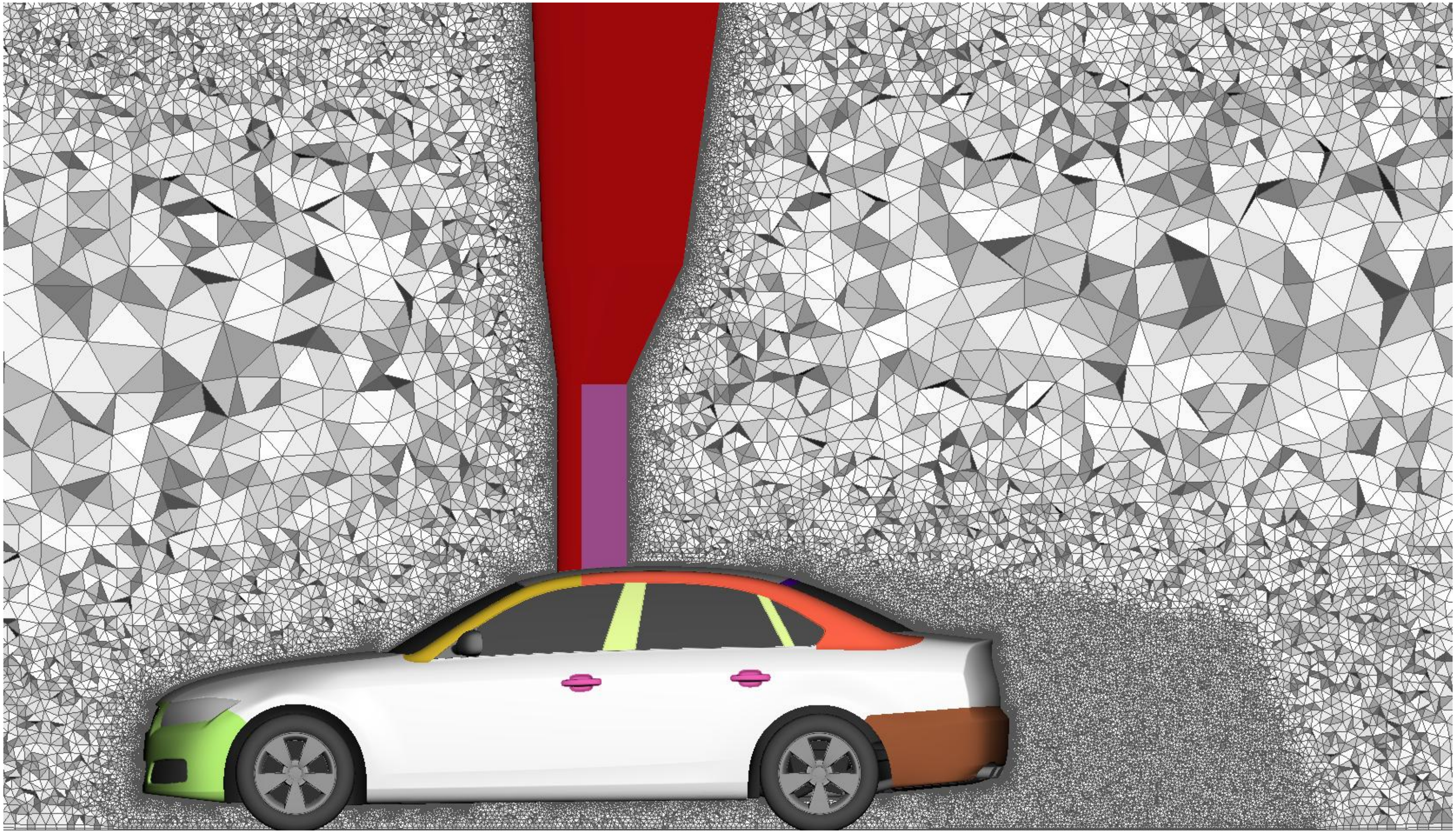




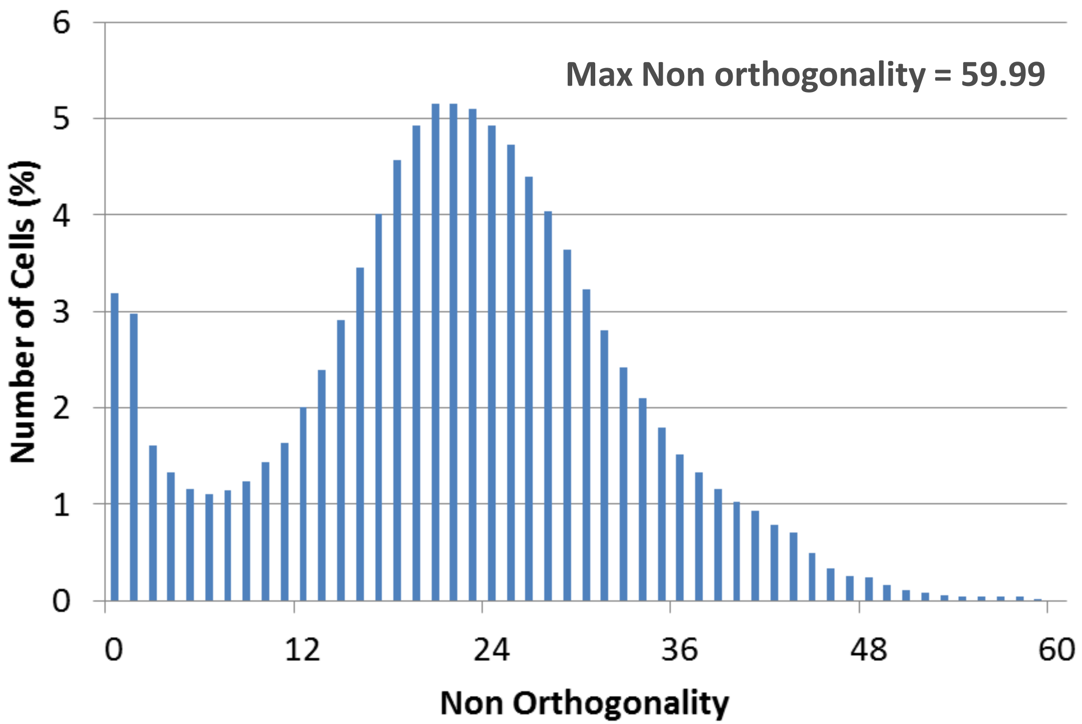


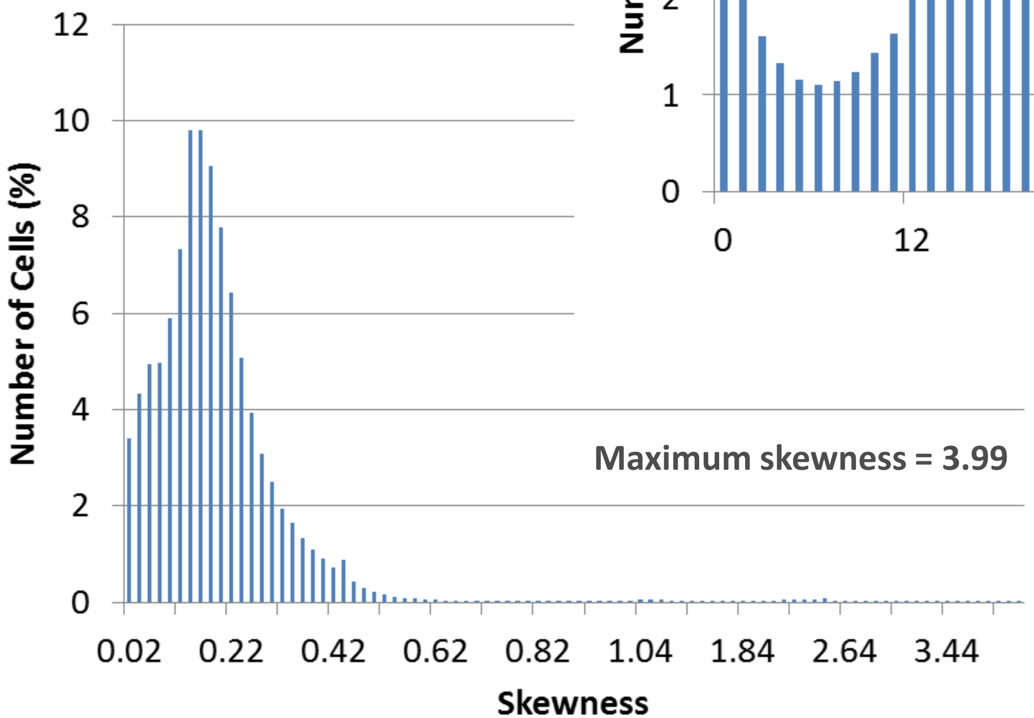
Batch mesh generated volume mesh

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



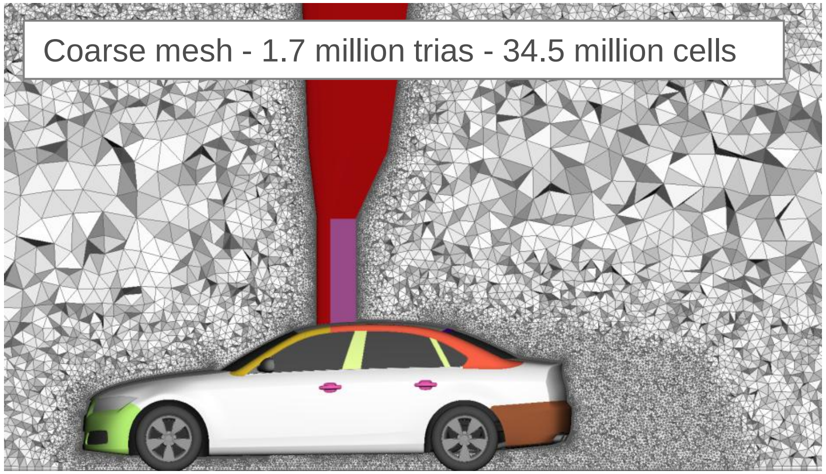
Indicative mesh quality statistics : Notchback tetra medium with layers

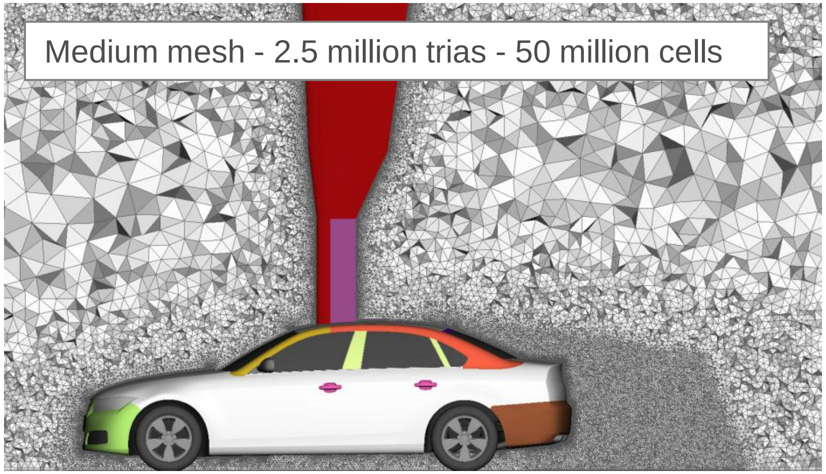


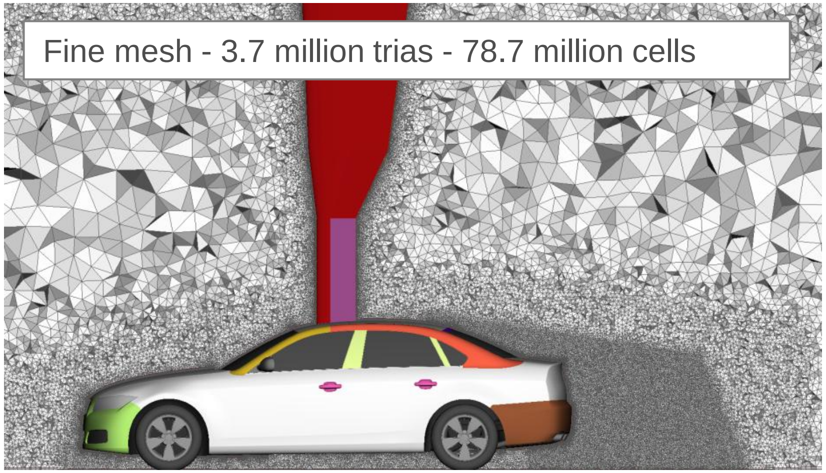


Mesh refinement study for tetra with layers case

Automatic generation of models with variable resolution using batch meshing

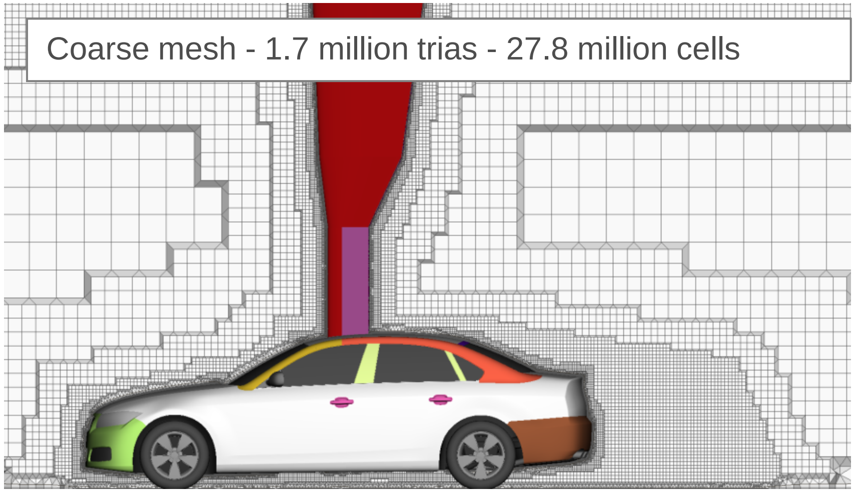


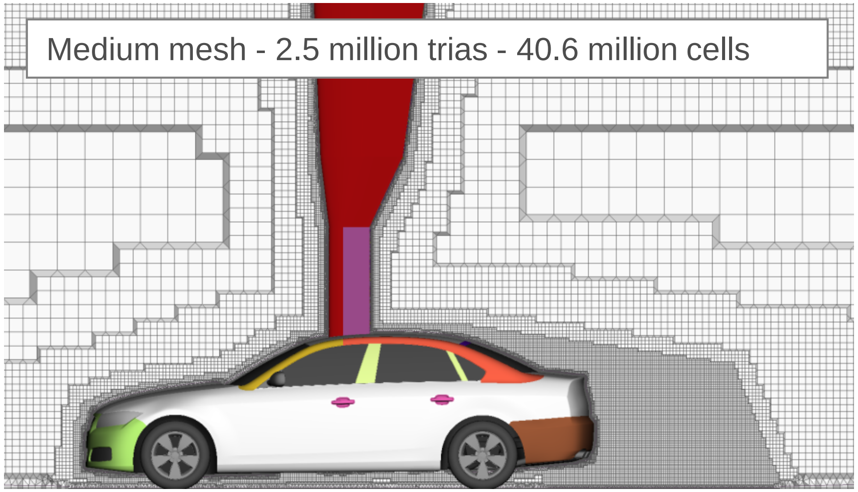


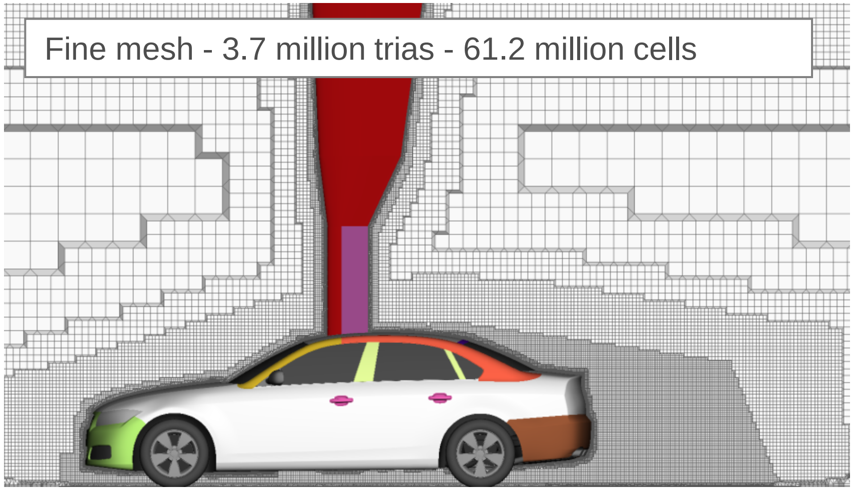


Mesh refinement study for HexaInterior with layers case

Automatic generation of models with variable resolution using batch meshing

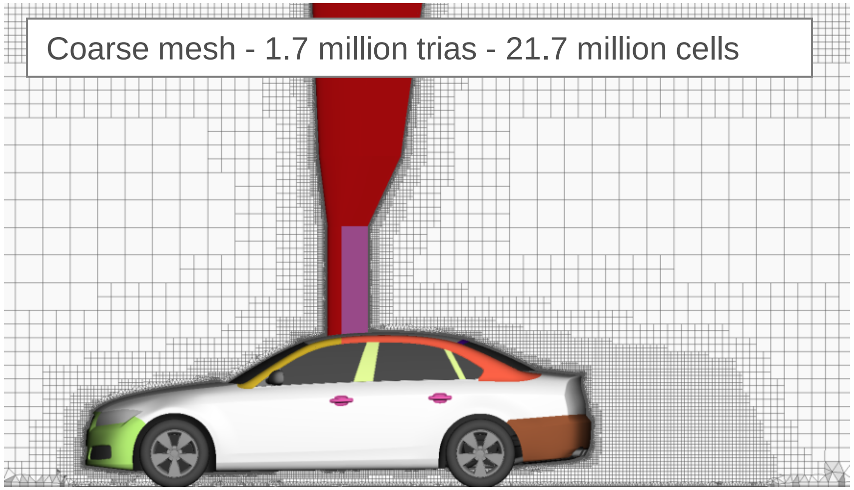


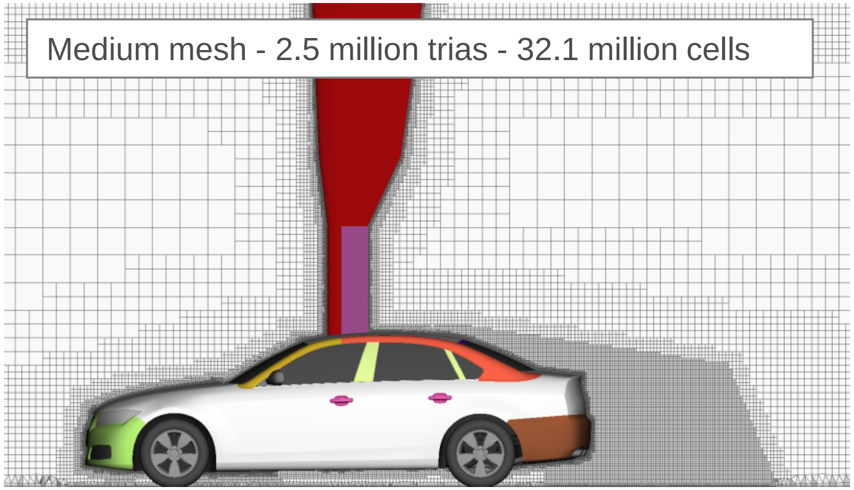


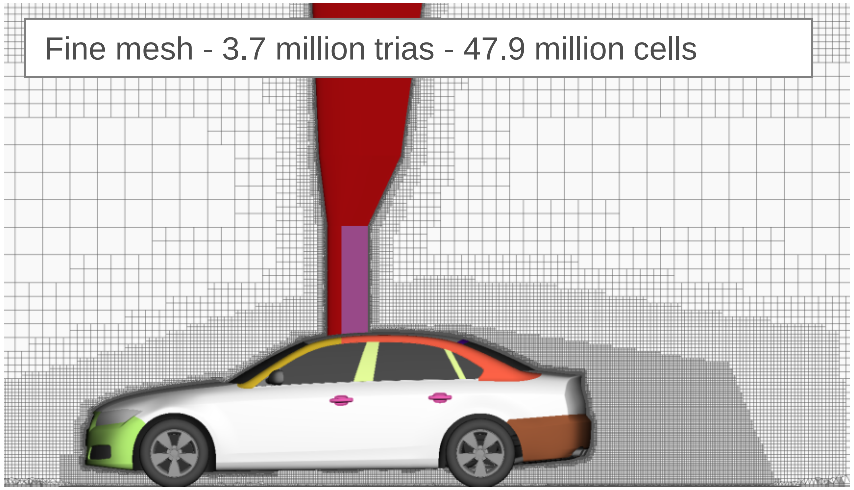


Mesh refinement study for HexaPoly with layers case

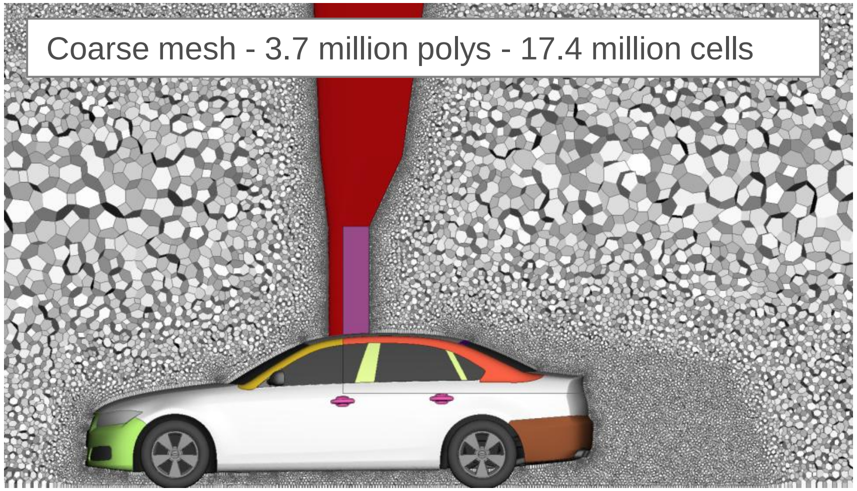
Automatic generation of models with variable resolution using batch meshing

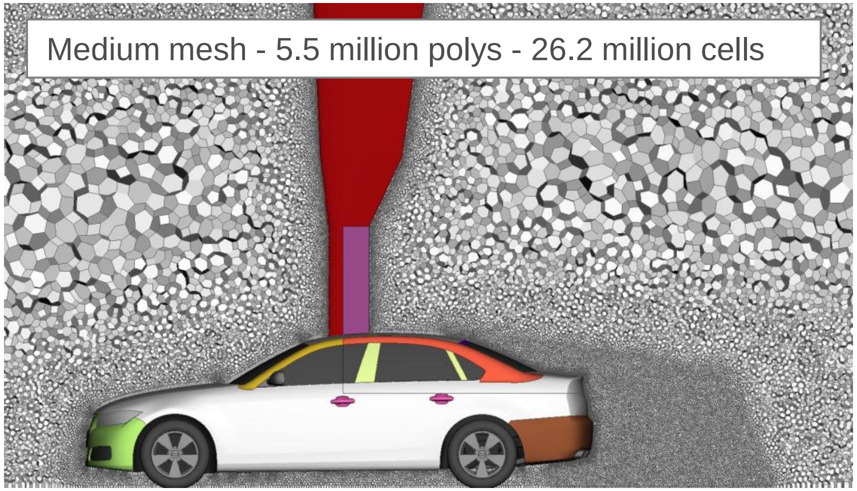


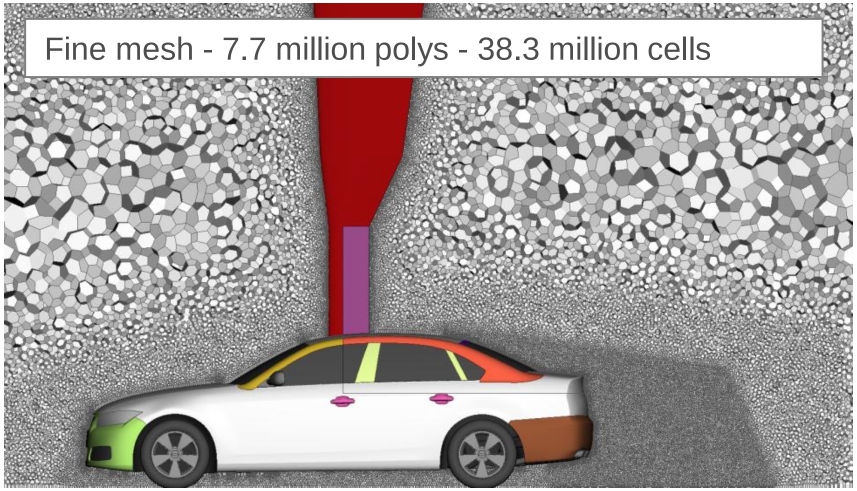




Generation of Polyhedral mesh from hybrid mesh conversion

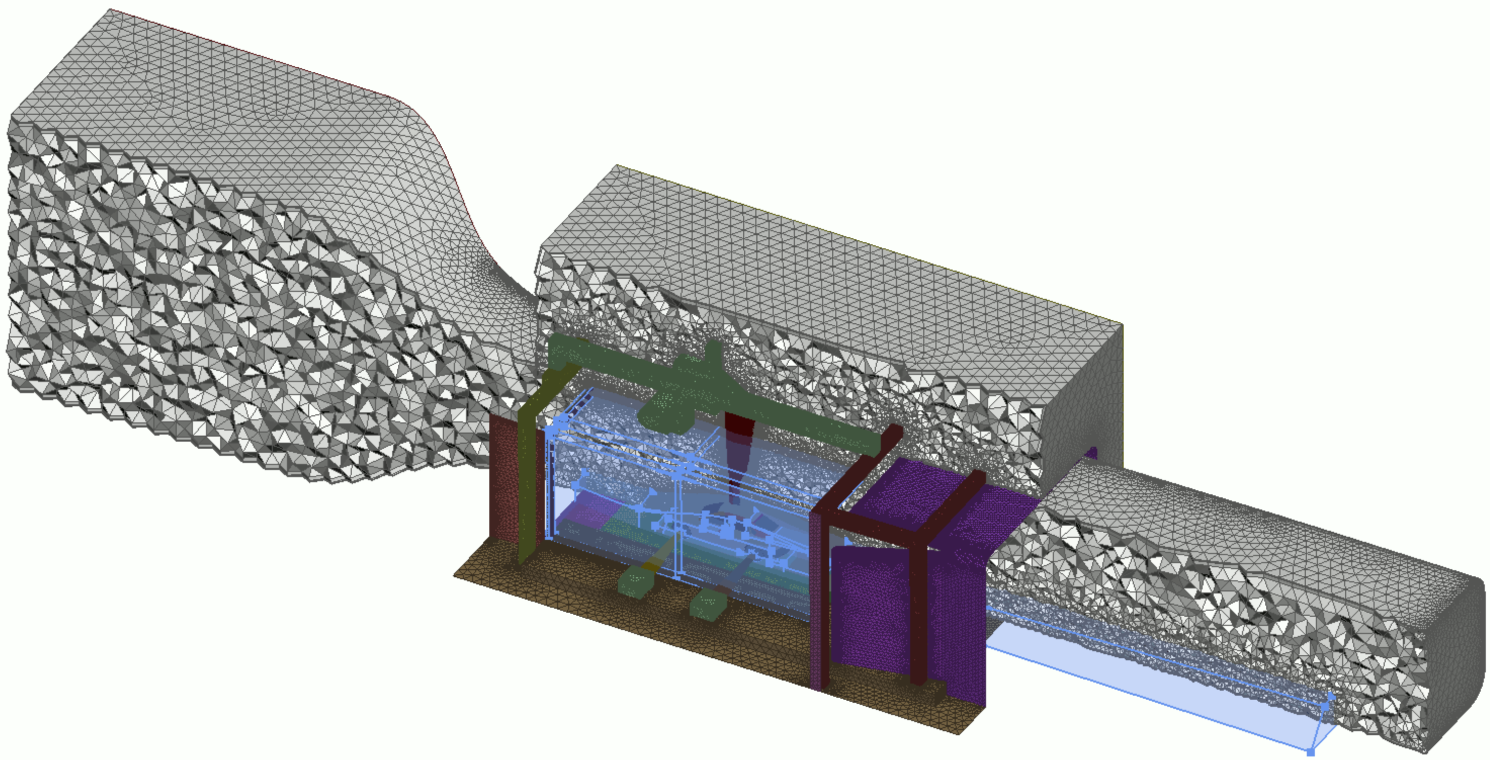




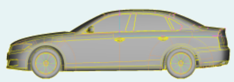
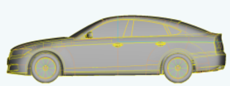


Overview of final volume mesh

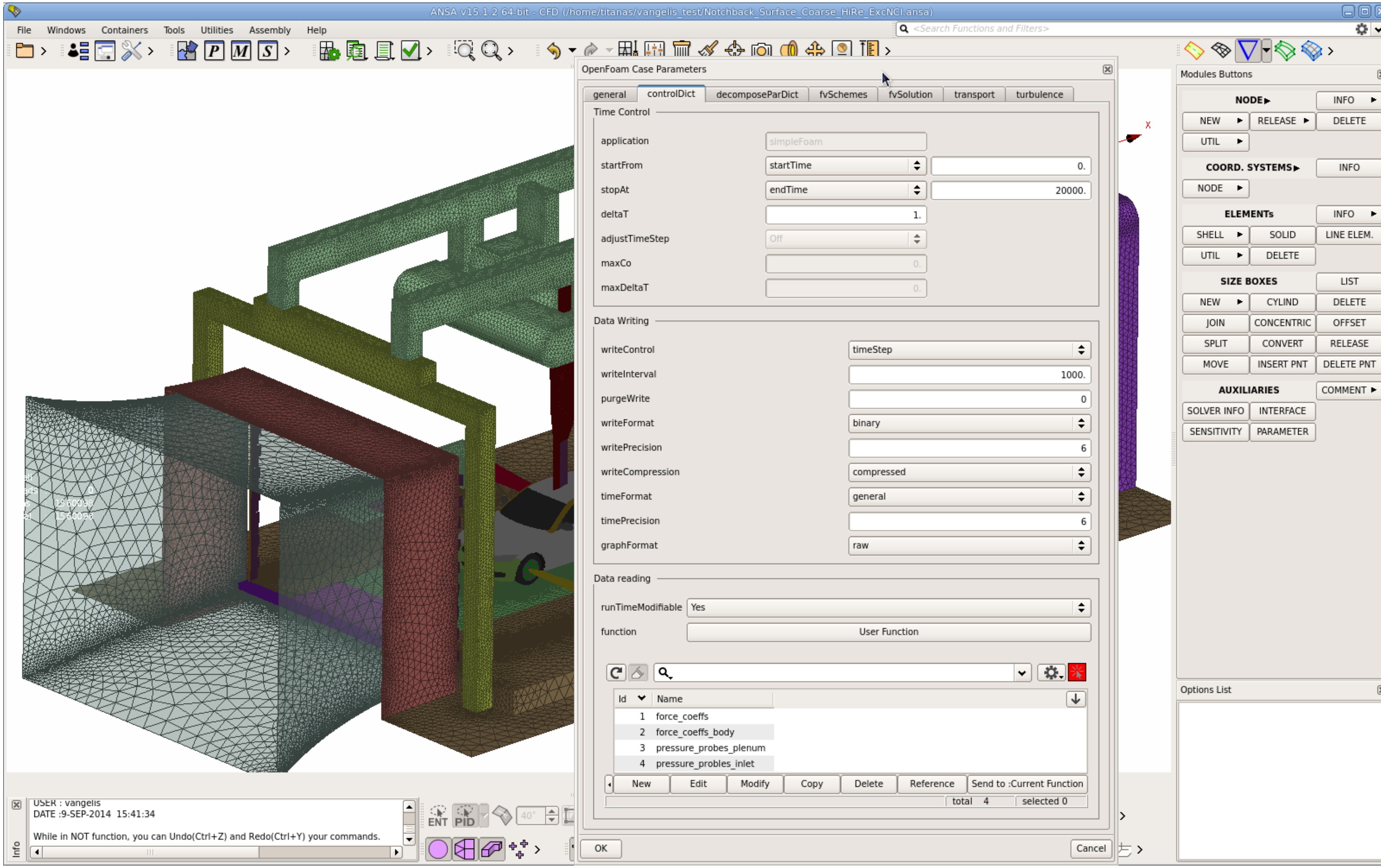
Medium tetra model



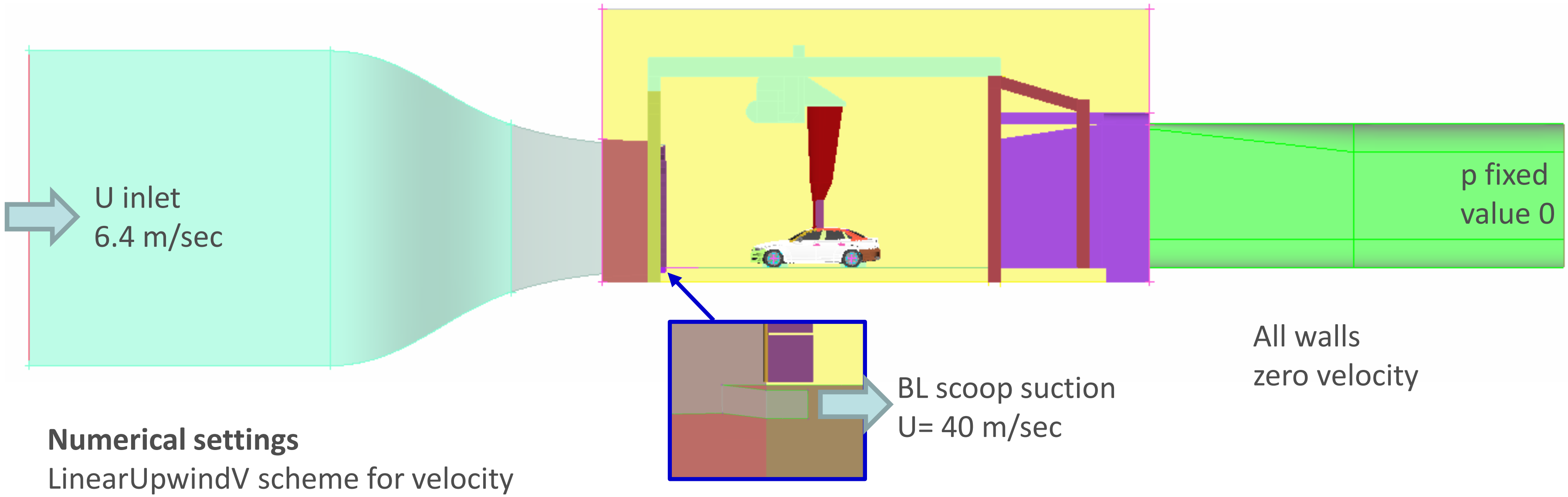
Summary of mesh models for different variants

		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 	Windtunnel	-	Tetra (50.1 million)	-
Estate 	Windtunnel	-	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

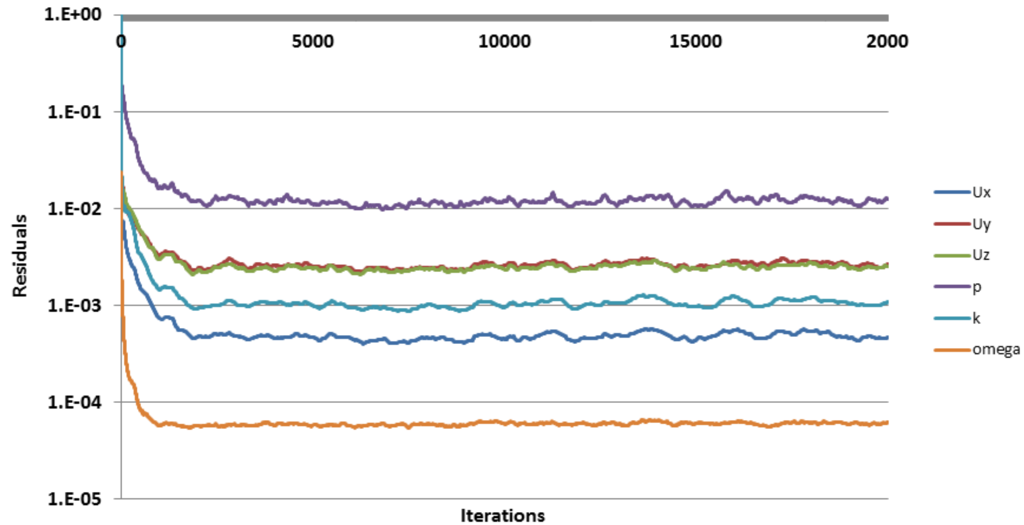
run for 3.5 sec real time

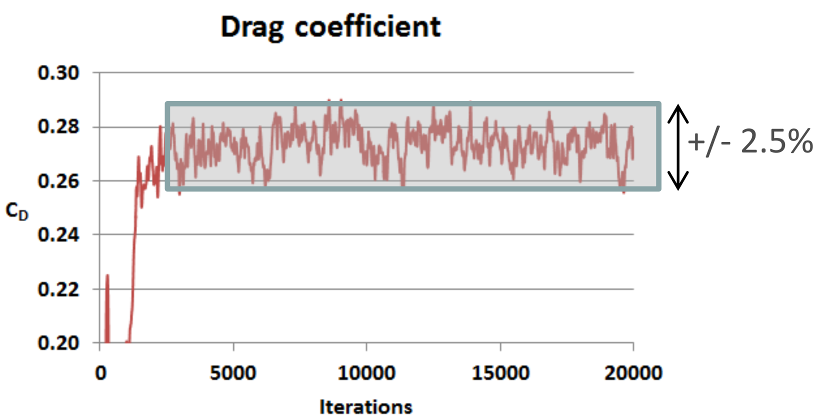
Turbulence model: IDDES Spalart Almaras model for near wall

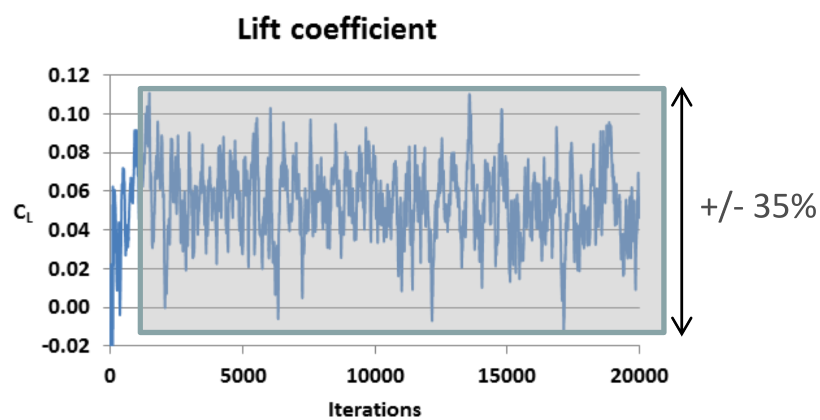
Run starting from converged steady state solution

OpenFOAM simulations: Steady state simpleFoam convergence

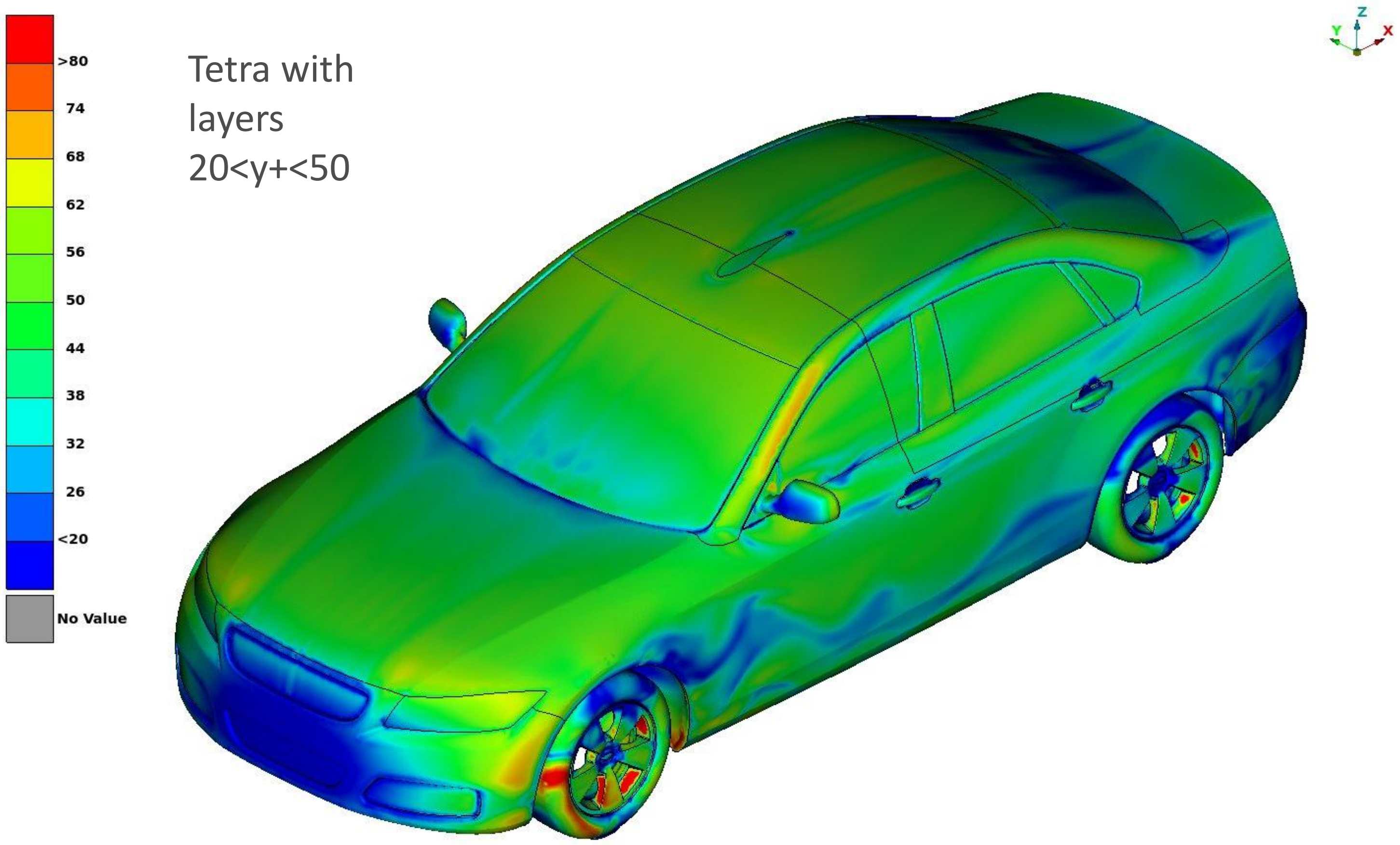
Indicative convergence history of residuals and drag and lift coefficients for Notchback TetraRapid medium model







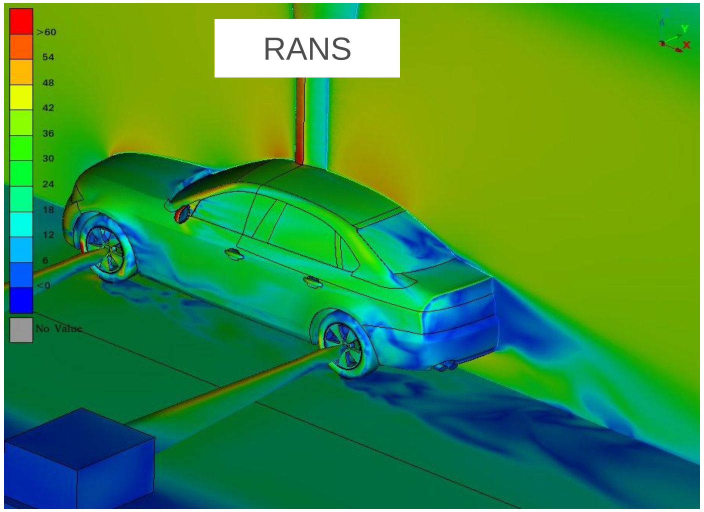
Post-processing in μETA: y+ results

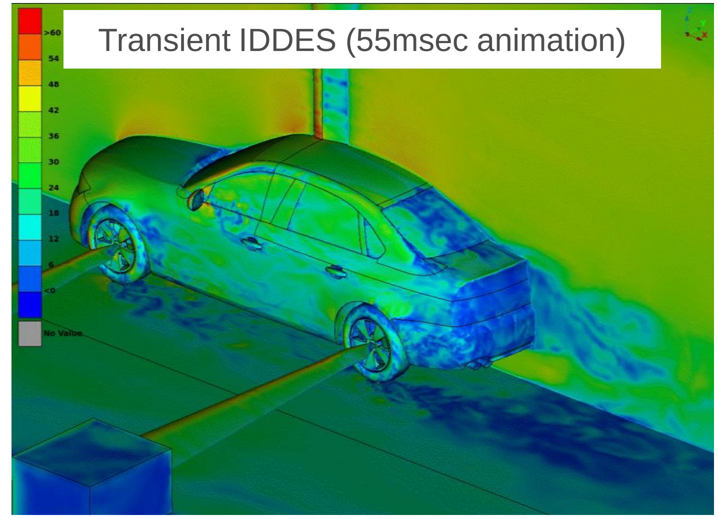


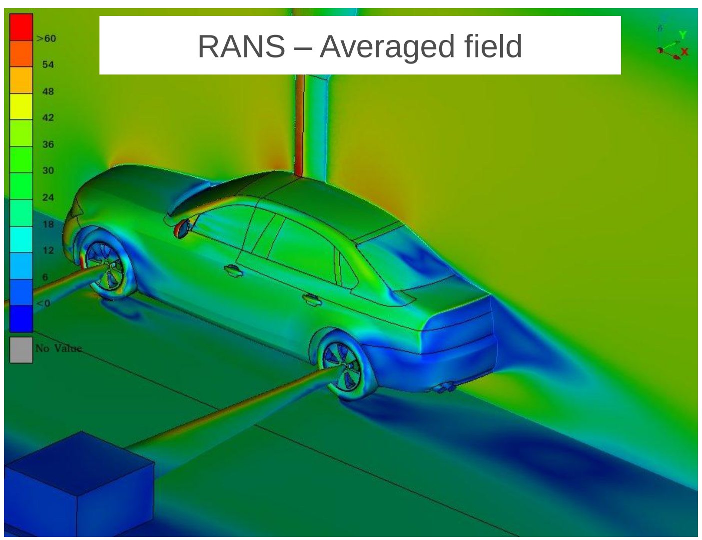
Post-processing was performed manually for one CFD run and then META run in batch mode for the other 14 simulations producing automatically the same images

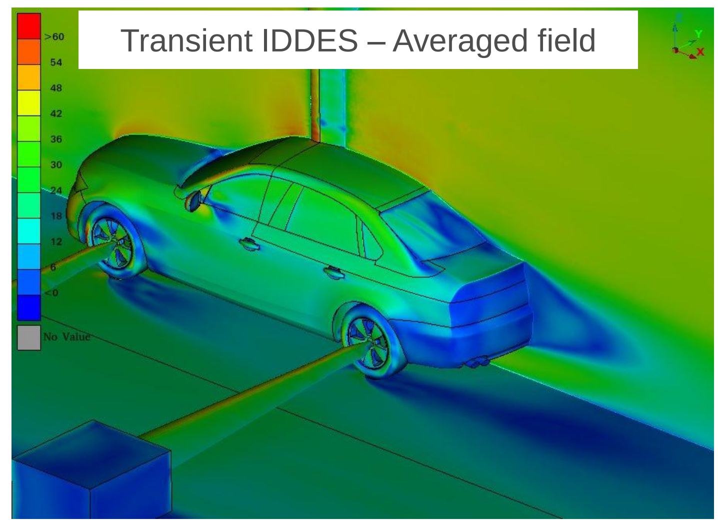
Velocity field at symmetry plane of notchback

Tetra medium mesh

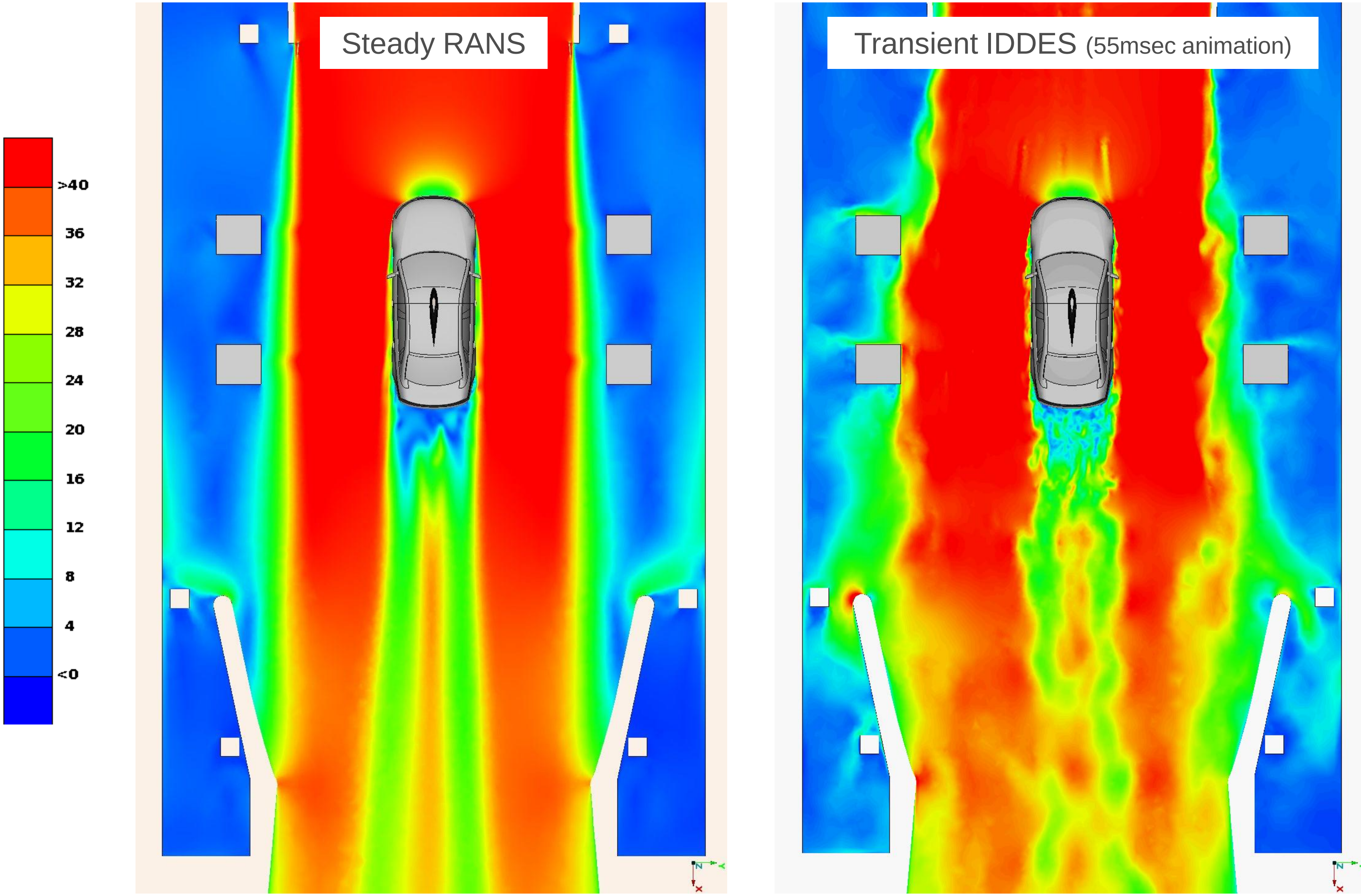






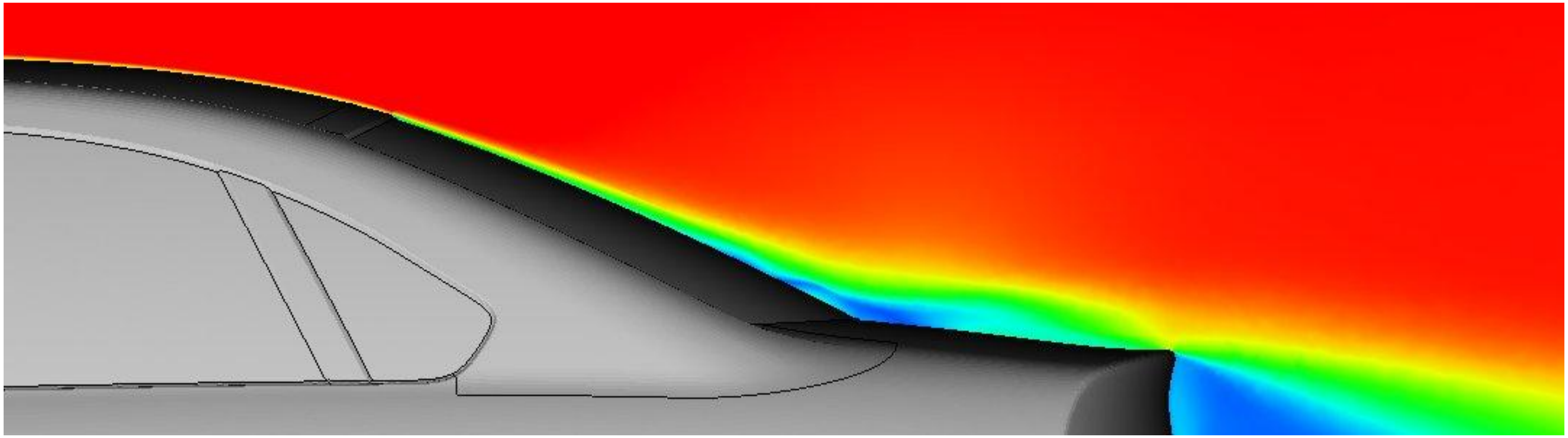


Cut-plane of velocity magnitude

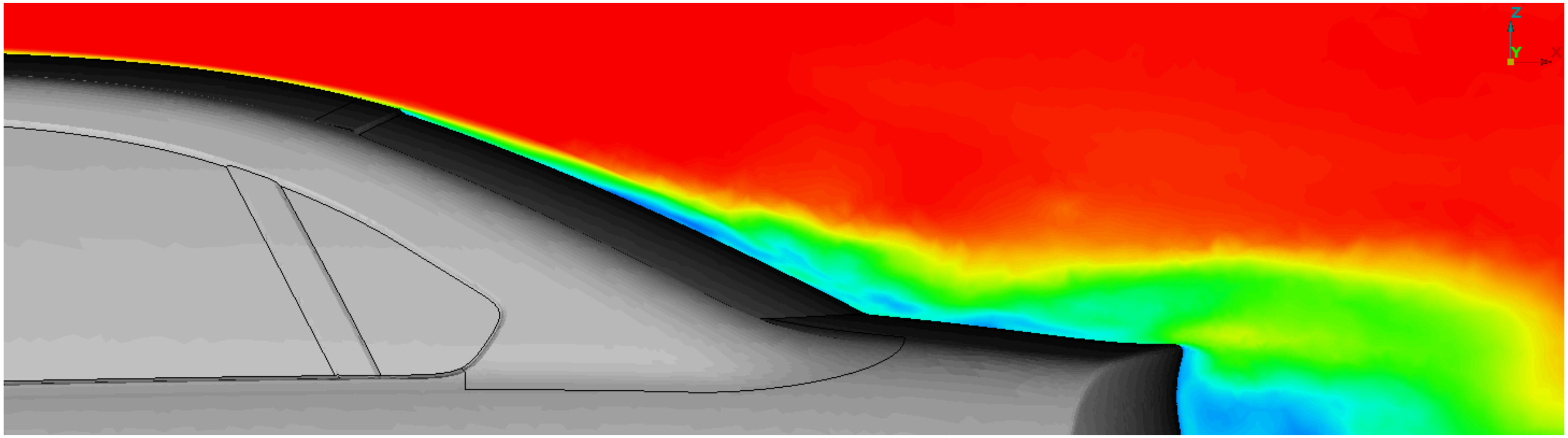


Velocity field at symmetry plane of notchback (tetra medium mesh)

RANS

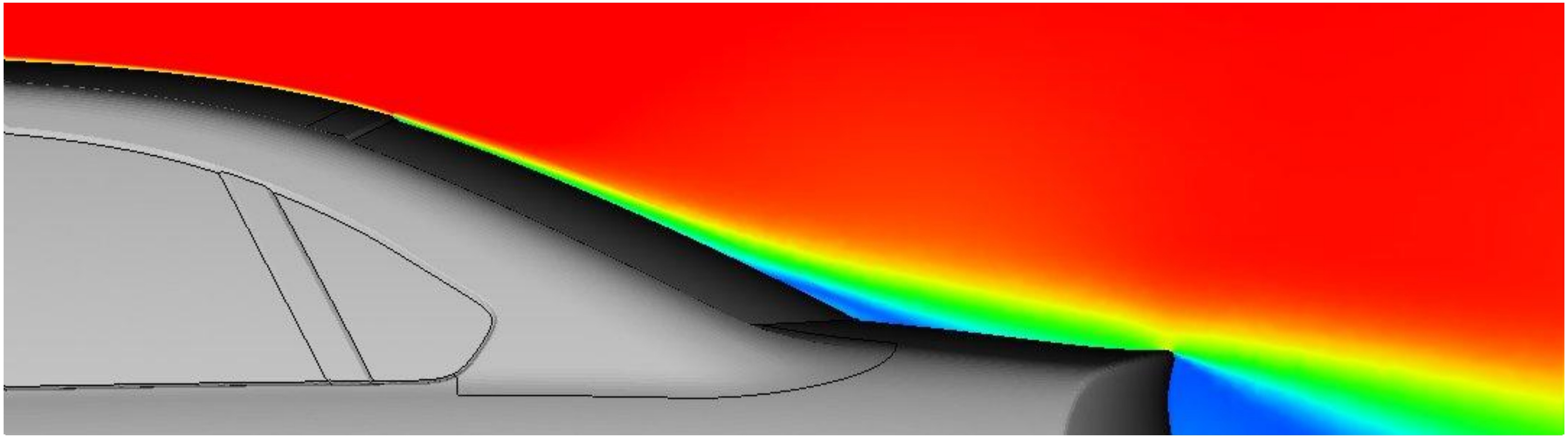


Transient IDDES (55 msec animation)

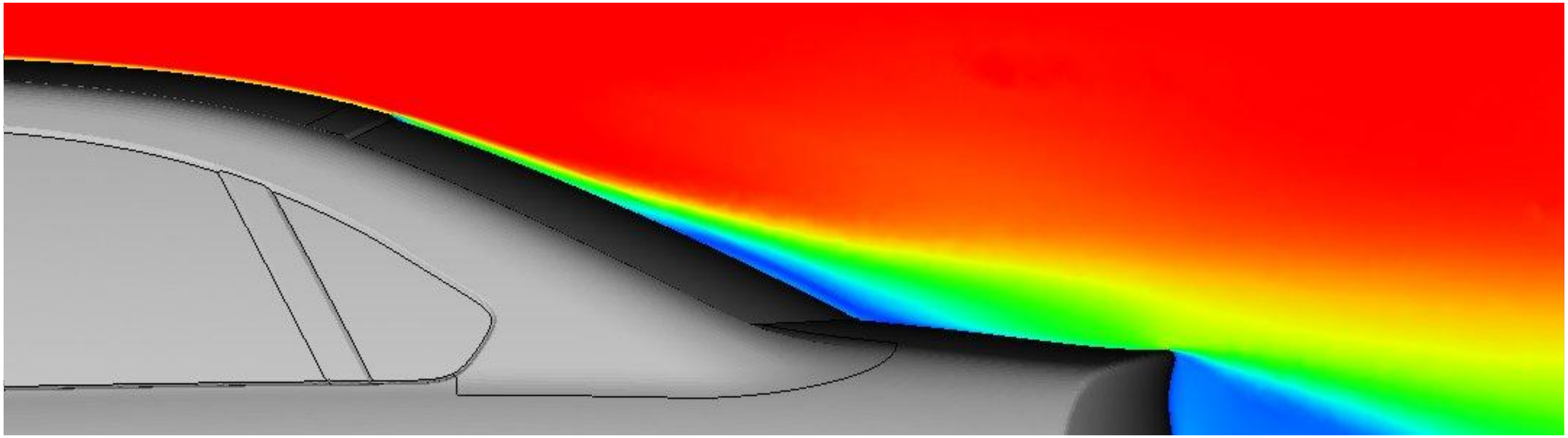


Averaged velocity field at symmetry plane of notchback (tetra medium mesh)

RANS

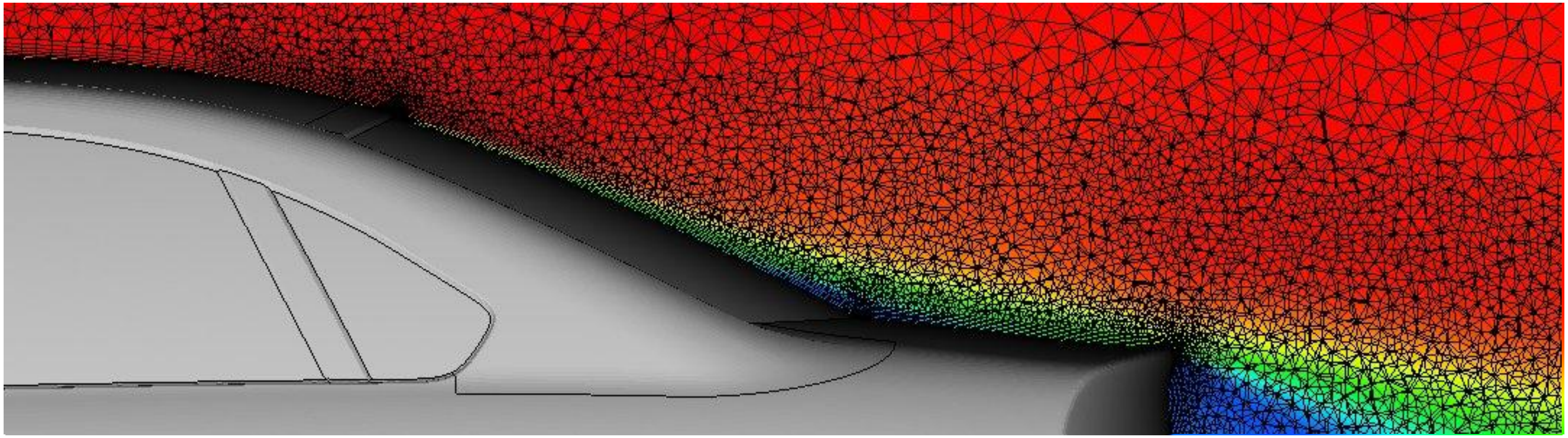


Transient IDDES (55 msec animation)

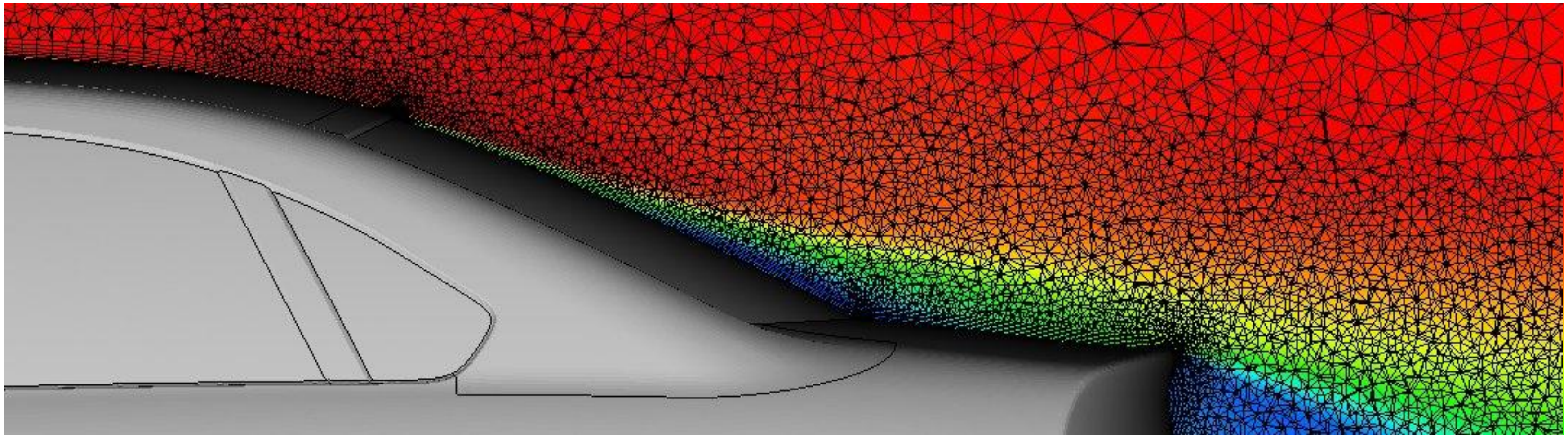


Averaged velocity field at symmetry plane of notchback (tetra medium mesh)

RANS

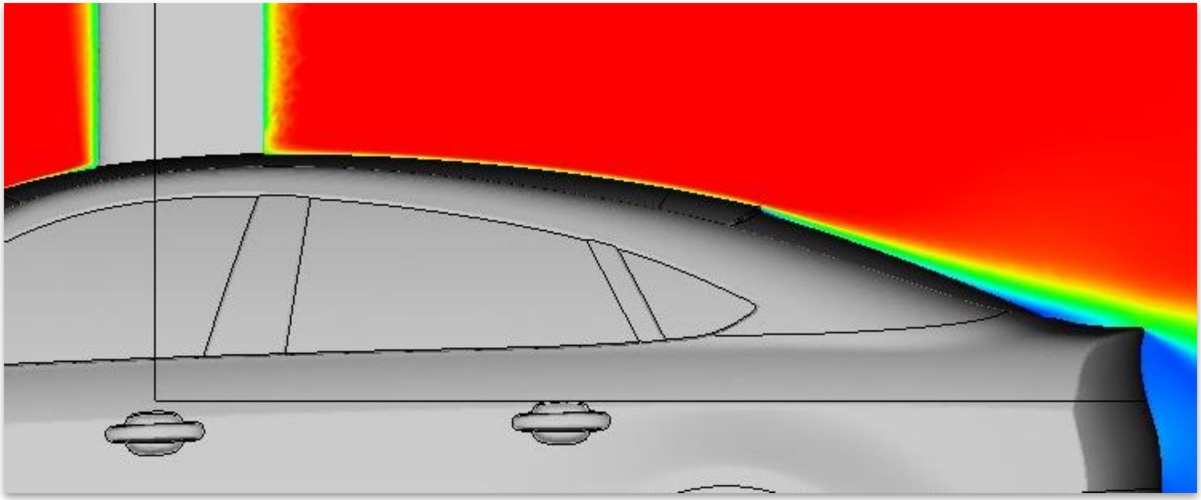


Transient IDDES (55 msec animation)

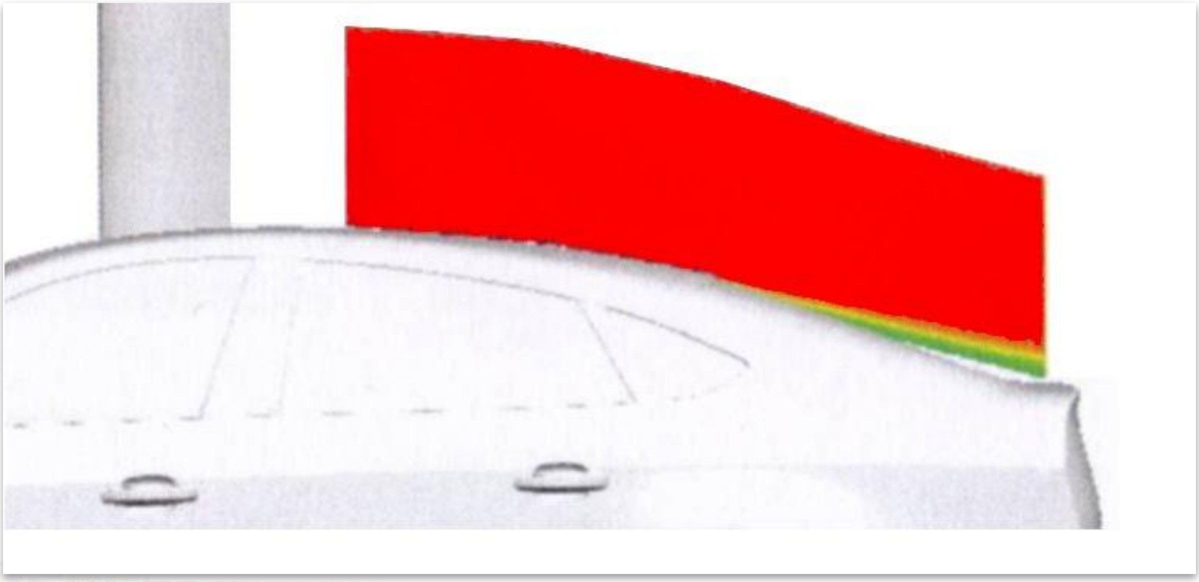


Velocity field at symmetry plane of fastback model

Averaged Velocity



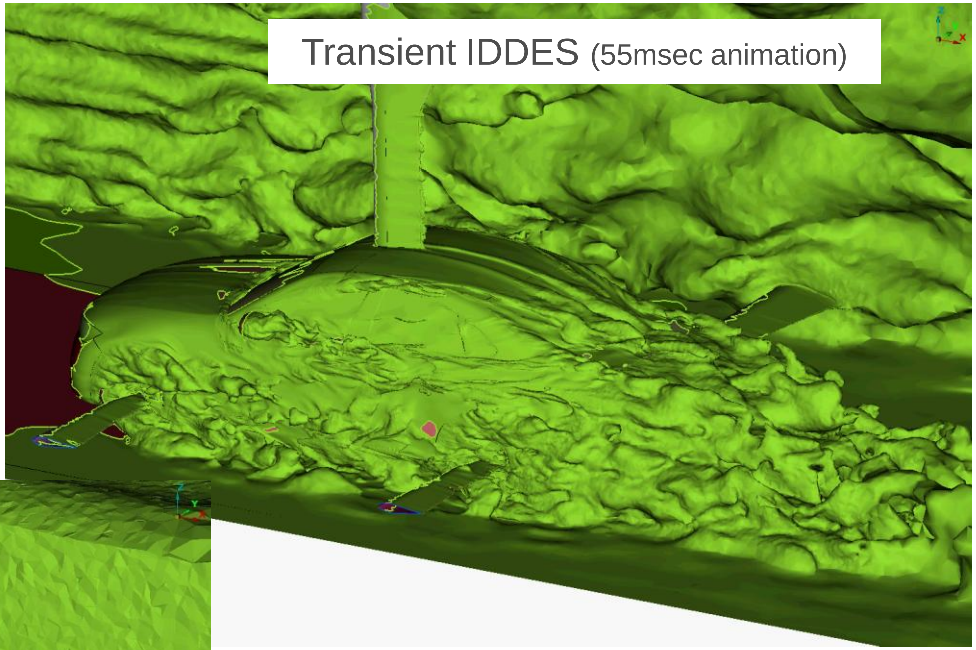
RANS k-omega SST
(Tetra Medium Mesh)

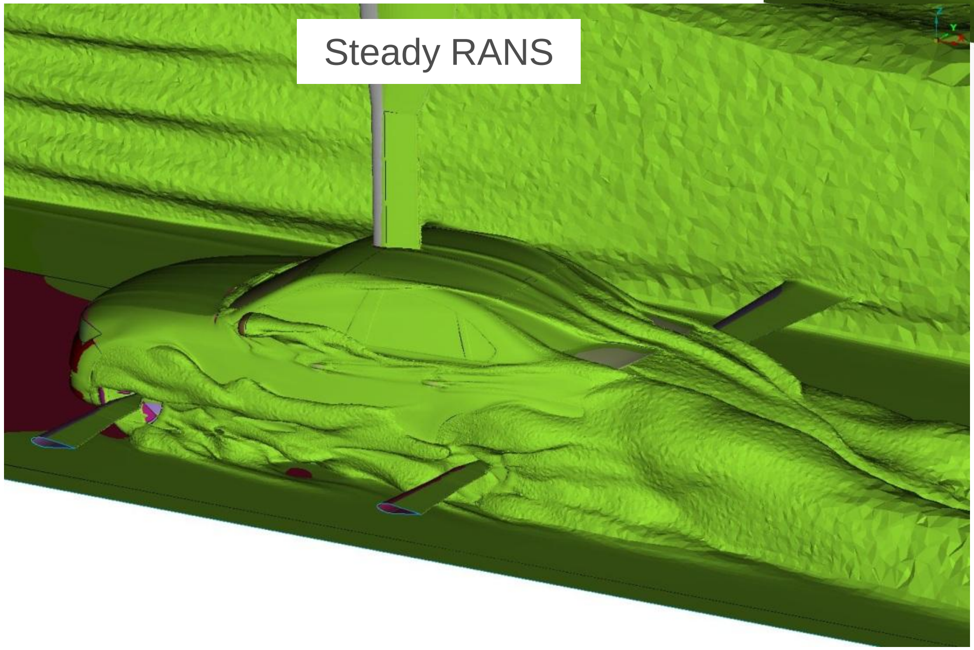


Experiment

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

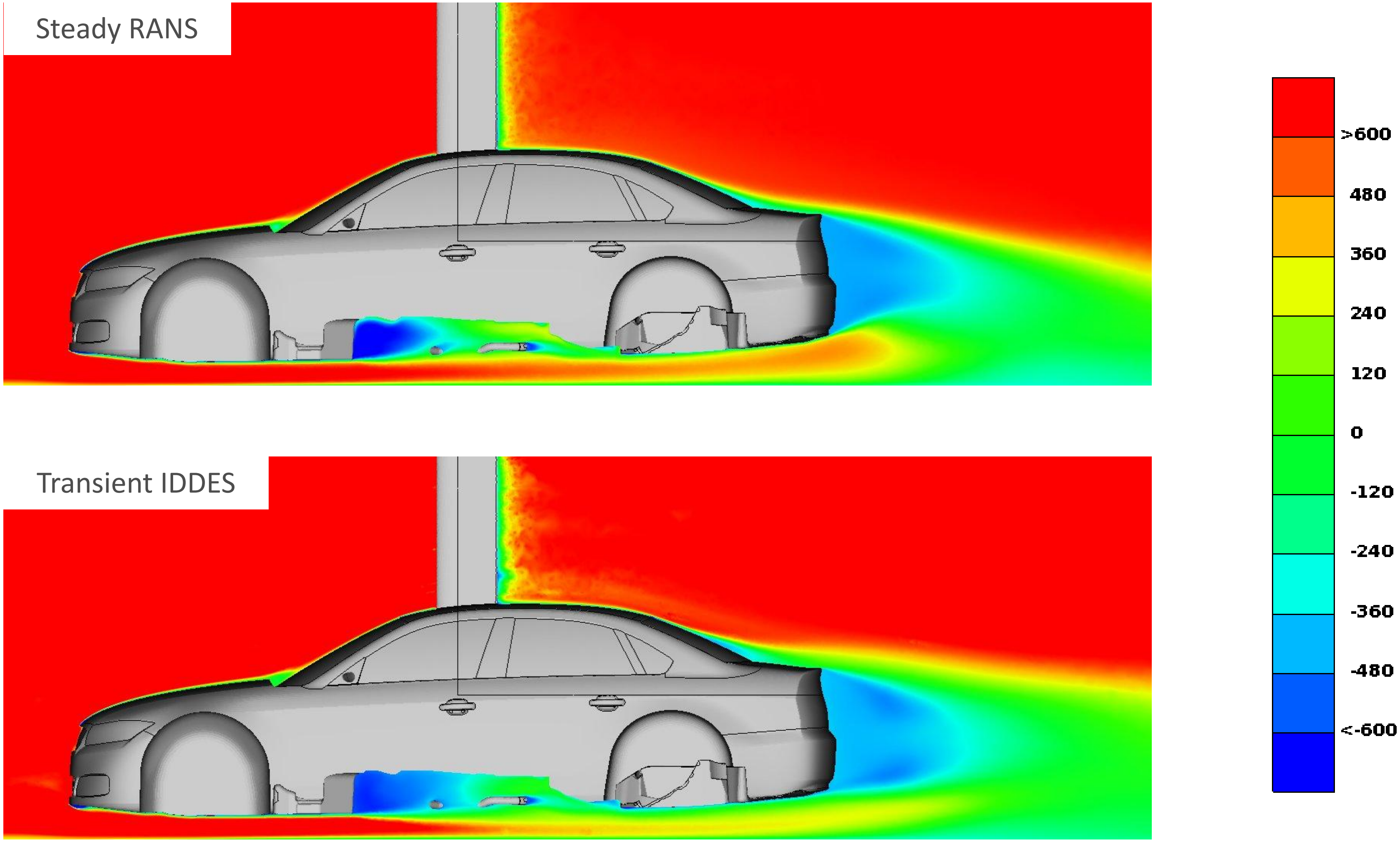
Tetra medium mesh





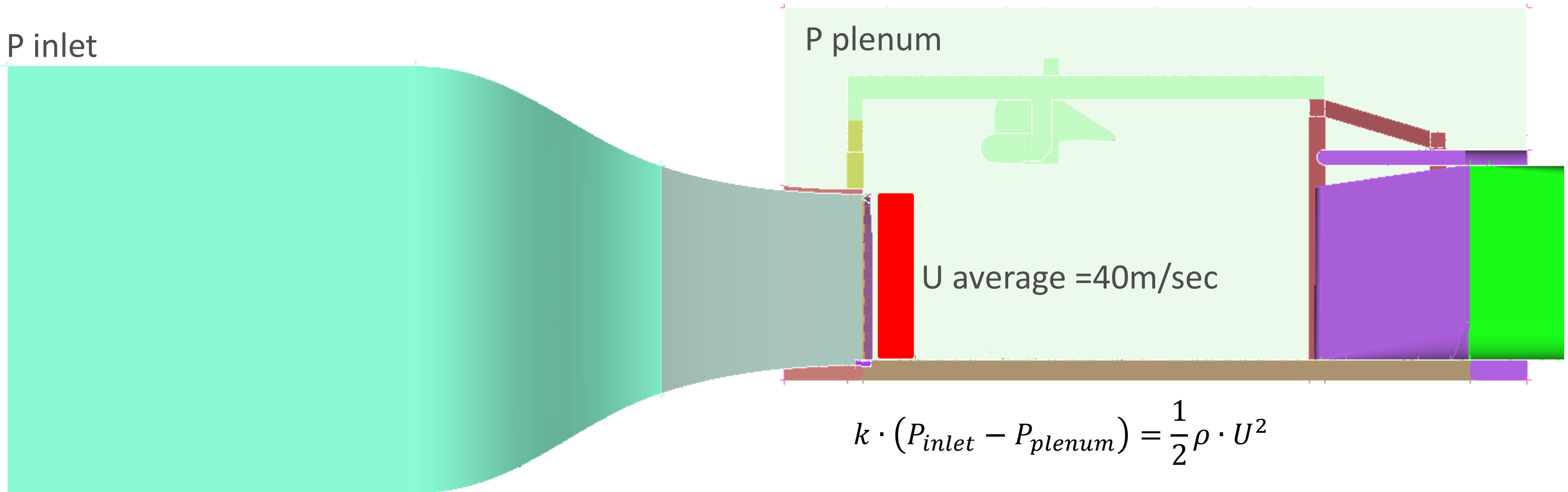
Pressure loss regions: Total pressure at symmetry plane of notchback

Tetra medium mesh – Iteration / Time averaged values

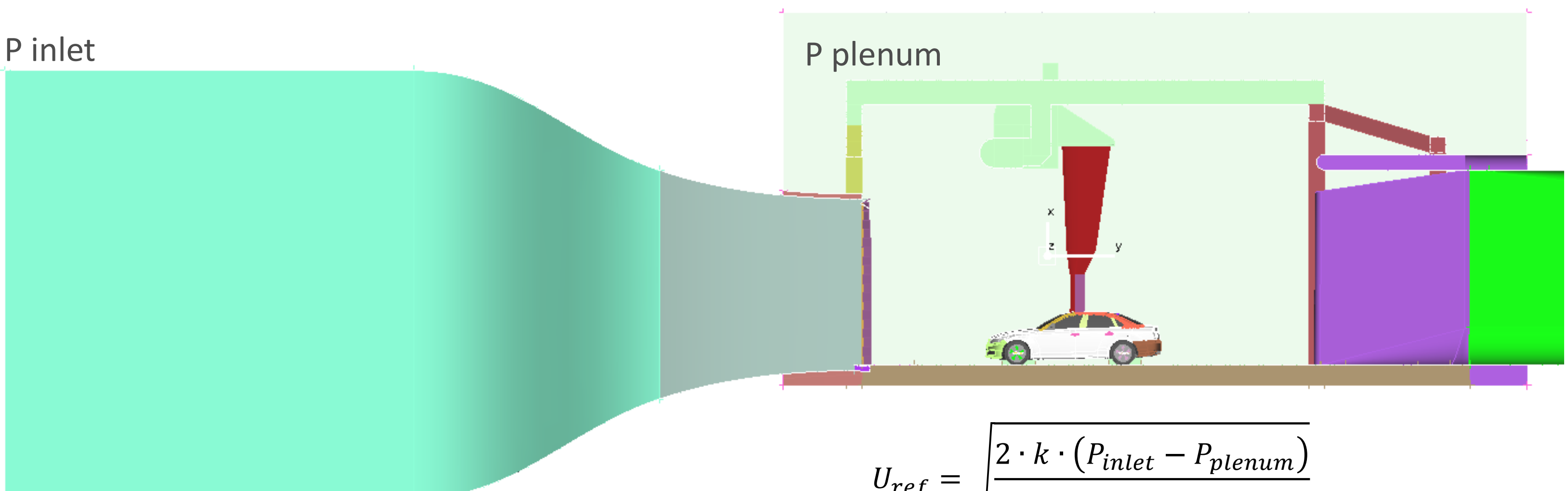


Open section wind tunnel corrections

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

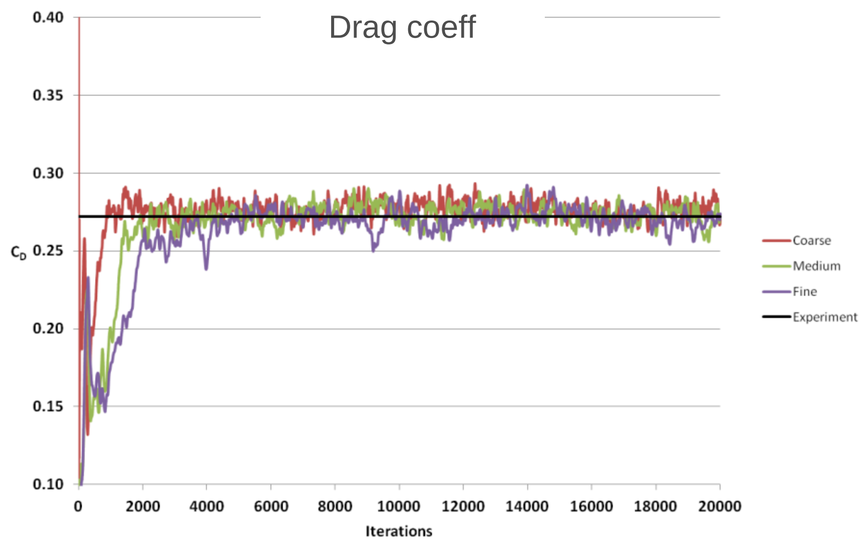


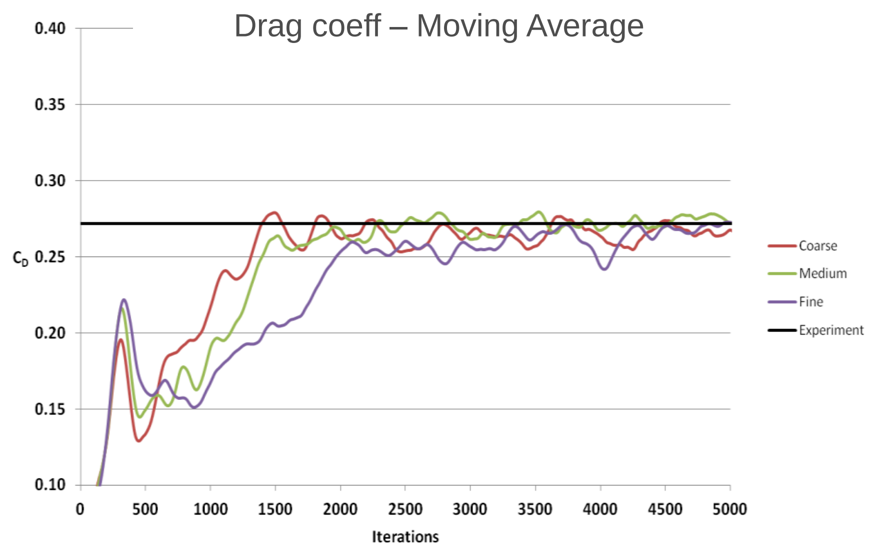
$$k \cdot (P_{inlet} - P_{plenum}) = \frac{1}{2}\rho \cdot U^2$$

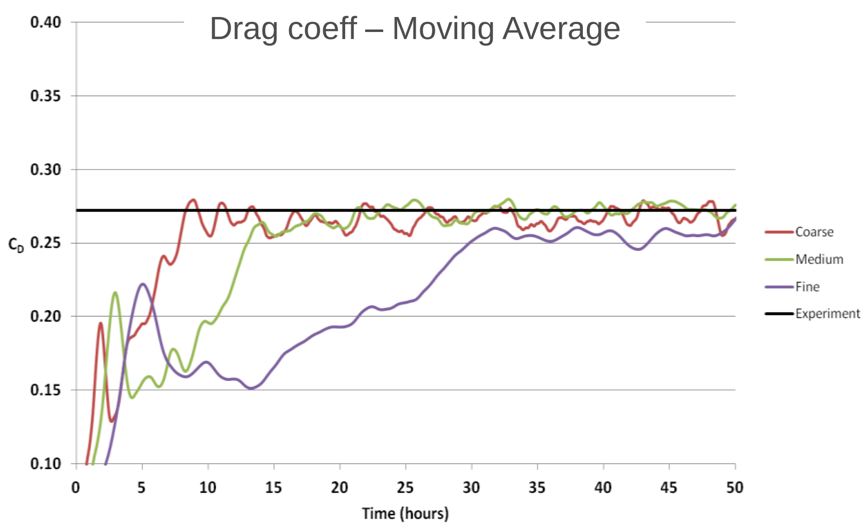


$$U_{ref} = \sqrt{\frac{2 \cdot k \cdot (P_{inlet} - P_{plenum})}{\rho}}$$

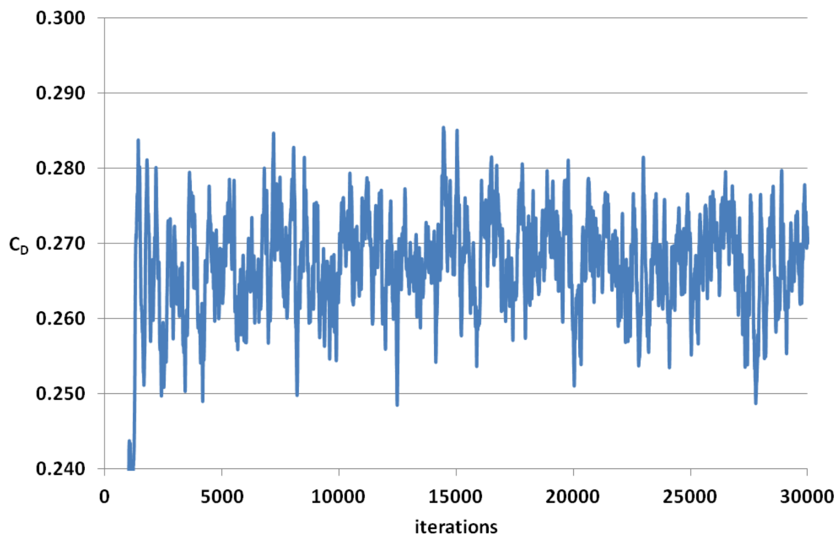
Convergence of Drag Coefficient: Tetra case - Notchback

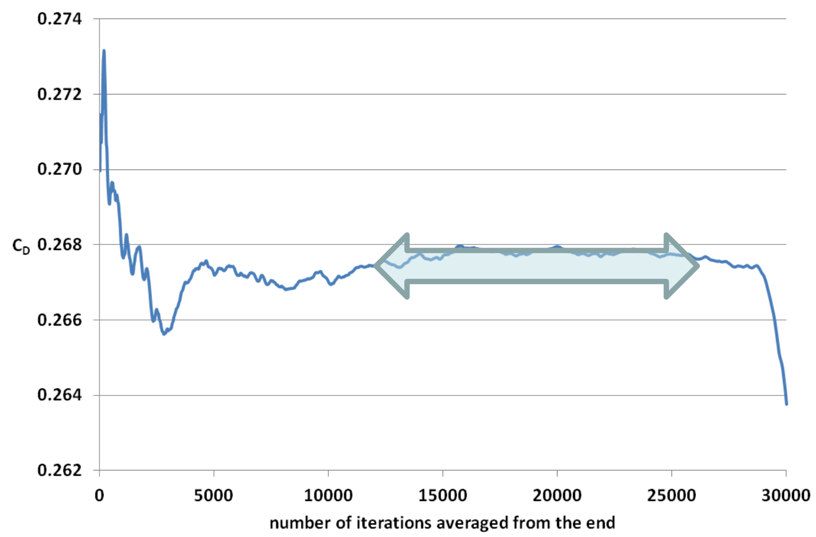




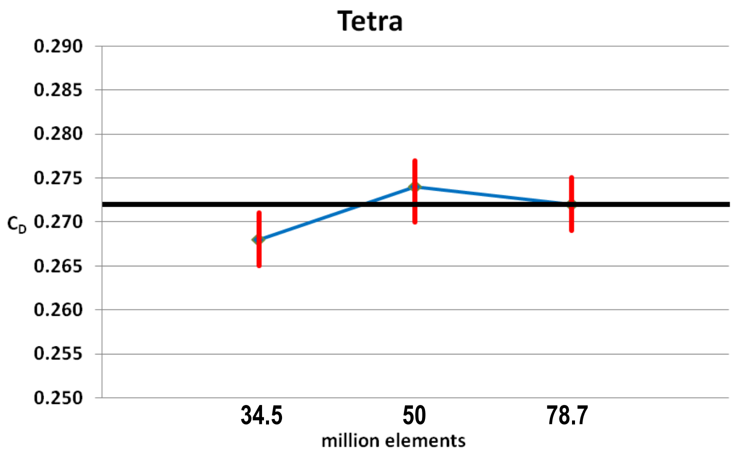


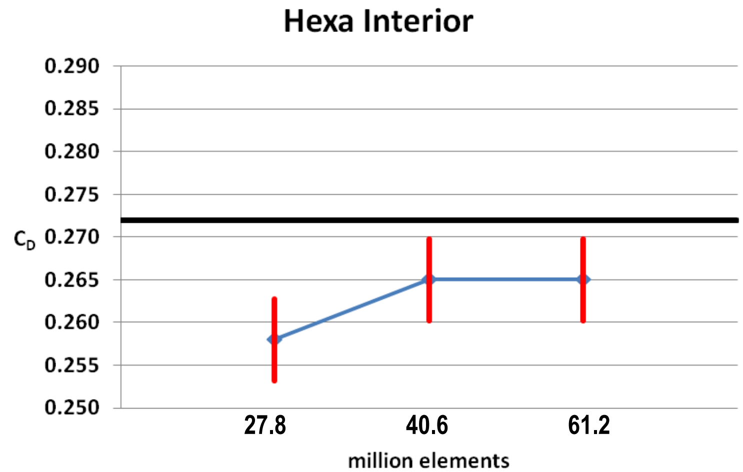
Averaging of fluctuating forces: Tetra medium mesh - Notchback



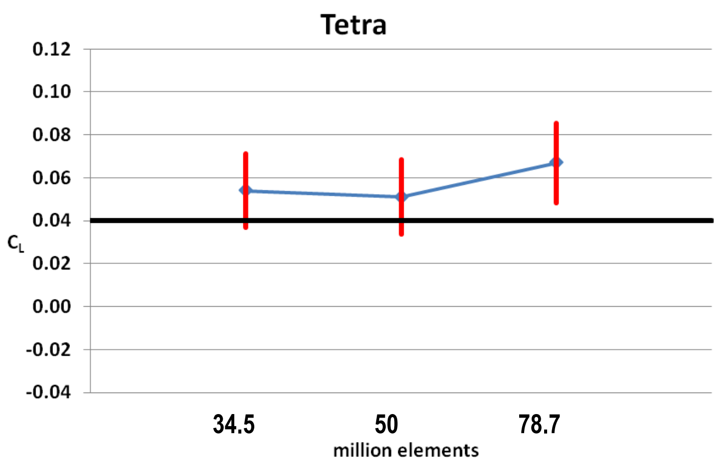


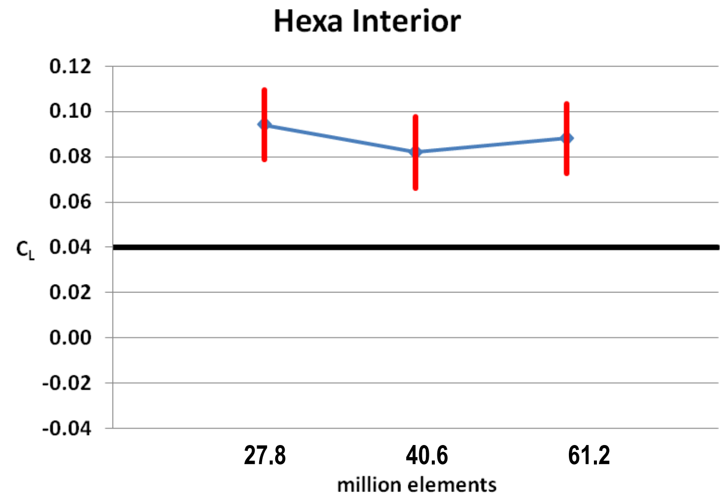
Mesh refinement study for Tetra and Hexa Interior meshes: C_D & C_L convergence





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%)

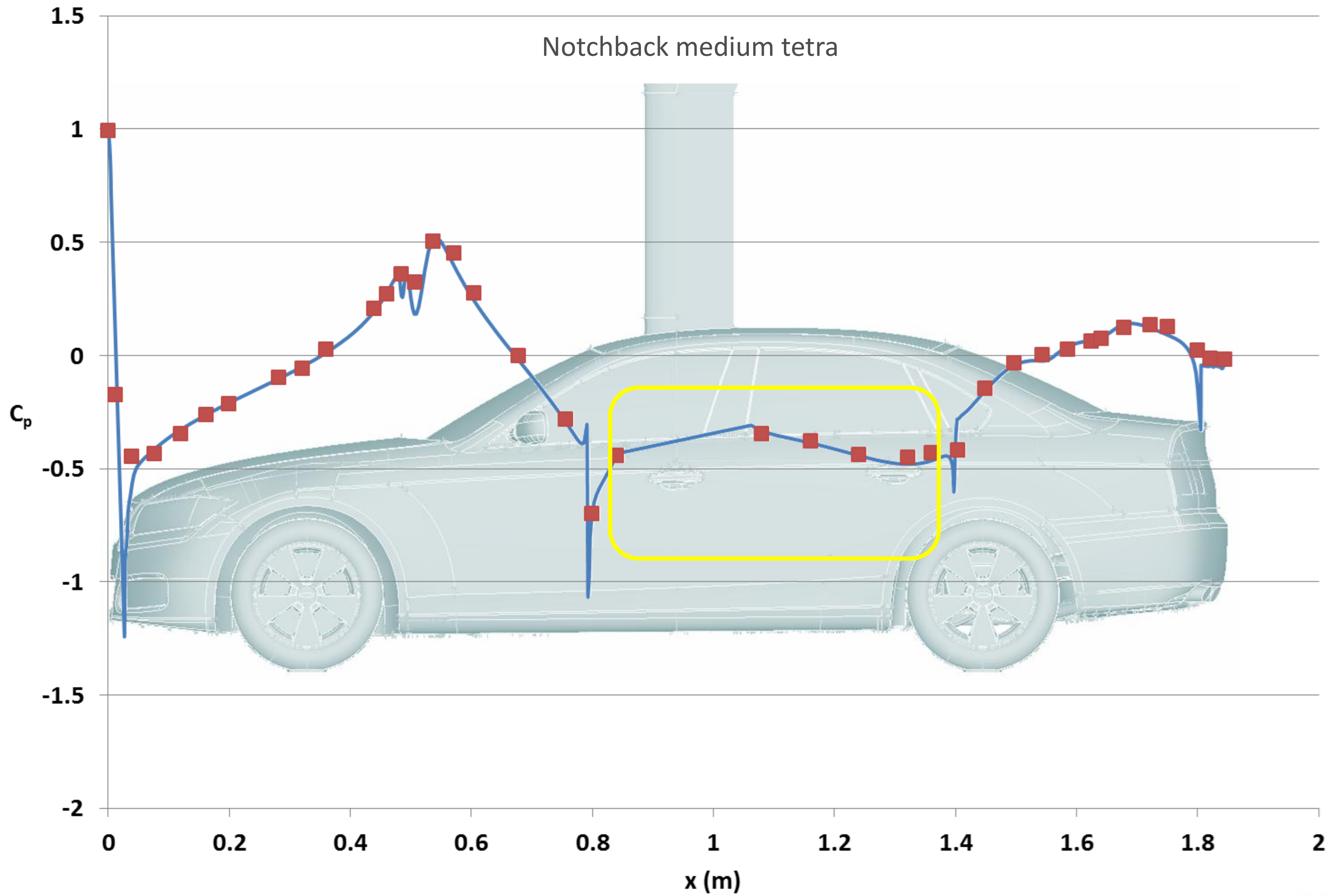
Summary of C_D and C_L values for three variants

Tetra medium meshes RANS simulations

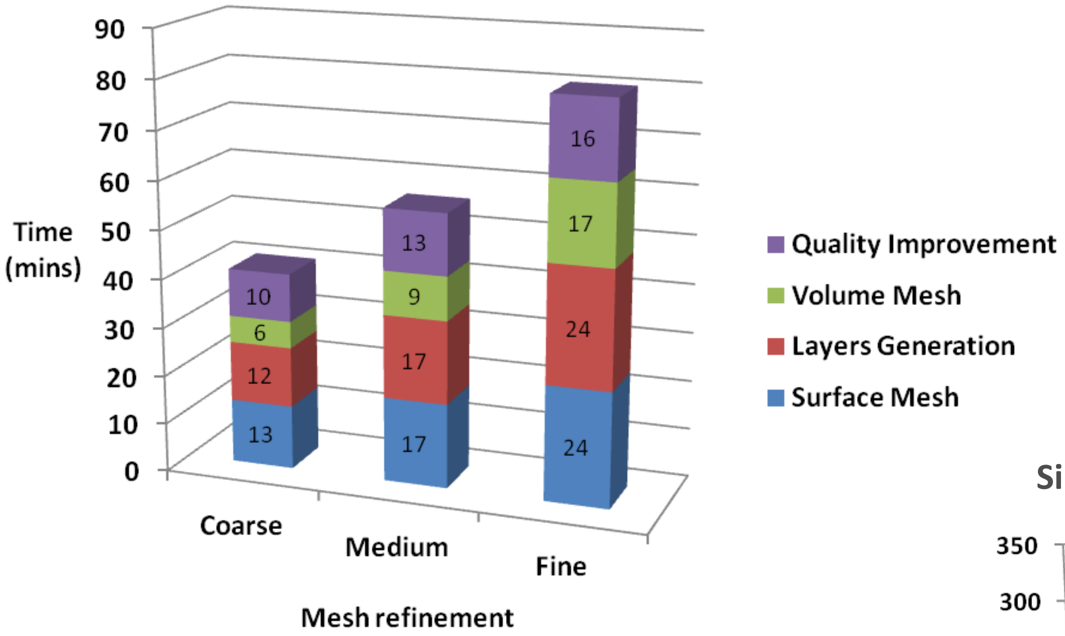
	C_D Experiment	C_D CFD	C_L Experiment	C_L CFD
Notchback	0.272	0.274 (+1%)	0.04	0.050 (+25%)
Fastback	0.274	0.271 (-1%)	0.05	0.058 (+16%)
Estate	0.314	0.279 (-11%)	-0.07	-0.050 (+29%)

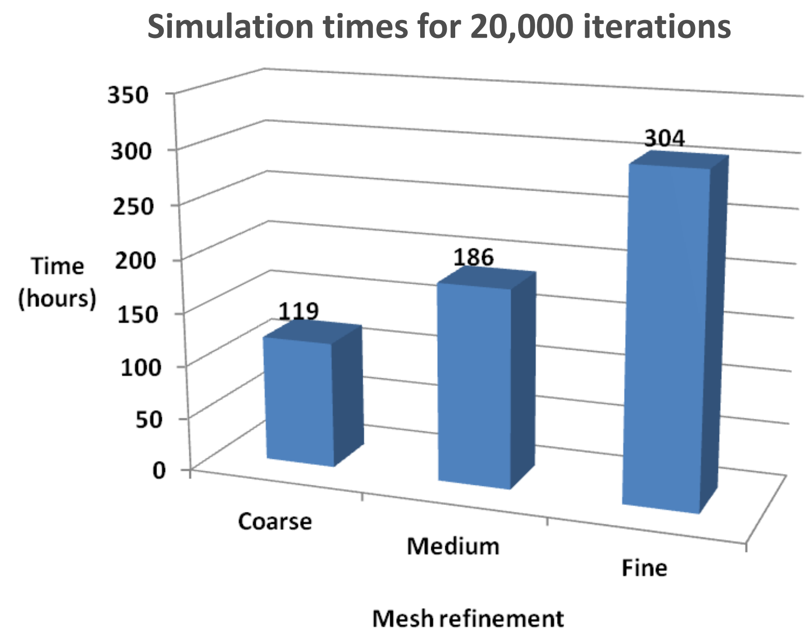
Plenum method corrected values presented (correction can be as high as 15%)

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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website

www.beta-cae.gr

support

ansa@beta-cae.gr

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