Investigation of the Effect of Targeted Octree Mesh Refinement on WFLES and SBES solutions for the DrivAer Notchback Configuration

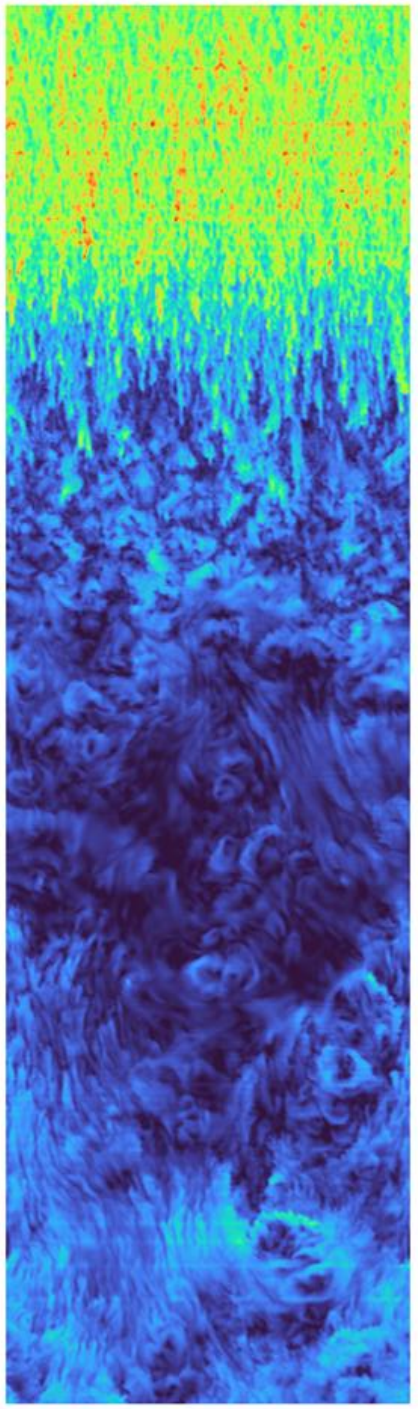
Patrick Sharkey

Presenter Florian Menter

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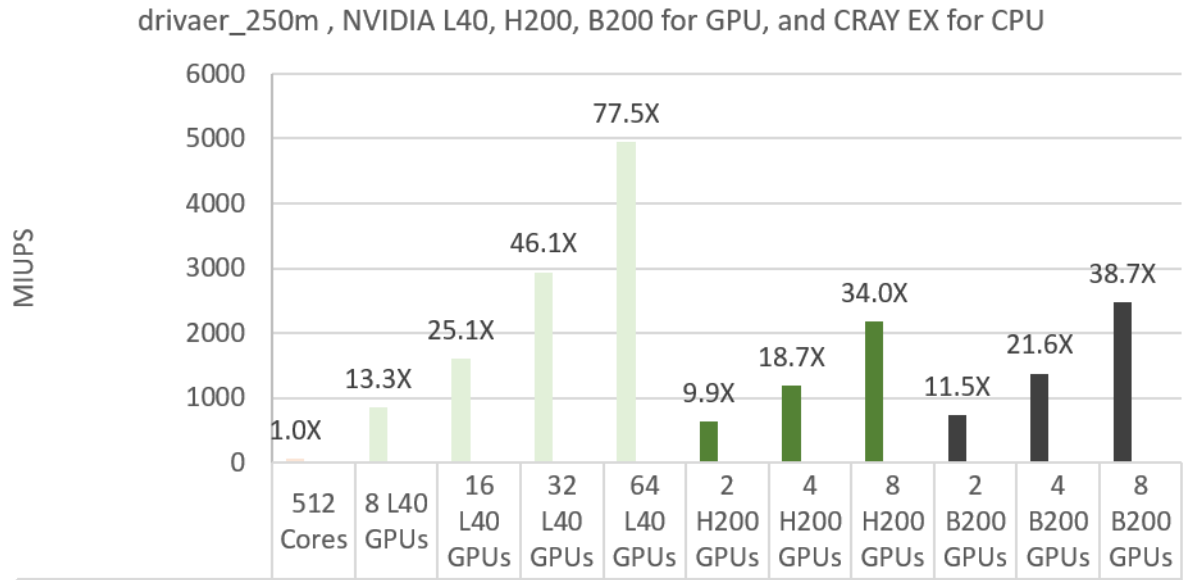
Overview

- Overview Solver
- Turbulence models
- Basic calibration
- DrivAer results
  - Comparison SBES/WFLES/WMLES
- Conclusions



HPC Performance GPU Solver

- Solver
  - Native GPU solver
  - 2nd order cell centred FV
  - 2nd order implicit time stepping (Gear's method)
  - Pressure-base discretization using SIMPLEC
  - Skew symmetric formulation (central reconstruction)
  - High under-relaxation (~1.0) and low iteration count
  - Hybrids RANS-LES (SBES), Wall function LES and WMLES



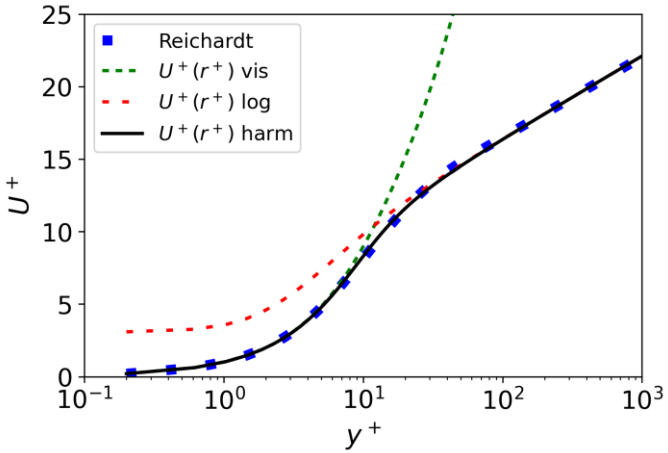
	512 Cores	8 L40 GPUs	16 L40 GPUs	32 L40 GPUs	64 L40 GPUs	2 H200 GPUs	4 H200 GPUs	8 H200 GPUs	2 B200 GPUs	4 B200 GPUs	8 B200 GPUs
MIUPS	64	848	1598	2939	4943	630	1191	2170	734	1375	2470
Parallel efficiency	100%	100%	94%	87%	73%	100%	95%	86%	100%	94%	84%
Time per iteration	3,92	0,29	0,16	0,09	0,05	0,40	0,21	0,12	0,34	0,18	0,10

40 minutes (64 L40 GPUs) to run 10,000 timesteps on 250 million cells with WFLES

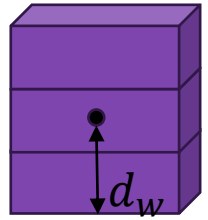
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Non-Iterative Wall-Function (Wall-Stress Model)

- Based on r^+ not y^+
- Approximation of logarithmic layer
- Harmonic blending of sub- and log-layer
- Is ‘equilibrium’ good enough?



$$r^+ = y^+ u^+ = \frac{u d_w}{\nu}$$



$$u^+_{sub} = \sqrt{r^+}$$

$$u^+_{log} = C_1 ln(r^+ + C_2)$$

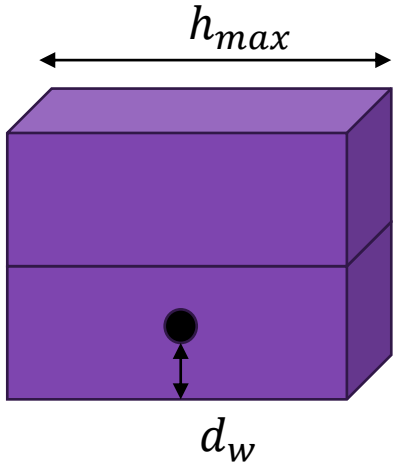
$$u^+_{eq}(r^+) = \left((u^+_{sub})^{-\alpha} + (u^+_{log})^{-\alpha}\right)^{-\frac{1}{\alpha}}$$

EVALUATION OF A NEW EXPLICIT WALL-FUNCTION FORMULATION FOR LARGE EDDY SIMULATION
ETMM15
E.K. Guseva[1], D.G. Flad[1], A.L. Nogueira[2], D.P. Graebin[2] and F.R. Menter[1]
In Print

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Algebraic WMLES Channel

- Blend of Prandtl and any alg. LES model
- Blending based on d_w/h_{max}
- Function f_{sw} has two parameters
  - C_{w1} switching location
  - C_{w2} steepness



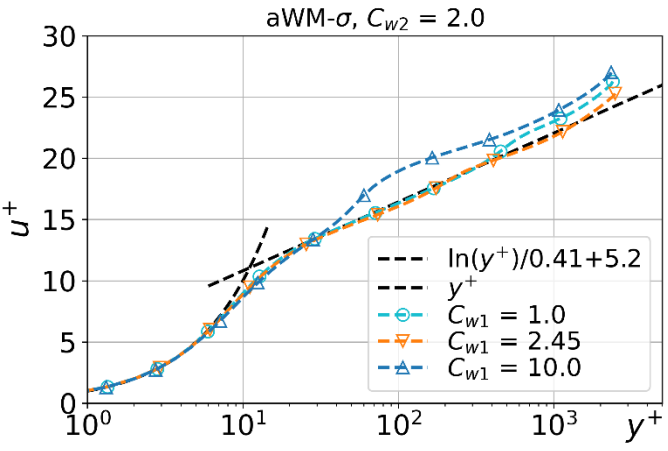
$$\nu_t = f_{sw}\nu_{t,RANS} + (1 - f_{sw})\nu_{t,LES}$$

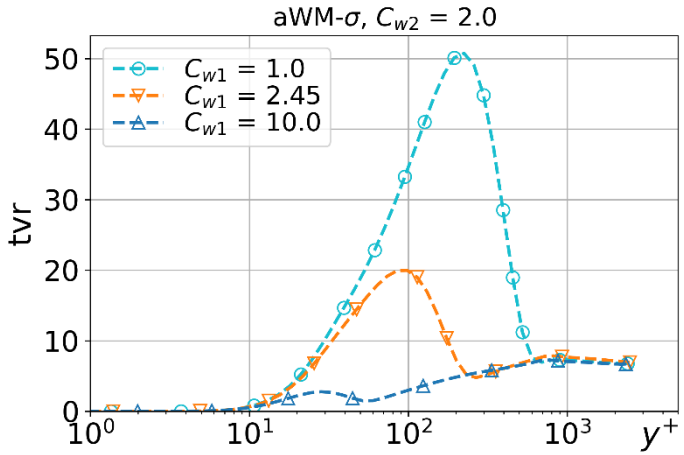
$$f_{sw} = e^{-\left(\frac{C_{w1}d_w}{h_{max}}\right)^{C_{w2}}}$$

$$\nu_{t,RANS} = l_{RANS}^2 S$$

$$l_{RANS} = 0.41 d_w \sqrt{f_{wd}}$$

$$f_{wd} = 1 - e^{-\left(\frac{l^+}{25}\right)^3}$$





ETMM14 Conference Barcelona 2023

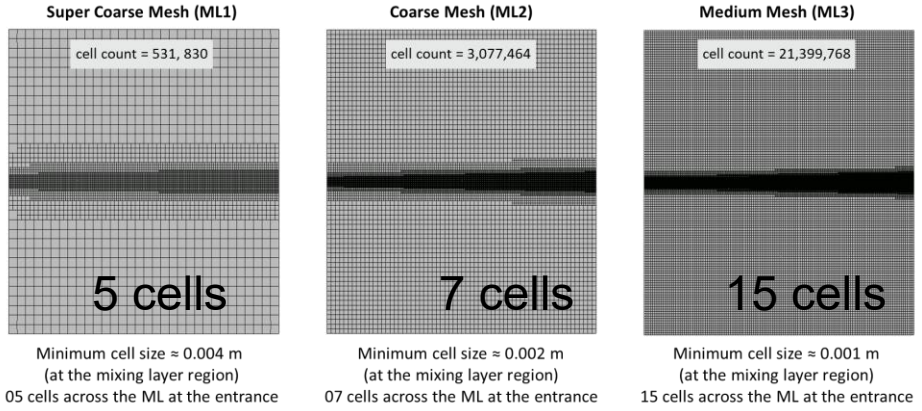
A Family of Wall-Modeled Large Eddy Simulation Formulations

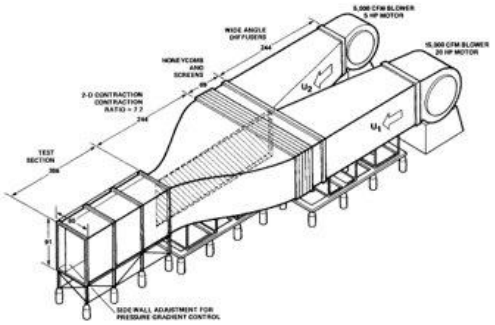
F. R. Menter[1], E. Guseva[1], A. Stabnikov[2], A. Matyushenko[2] and A. Garbaruk[2]

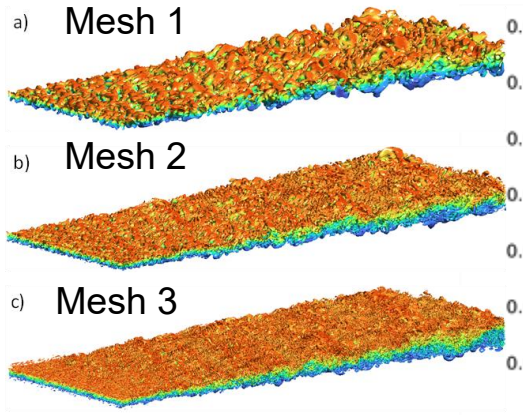
[1] Ansys Germany GmbH
[2] SPbPU St. Petersburg

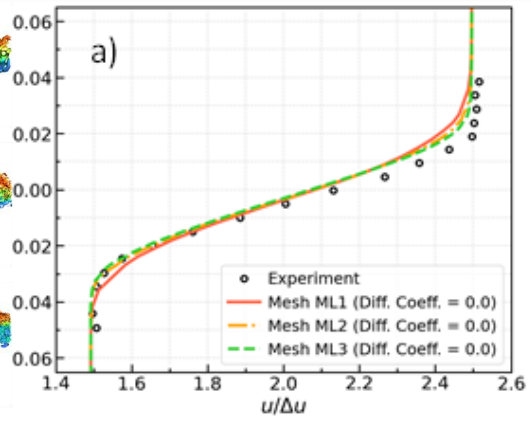
Example: Mixing Layer

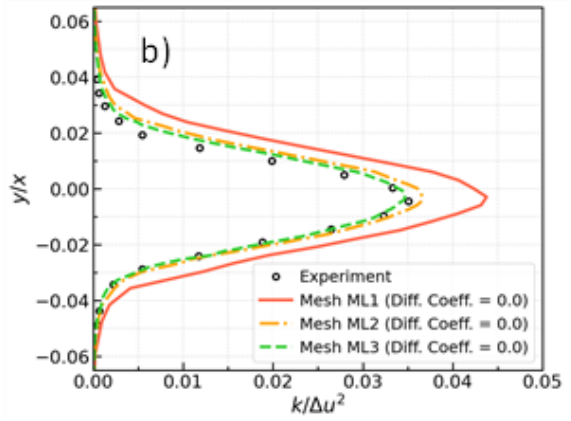
- 3 meshes (0.5, 3 and 21 million cells)
- Even with only 5 cells across the inlet mixing layer the velocity profile is captured well
- With increasing cells count the turbulent kinetic energy converges quickly
- The maximum CFL number can be increased
  - CFL=2 very small error increase
  - CFL=5 still reasonable accuracy in velocity profile

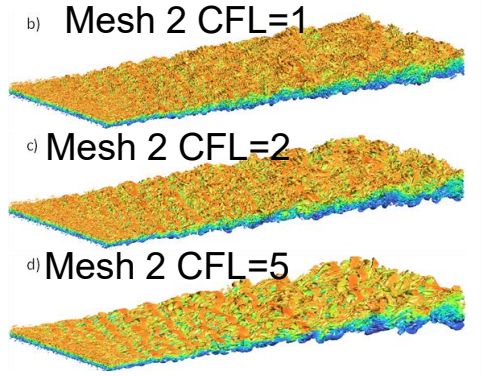


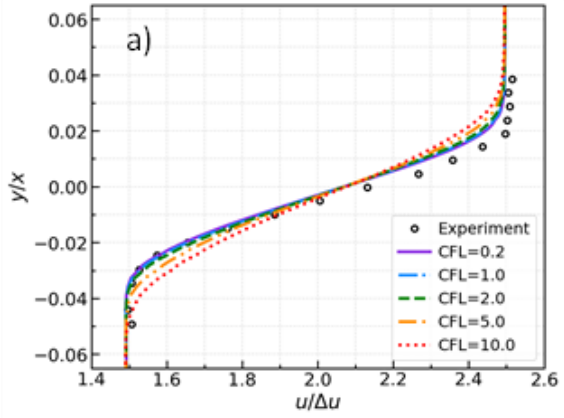


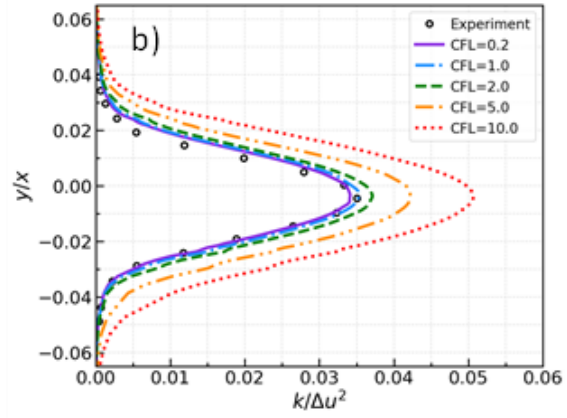


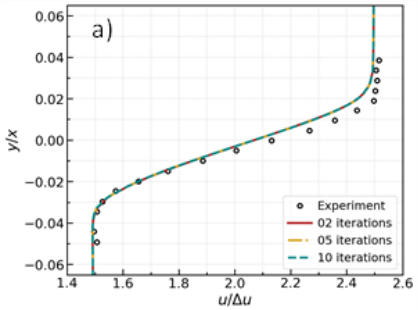


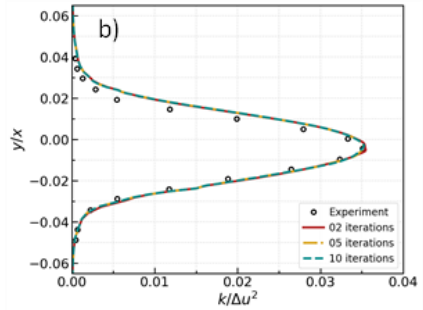








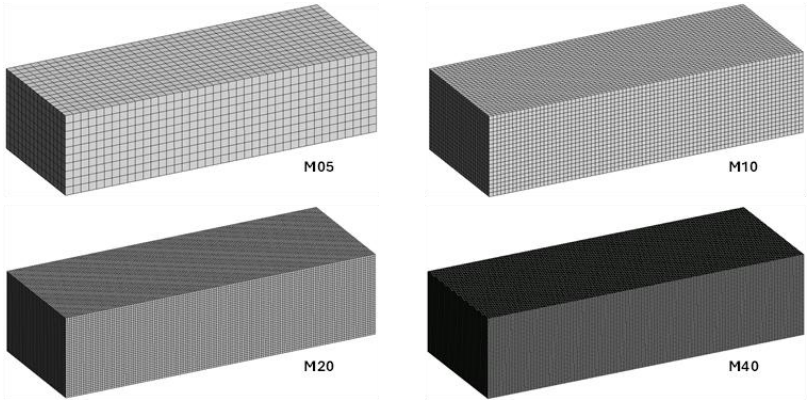




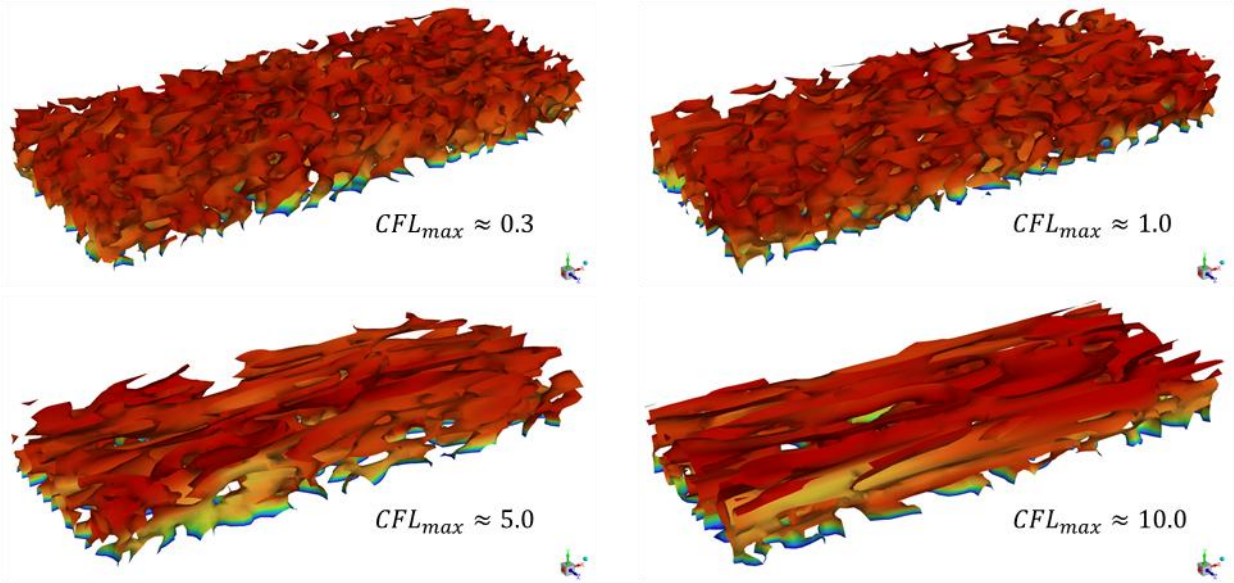
*Bell, J.H., Mehta, R.D., Development of a Two-Stream Mixing Layer from Tripped and Untripped Boundary Layers, AIAAJ (1990), Vol. 18, N. 12

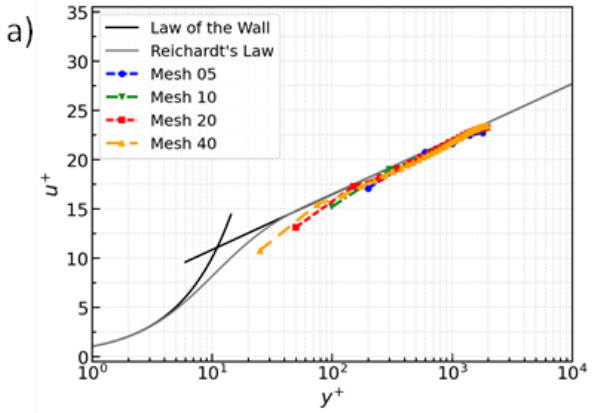
Example: WFLES Channel

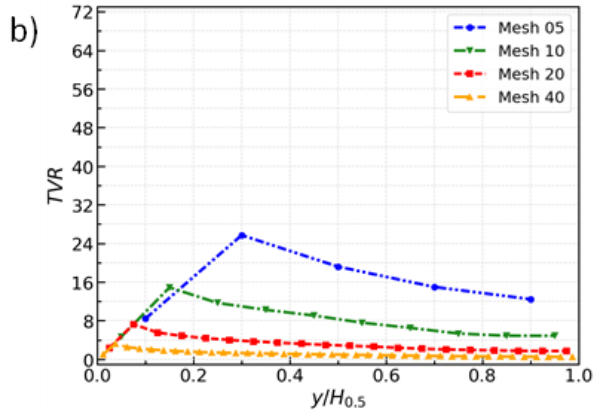
- Grid study
  - Even with only 5 cells across the half-channel – good match to log-layer
  - Sensitivity to CFL number moderate – even though turbulence structures affected

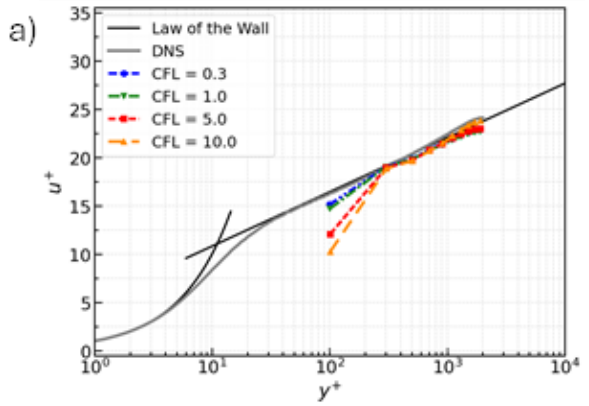


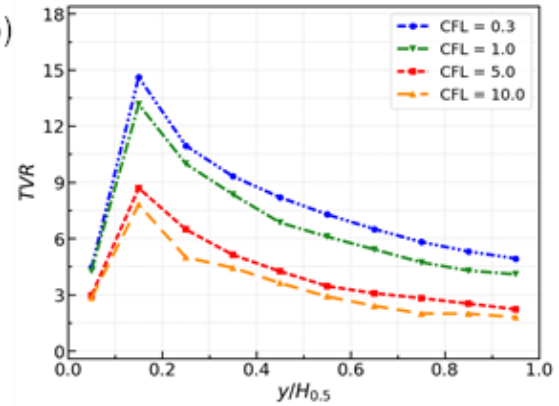
Mesh	Cells per $H/2$	Cell Count
M05	5	6,000
M10	10	48,000
M20	20	384,000
M40	40	3,072,000











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Smooth ramp

- High-Fidelity CFD Verification Workshop 2024
- $Re_L = 6.67 \times 10^5$
- 4 Octree-type meshes with 2 prisms

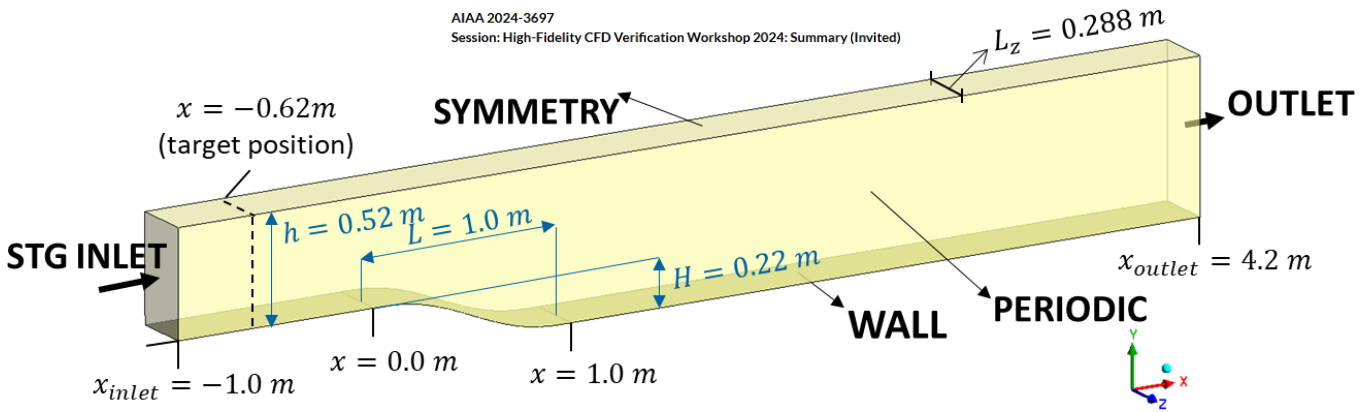
Mesh	Base cell size Δ, mm	$\delta_{target\ position}/\Delta$	Cells, M
M1	8	5	0.57
M2	4	10	3.7
M3	2	20	27
M4	1	40	200

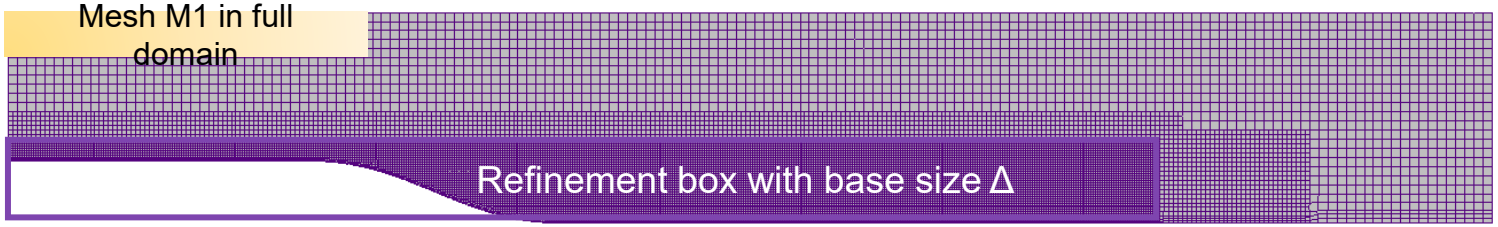
- RANS Velocity profile + unsteady fluctuations
  - ➢ Synthetic Turbulence Generator

Summary of the Wall-Modeled LES Test Suite From the 2024 AIAA High-Fidelity CFD Verification Workshop

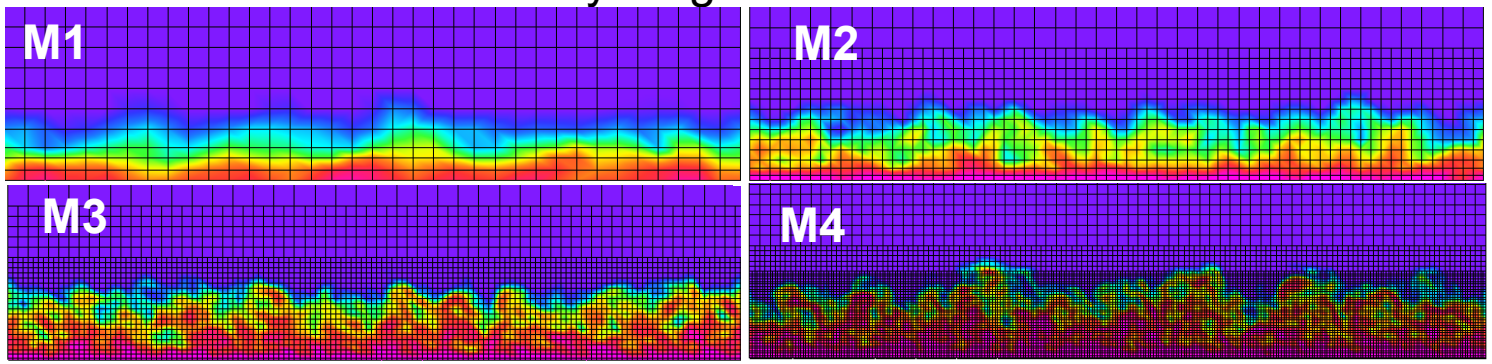
Daniel J. Garmann, Matthew J. Schwartz, Johan Larsson, Ivan Bermejo-Moreno, Ali Uzun, Sparsh Ganju, Christoph Brehm, Timofey Mukha, Matteo Parsani, David Flad and Jannik Schrempp

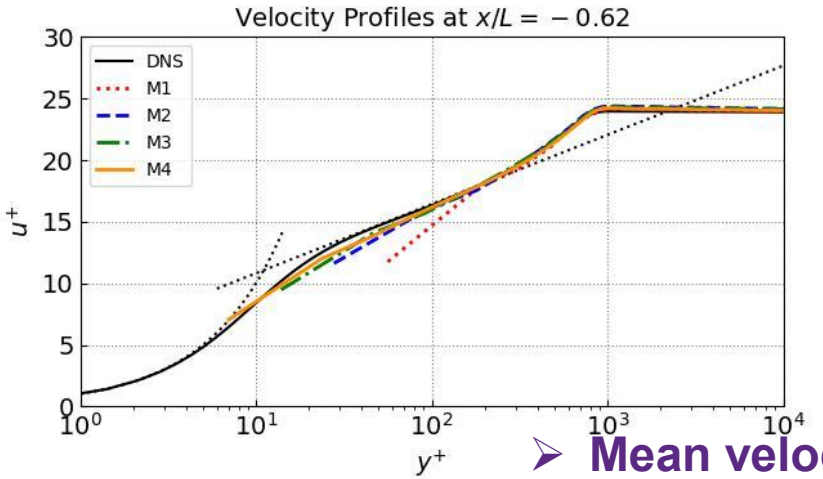
AIAA 2024-3697
Session: High-Fidelity CFD Verification Workshop 2024: Summary (Invited)





Mesh and vorticity magnitude contours at x/L = -0.62

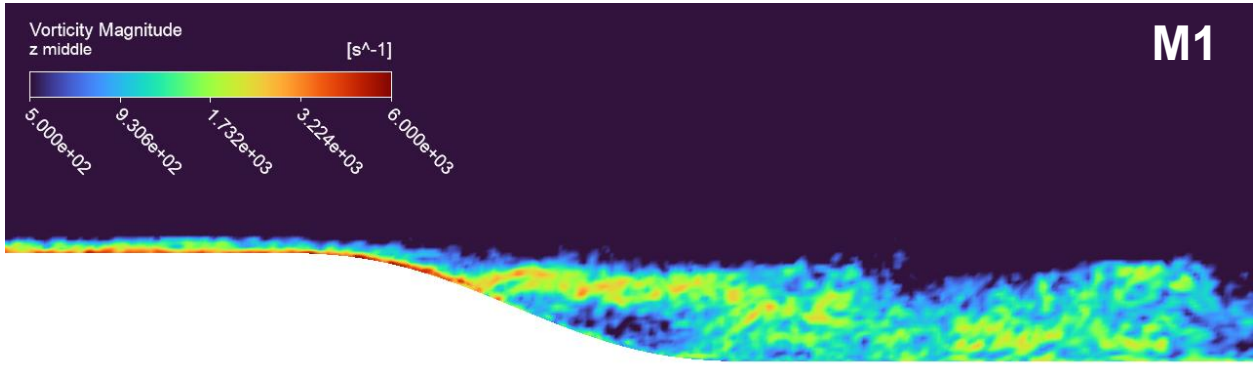


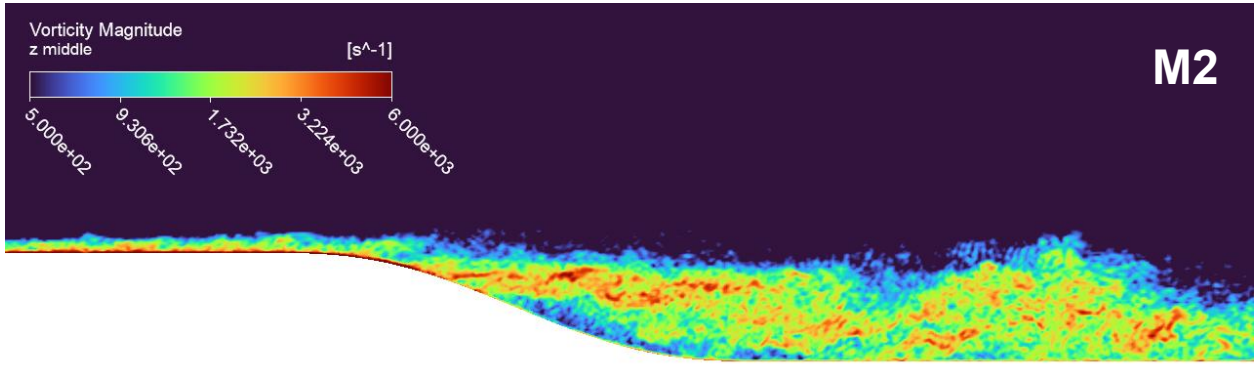


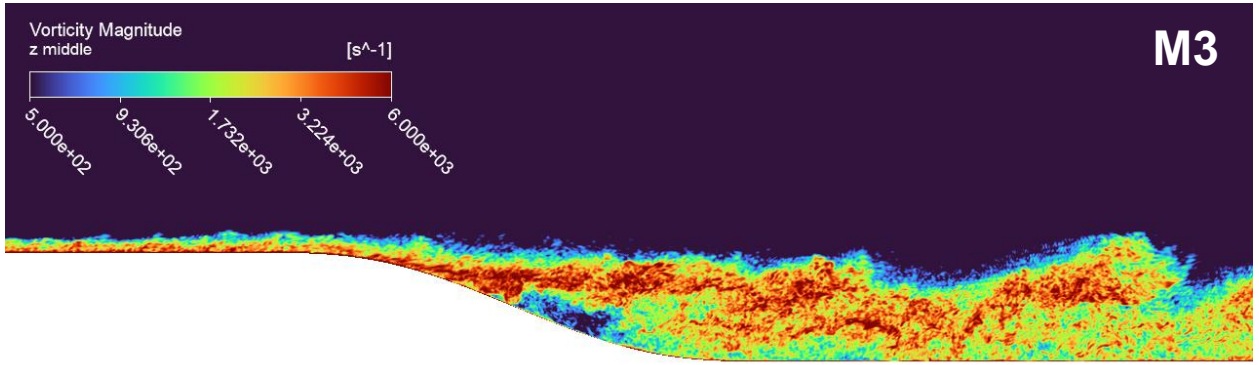
➢ **Mean velocity profile predicted well even on the extreme coarse mesh**

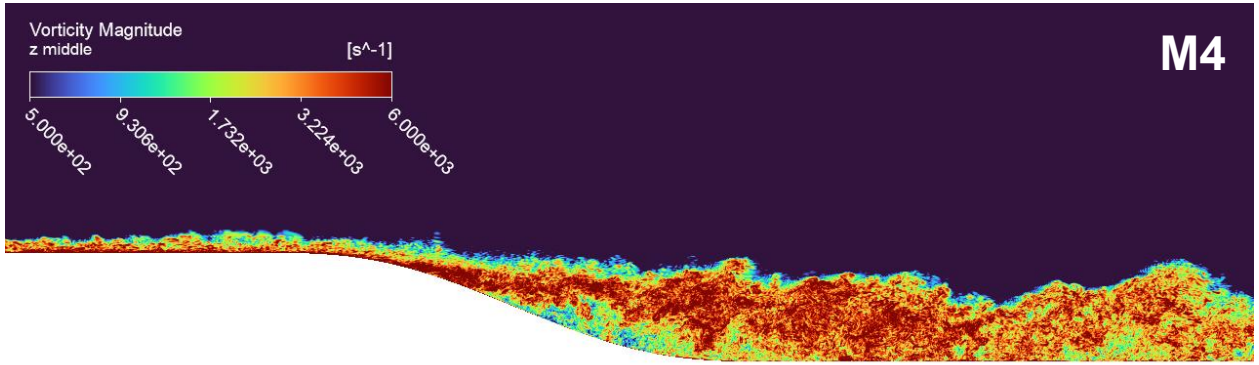
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Flow visualization. Vorticity magnitude contours



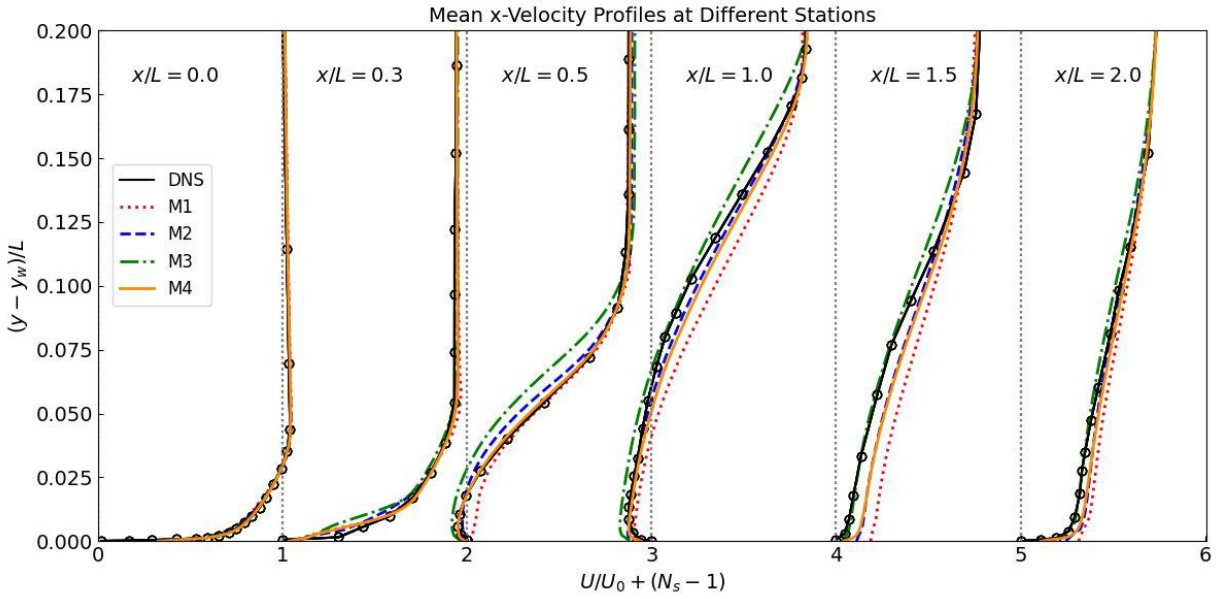


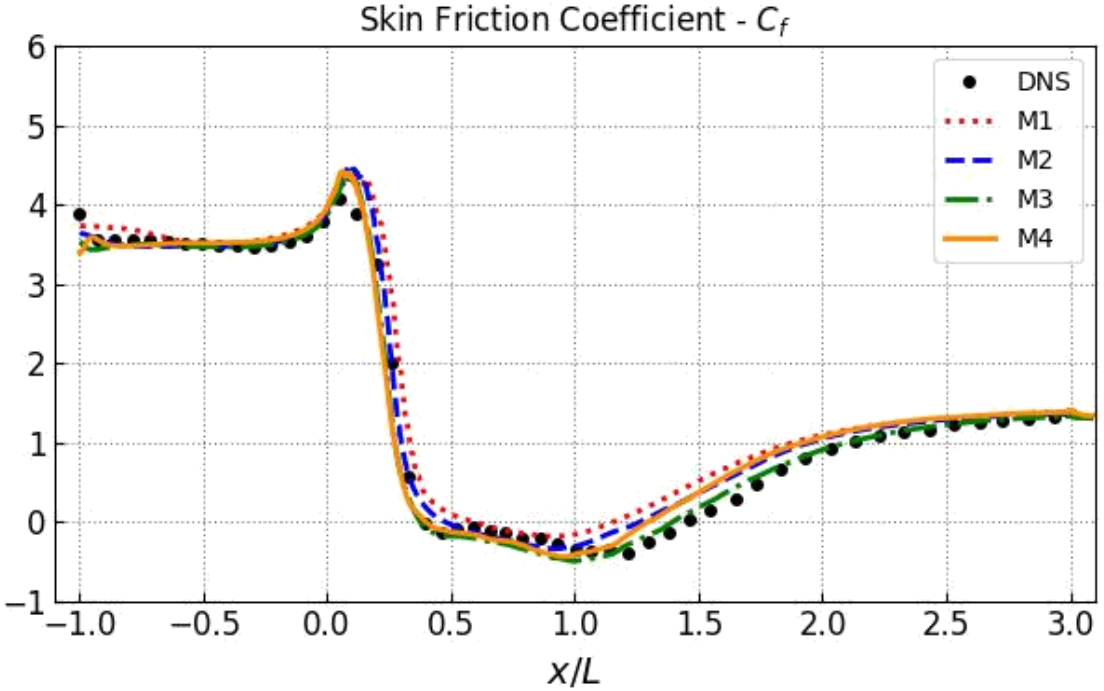




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Smooth ramp





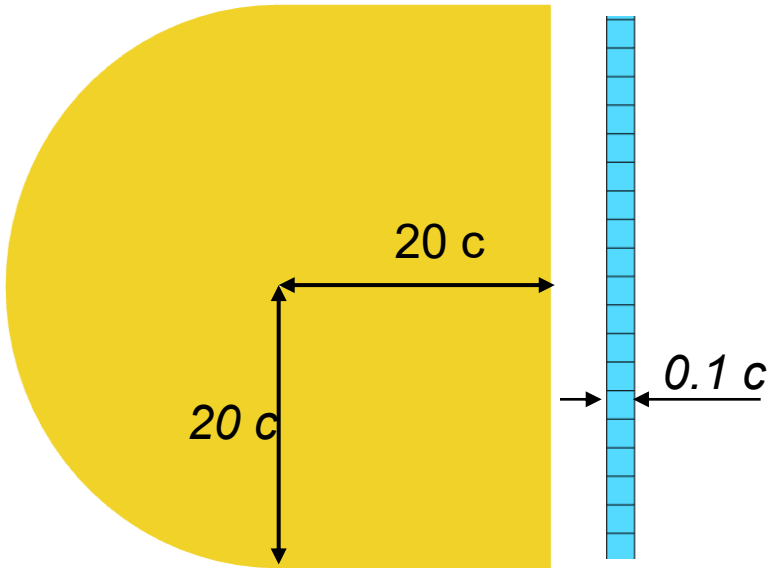
- On all the meshes, except on the coarsest mesh, the separation point is accurately captured
- The recirculation bubble size is somewhat underpredicted
- Some mesh dependency still observed between M2-M4
- Overall, good agreement with the DNS results was achieved

➢ **No systematic failure of equilibrium wall function in non-equilibrium conditions**

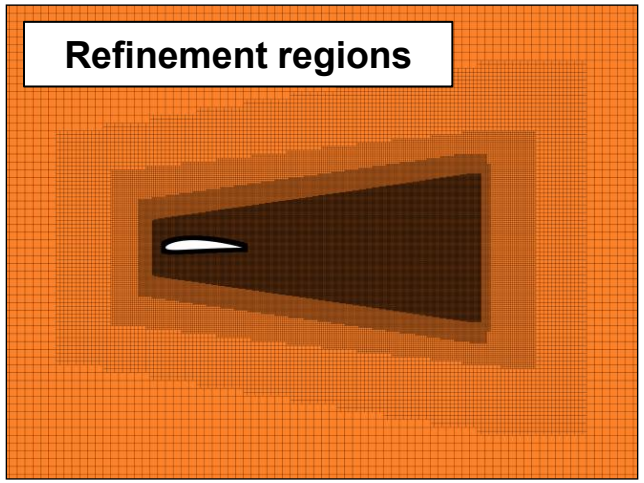
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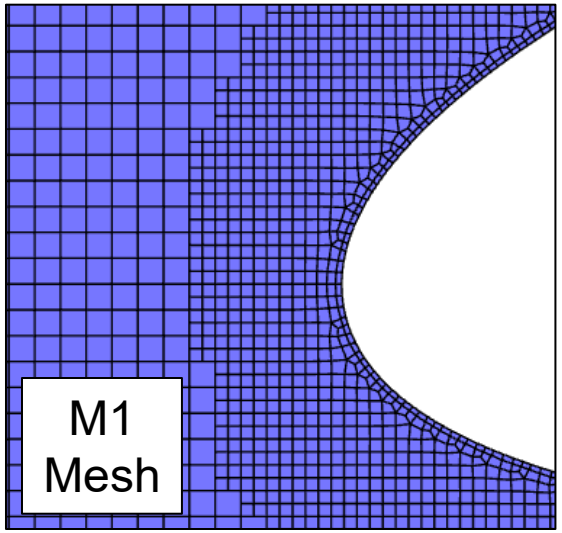
NACA 4412

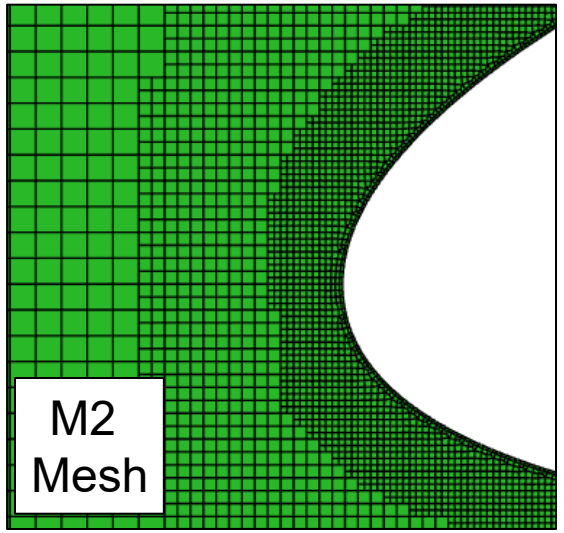
- NACA-4412 with $c = 1$ m and s/c=0.1
- Angle of attack: 13.87°
- Experiment - Wadcock (1979)
- $Re_c = 1.5 \cdot 10^6$
- 2 prisms layers near the wall

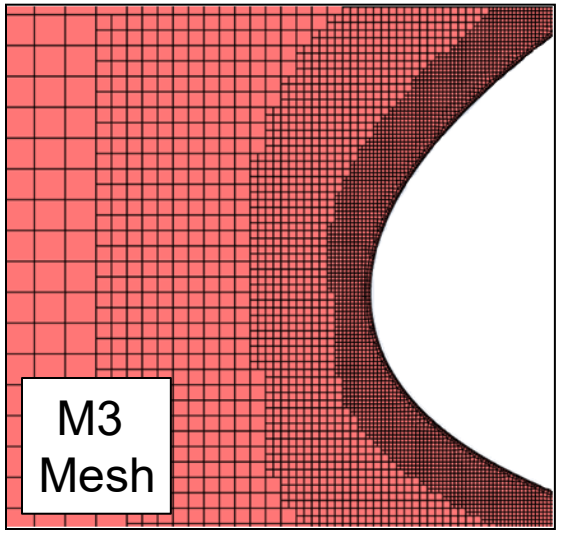


Mesh	Cell Size at Airfoil	Number of cells	y^+_{max}	Number of cells in BL*
M1	$1.6 \cdot 10^{-3}$ c	3,898,080	90	12
M2	$0.8 \cdot 10^{-3}$ c	8,117,776	48	19
M3	$0.4 \cdot 10^{-3}$ c	24,917,296	24	28









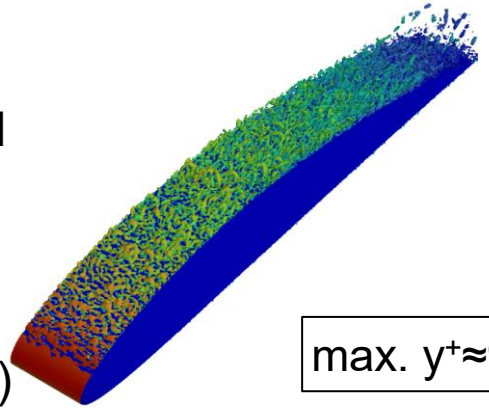
* Measured at *x/c = 0.5*

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Results – iPBNS

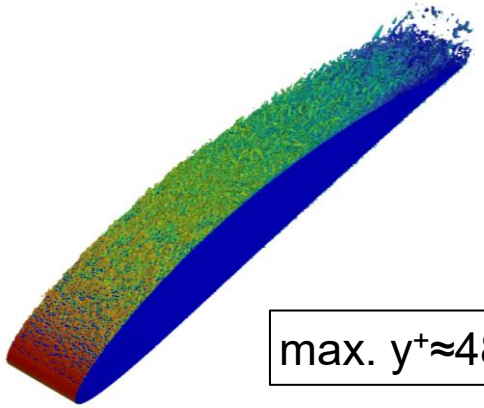
- Boundary Layer resolution
  - 12, 19 and 28 cells per BL at x/c = 0.5
  - 6, 9, and 16 cells per BL at x/c = 0.1
- Transition is noticeably delayed at meshes M1 and M2
  - (no trip was used in the simulations)
  - Local mesh refinement is an option

M1 mesh ($4 \cdot 10^6$)



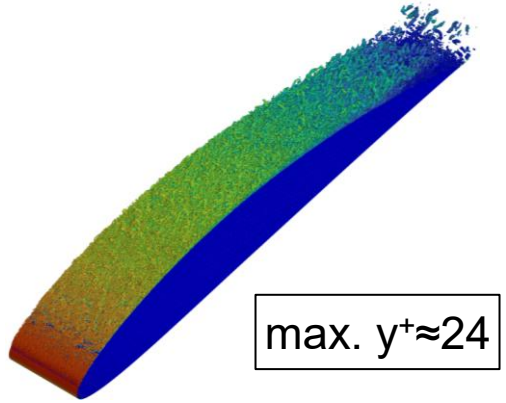
max. $y^+ \approx 90$

M2 mesh ($8 \cdot 10^6$)

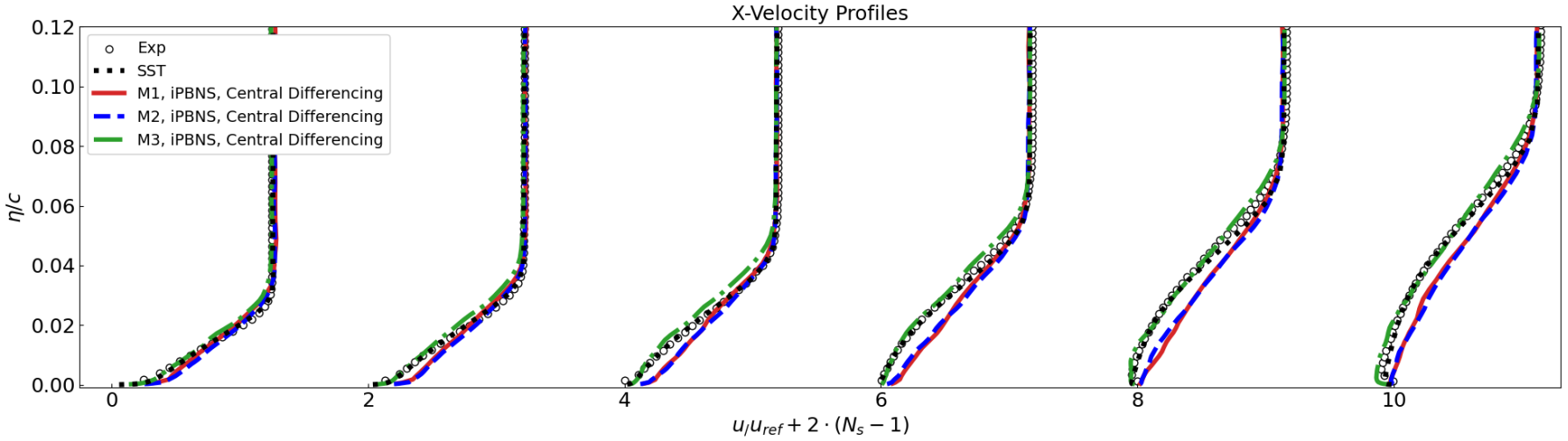


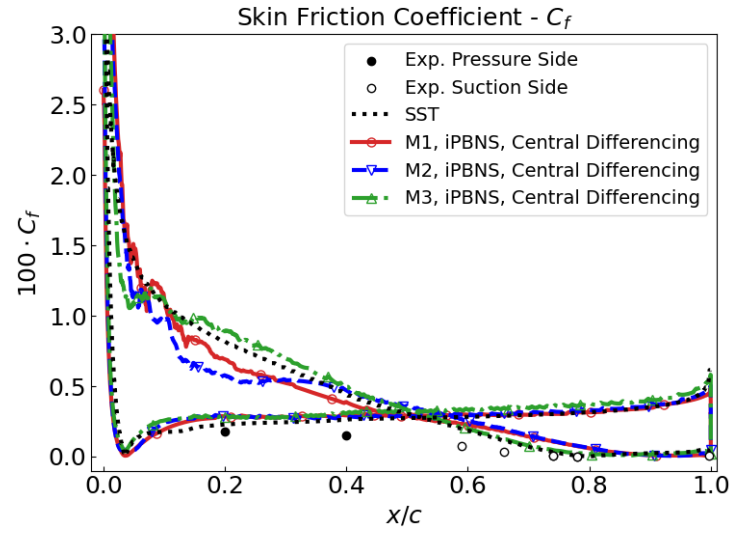
max. $y^+ \approx 48$

M3 mesh ($25 \cdot 10^6$)



max. $y^+ \approx 24$

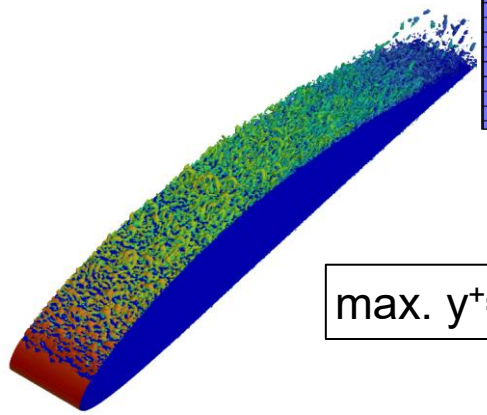


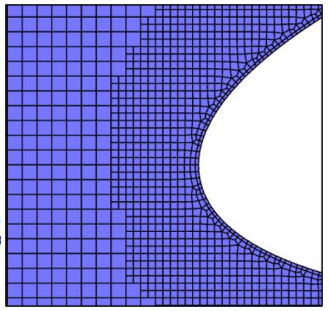


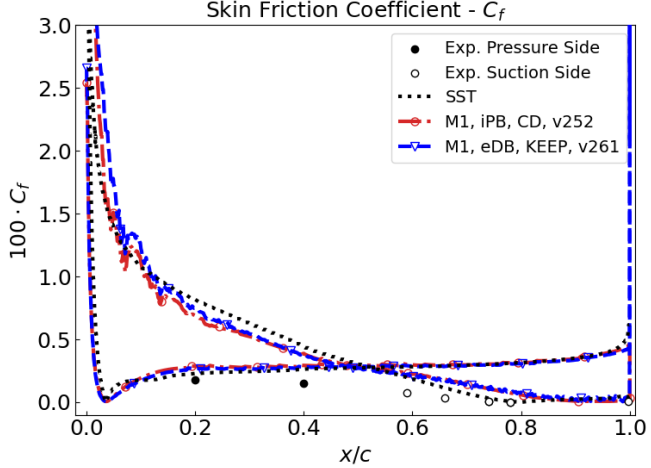
Results – iPBNS

- Results with current Pressure-based Skew-Symmetric scheme almost identical
- Compared with eDBNS:
  - Explicit Density solver
  - KEEP (Kinetic Energy and Entropy Preserving) scheme
  - Accepted LES/DNS numerical method (Kawai et al).
- Transition is noticeably delayed at meshes M1 and M2
  - (no trip was used in the simulations) but in experiments
  - Local mesh refinement is an option

M1 mesh ($4 \cdot 10^6$)

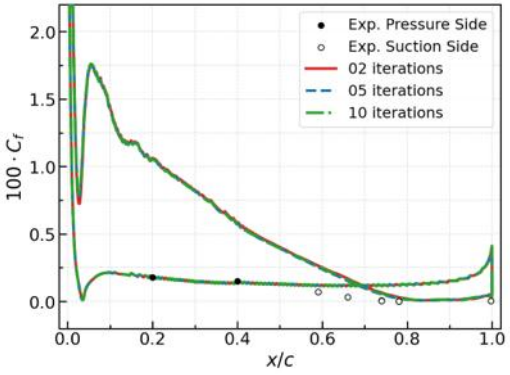


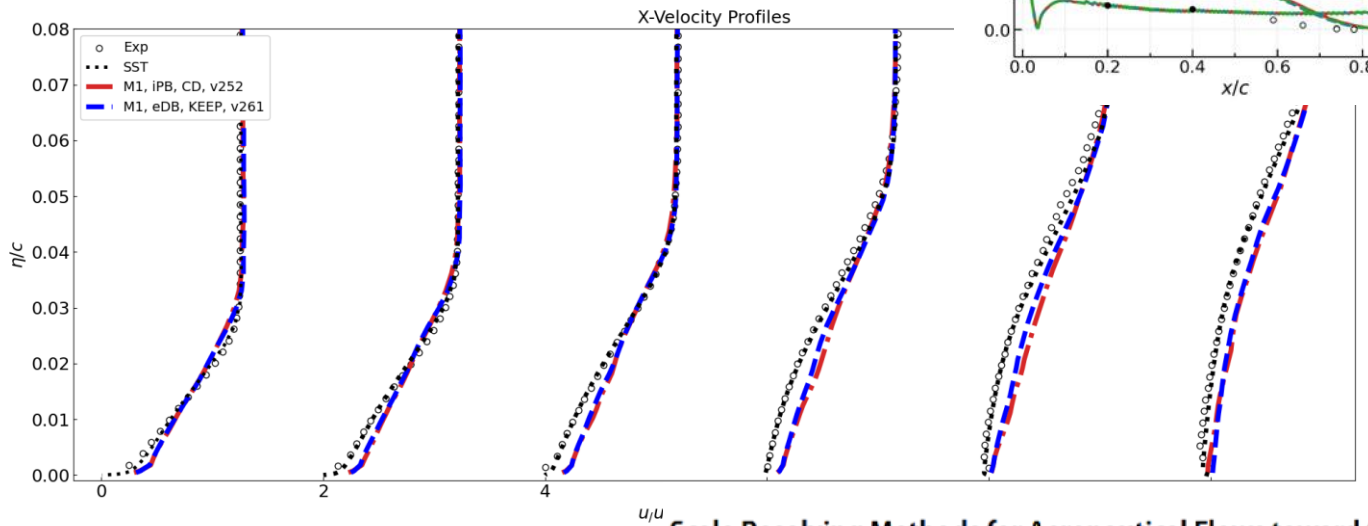




max. $y^+ \approx 90$

4 Million Cells





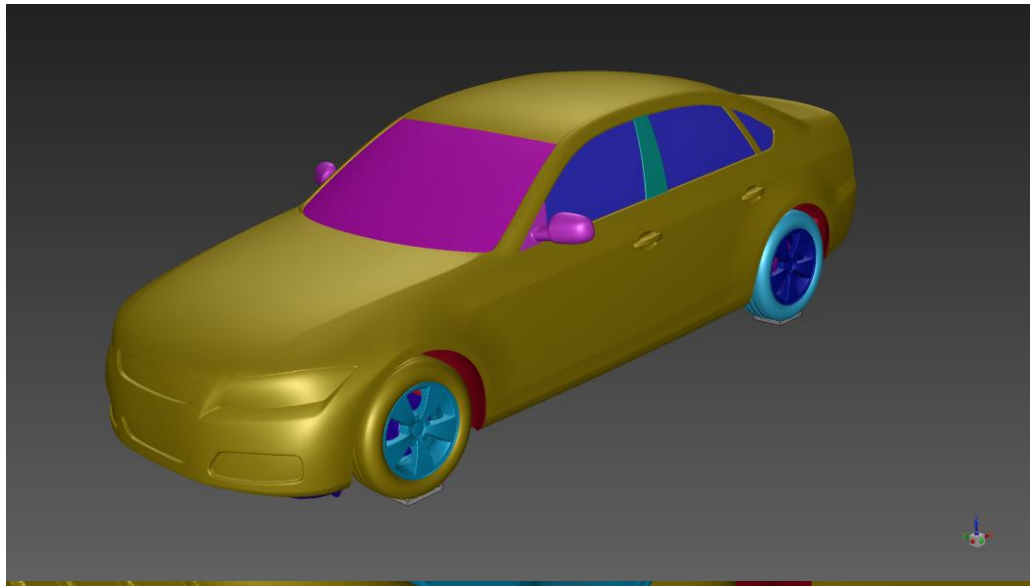
KEEP Scheme:

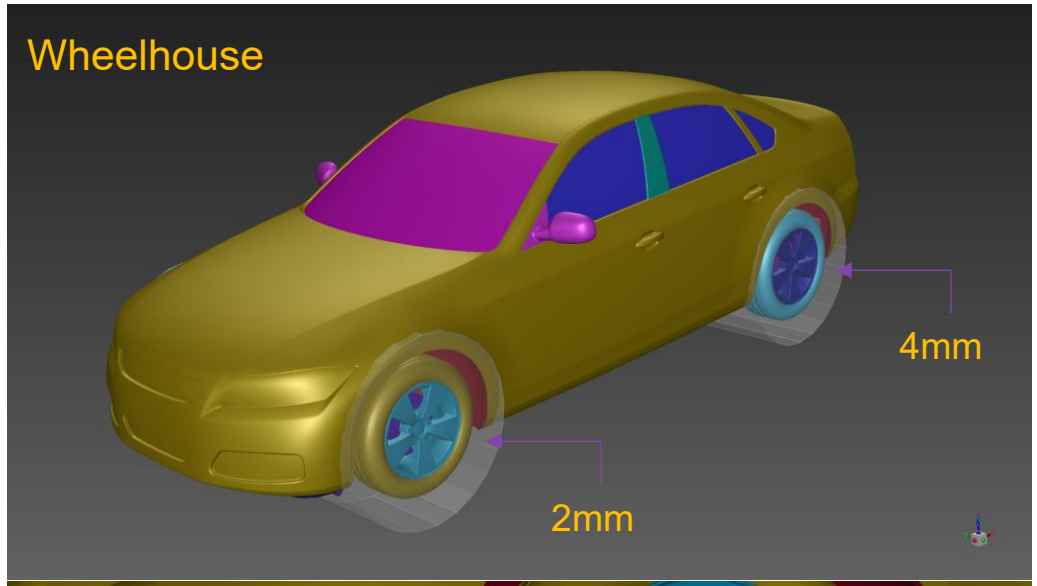
Scale Resolving Methods for Aeronautical Flows toward the Era of "Industrial LES"

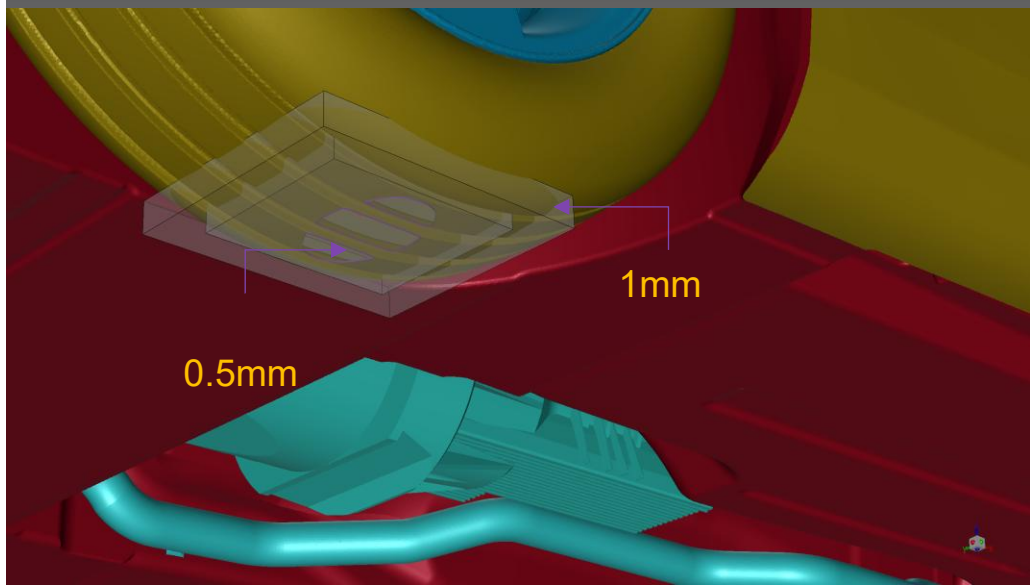
Kozo Fujii[1] · Soshi Kawai[2] · Datta Gaitonde[3]

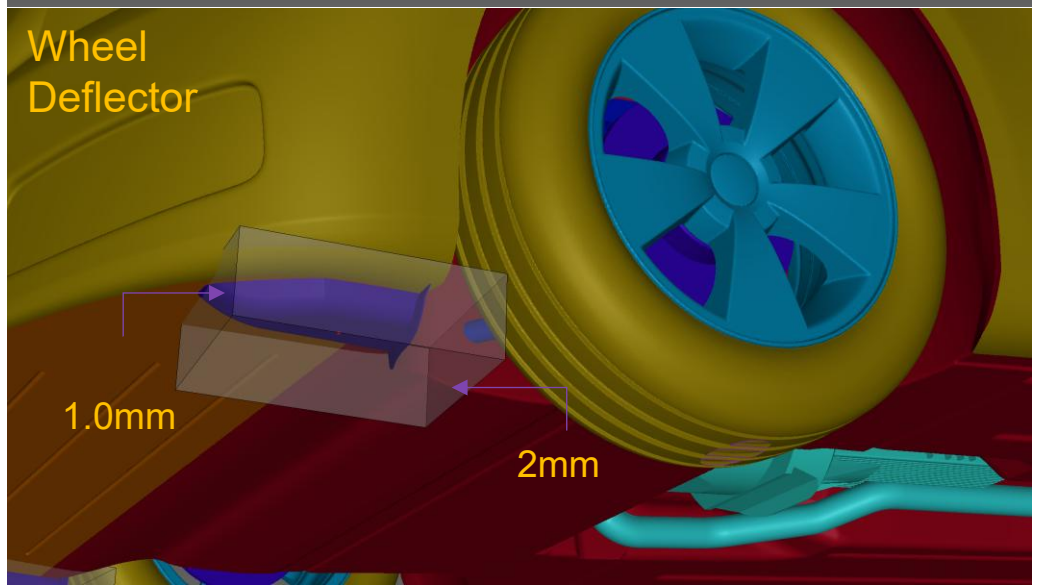
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Some Targeted Mesh Refinements





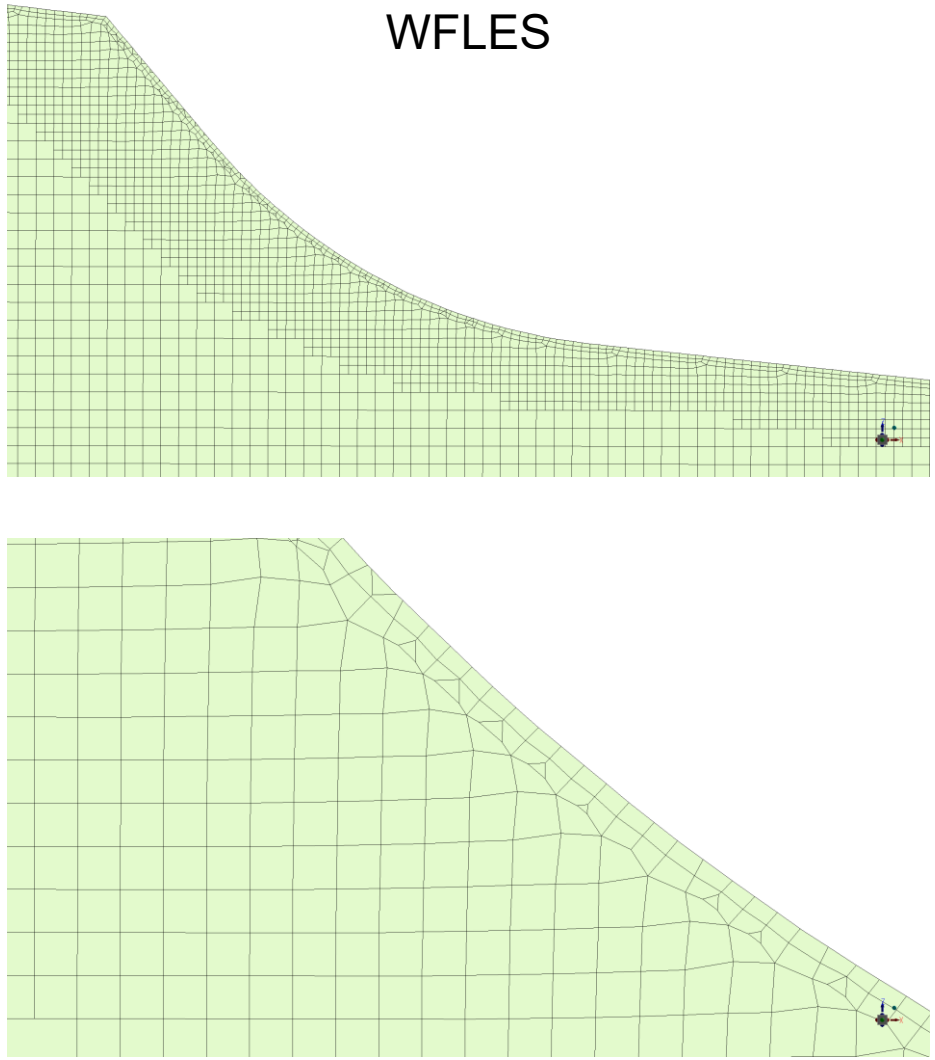




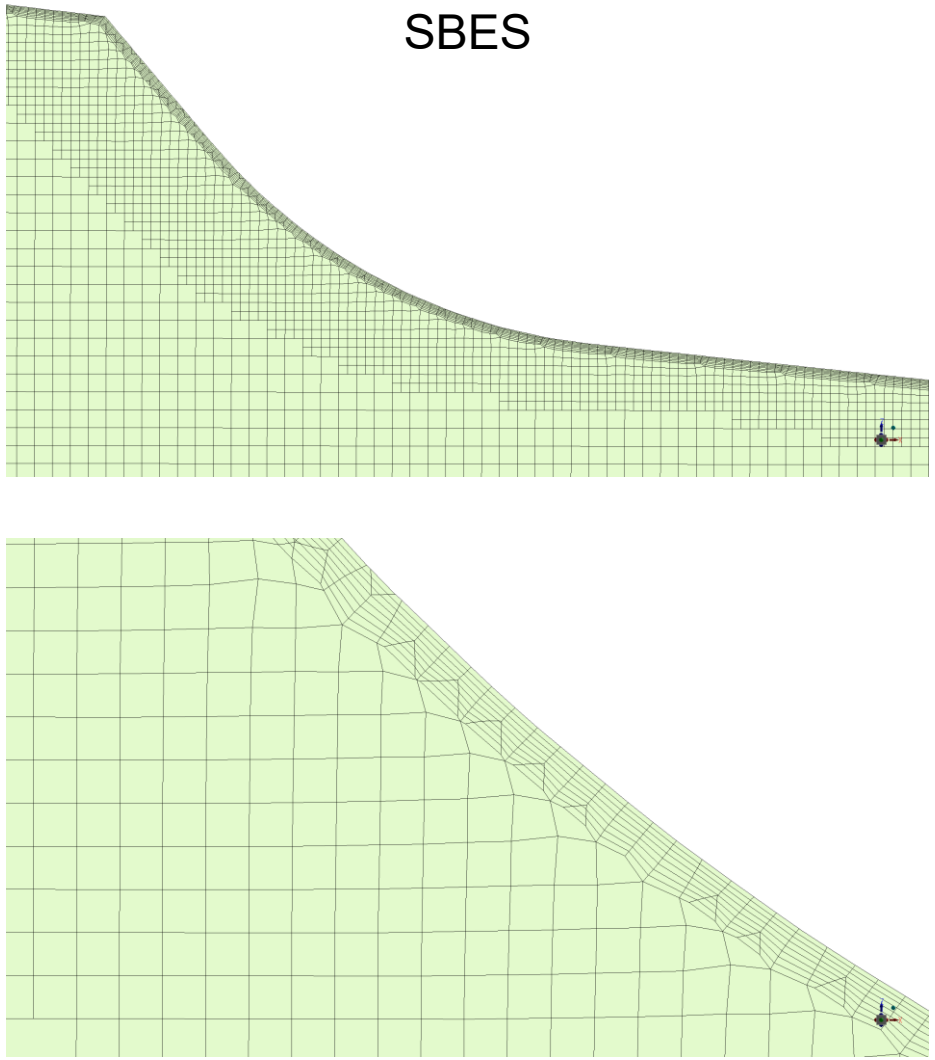
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Mesh Details – Wheel Deflector

WFLES



SBES



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Mesh Details

Surface Mesh Sizes	Case2a	Case2b
Max size on model	4mm	4mm
Min size on model	0.5mm	0.5mm
SBES Mesh Settings	**Case2a**	**Case2b**
Prism layer count	8	8
First layer aspect ratio	40	40
Growth Rate	1.2	1.2
WFLES Prism Settings	**Case2a**	**Case2b**
Prism layer count	2	2
First layer aspect ratio	2	2
Growth Rate	1.0	1.0
Volume Mesh Sizes	**Case2a**	**Case2b**
WFLES	116.7M	120.7M
SBES	126.5M*	135.1M

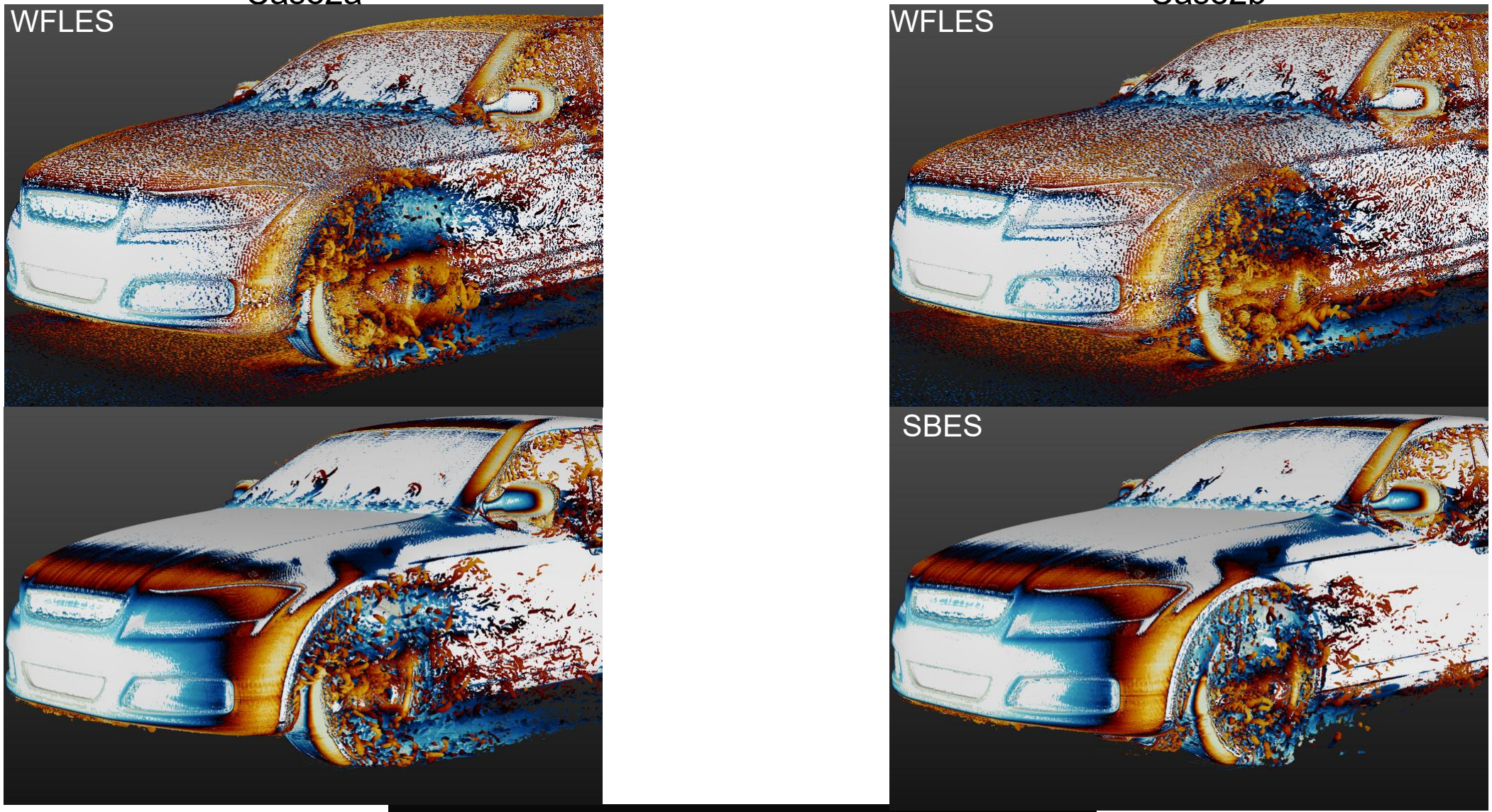
*No wheel deflector refinement box

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Qcrit (1e6)

Case2a

Case2b

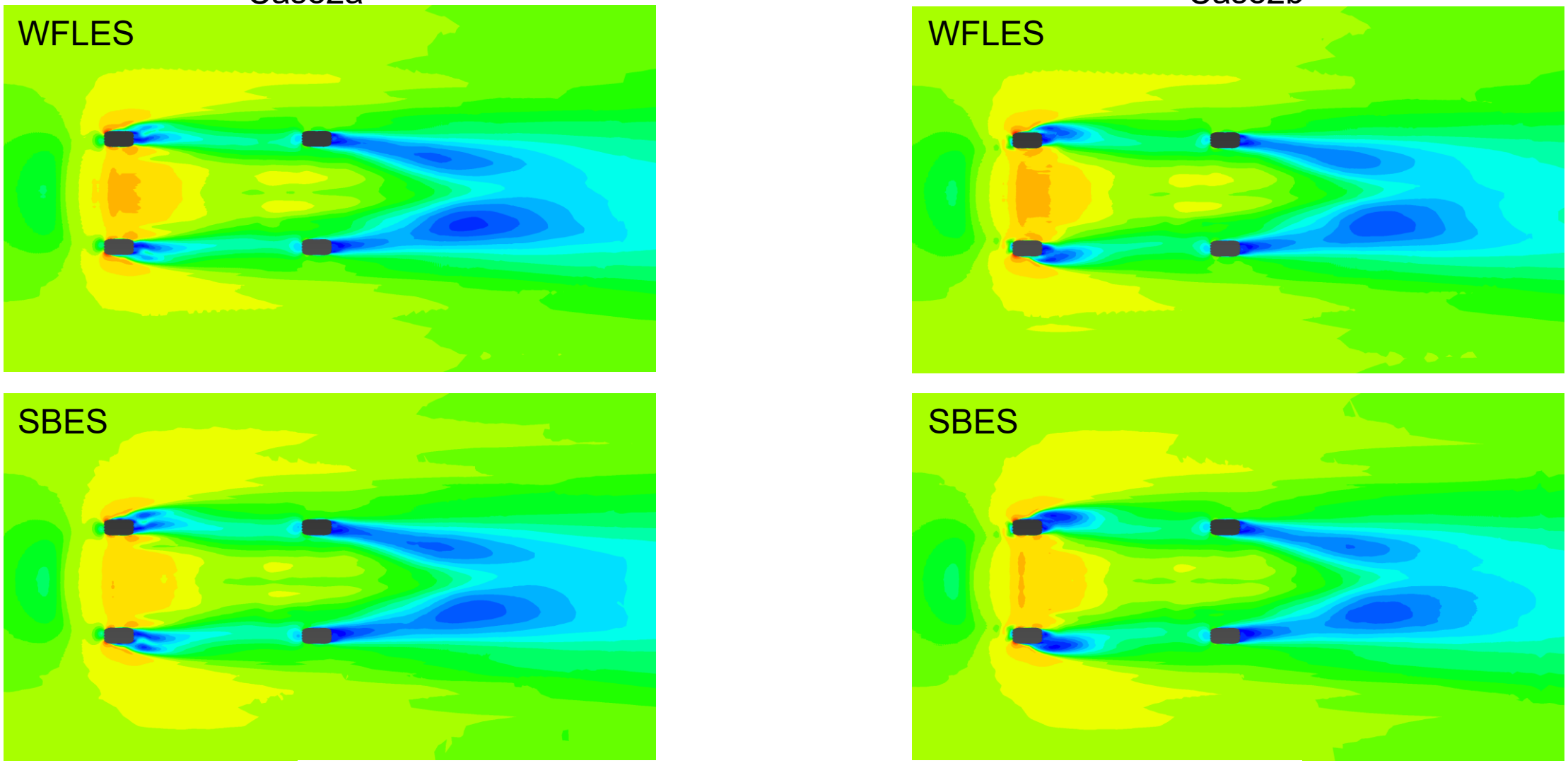


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Normalized velocity @L1

Case2a

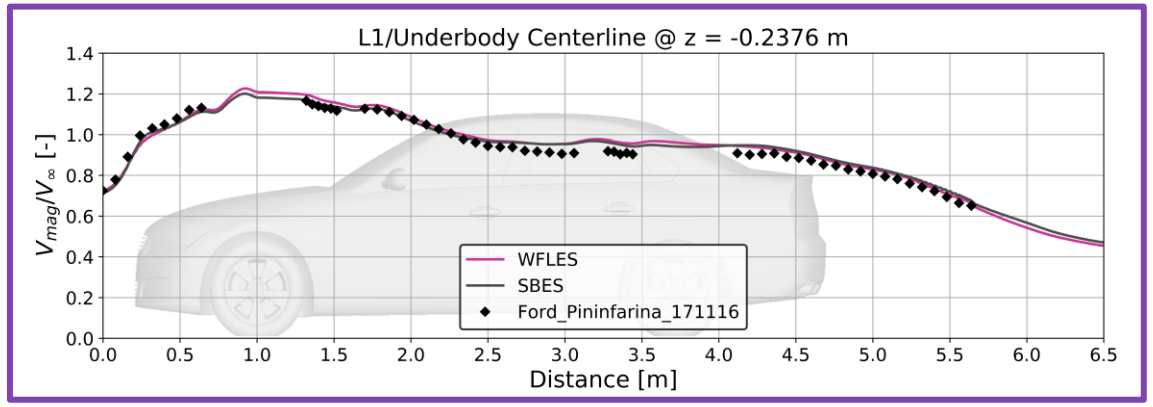
Case2b



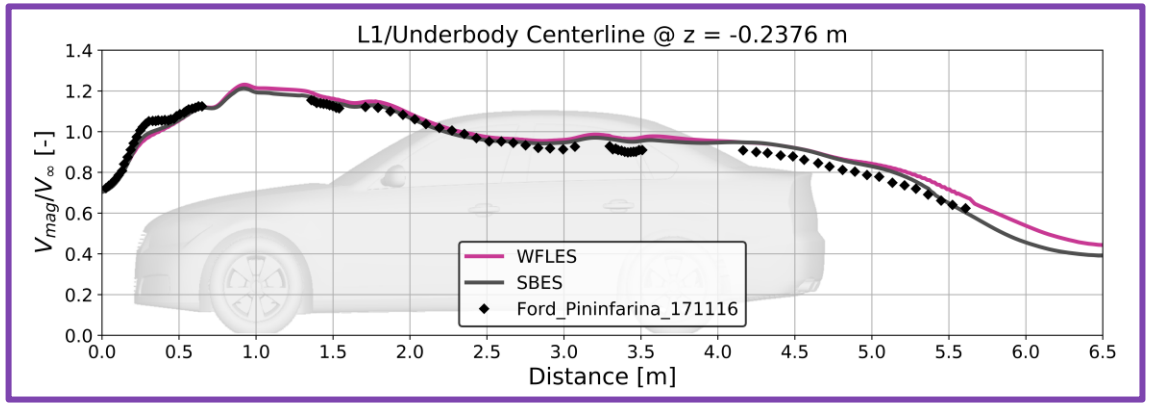
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L1-Underbody Centreline

Case2a



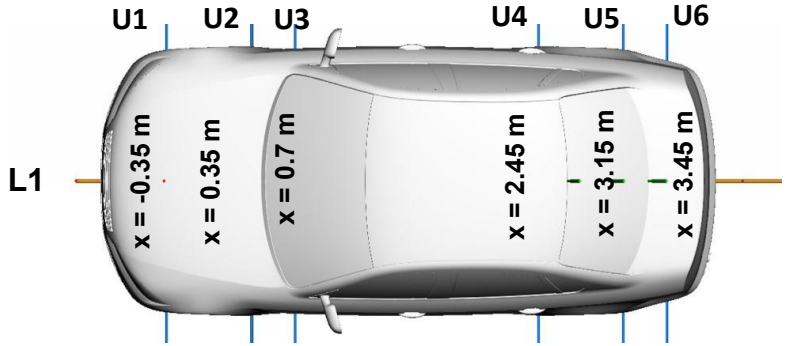
Case2b



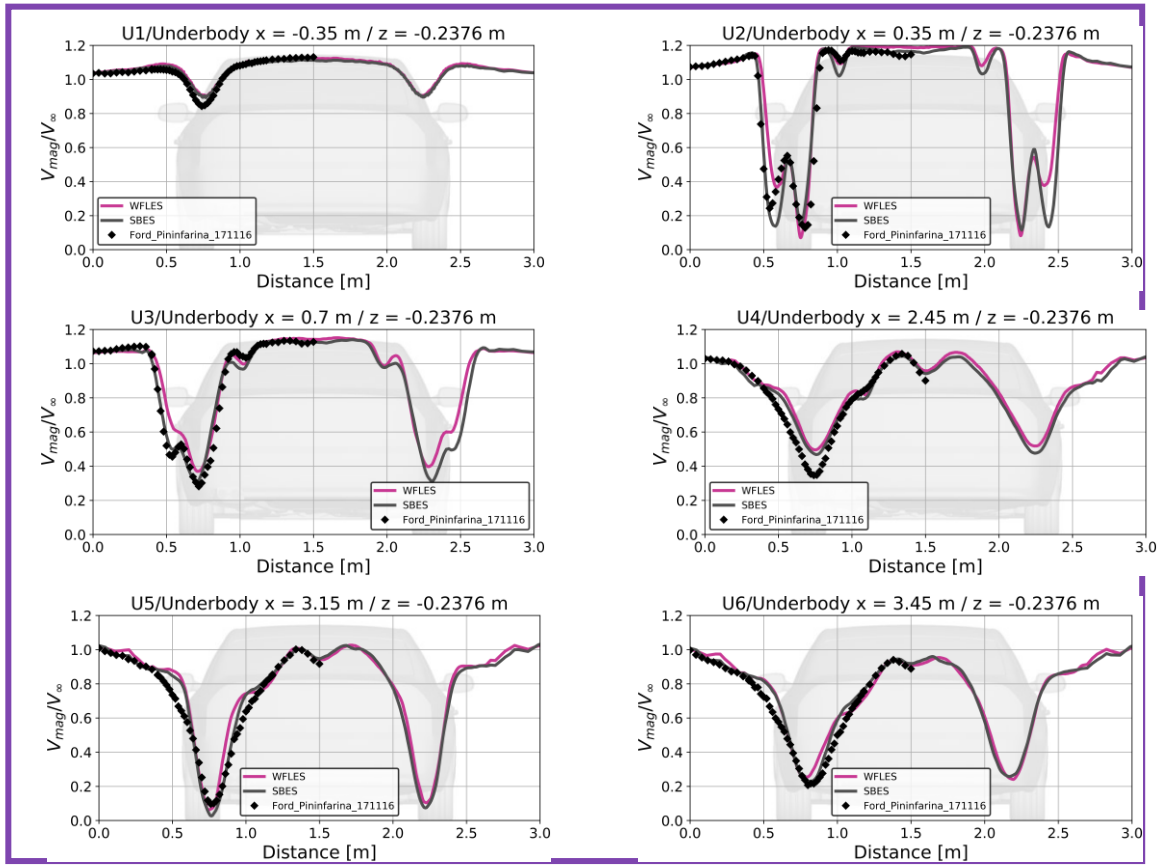


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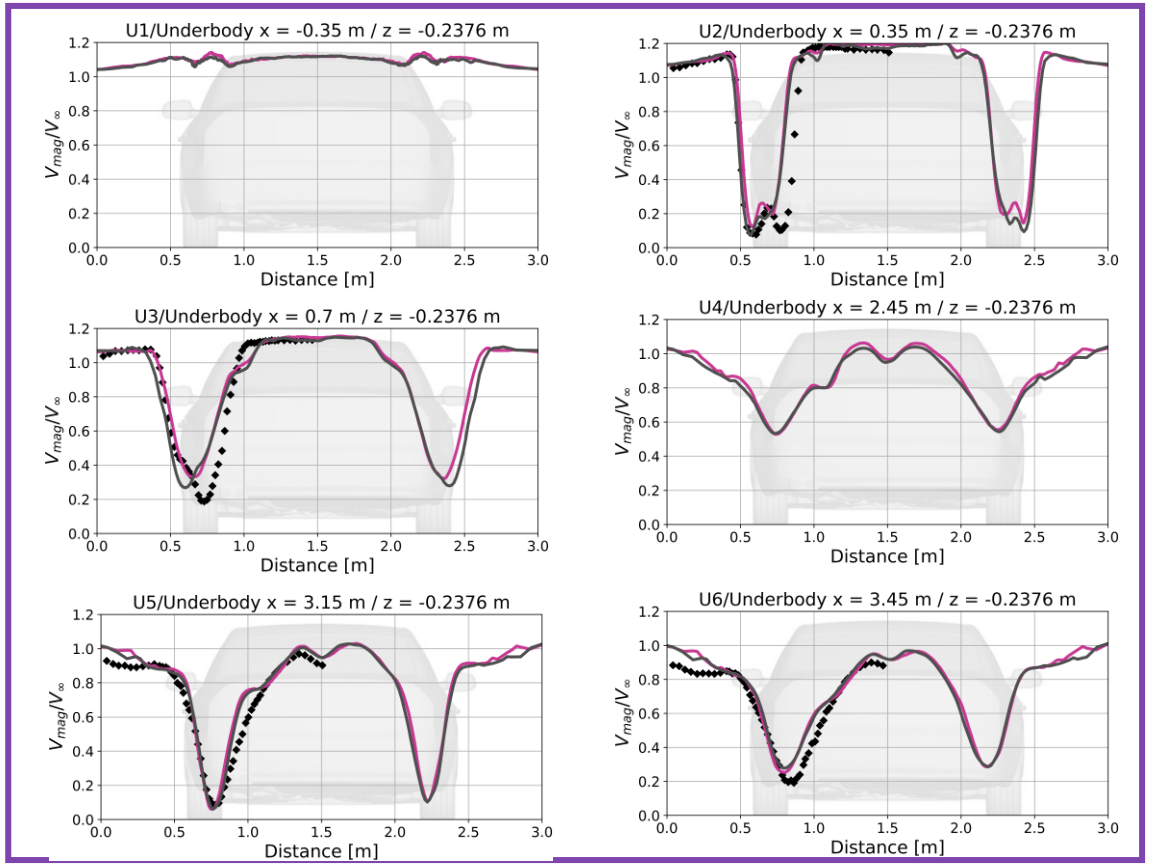
Velocity profiles



Case2a



Case2b

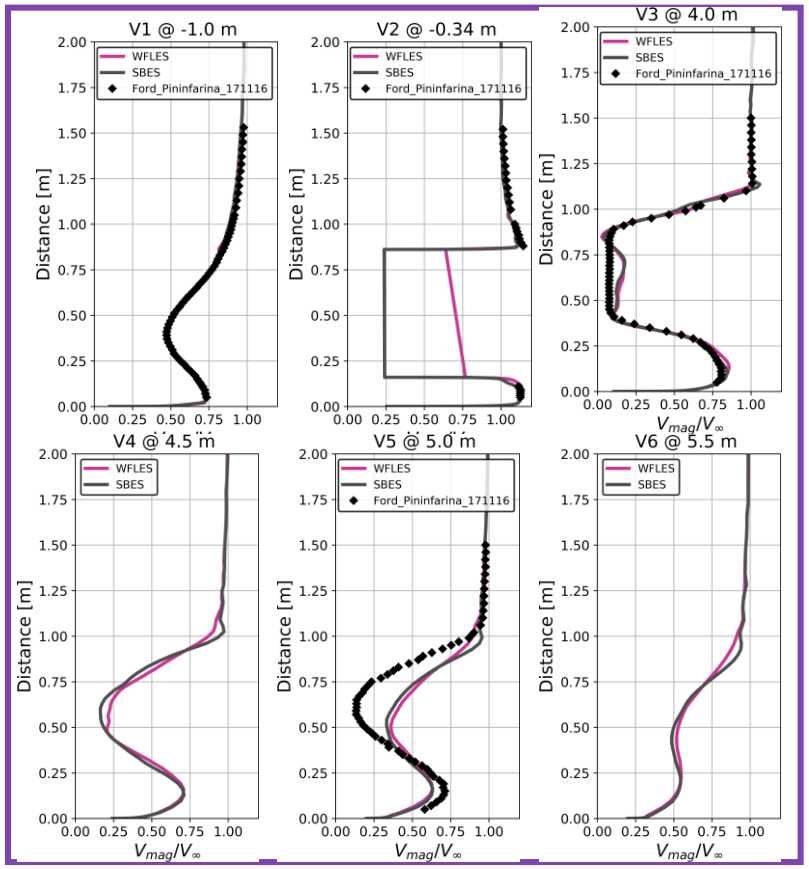


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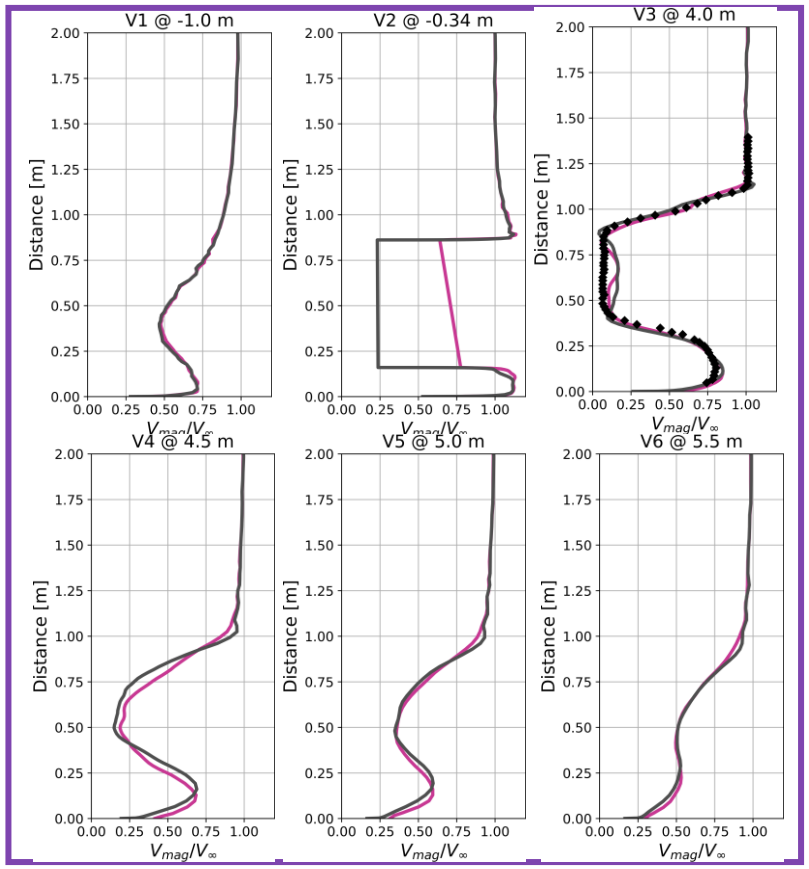
V-velocity



Case2a

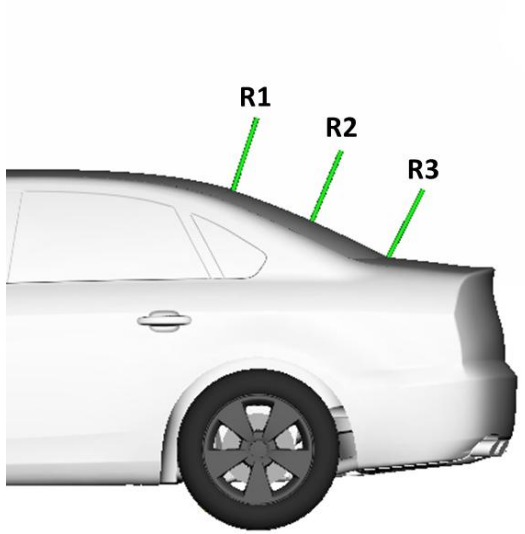


Case2b

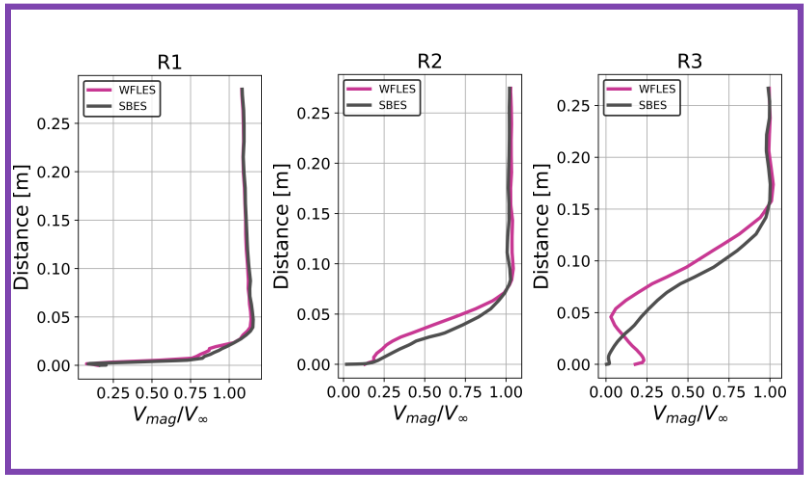


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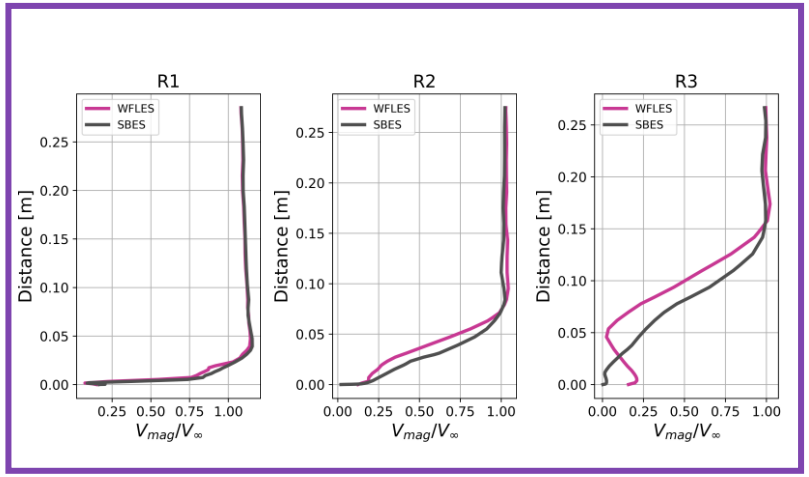
R-profiles



Case2a



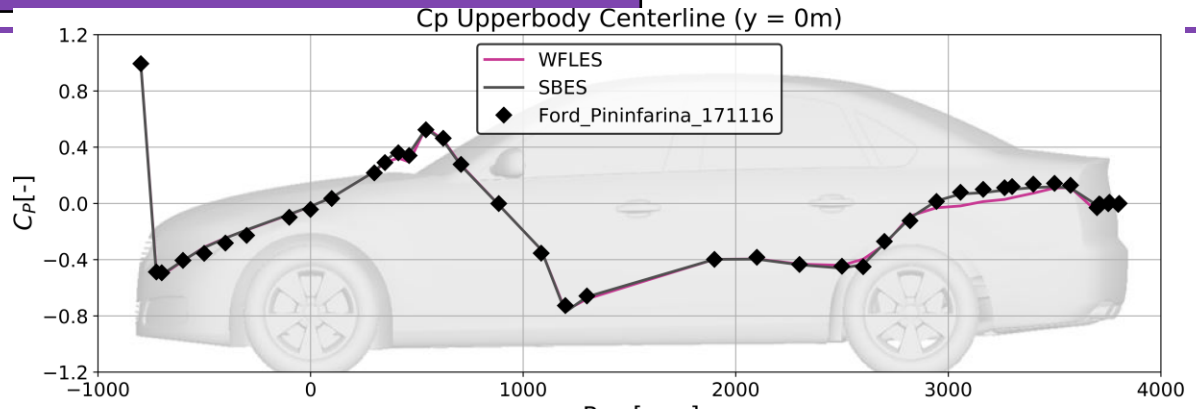
Case2b

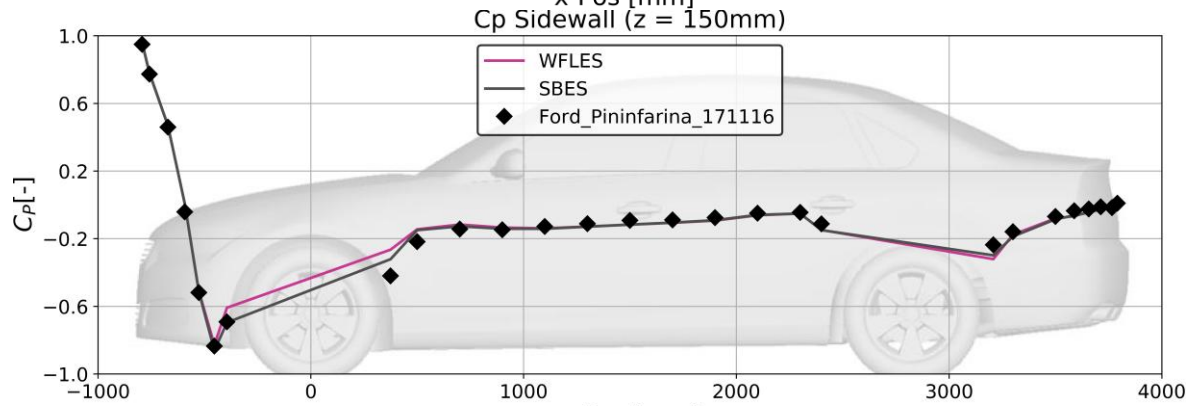


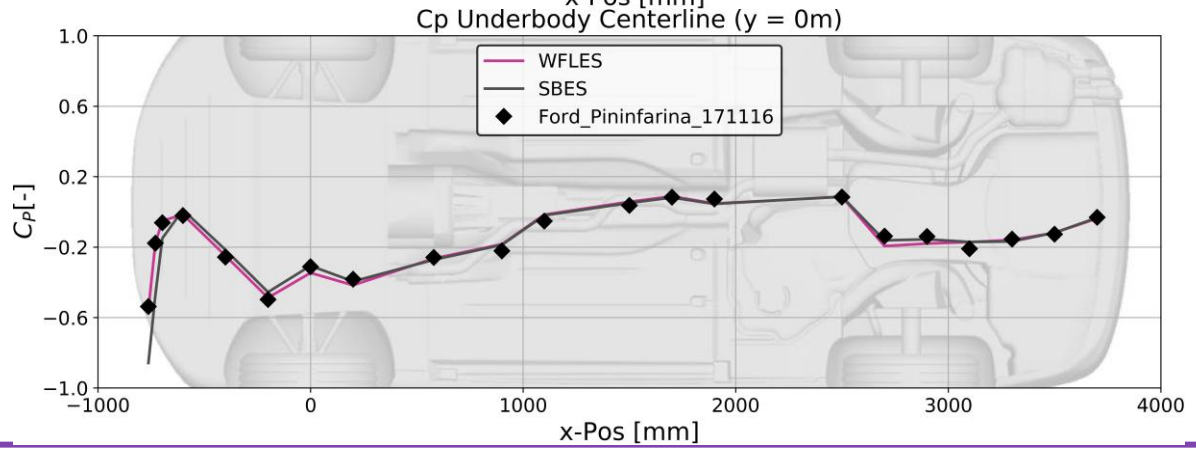
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Surface Pressure

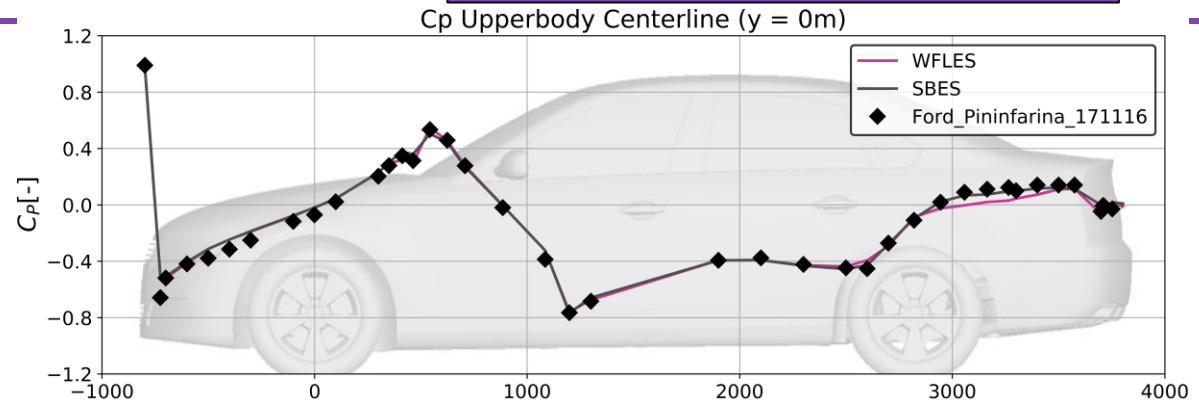
Case2a

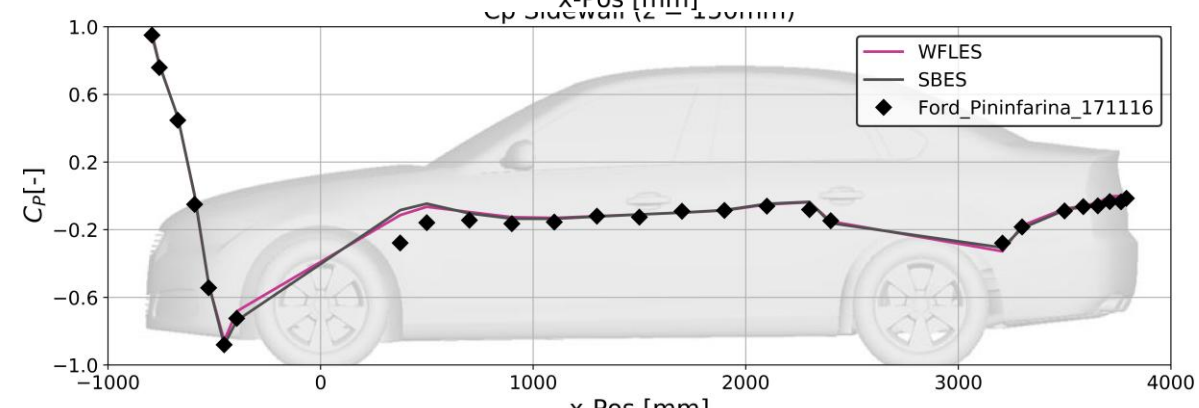


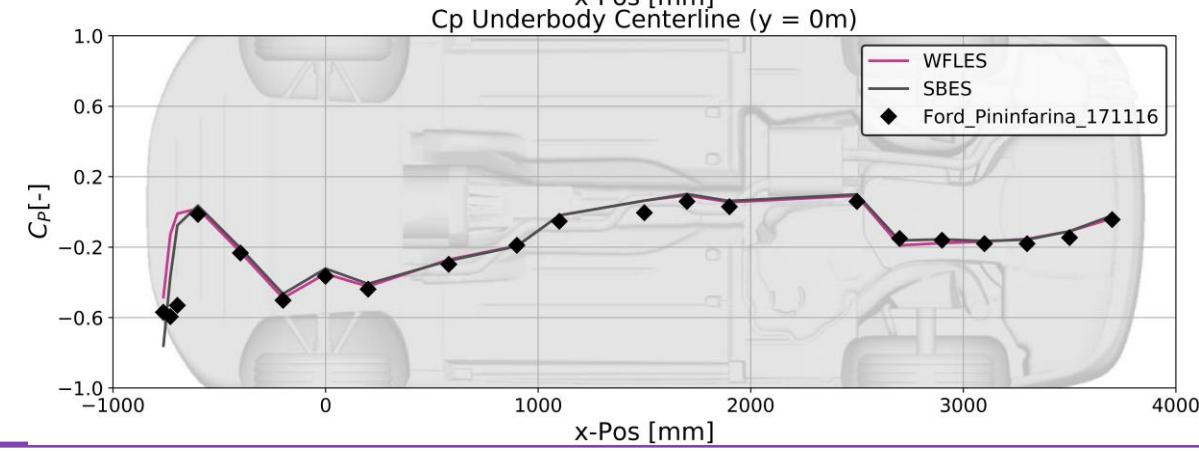




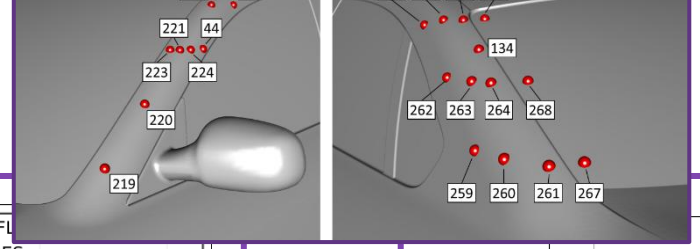
Case2b

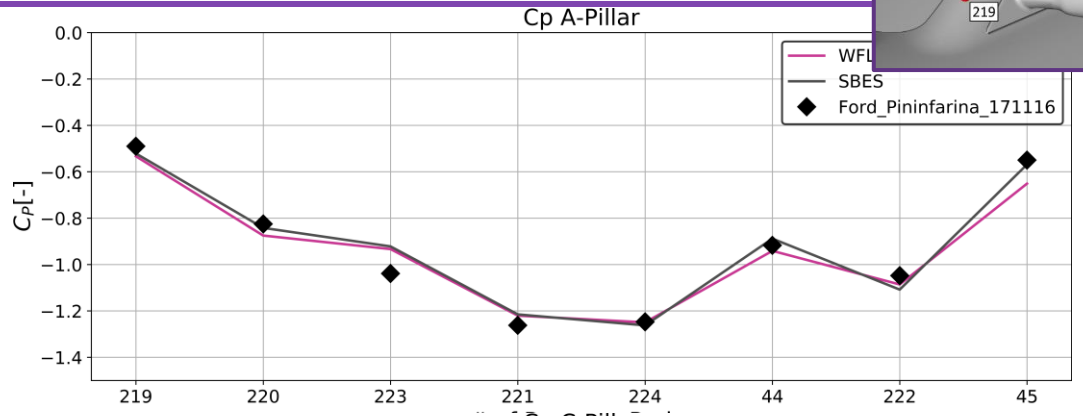


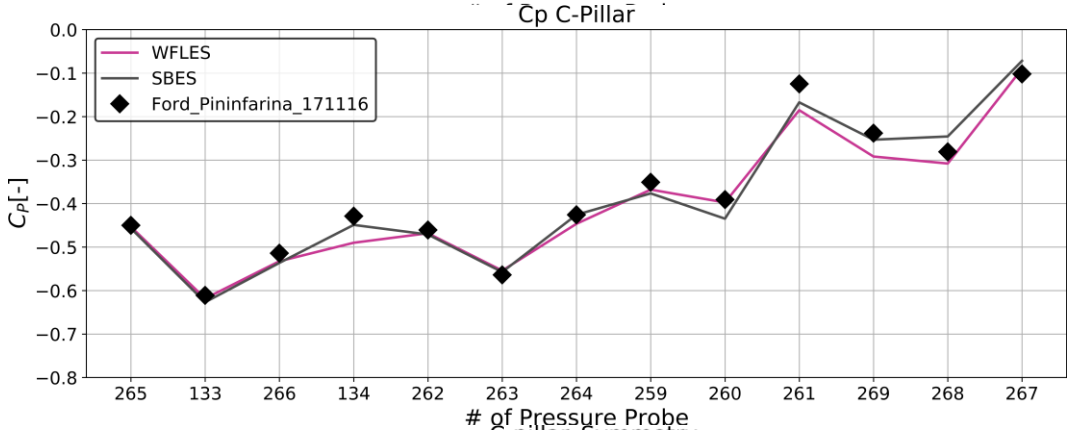


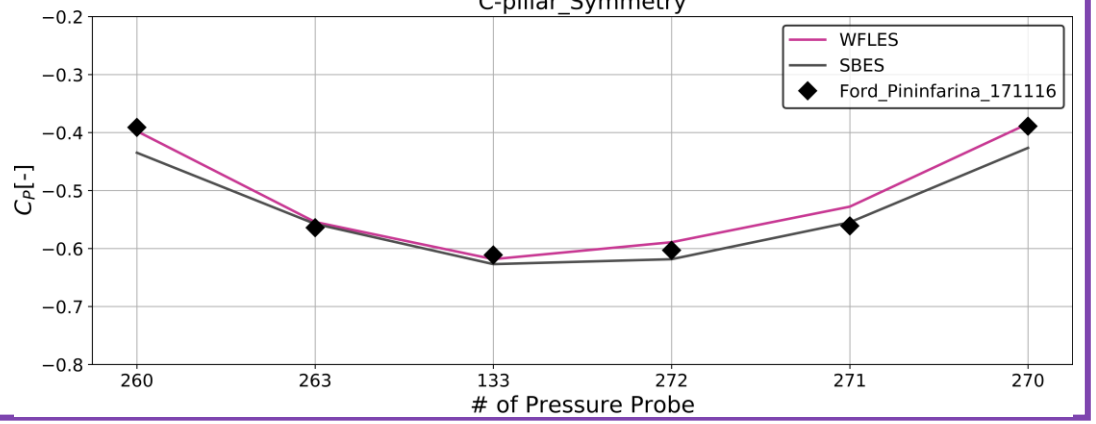


Case2a

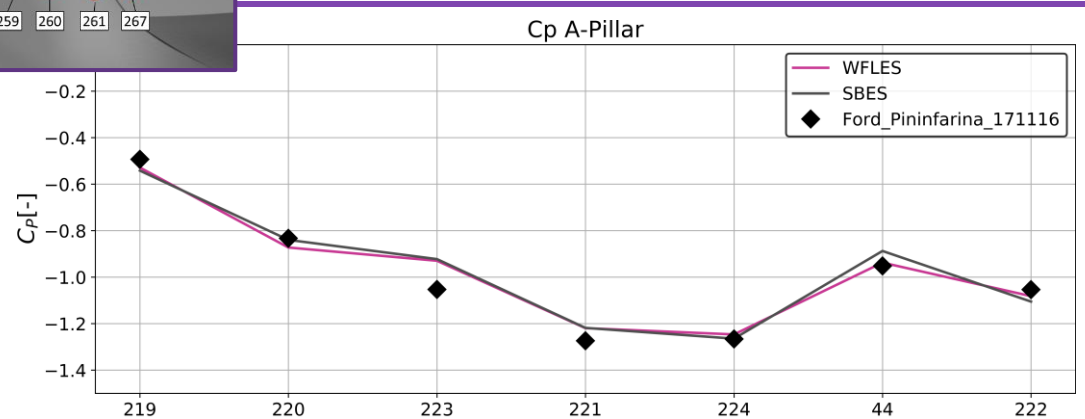


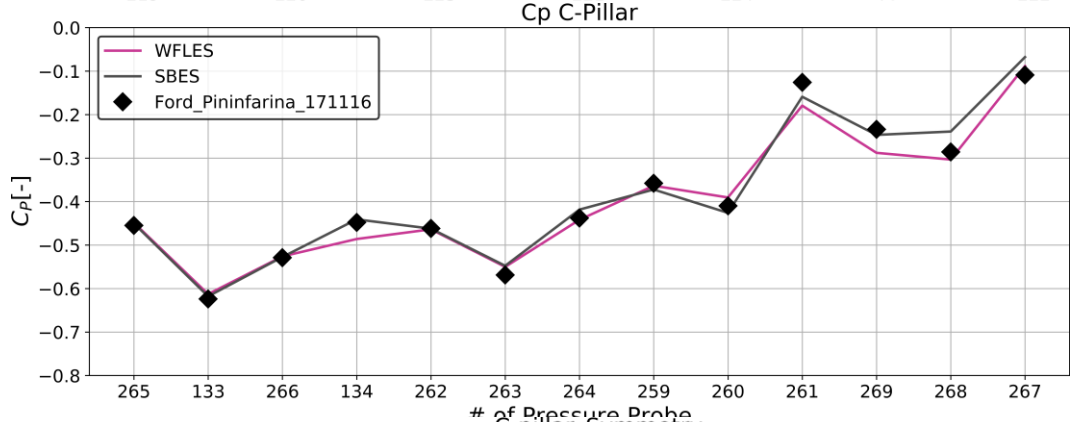


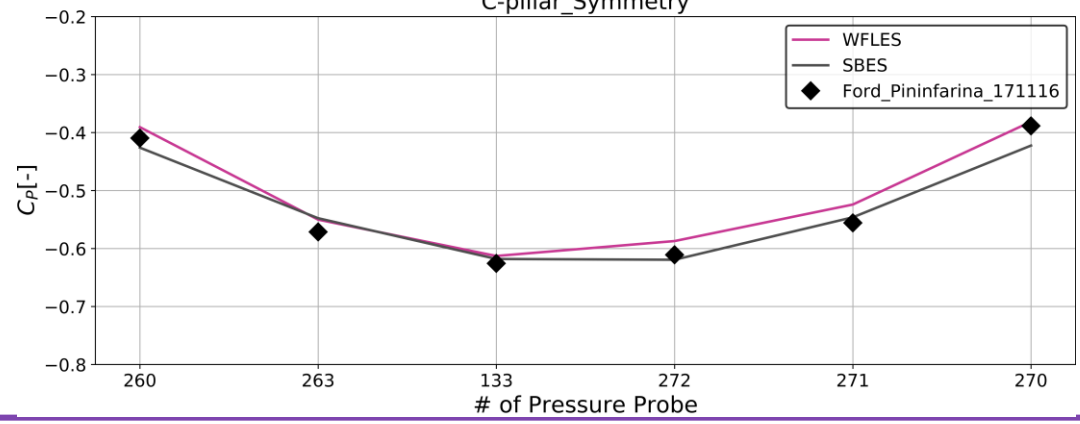




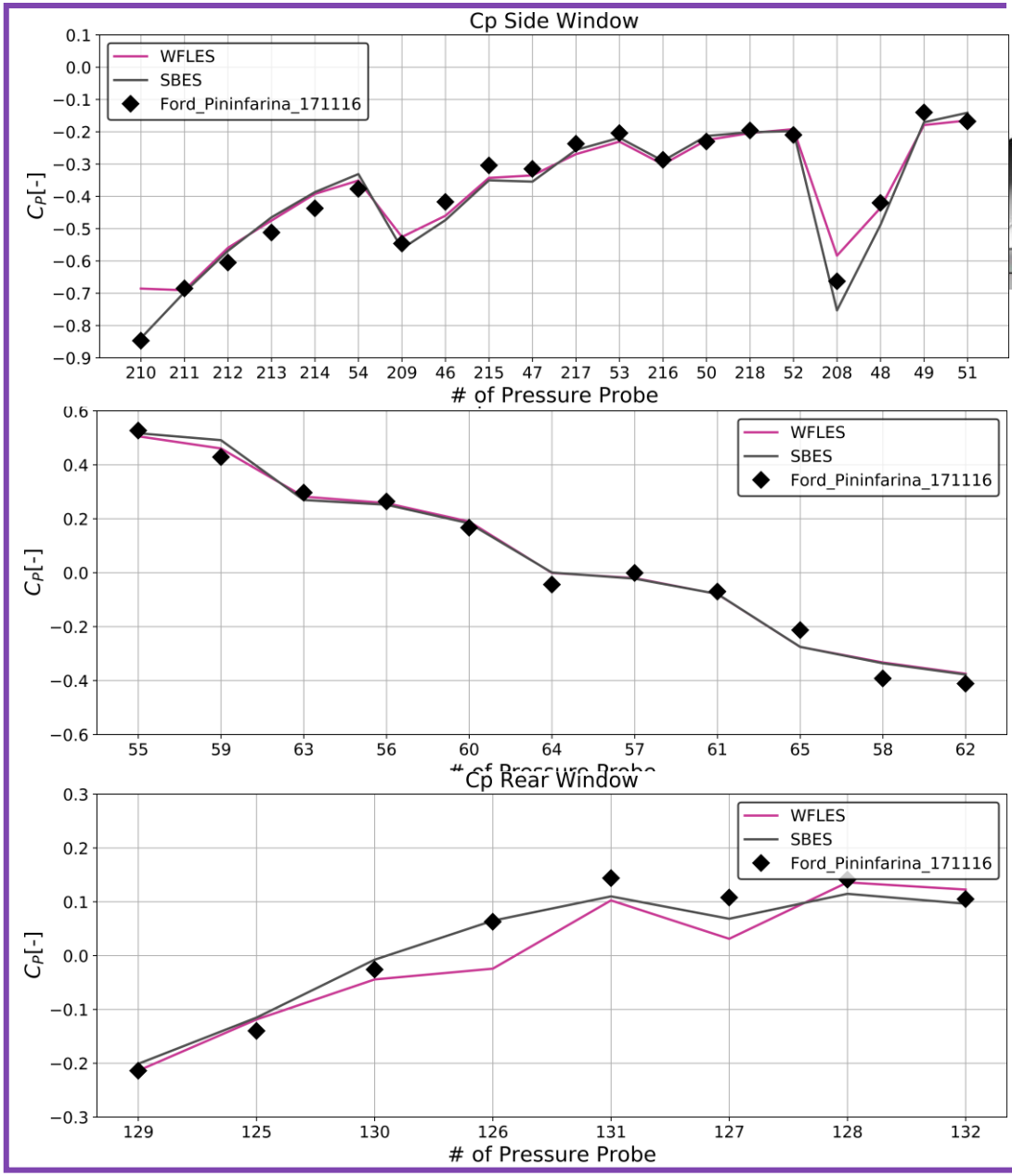
Case2b

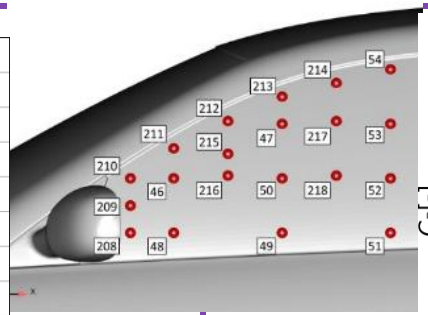


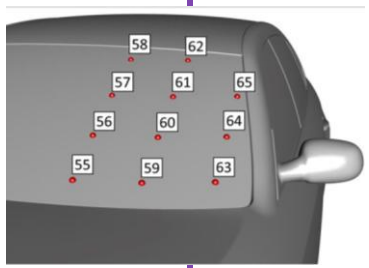


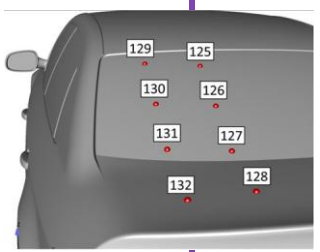


Case2a

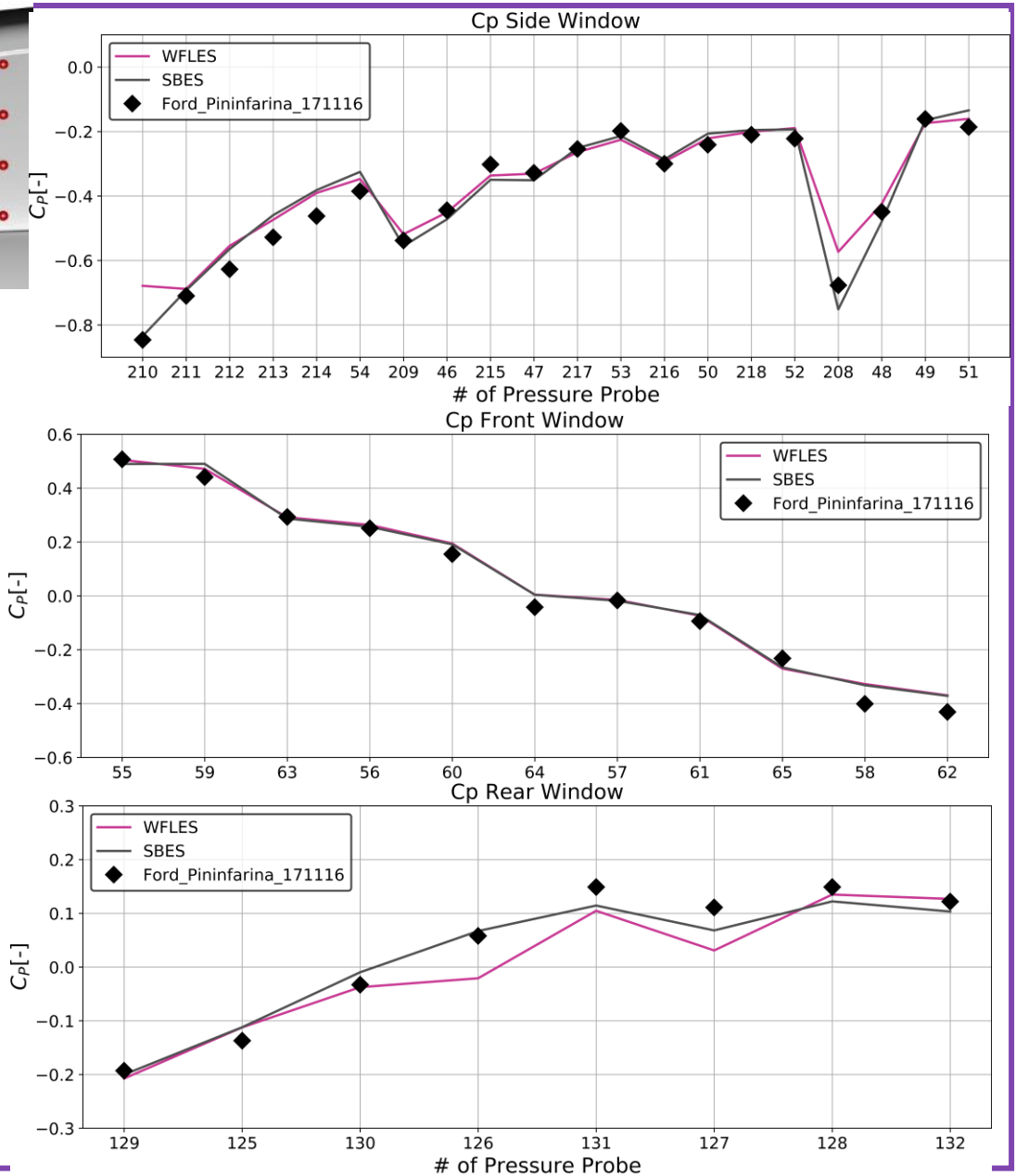






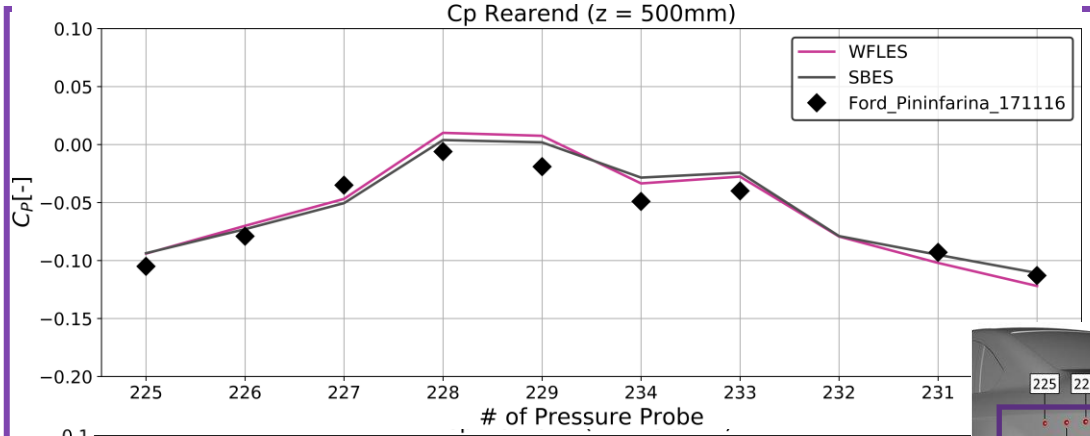


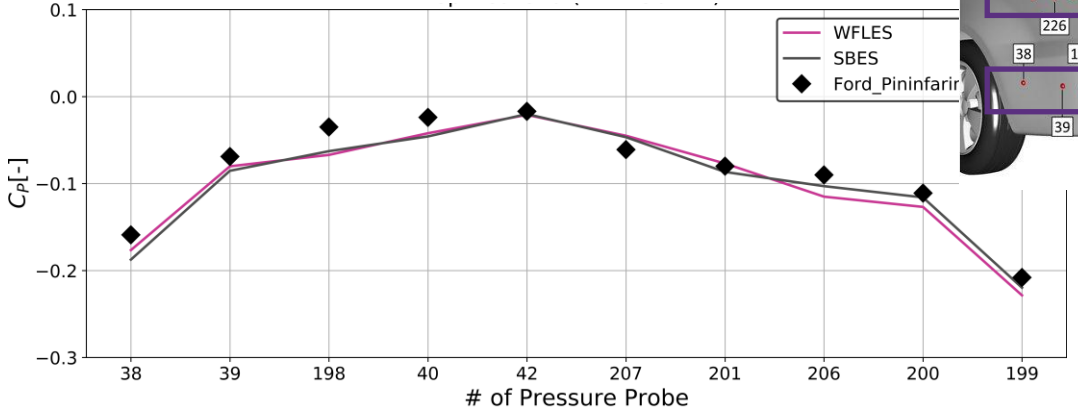
Case2b

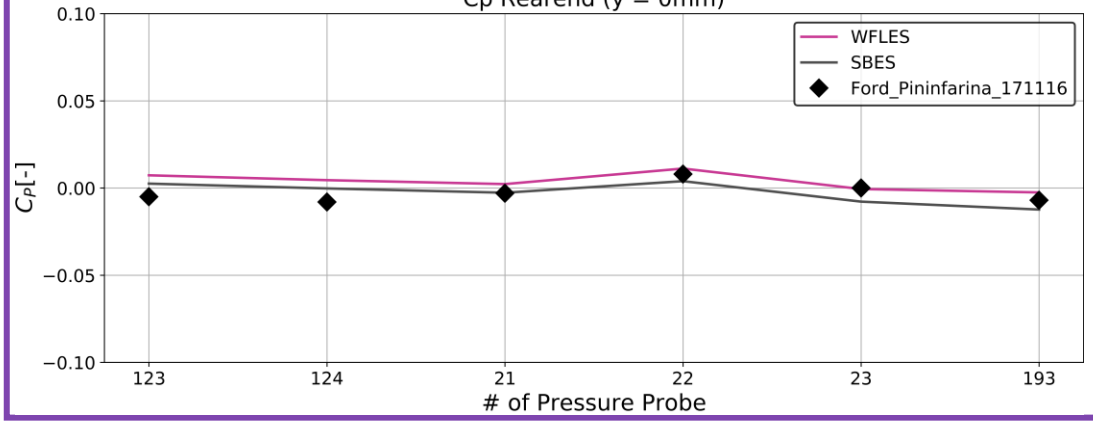


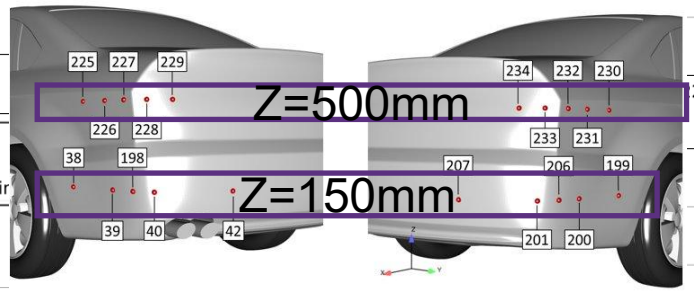
Rear End

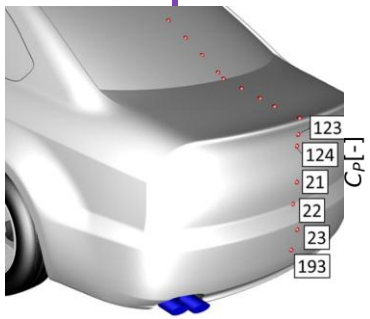
Case2a



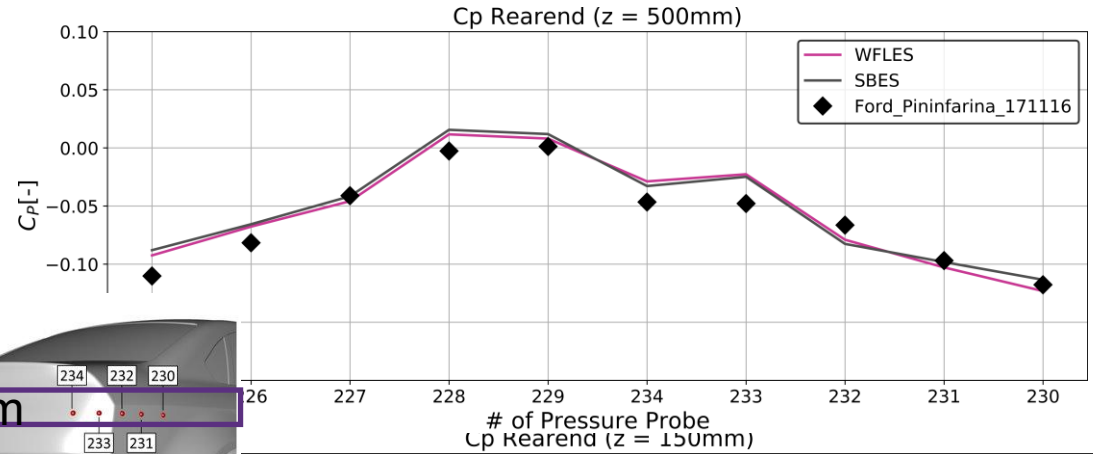


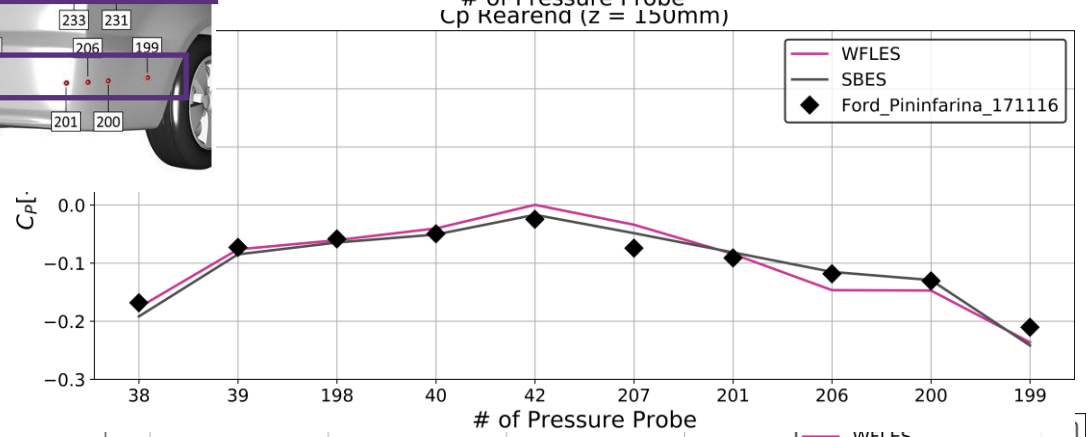


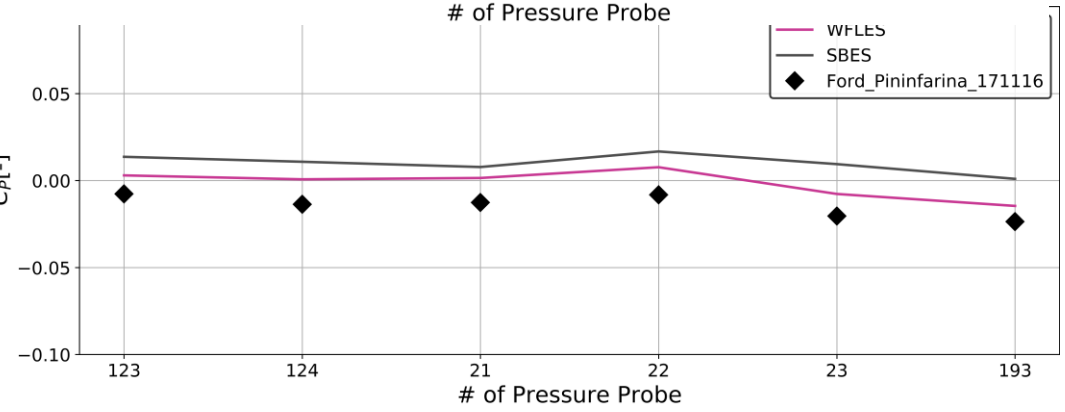




Case2b

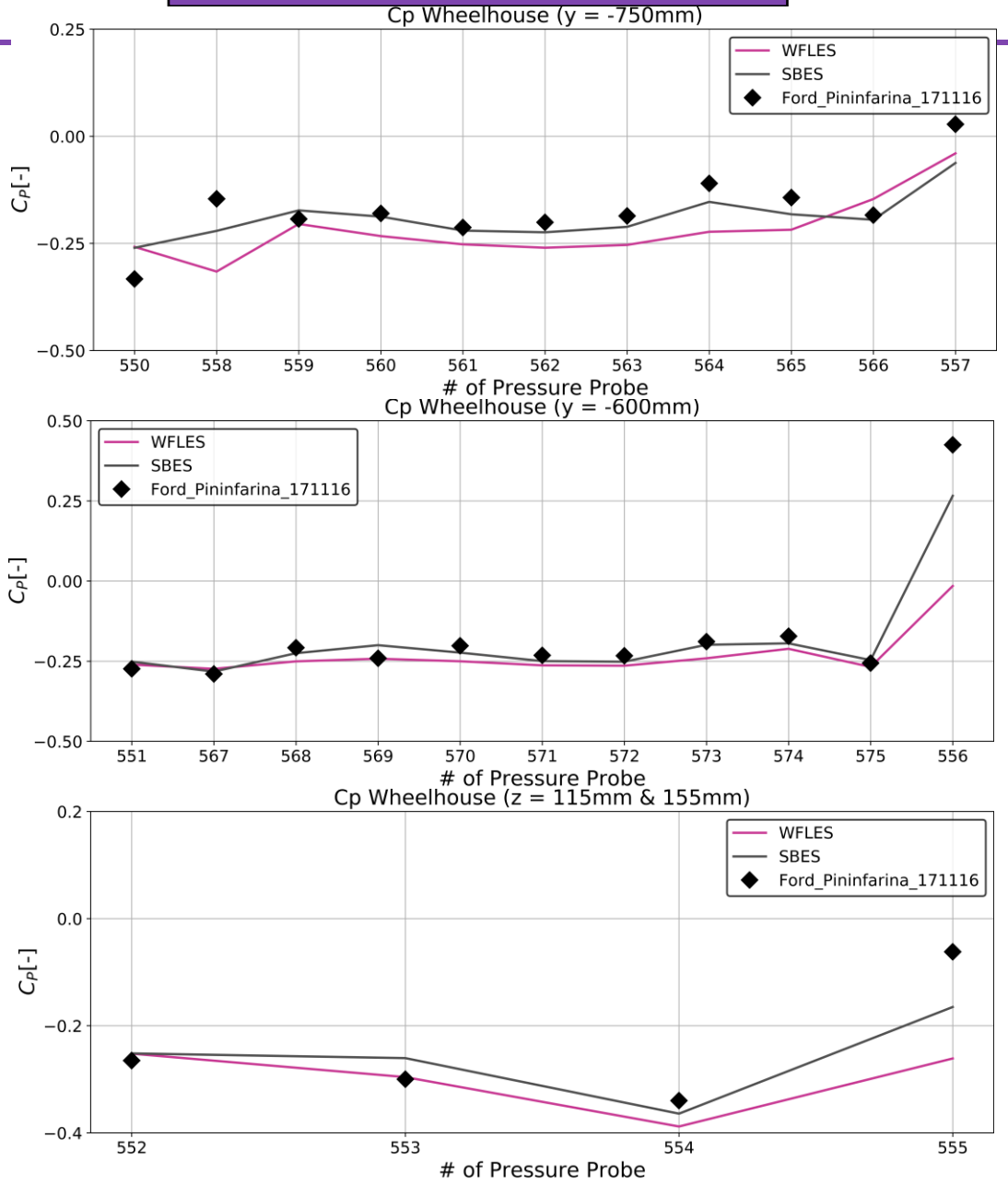


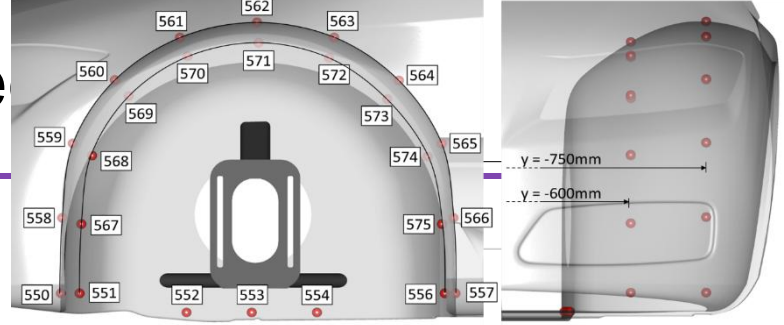




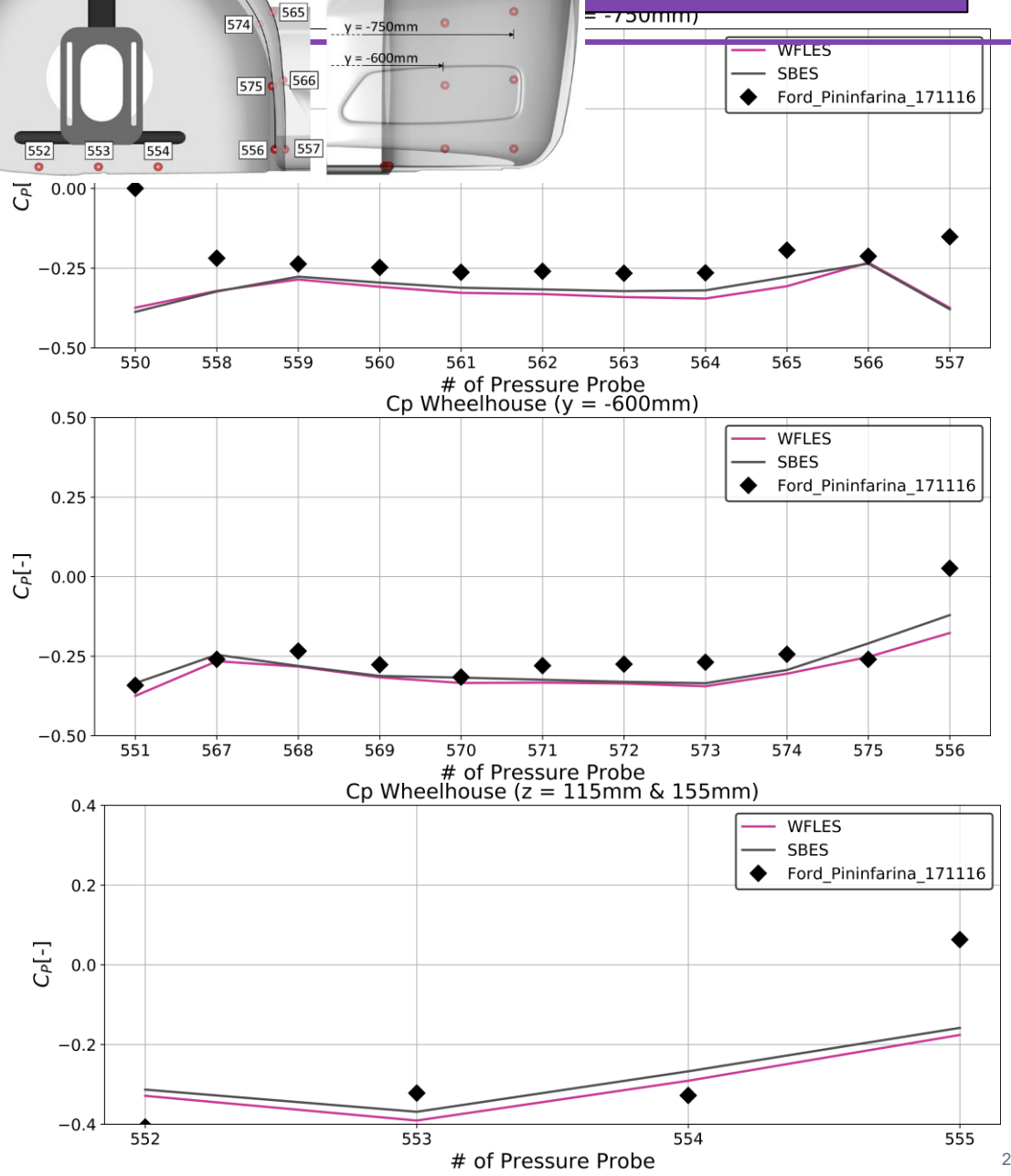
Whe

Case2a



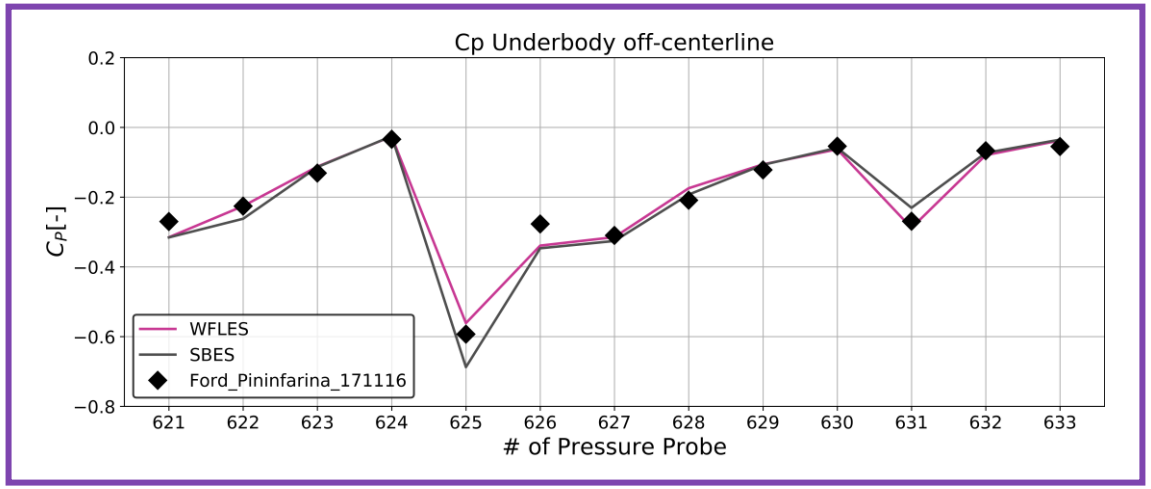


Case2b

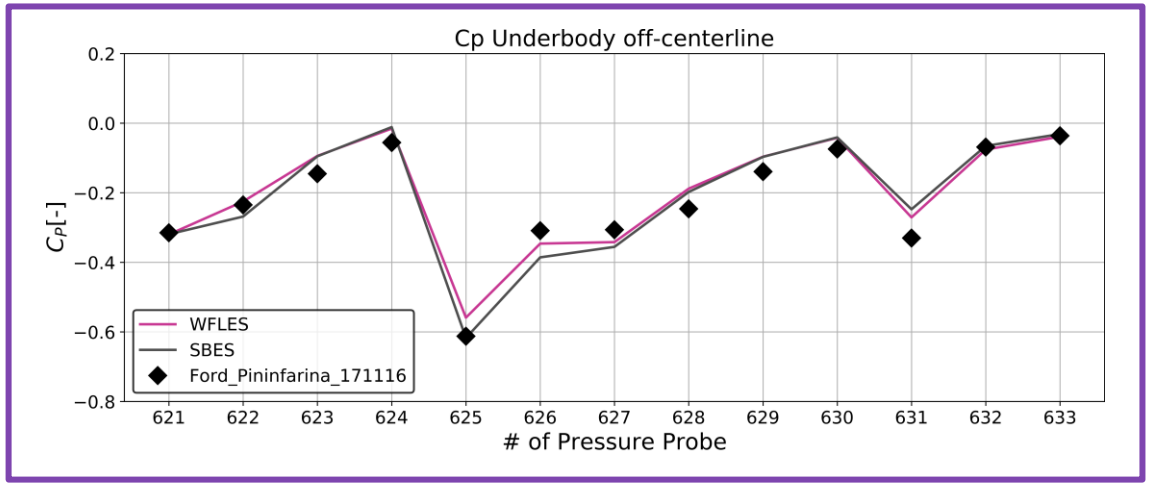


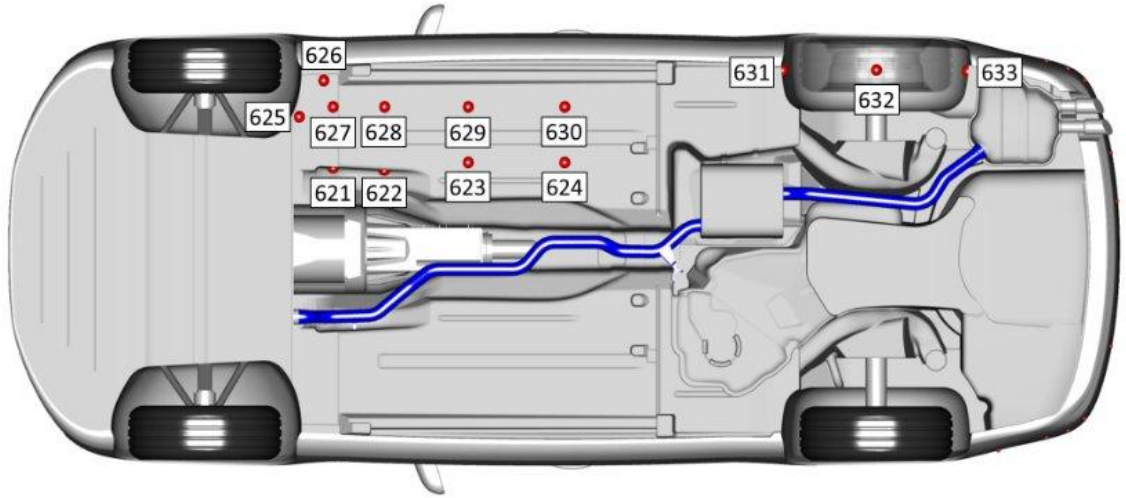
Underbody Off Centreline

Case2a



Case2b

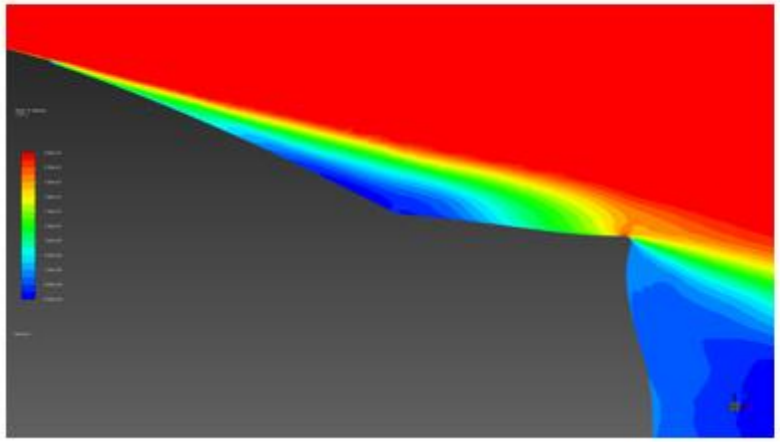




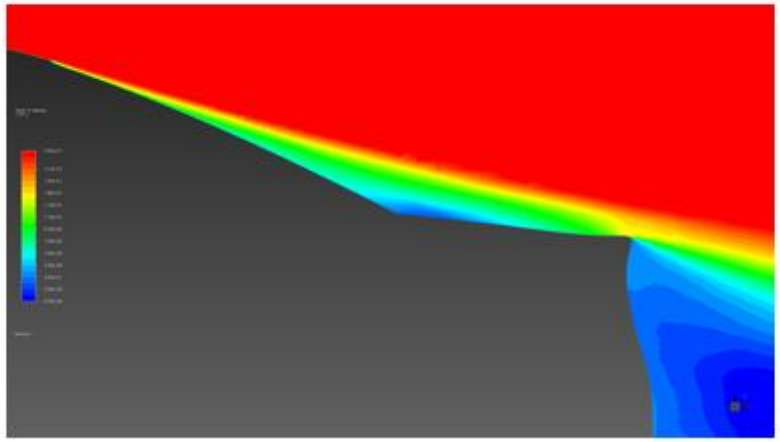
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Picture for WFLES versus WMLES

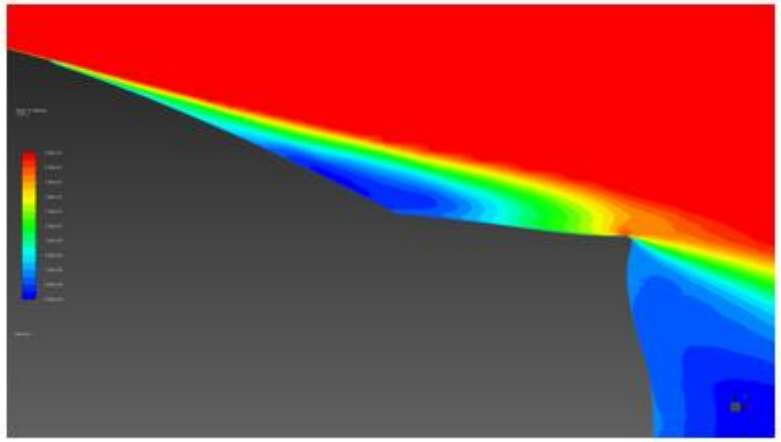
WFLES (baseline)



SBES (baseline)



WMLES (baseline)



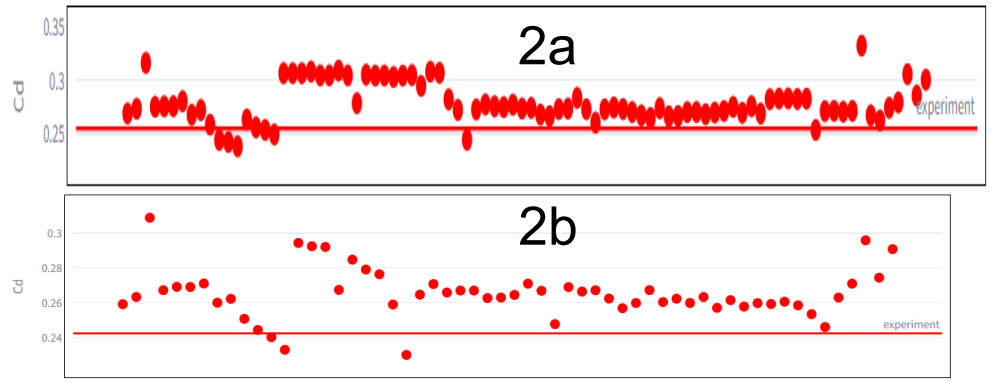
- WFLES and WMLES tend to give slightly larger separation at back-window – trunk intersection
  - This indicates that equilibrium wall treatment is not an issue of much relevance
- According to Cp distribution, SBES is closer to data

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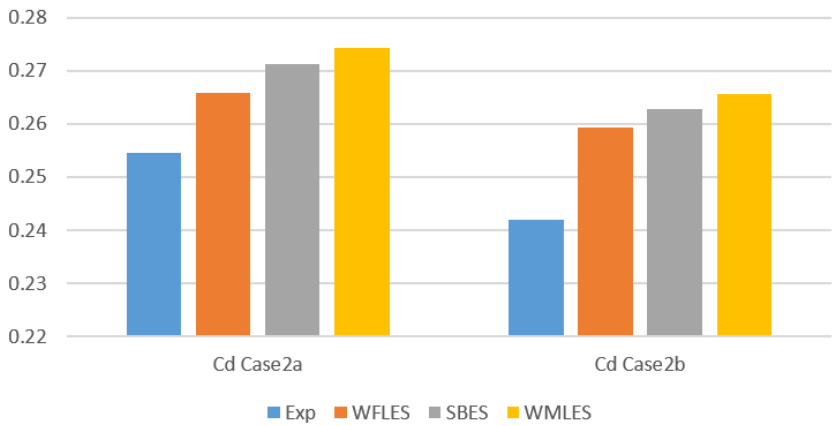
Aerodynamic Coefficients

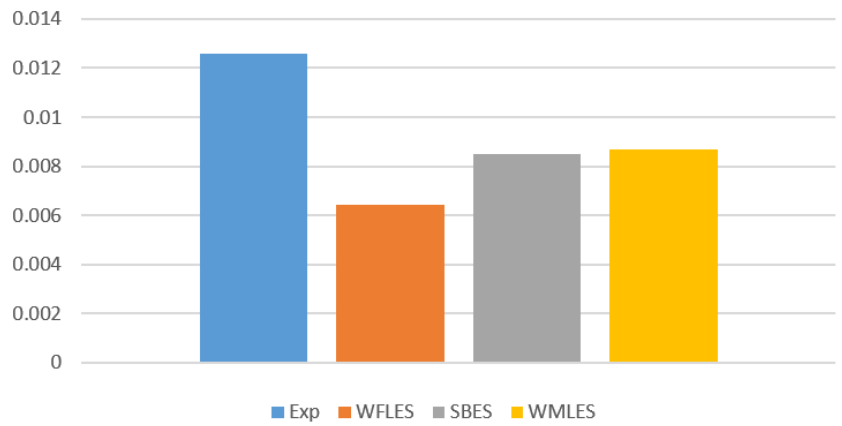
- Drag C_D
  - all simulations show an upward shift
  - Consistent with majority of submissions
- Drag difference between 2a/2b C_D Δ
  - Right direction
  - Underestimated – seems consistent with trend in other simulations
- Numerous other grids have shown similar trends (see dashboard)

*WMLES cases run on SBES mesh

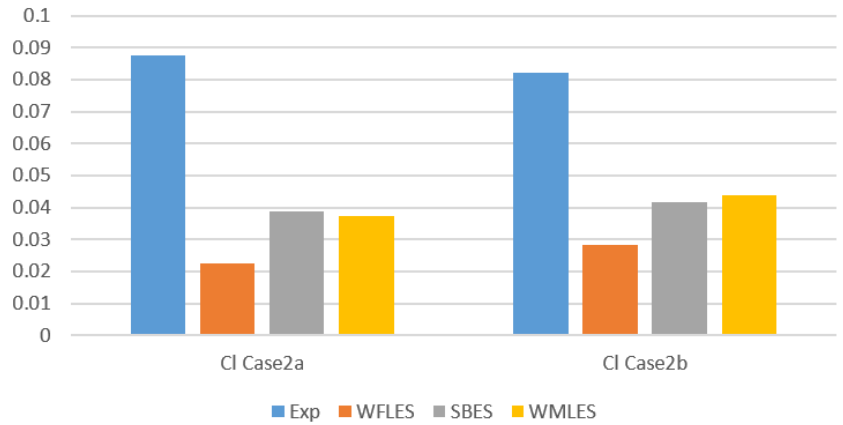


Cd





Cl

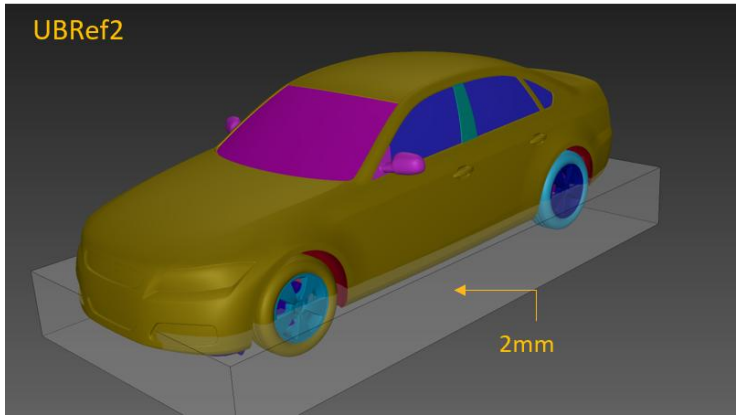


Cl Δ

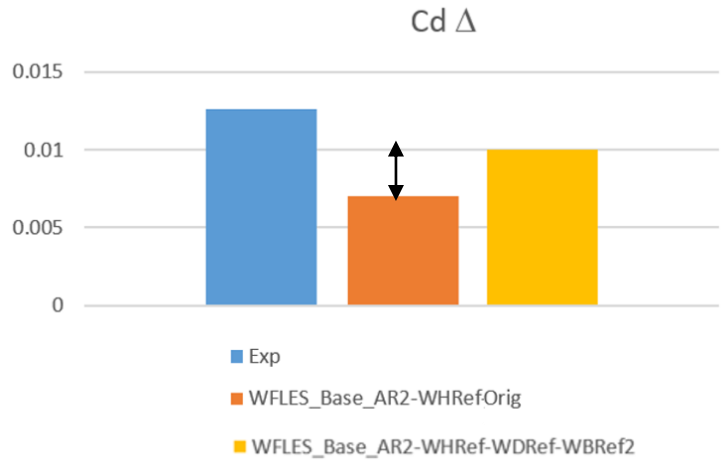


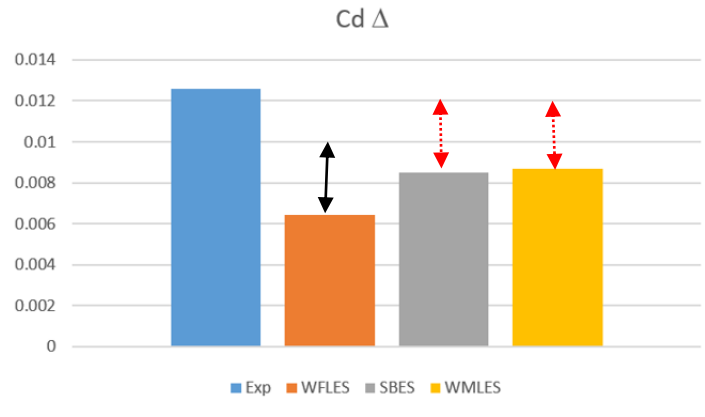
Aerodynamic Coefficients - Sensitivity

- Underbody refinement had an effect on C_D
- With a 2mm UBRef2 underbody grid and WFLES ΔC_D increased from $\Delta C_{D-WFLES} = 0.0062 \rightarrow 0.01$.
- There was not enough time to explore the same refinement for the SBS/WMLES runs which had larger ΔC_D. The same increase in ΔC_D would get SBES/WMLES solutions close to data (see red arrows).
- We did also not explore at which location the 2mm refinement had the strongest impact



WFLES





Summary

- GPU Solver
  - SBES, WFLES, WMLES
  - Low-Dissipation Scheme
  - Systematic validation and ‘robustness’ tests for coarse meshes
- Turbulence models
  - Very limited differences between models for similar meshes
  - Good match across data points
- Solutions are similar also for other meshes (workshop meshes and refined internal meshes)
- Systematically higher C_D and smaller ΔC_D for standard meshes
- Refinement of underbody region gives better ΔC_D

