Multimatic



AutoCFD5

Additional Mesh Coarsening Approaches and Their Effects

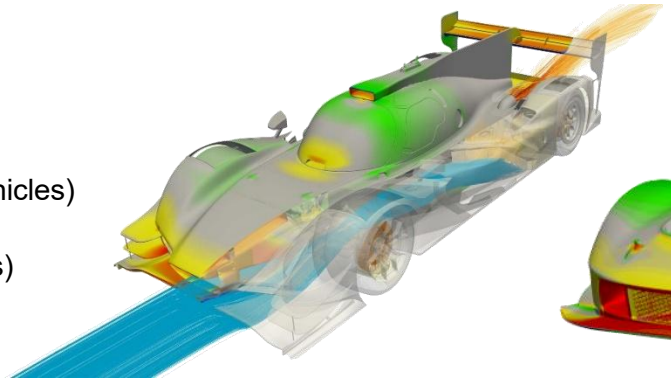
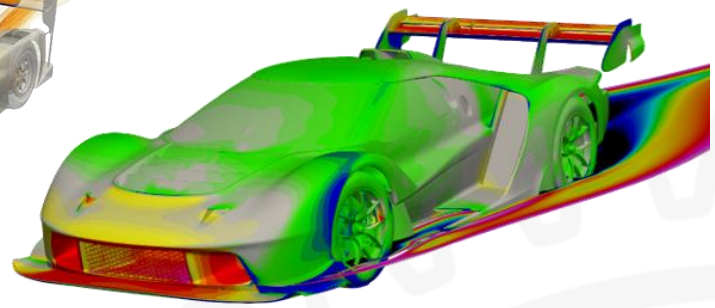
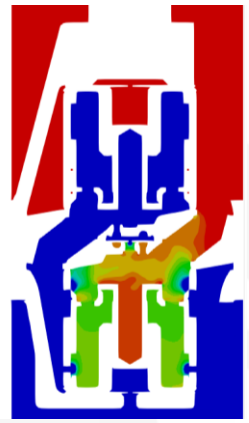
Authors: Maurice Nayman, Elio Xhemalaj, & Lucas Heathcote

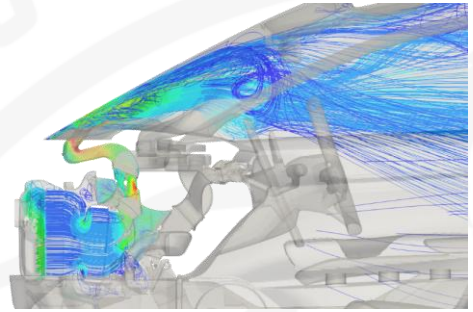
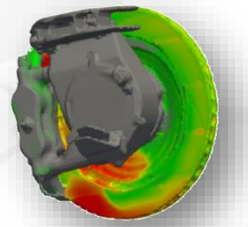
October 8, 2025

About Us

Primary focus:

- Full-vehicle aero/thermal design
  - Downforce and balance (high performance vehicles)
  - Drag and lift balance (EVs)
  - Cooling architecture development (all vehicles)
- Internal aero / cabin HVAC
  - HVAC flow balance & pressure drop analysis
  - Air-intake-system (AIS) design
  - Cabin heating/cooling & passenger comfort
- Complex physics
  - Damper design support (ASV, TASV)
  - Air/water multiphase (hot-form blow-form quenching)
- Scale-model & full-size wind tunnel testing

Road cars → **High-performance road cars** → **Track cars** → **Motorsports**

BEVs

- Drag minimization
- High-speed lift balance

Supercar / Hypercar

- Drag minimization for V_{MAX} targets
- Downforce and aero balance for racetrack lap time targets
- Cooling architecture development

Track-Day Cars/Racecars

- Drag / downforce / aero balance
  - *Aero balance suited to driver skill*
- Cooling architecture development

Workshop Contribution

AutoCFD4 indicated the cell count for the existing Case 2 committee meshes was too high.

- Multimatic worked with Cadence to reduce the cell count, while still providing comparable predictions

Workshop	Cell Count [million cells]	
	Case 2a	Case 2b
AutoCFD4	157	158
AutoCFD5	123 ***(-22%)***	126 ***(-20%)***

Mesh recipe changes for AutoCFD5 were implemented incrementally. This report will cover adopted cell-count reduction strategies, alternatives not adopted in the final mesh, and practices to avoid

Mesh Change	Adopted for AutoCFD5?	Discussed
Bulk surface refinement/number of layers changes	Yes	No (In Appendix)
Utilizing local layer collapse based on local aspect ratio	No	Yes
Reducing the number of transition layers in octree	Yes	Yes
Modifying size field refinements	Partially	No (In Appendix)

Simulation Conditions

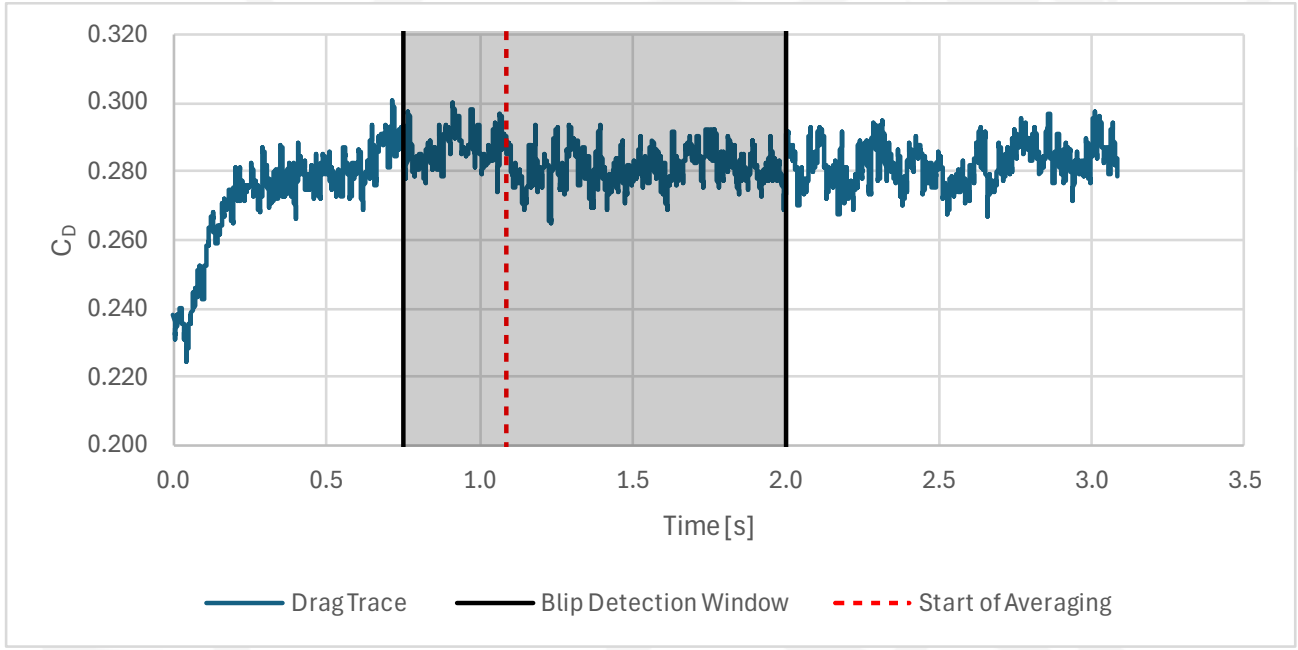
CFD model evaluated with:

- Transient, incompressible flow
- SA-DDES turbulence model

- 0.2 ms timestep (noted runs with 0.5 ms timestep)
- 2.0 s averaging window

- Automatic transient detection (TotalSim-based method)
  - *0.75 s min blip duration, 2.0 s max blip duration*
  - *Used to wash out transient warmup consistently*





Multimatic

Layer Collapse



Layer Collapse Concept

With Hextreme, users can control layer behavior once local layer height hits a defined aspect ratio relative to the local cell size

- Layers can be collapsed (reduces cell count), or grown at a constant size (no change in cell count)

We wanted to see the impact of different levels of layer collapse

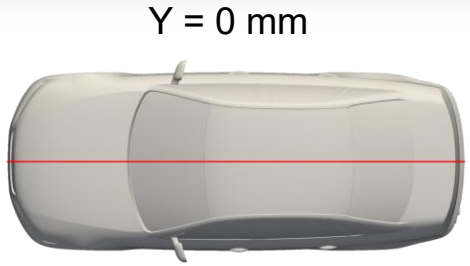
- Aggressive layer collapse (based on AutoCFD4 mesh, collapse 7 layers to 1 layer minimum)
- Conservative layer collapse (based on AutoCFD5 initial developments, collapse 5 layers to 3 layers minimum)

Layer Collapse Approach	Relative Cell Count Reduction
Aggressive (7 layers to 1)	25.8%
Conservative (5 layers to 3)	11.8%

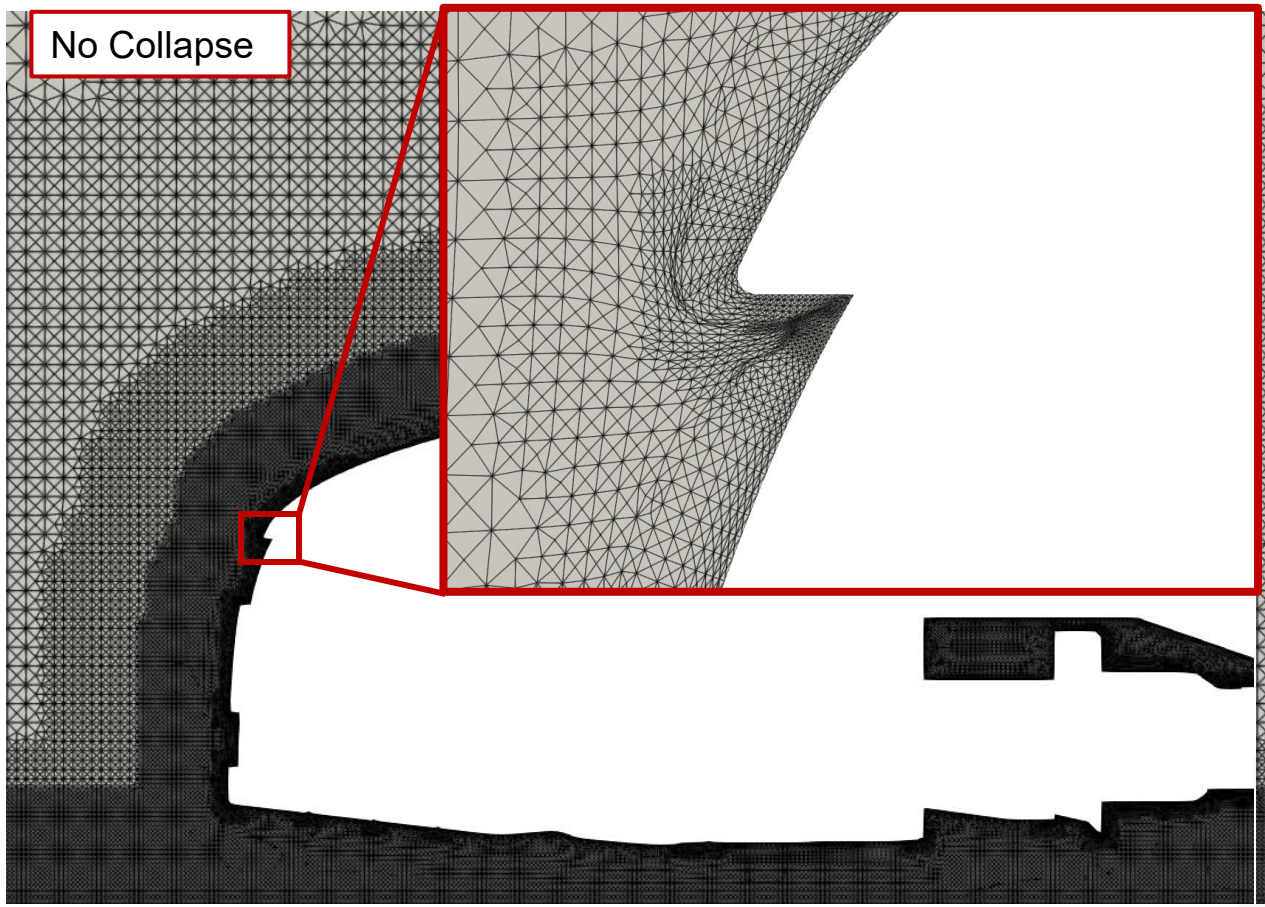
Allowing layer collapse reduces total layer height around fine features:

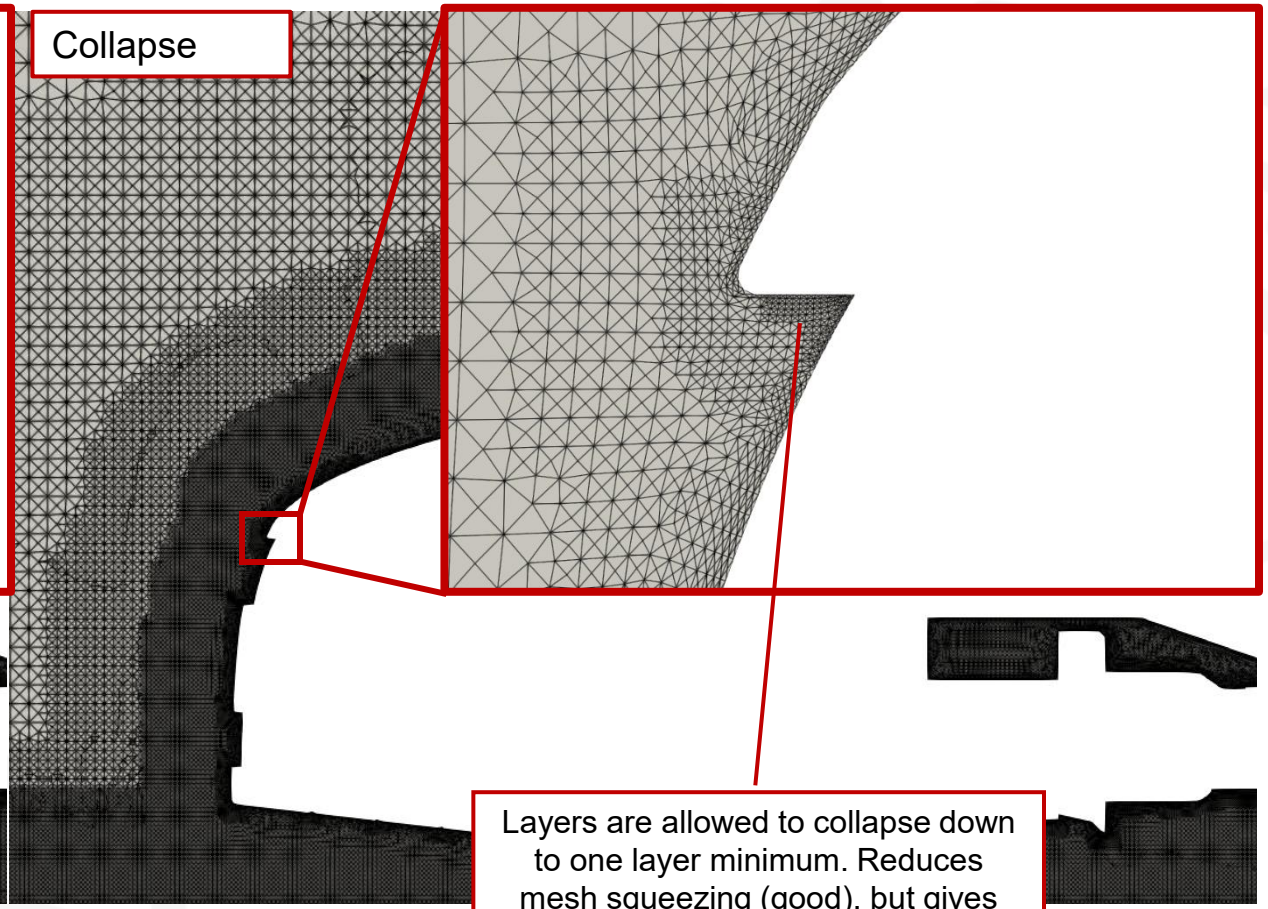
- Tight radii (bumper fillets, roof fillets, etc.)
- Areas of higher refinement

Aggressive Layer Collapse



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Layers are allowed to collapse down to one layer minimum. Reduces mesh squeezing (good), but gives sharp boundary layer transitions

Note: These runs used a 0.5 ms timestep instead of 0.2 ms (used everywhere else)

Mesh change tested prior to majority of AutoCFD5 mesh recipe changes

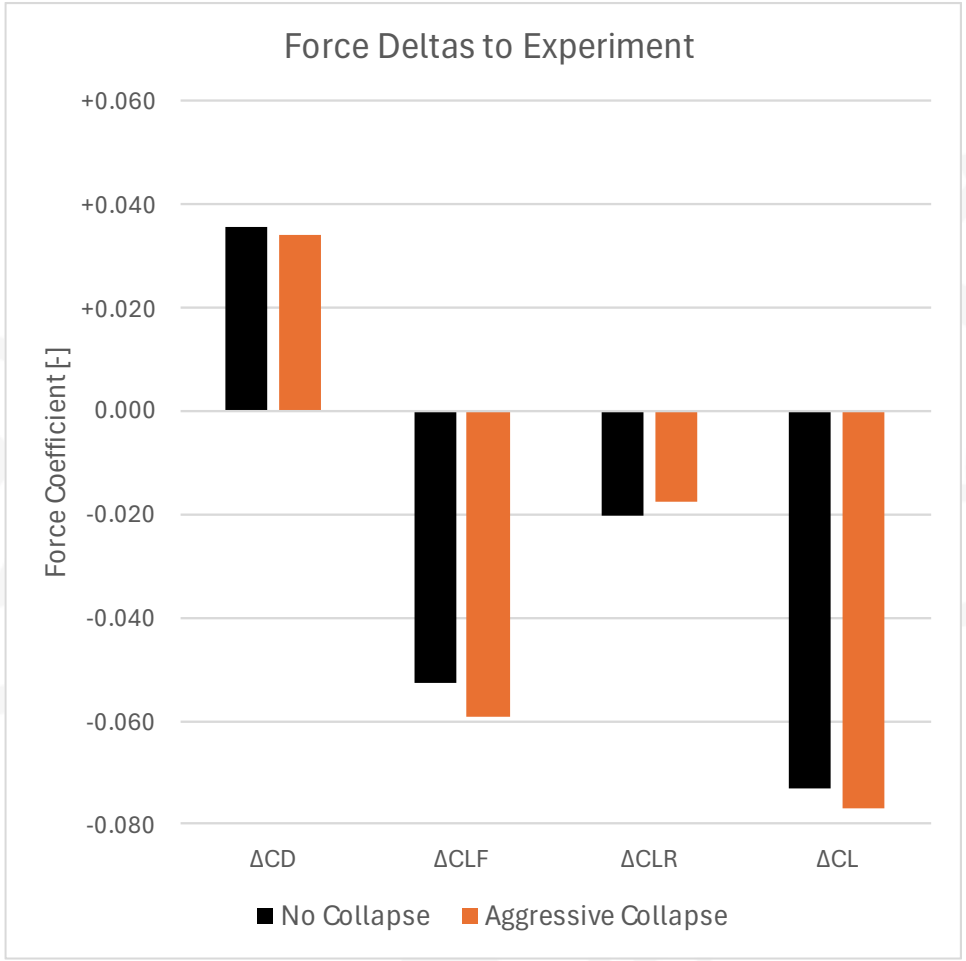
Effect on Forces – Aggressive Collapse

Allowing for boundary layer collapse to 1 layer had a small effect on forces

- Drag was effectively **unchanged**
- Front lift correlation **worsened 6 counts**
- Rear lift correlation **improved 3 counts**

Impact on forces of layer collapse is minor, but it worsens lift correlation

- Would not recommend aggressive layer collapse from a forces perspective



Note: These runs used a 0.5 ms timestep instead of 0.2 ms (used everywhere else)

Mesh change tested prior to majority of AutoCFD5 mesh recipe changes

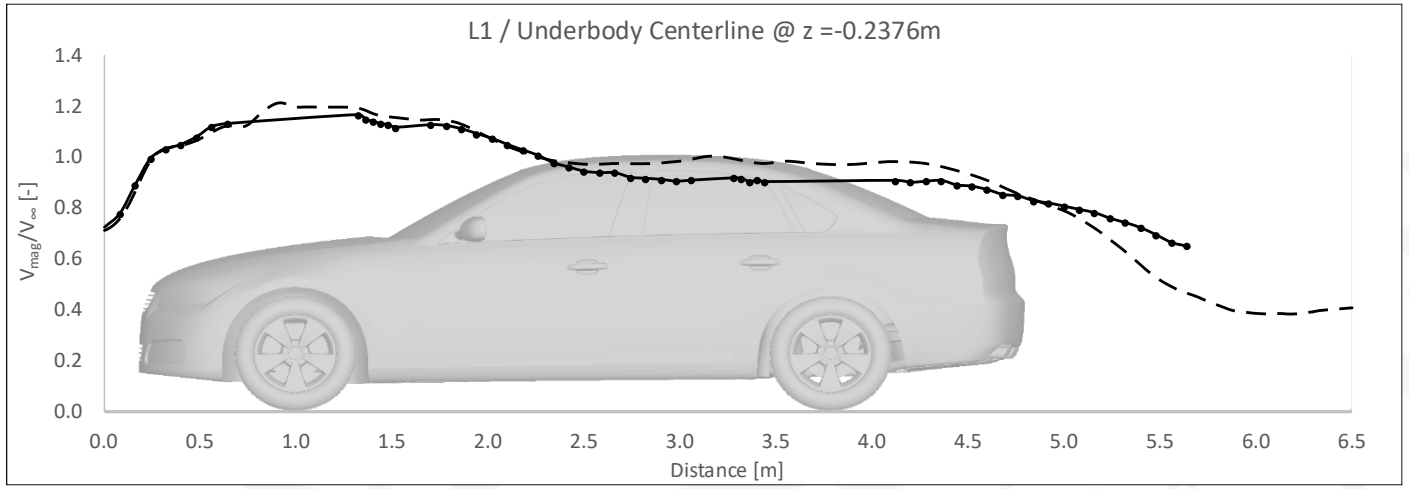
Flow Surveys – No Collapse

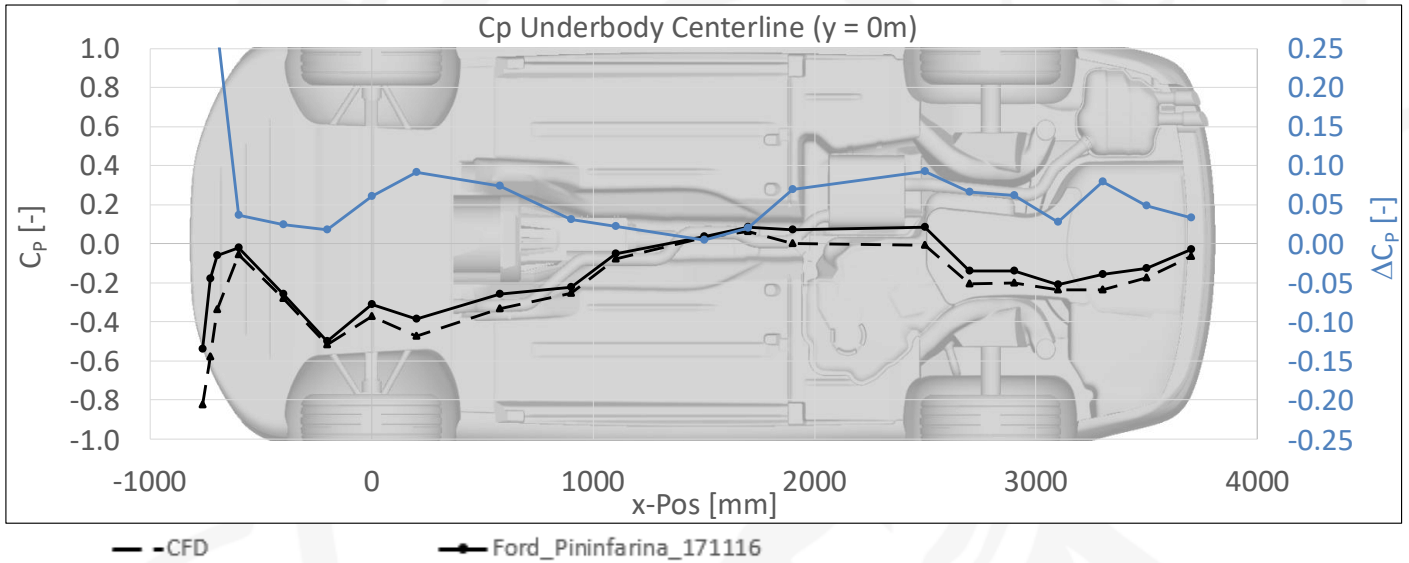
No collapse has a largely smooth underbody velocity prediction

- Energy deficit in the wake downstream of the car

Underbody surface pressures are largely accurate

- Separation/suction at the bumper lip is higher than experimental, but follows the main trend





Note: AutoCFD4 mesh recipe (7 surface layers)

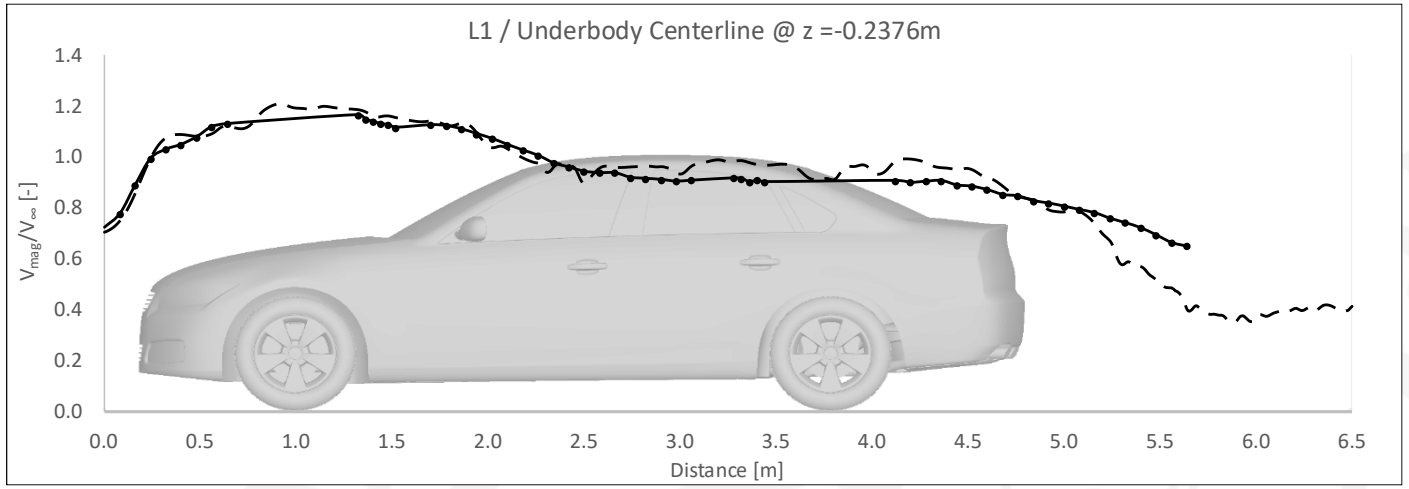
Flow Surveys – Aggressive Collapse

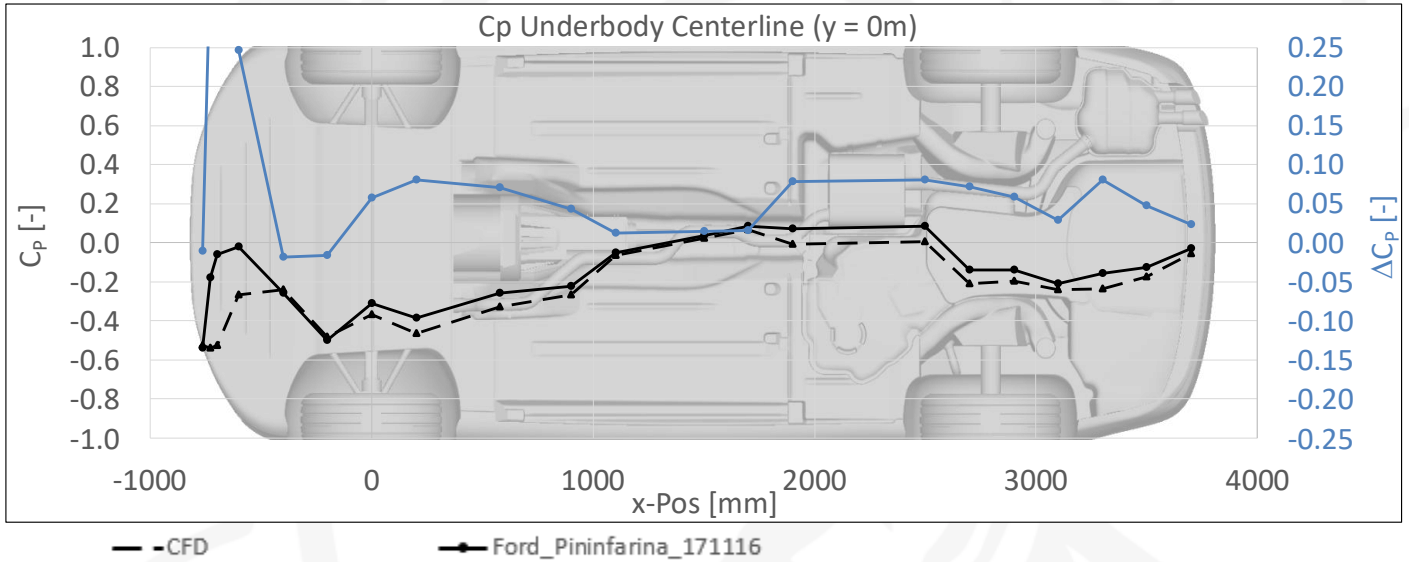
Velocity probes are far noisier, despite the same averaging window

- Addition of aggressive layer collapse seems to affect flow field fluctuations more noticeably

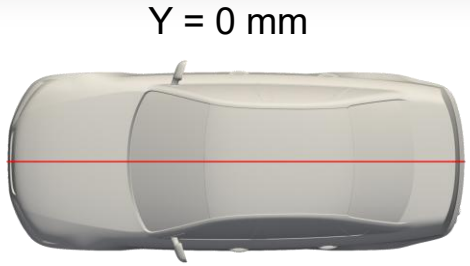
Underbody surface pressures are largely similar, except for at the bumper lip

- Pressures at the leading edge of the lip are more accurate, but overall separation bubble shape is less accurate

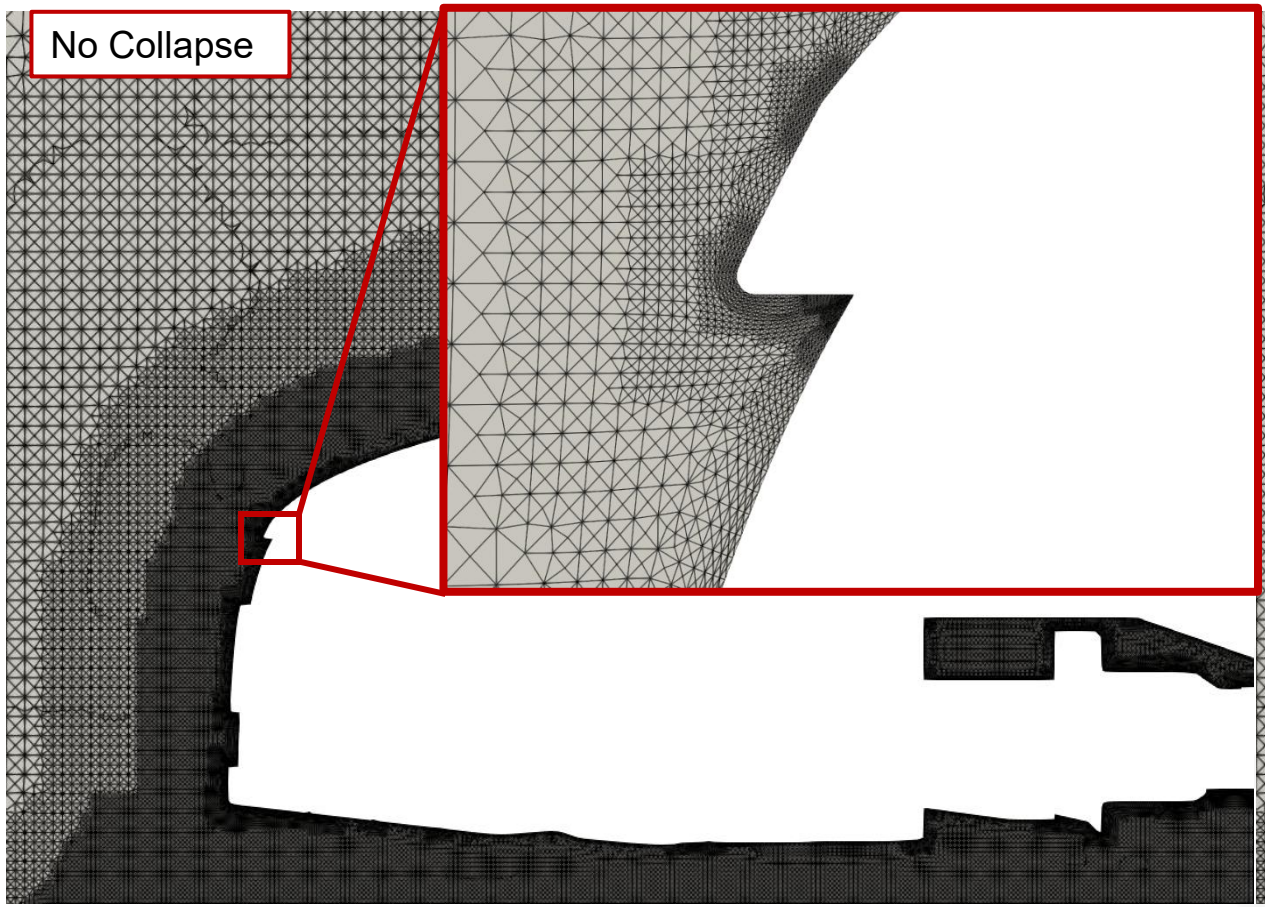


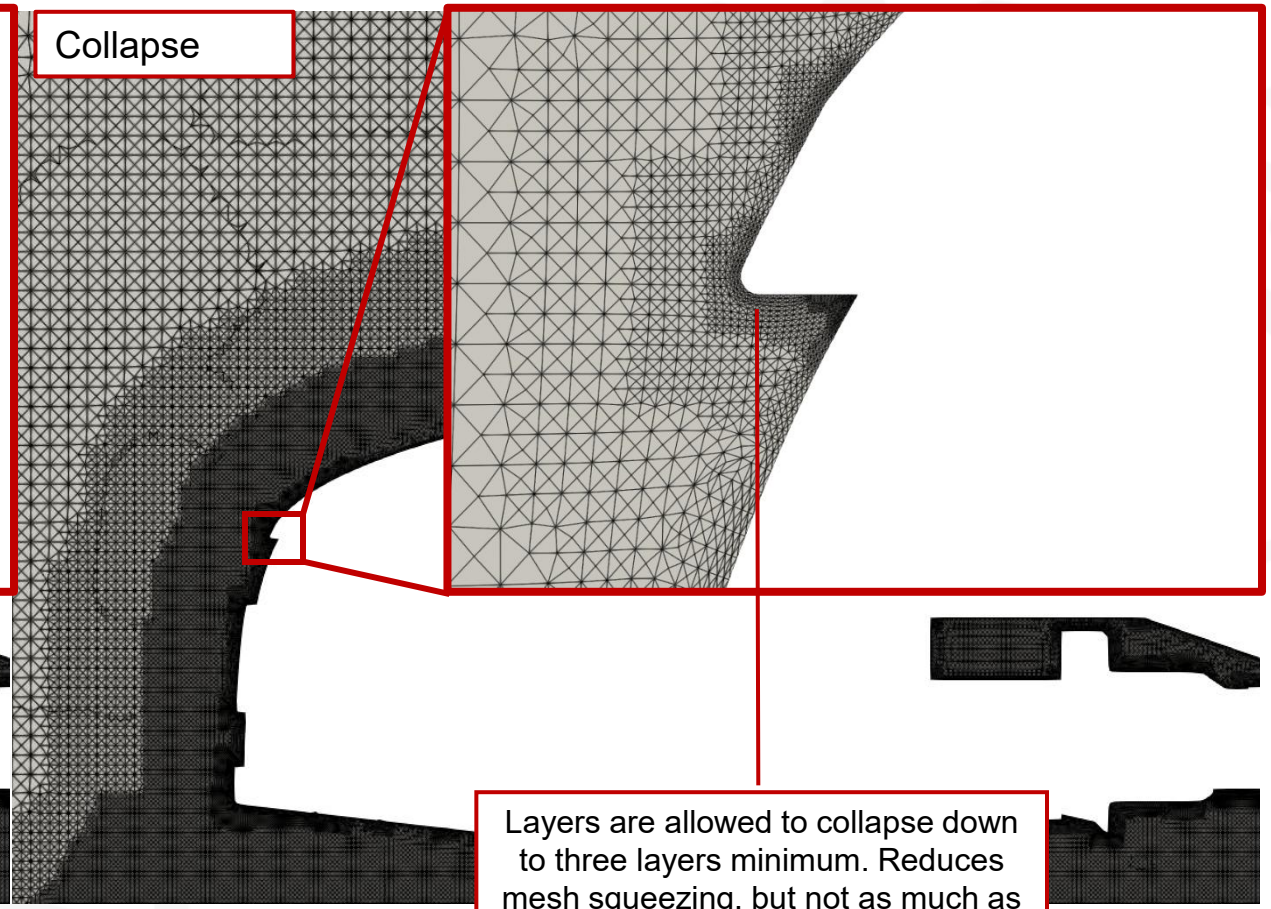


Conservative Layer Collapse



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Layers are allowed to collapse down to three layers minimum. Reduces mesh squeezing, but not as much as the aggressive collapse

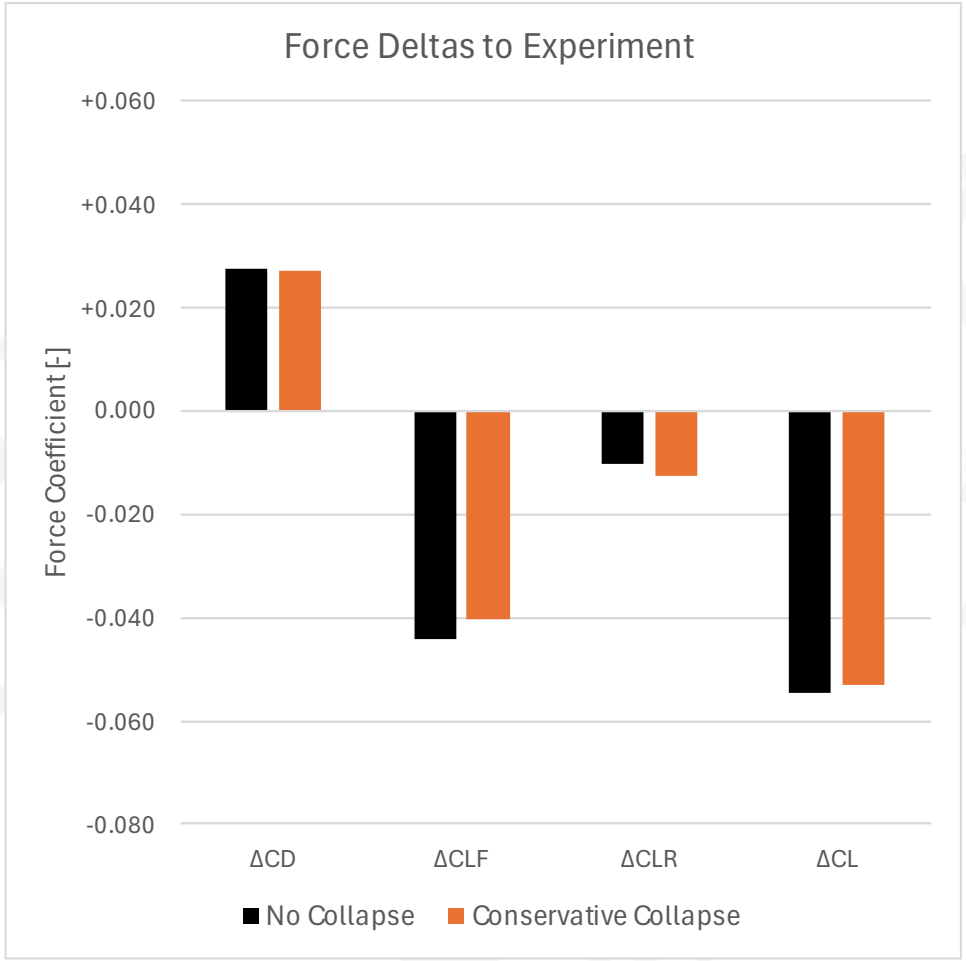
Note: These runs used a 0.2 ms timestep (in-line with other studies)

Effect on Forces – Conservative Collapse

Allowing for boundary layer collapse to three-layer cells minimum also had a marginal effect on forces

- Drag was effectively **unchanged**
- Front lift correlation **improved 4 counts**
- Rear lift correlation **worsened 3 counts**

From a force prediction perspective, conservative layer collapse is not a large change



Note: These runs used a 0.2 ms timestep (in-line with other studies)

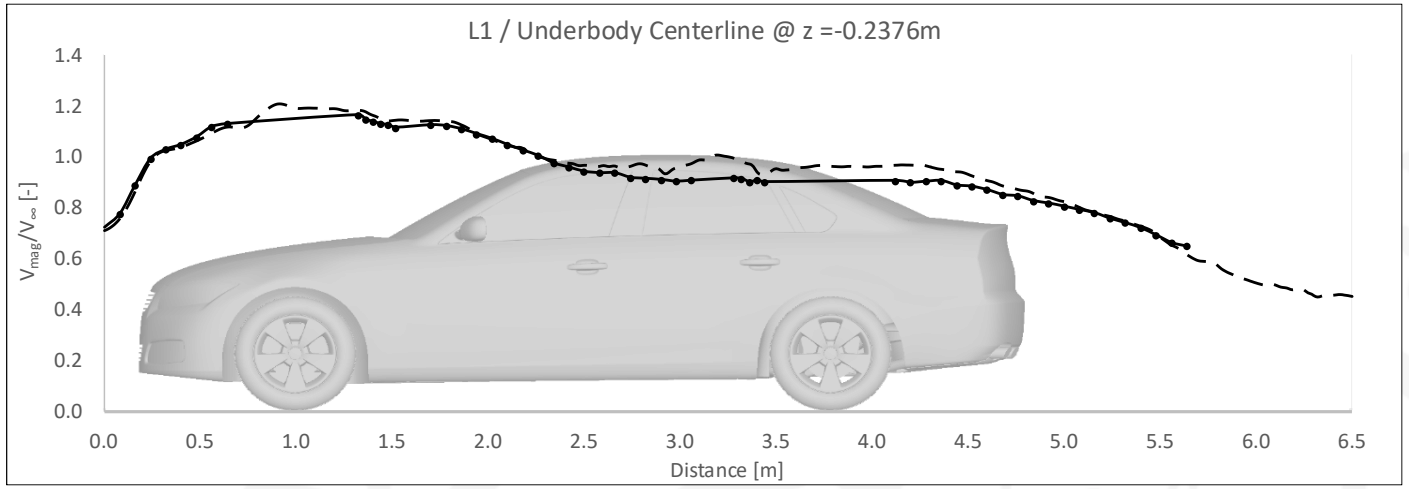
Flow Surveys – No Collapse

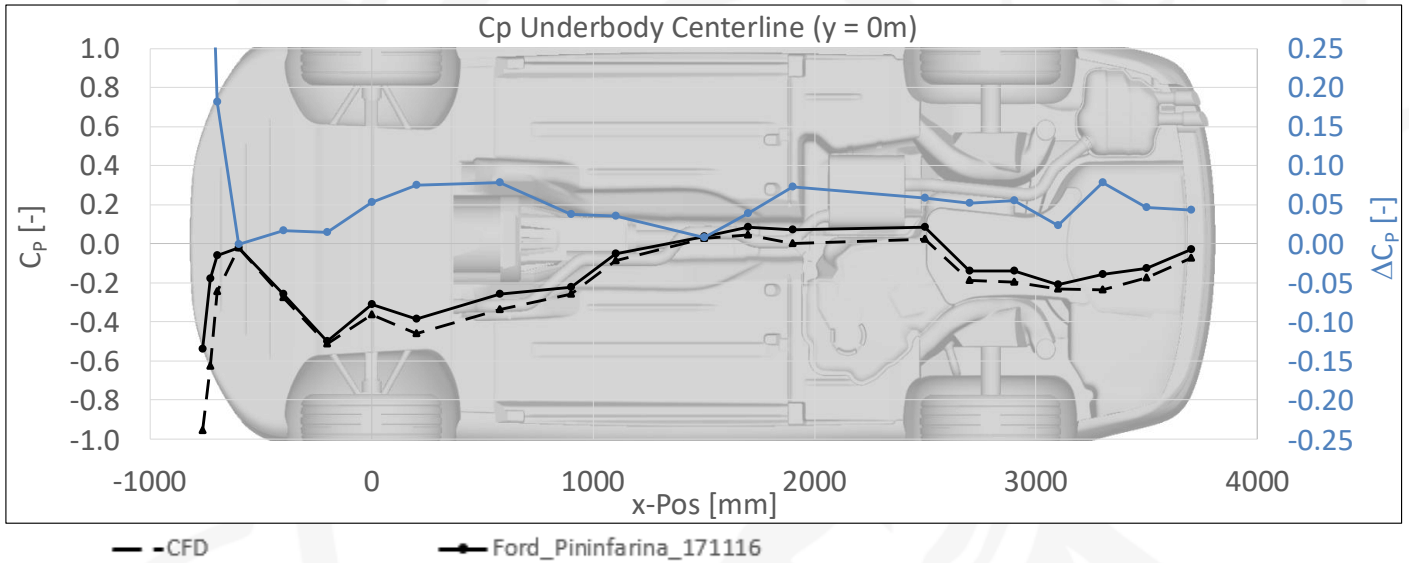
No collapse has a largely smooth underbody velocity prediction

- Changes made for the AutoCFD5 recipe largely improved downstream wake energy

Underbody surface pressures are largely accurate

- Separation/suction at the bumper lip is still higher than experimental, but follows the main trend





Note: Initial AutoCFD5 mesh recipe (5 surface layers)

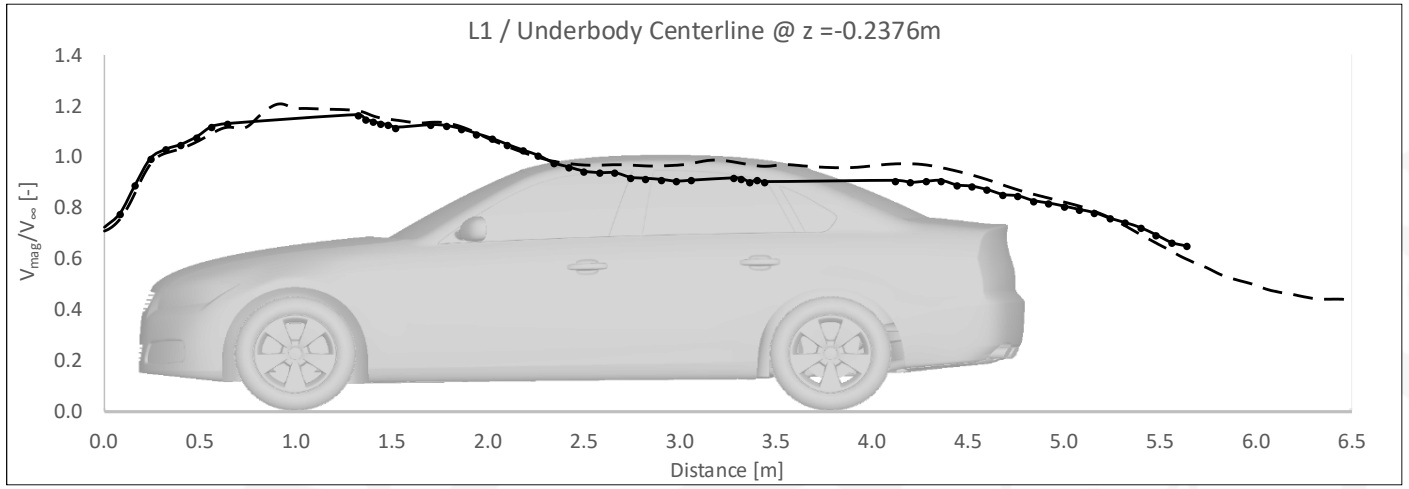
Flow Surveys – Conservative Collapse

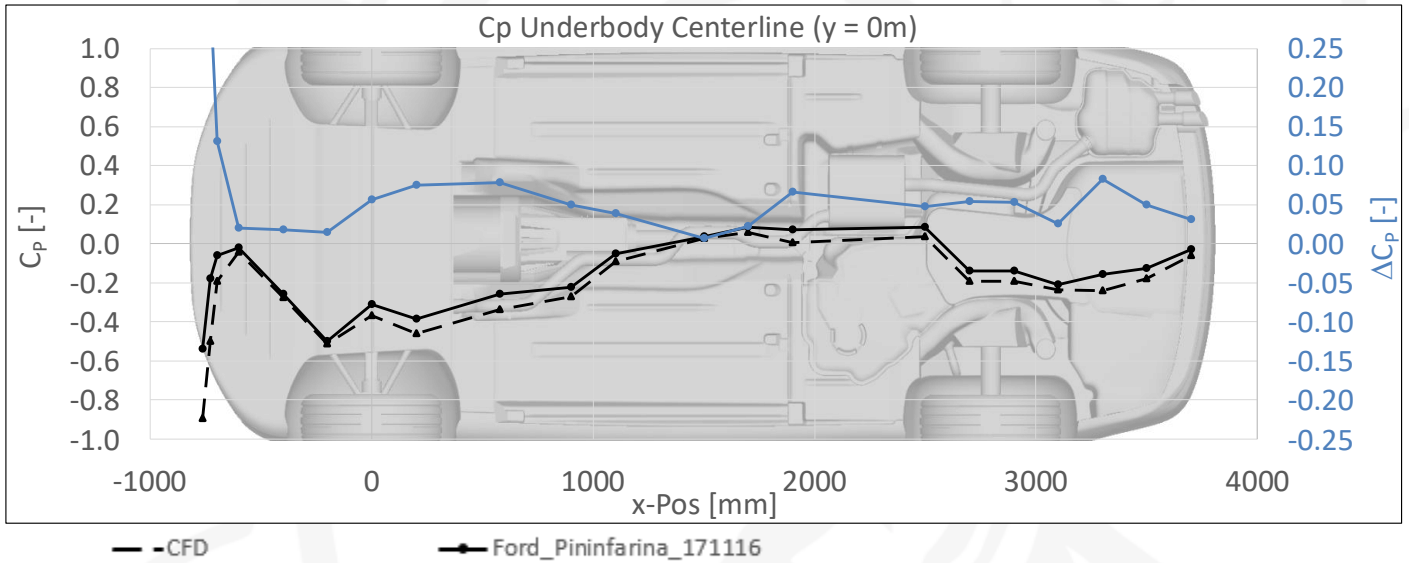
Allowing for some layer collapse mildly changed the energy in downstream wake

- Overall trend is not different enough to be a concern from an industrial setting

Underbody surface pressures are largely similar, if not improved

- Pressures at the leading edge of the lip are more accurate, with separation bubble shape being more accurate





Conclusions on Layer Collapse

Using layer collapse for cell count reduction was investigated

- 25.8% cell count savings with aggressive layer collapse
- 11.8% cell count savings with conservative layer collapse

Outside of the AutoCFD setting, allowing layer collapse can be an effective tool to reduce cell count, under the following recommendations:

- Don’t allow many layers to collapse to just one
  - *This drastically changes the local boundary layer calculation and impacts separation behaviour*
  - *Most noticeable around the bumper lip (high adverse pressure gradient)*
- If you are worried about specific areas, enforce no layer collapse
  - *ANSA Hextreme allows per-patch minimum number of layers*

Multimatic

Reducing Transition Layers

Transition Layers

For an octree-based mesher, the user can specify the number of transition layers between different cell levels

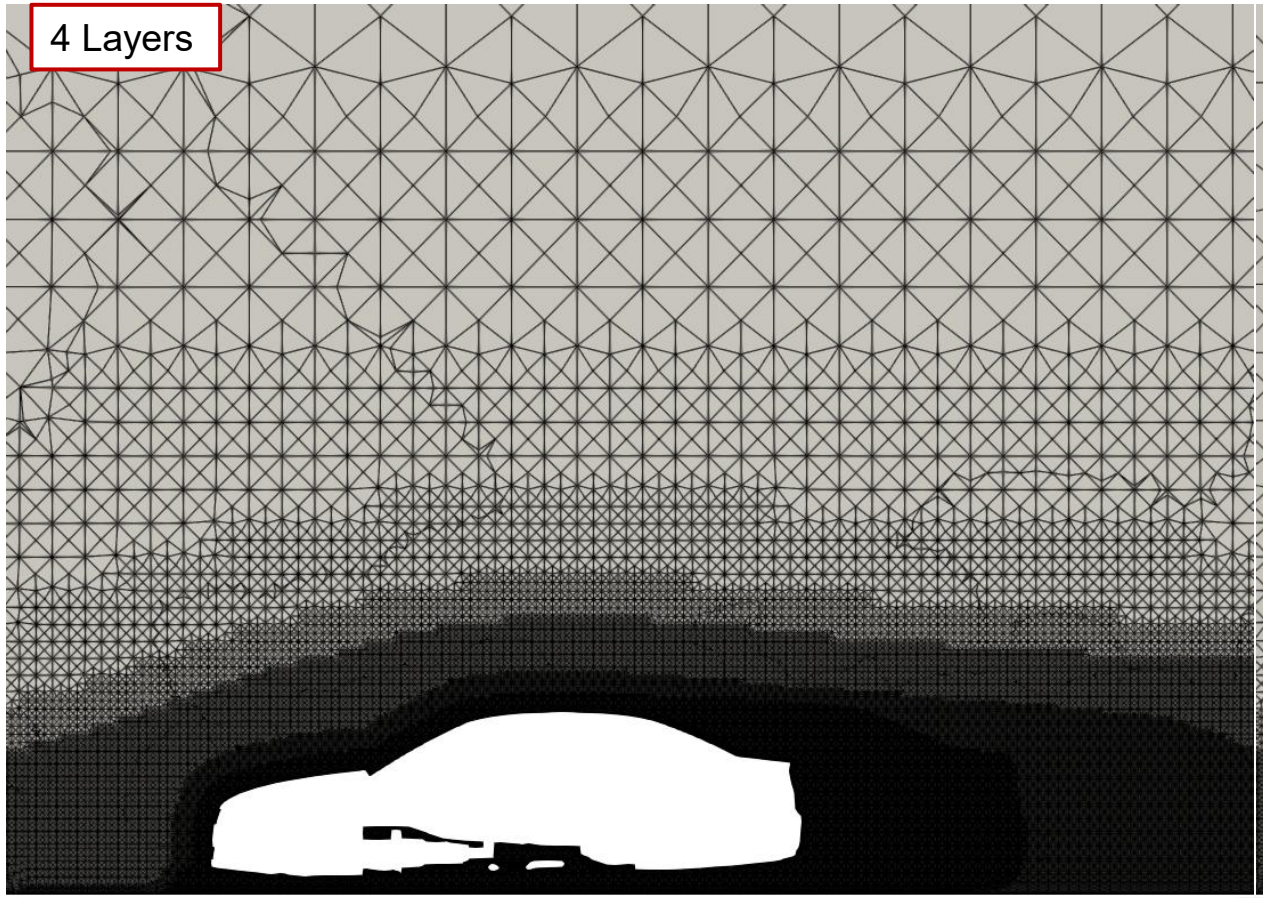
The impact of reducing the number of transition layers was studied

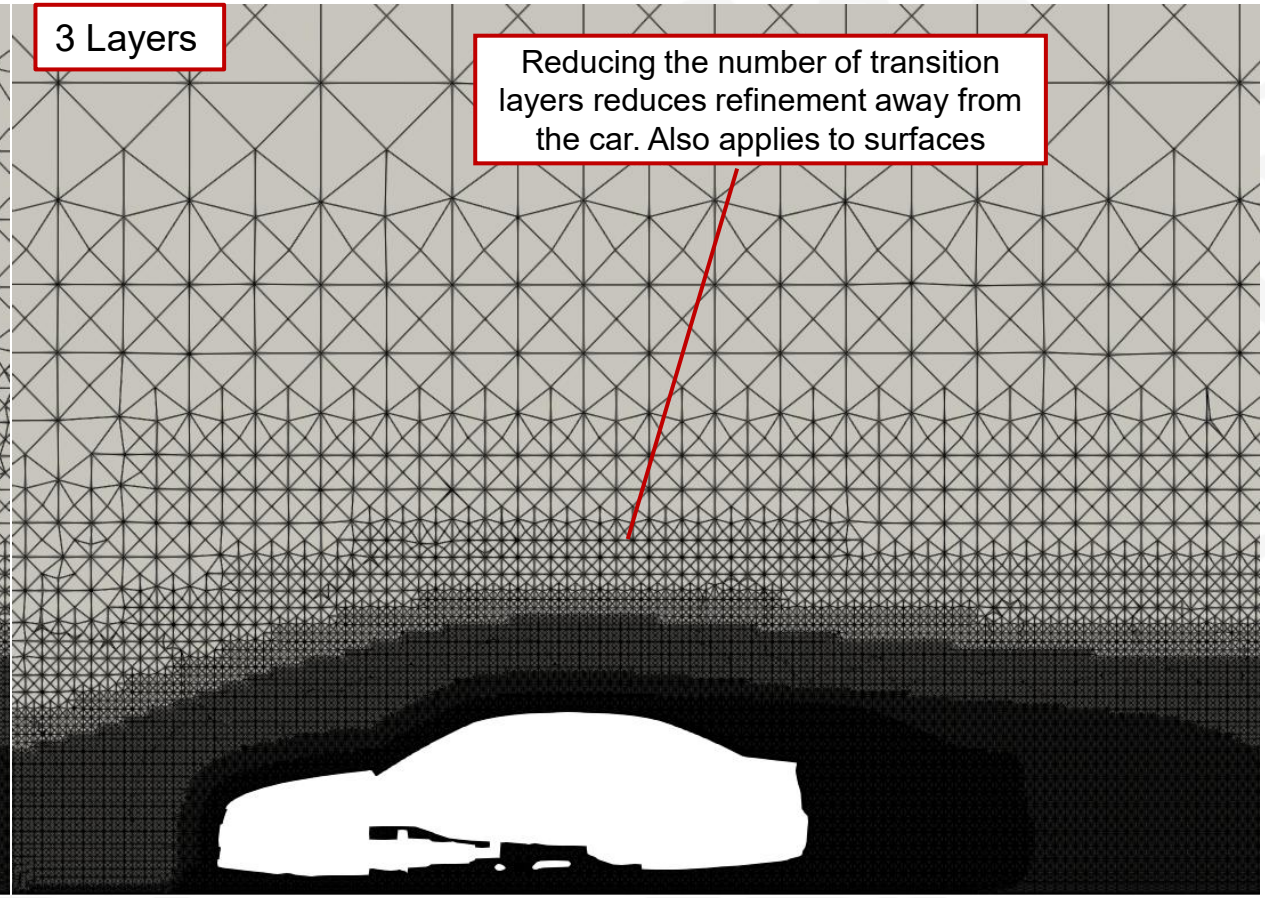
- AutoCFD4 mesh used 4 layers in between different cell levels
- Proposal for AutoCFD5 was 3 layers

Number of Transition Layers	Relative Cell Count Reduction
4 (AutoCFD4-esque)	--
3 (AutoCFD5-esque)	17.8%

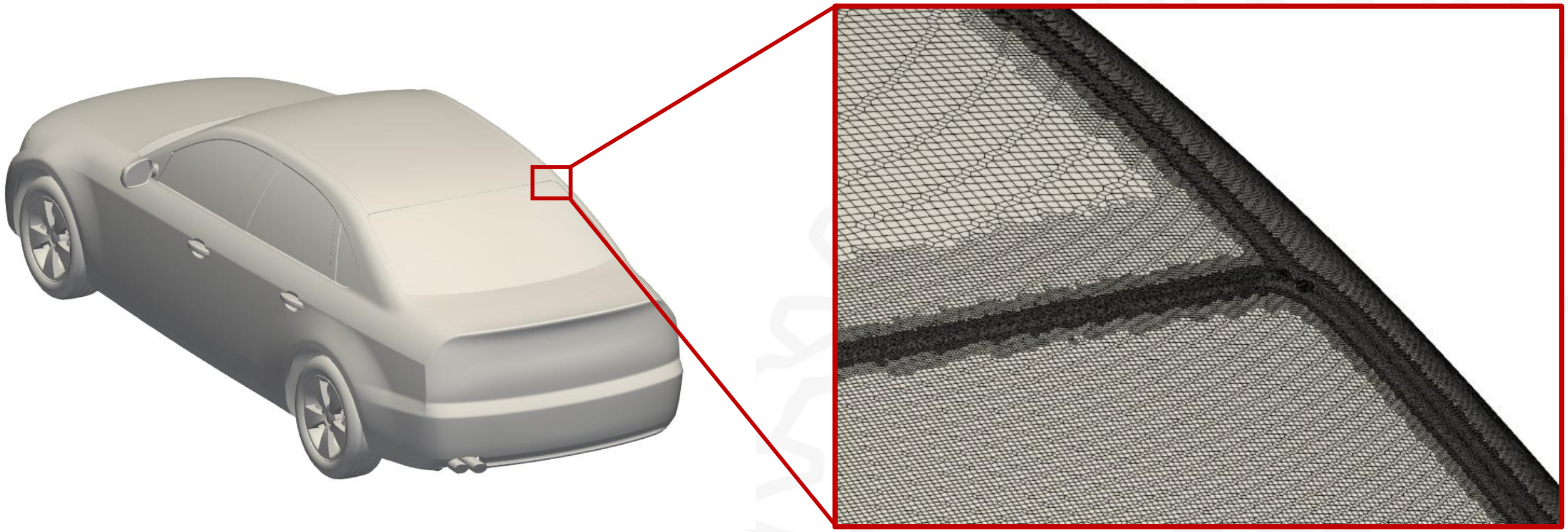
When developing the mesh recipe, two transition layers was not tested, but a valuable consideration for AutoCFD6

Transition Layers

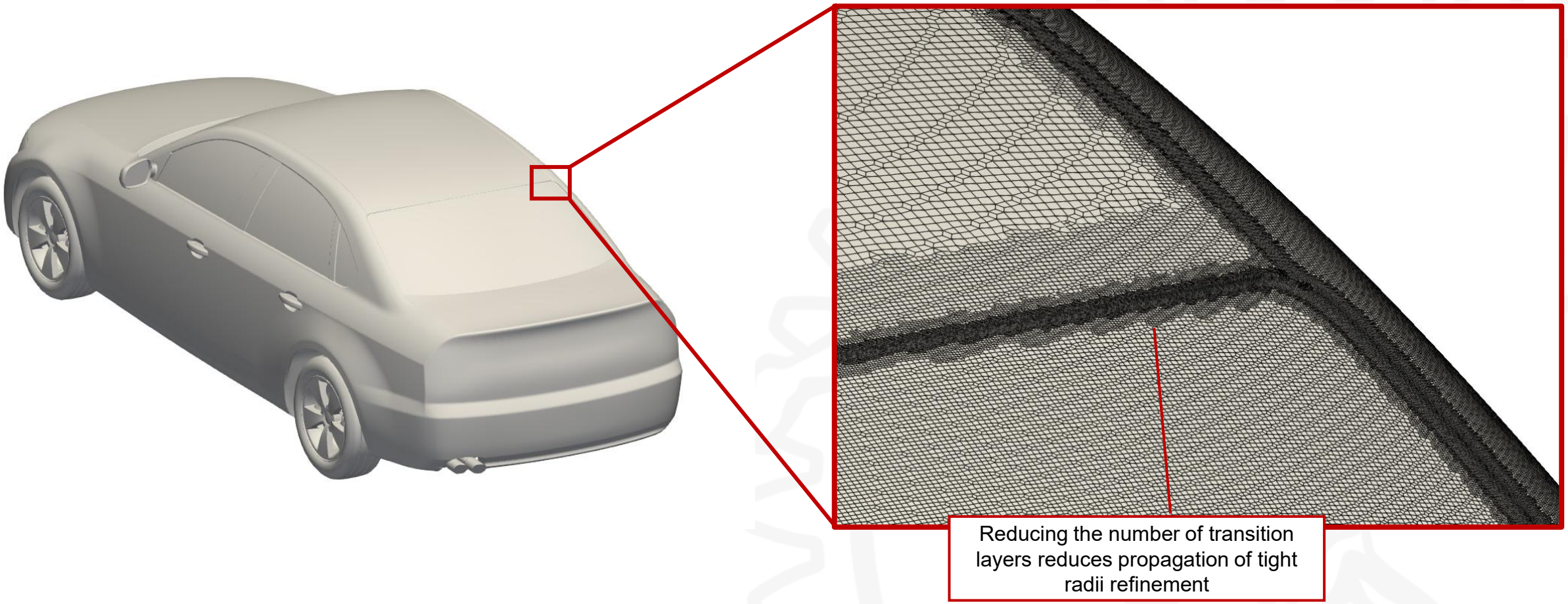




Transition Layers – 4 Layers



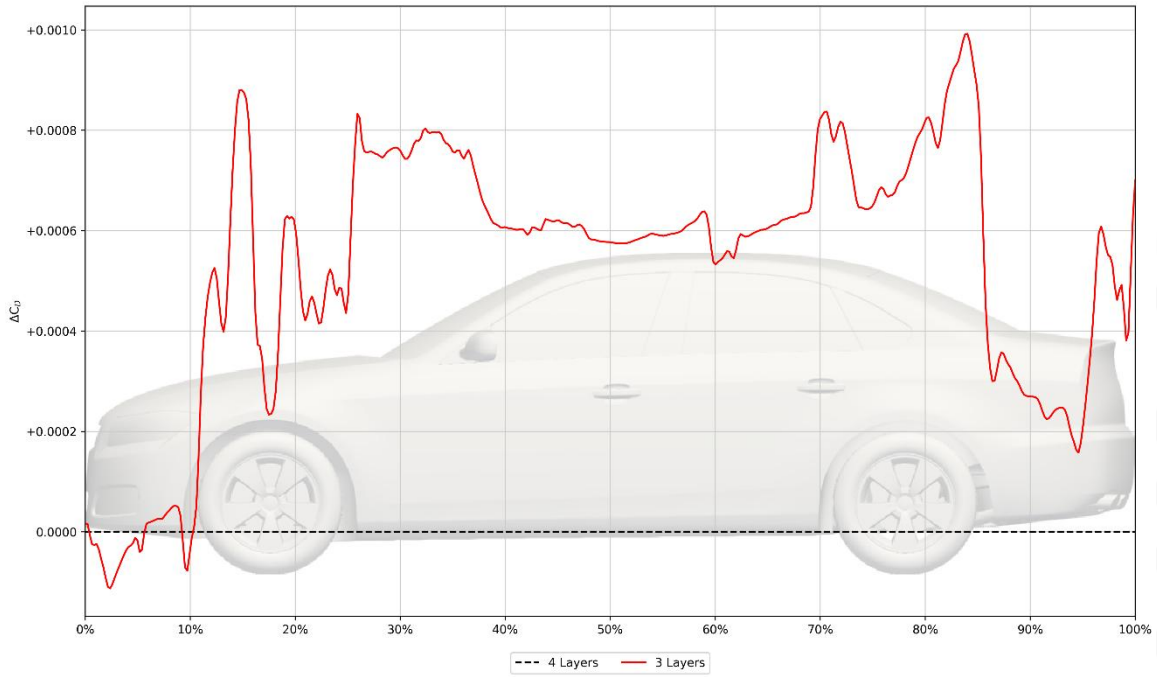
Transition Layers – 3 Layers

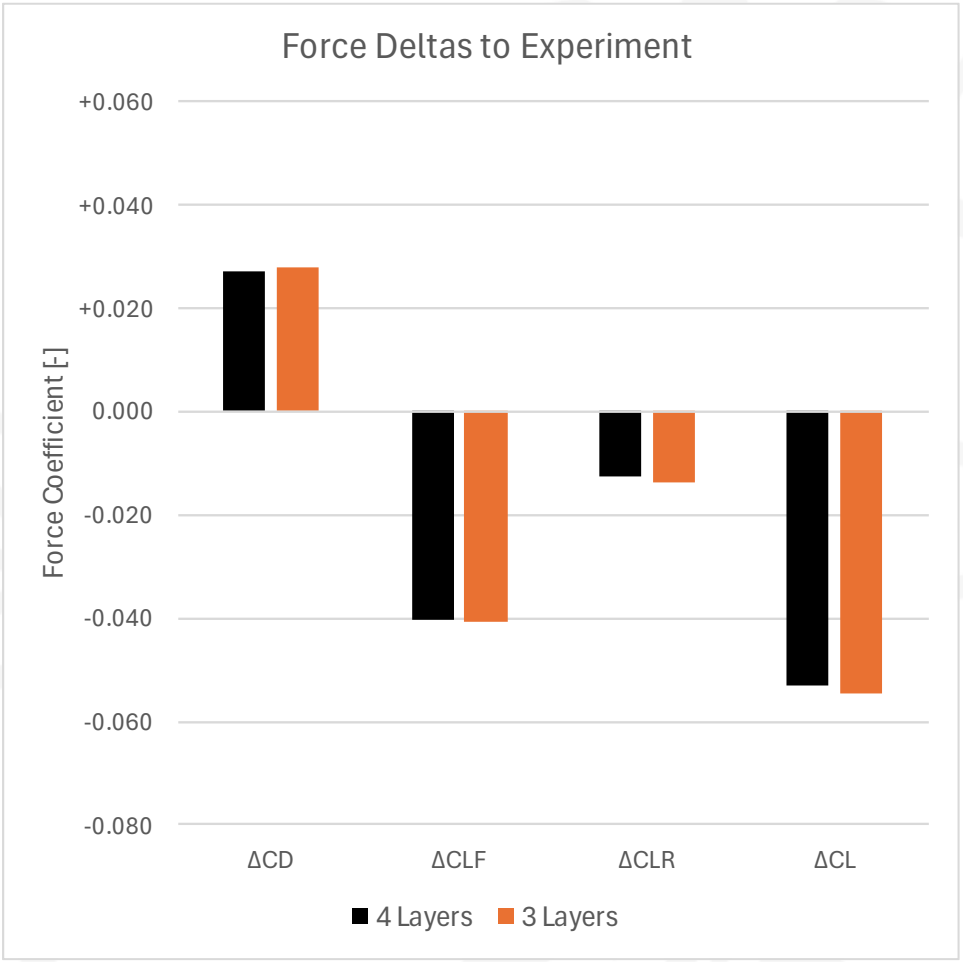


Effect on Forces

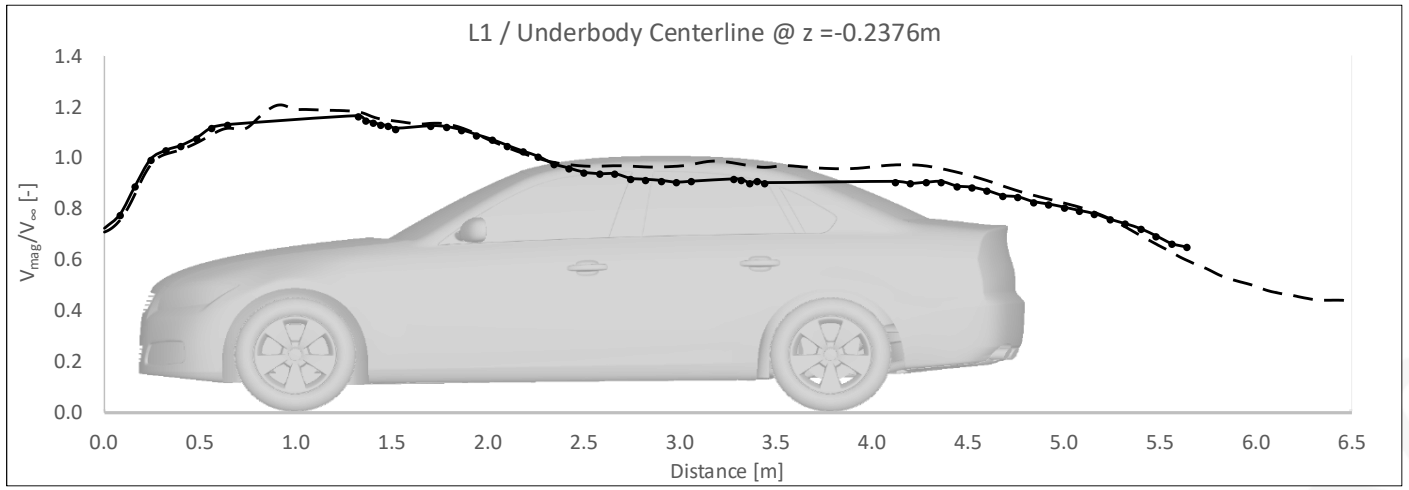
Changing the number of transition layers has a **negligible effect on forces**

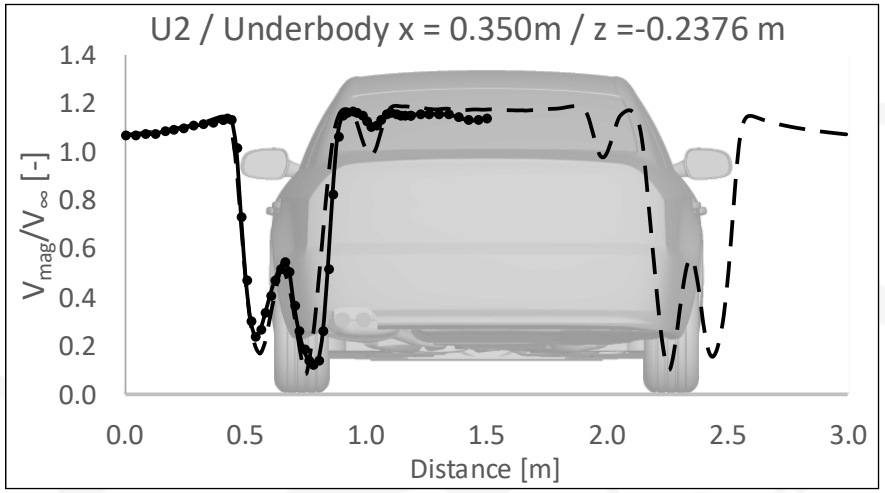
- Does not change overall refinement strategy, but transition between refinement zones
- Does not meaningfully affect drag accumulation (delta shown below, sub one-count changes)

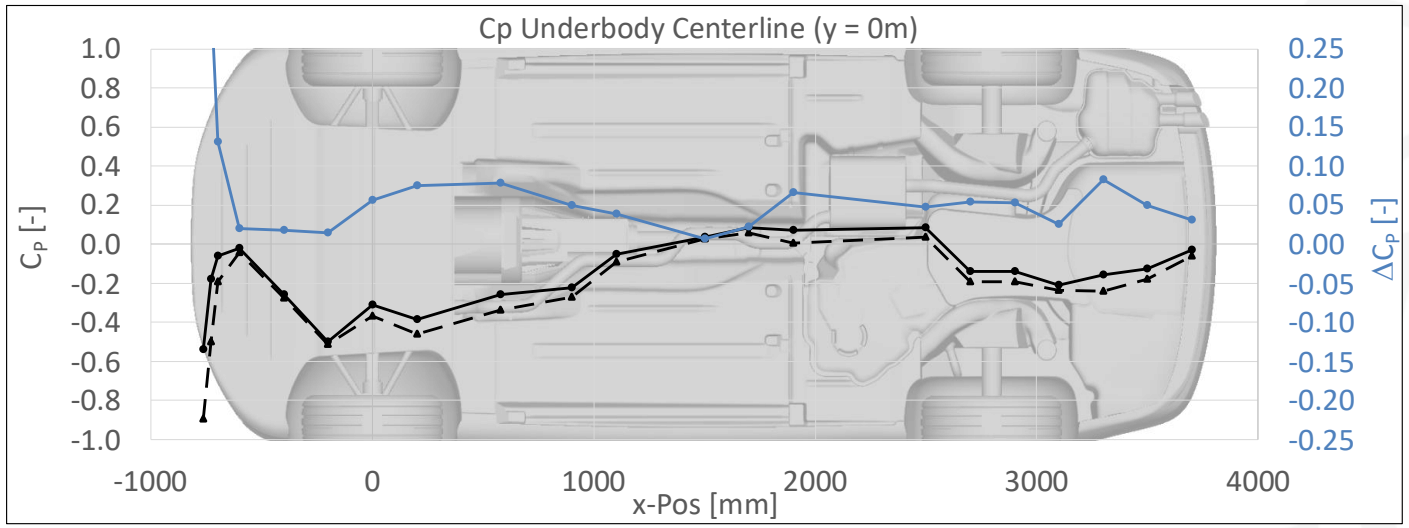


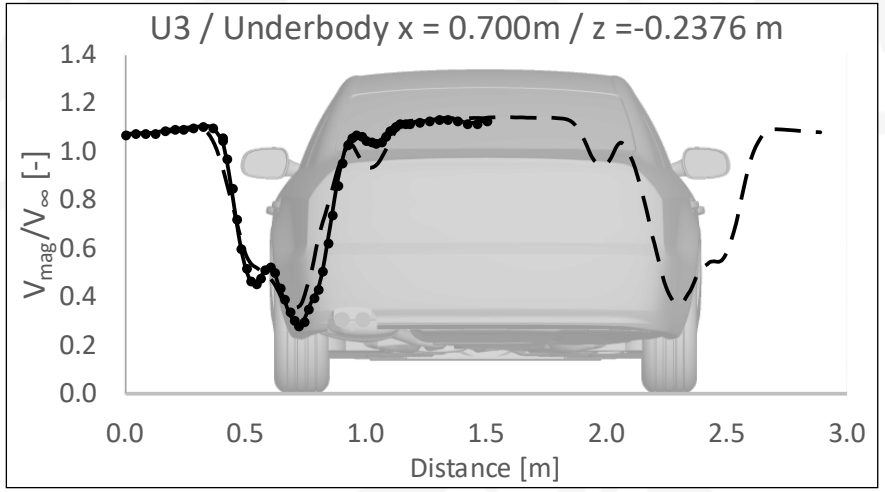


Flow Surveys – Four Layers

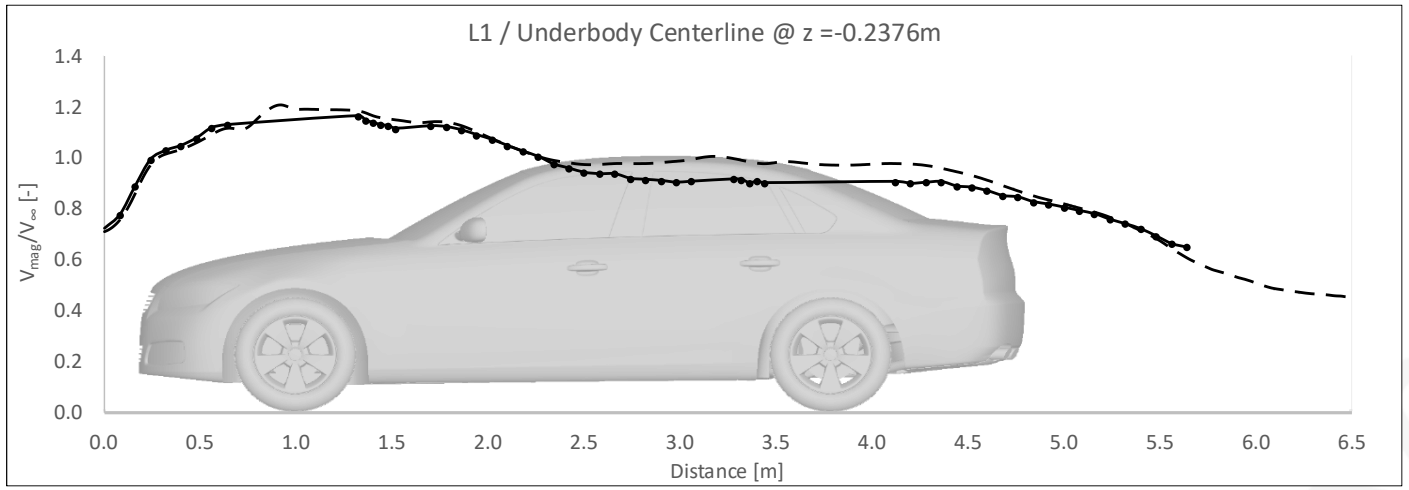


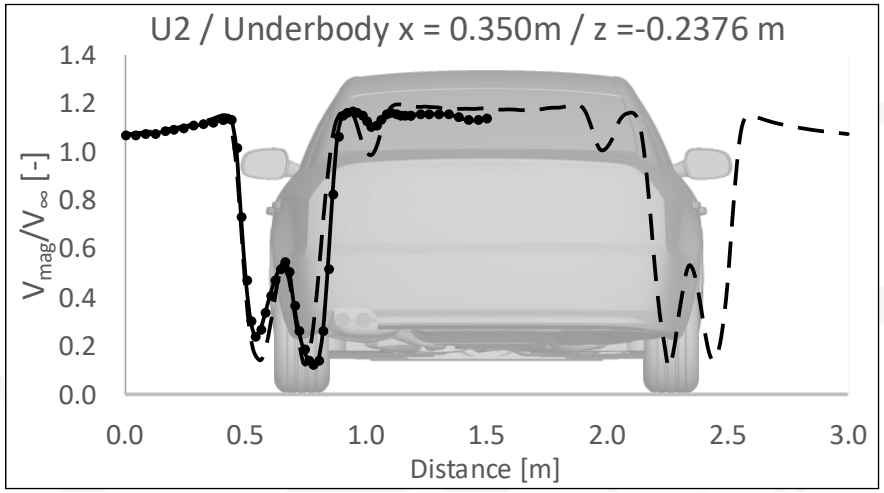


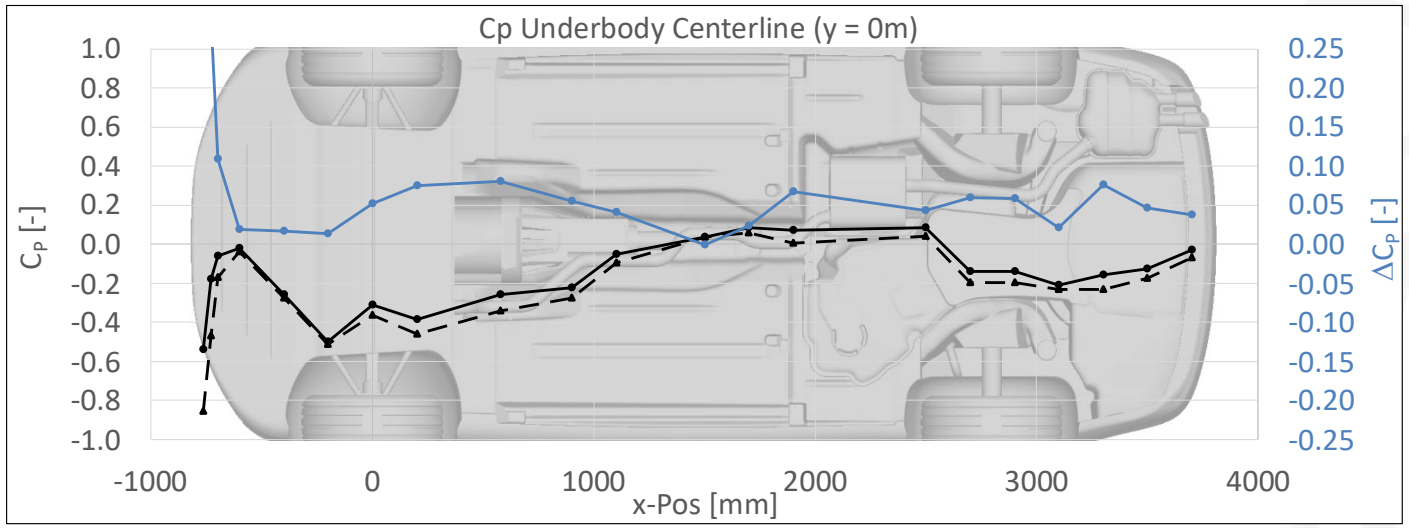


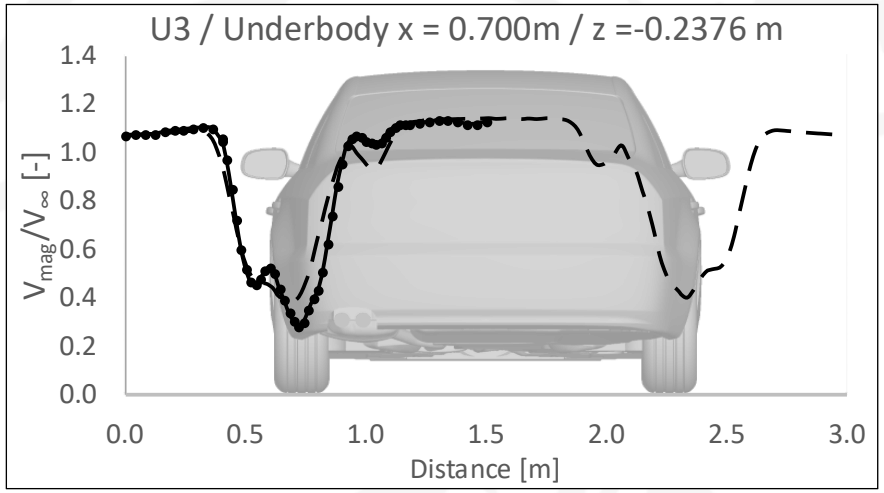


Flow Surveys – Three Layers









CFD

Ford_Pininfarina_171116

No considerable changes due to changing number of transition layers

Transition Layers Conclusions

Reducing the number of transition layers did not have a major impact on solution results, and was included as part of the mesh recipe change for AutoCFD5

- Yielded 17.8% reduction in mesh size

Opportunity to explore further reduction to two transition layers in future workshops

- Two transition layers is typical best-practice
- If two layers cause negative impacts from reduced volumetric refinement, adjust size fields to match current mesh standard
  - *Ensure target refinement areas are adequately captured directly*
  - ***Transition regions should only be used to fill the gaps, not as part of the refinement itself***
  - ***Relying on transition regions for refinement increases cell count elsewhere in the mesh***

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Conclusions

Conclusions

AutoCFD5's Case 2 meshes reflects a >20% reduction in cell count, with minimal changes in results

- Minimal change seen across Multimatic, Cadence, and Ford
  - *OpenFOAM and Fidelity solvers, different numerical schemes/turbulence models, etc.*

Workshop	Cell Count [million cells]	
	Case 2a	Case 2b
AutoCFD4	157	158
AutoCFD5	123 ***(-22%)***	126 ***(-20%)***

There is room to make further reductions to the cell count via continued reduction in the number of transition layers

- Layer collapse could be reintroduced, but may require input from the SRS TFG to get a better read on the impact to the turbulence model(s)

Further developments to the mesh recipe can focus on capturing different phenomena more accurately

- More resolution around the A- and C-pillars?
  - *May capture more detailed vortex structures*

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Questions?

Appendix – Bulk Mesh Recipe Changes

Major Mesh Recipe Changes

As part of AutoCFD5, there were major changes to the mesh recipe, evaluated as a single step. These changes resulted in a cumulative 2.5% decrease in cell count, reflecting:

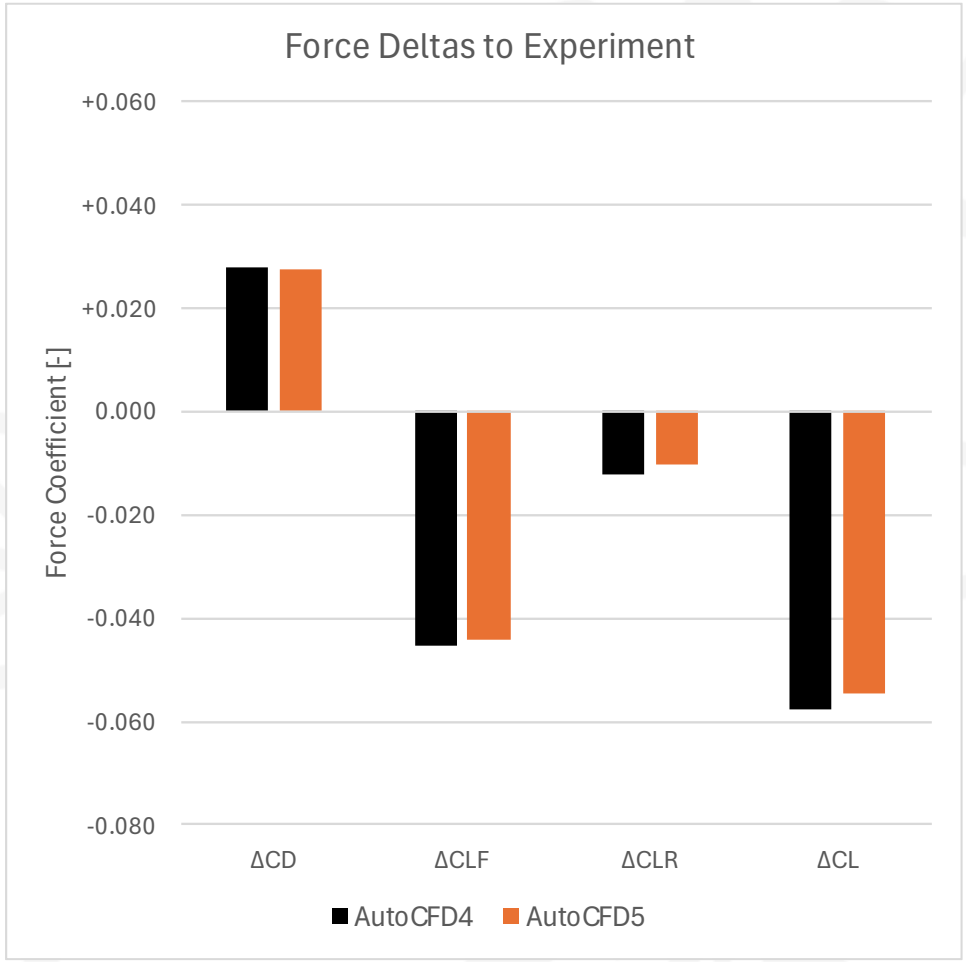
- Increasing surface refinement around the bumper lip -> increases cell count
- Finer curvature capturing of all tight radii -> increases cell count
- Switching from 7 layers to 5 -> decreases cell count
- Increase to the width of tire wake refinement -> increases cell count

The goal of these changes was to improve capturing of the underlying geometry/reduce excessive layering, before any dedicated changes to coarsening the model

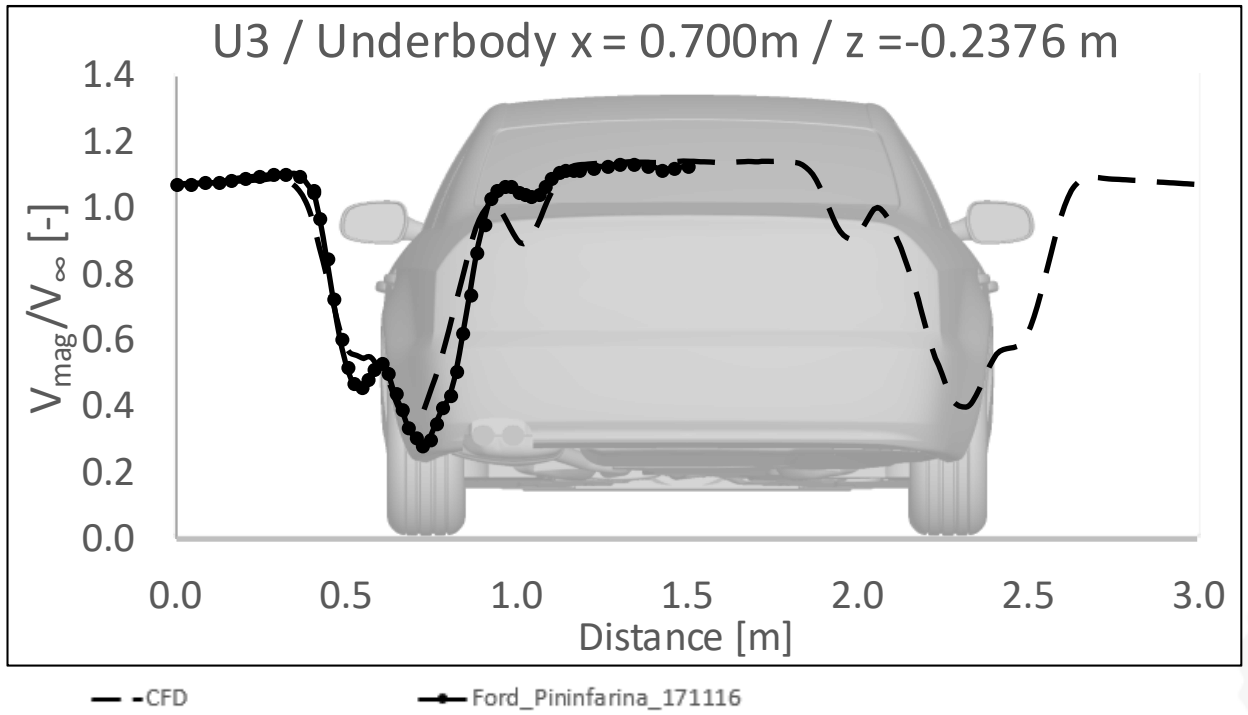
Effect on Forces

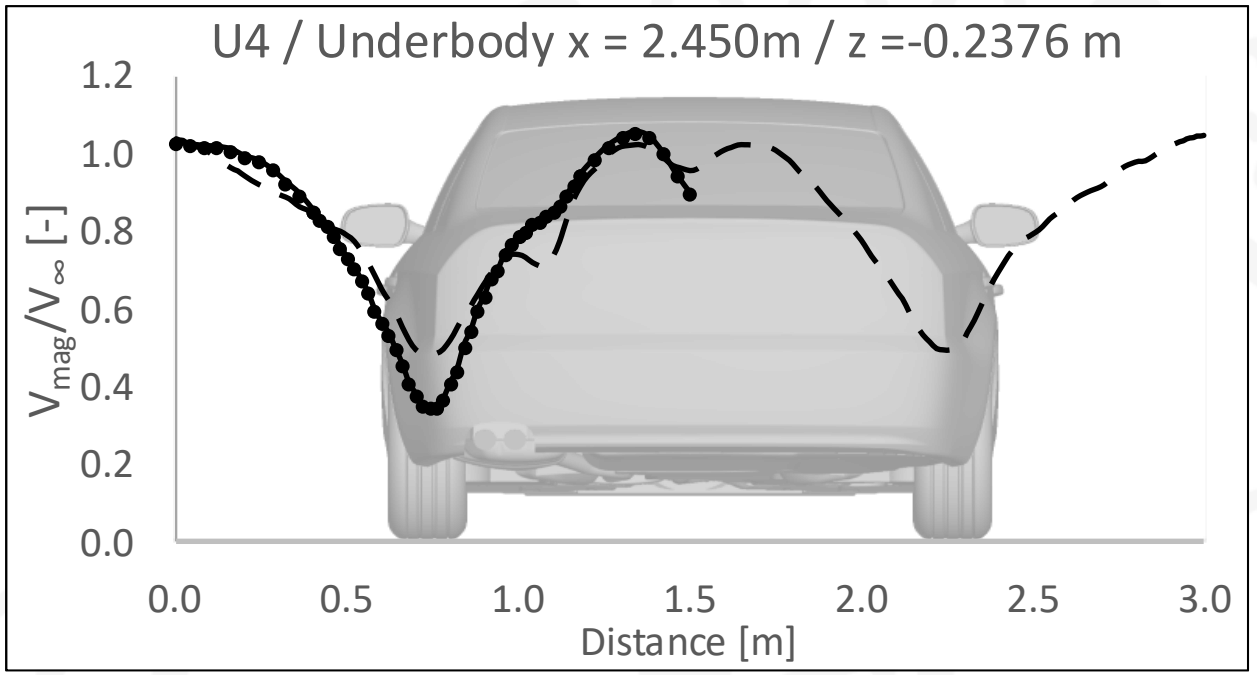
Making the bulk changes to the mesh recipe had a negligible effect on forces

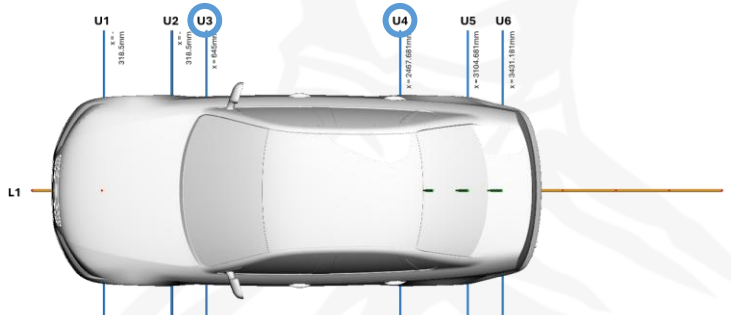
- Drag is effectively unchanged
- Lift correlation improved four counts



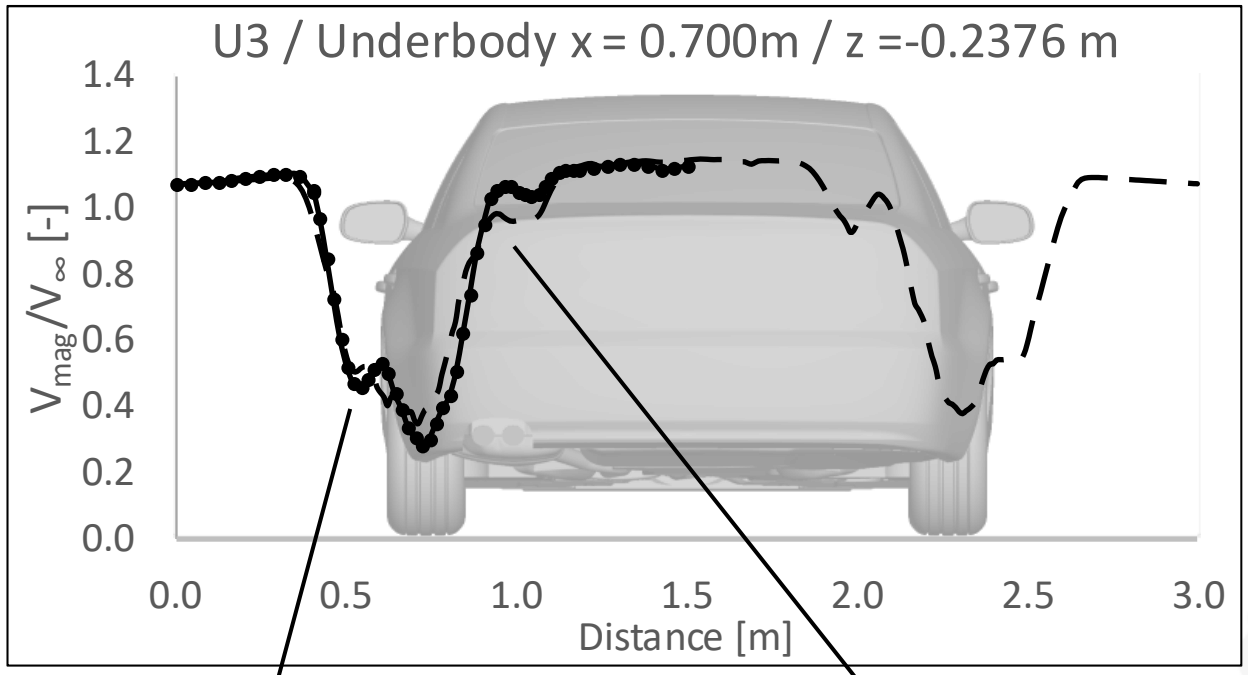
U3, U4 – AutoCFD4

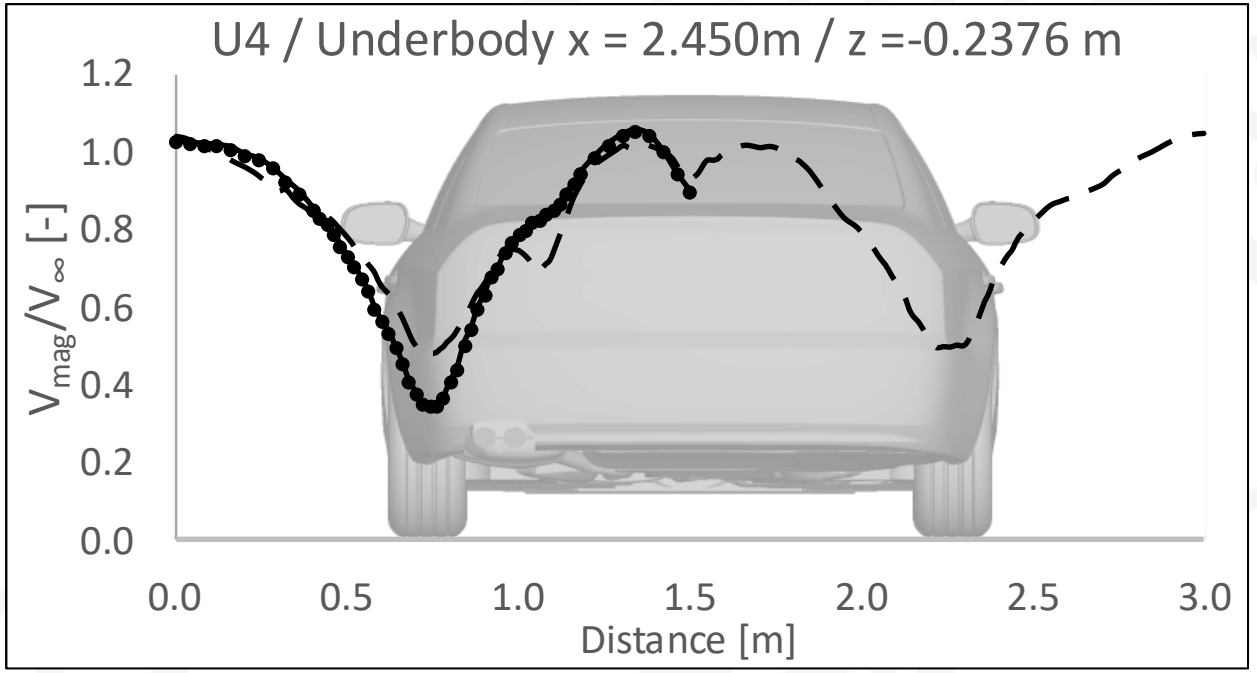






U3, U4 – AutoCFD5



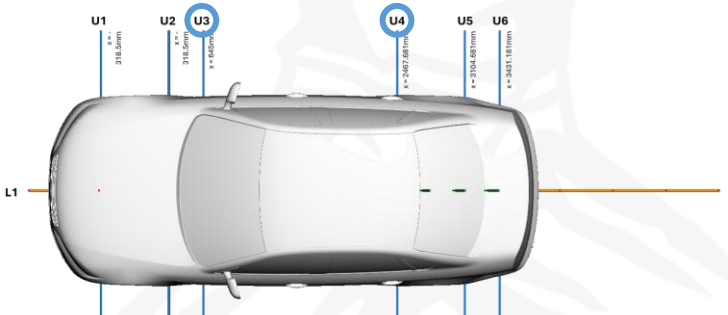


Mesh revisions help with outer tire wake prediction but slightly misses two hump overall shape.

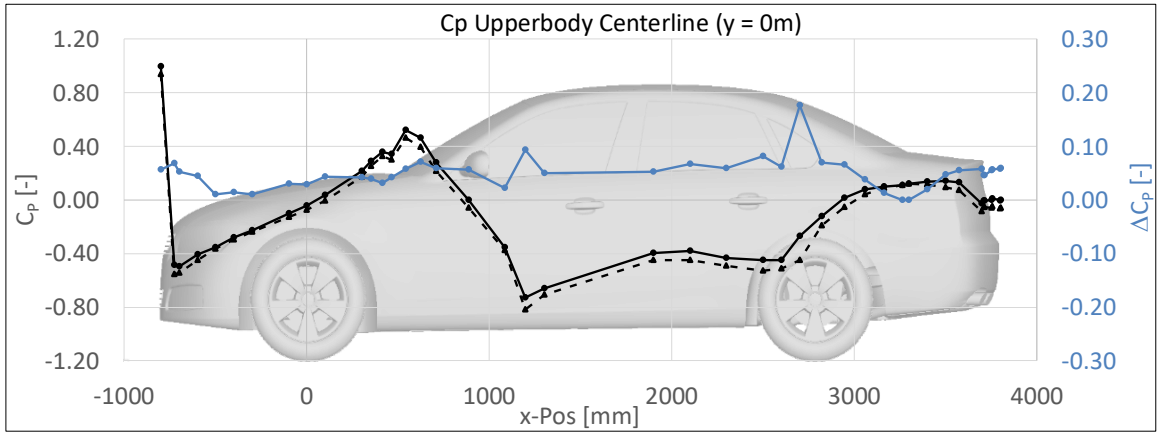
Step in the right direction

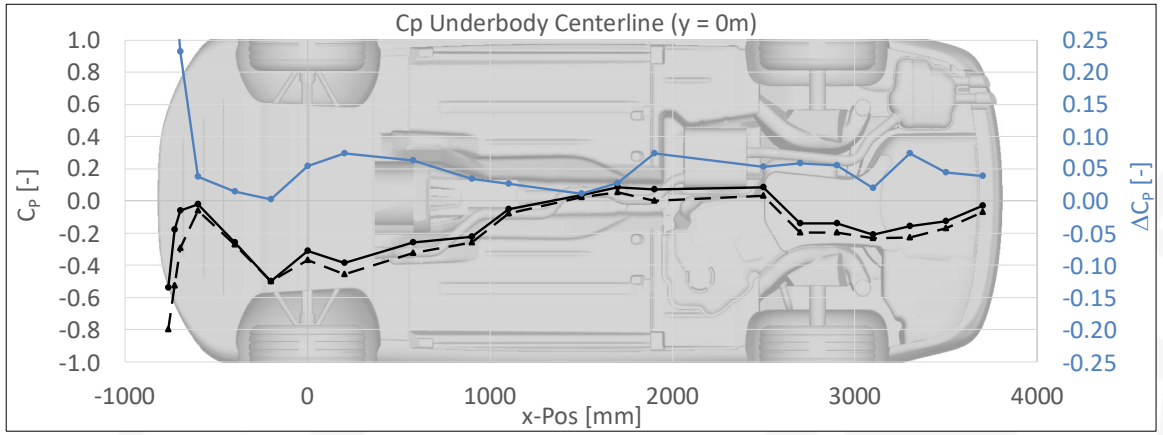
Innermost portion of the tire wake less accurately predicted.

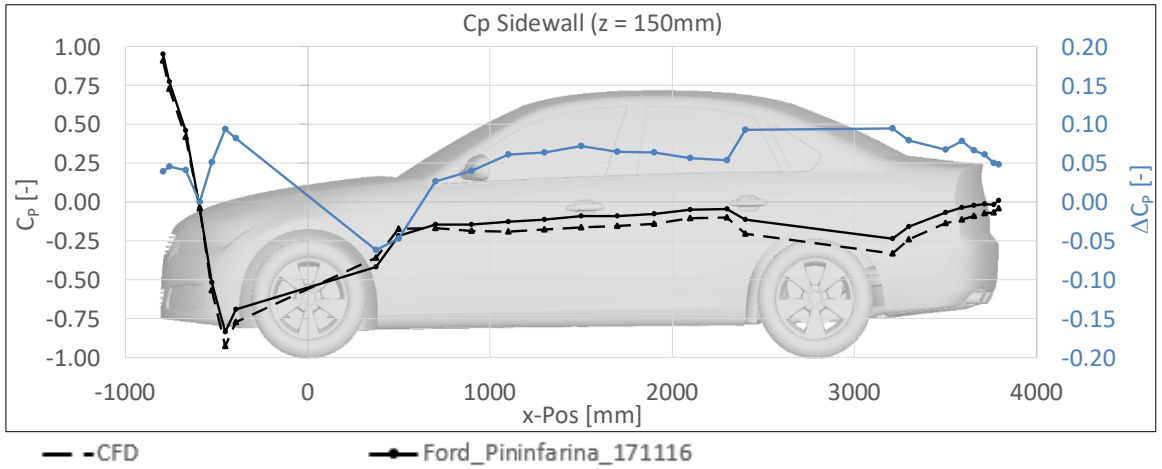
Points towards the overall mesh changes having a roughly net-zero effect

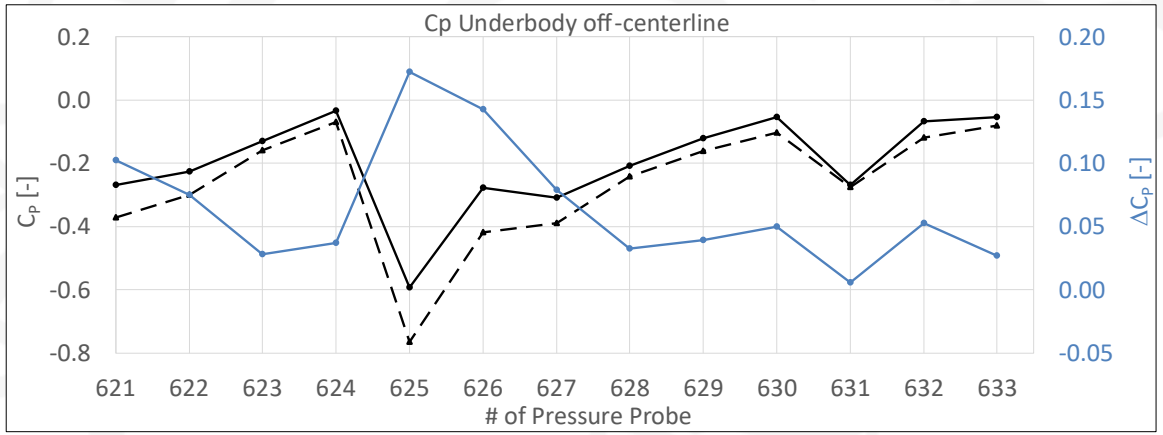


Pressure Taps – AutoCFD4





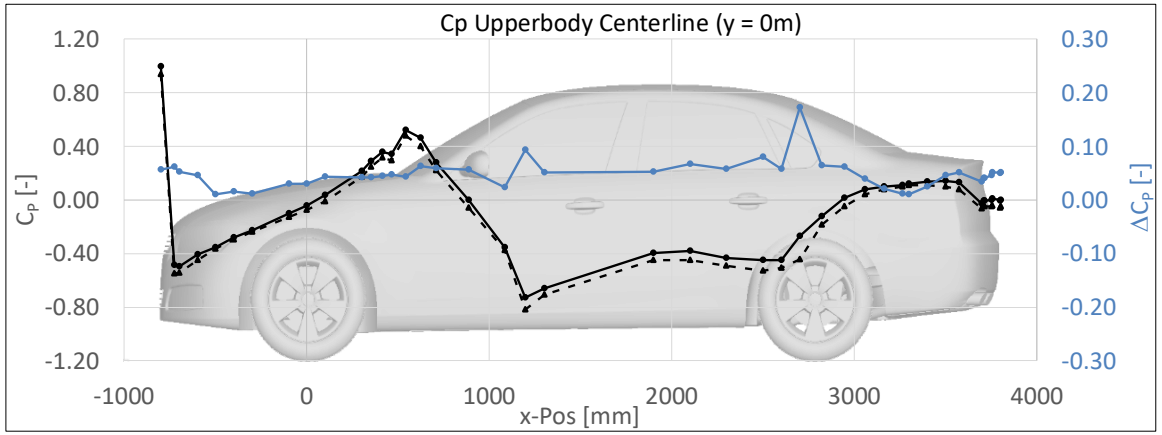


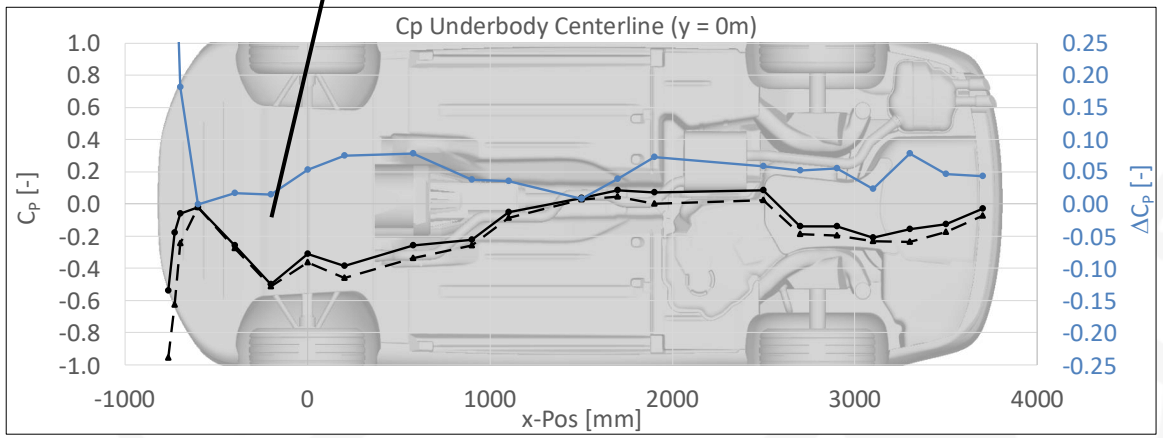


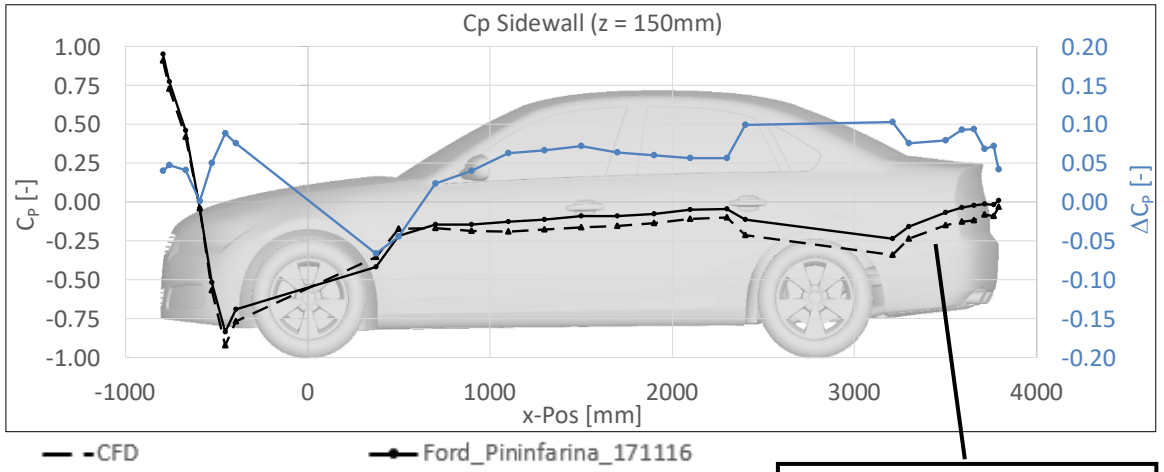
Pressure Taps – AutoCFD5

Centerline probes largely the same.

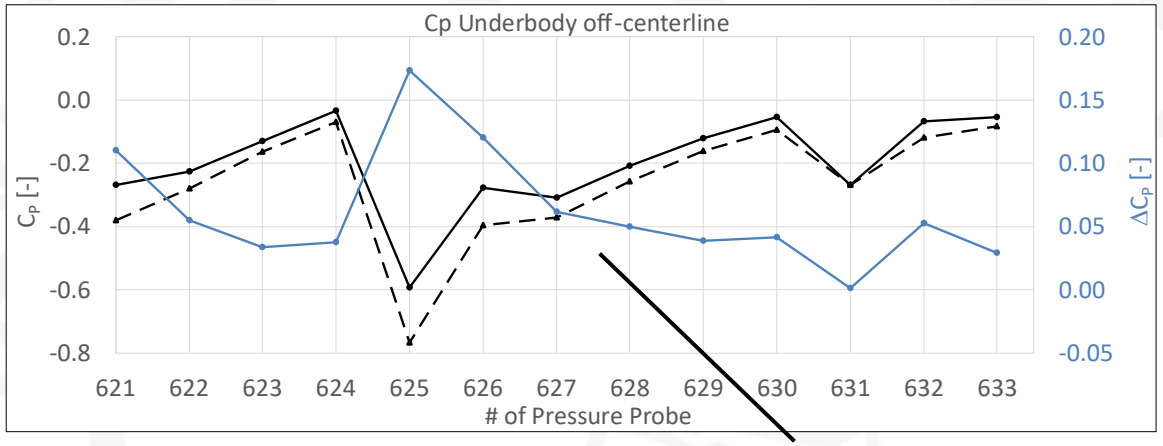
Some trends become more accurate







Slightly less accurate downstream of the rear tire



Underbody off-centerline generally more accurate.

Additional wheel/underbody refinement aids predictions

Mesh Recipe Changes Conclusions

Coarsening the AutoCFD4 mesh recipe through fewer layers, to the surface mesh settings, was the preliminary step

Mesh coarsening has had the following impact on forces, the flow field, and surface pressures:

- Forces have not changed meaningfully, consistently accurate solution provided
- Flow field predictions have improved with additional outboard wheel refinement, but are otherwise unaffected by changes to the mesh recipe

Appendix – Size Field Changes

Size Field Changes

Size field changes were investigated based on the major mesh recipes changes to AutoCFD5. Further changes to the mesh are as follows

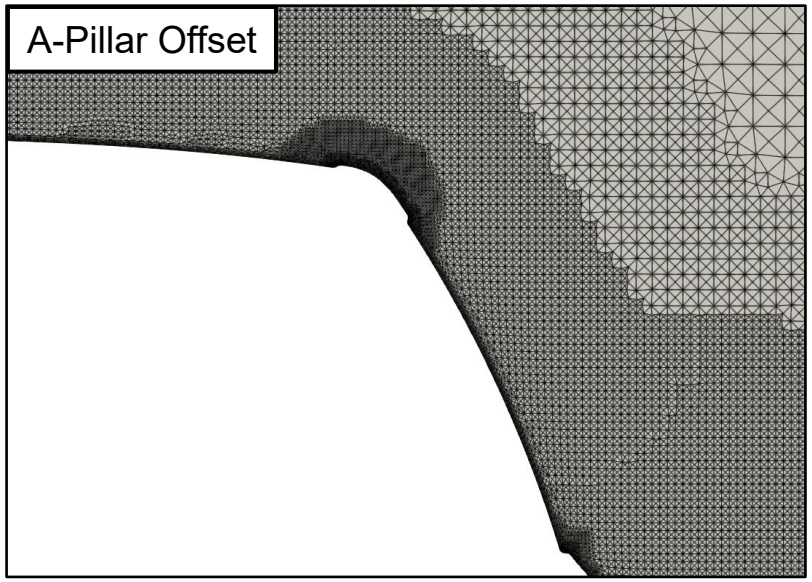
- Size Field Step 1 (Removal of A-pillar offset) (SF1)
- Size Field Step 2 (Removal of A-pillar offset and mirror wake refinement) (SF2)
- Size Field Step 3 (Removal of A-pillar offset, mirror wake refinement, and 4 mm tire wake refinement) (SF3)

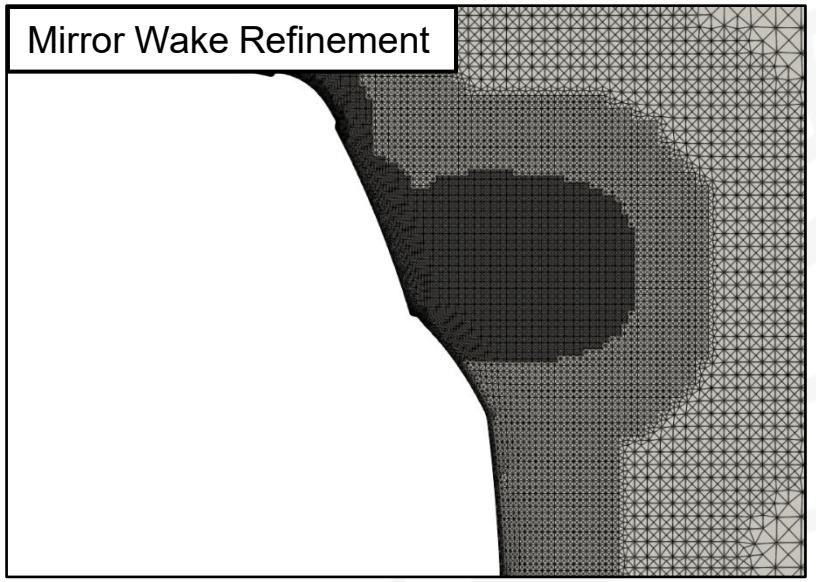
These changes have the following reduction in cell count:

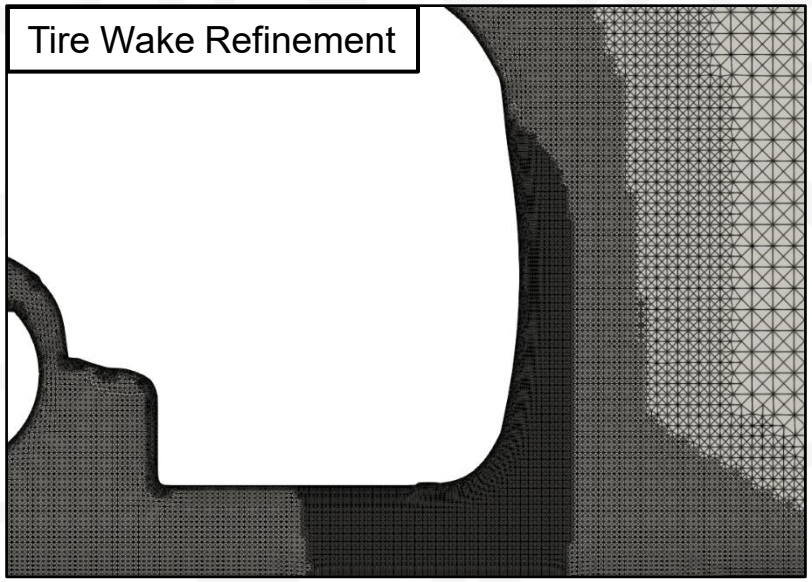
Mesh	Mesh Size [million cells]	Mesh Size % Change
SF1	126	-0.8%
SF2	125	-1.6%
SF3	115	-9.4%

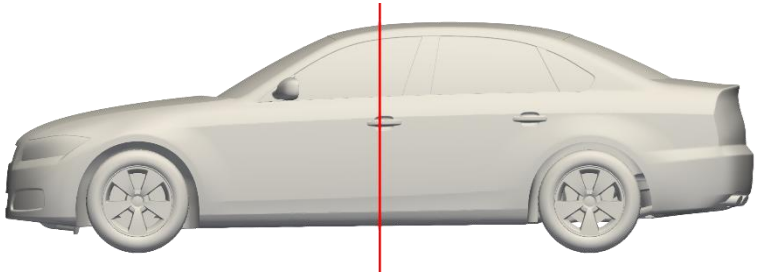
Note, these mesh changes were examined on the Case 2b model.

Size Field Changes

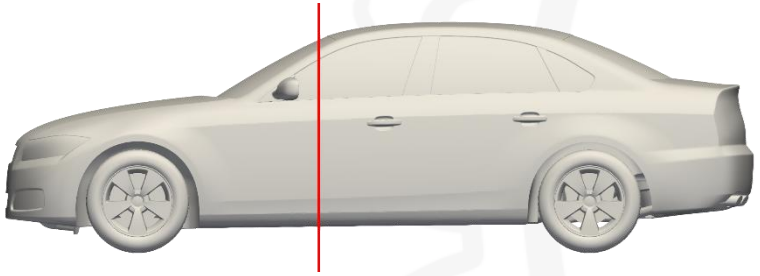








X = 1500 mm

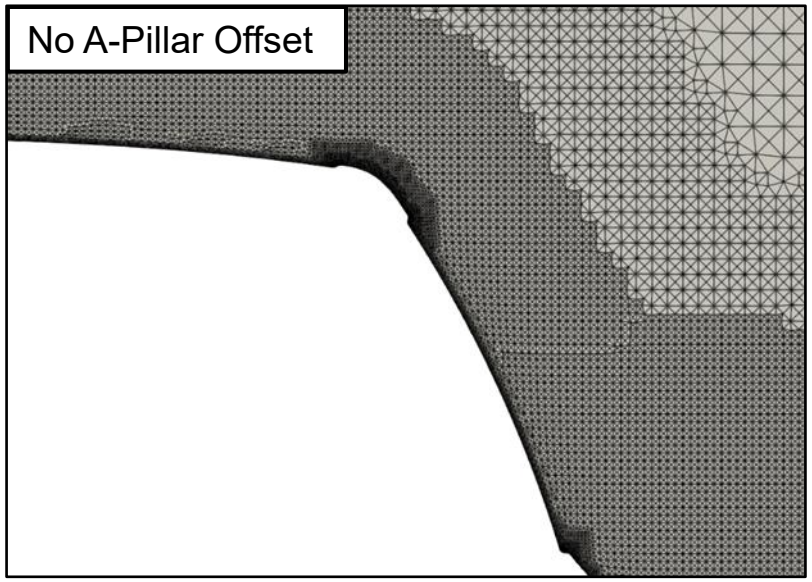


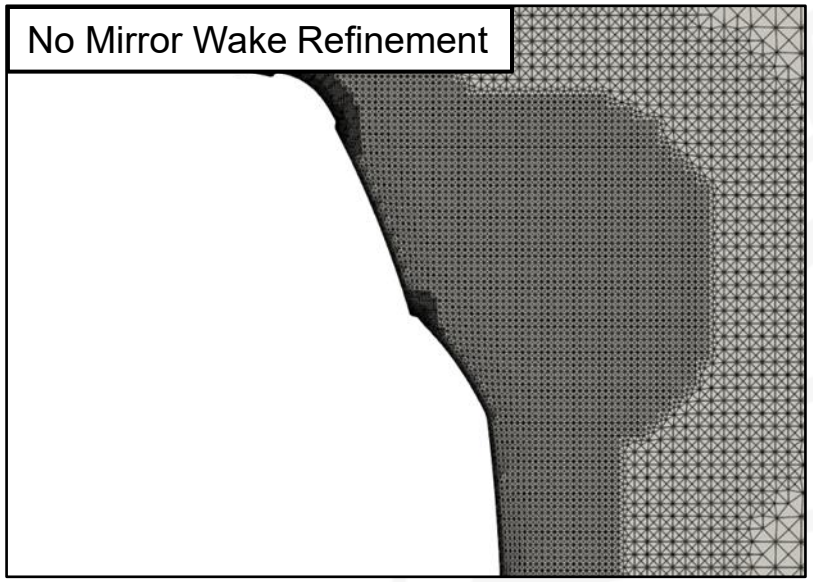
X = 1125 mm

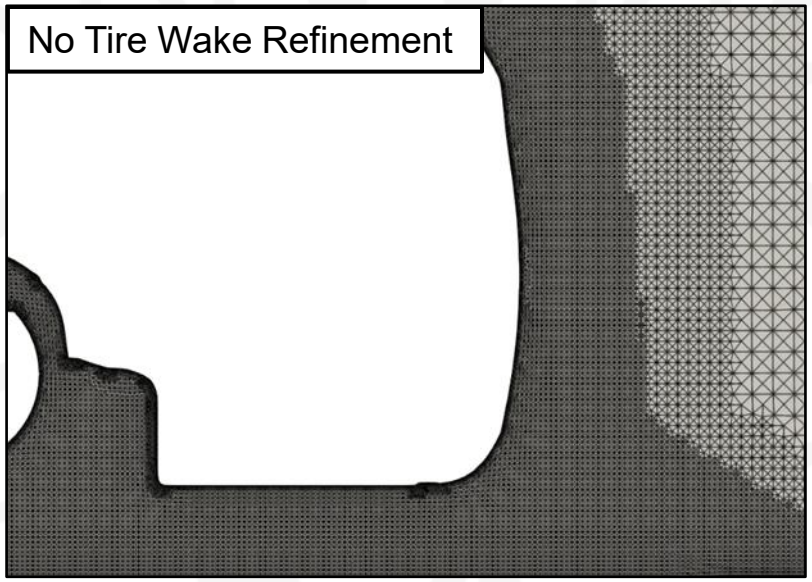


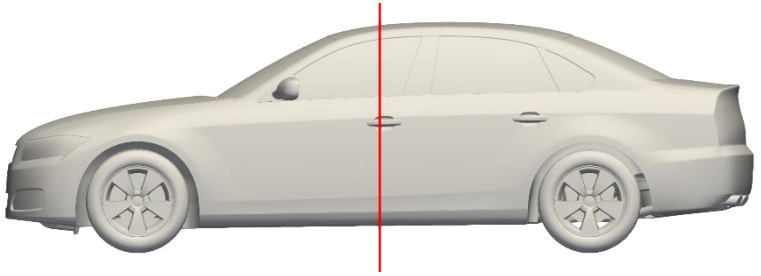
X = 450 mm

Size Field Changes

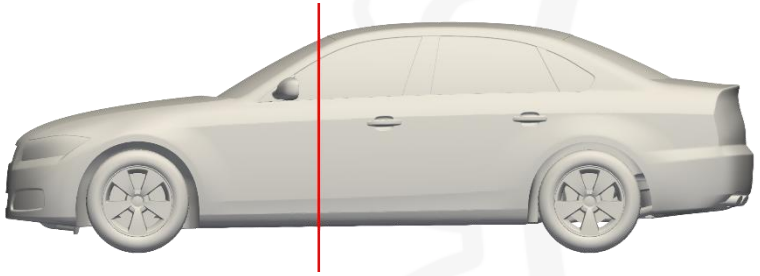








X = 1500 mm



X = 1125 mm

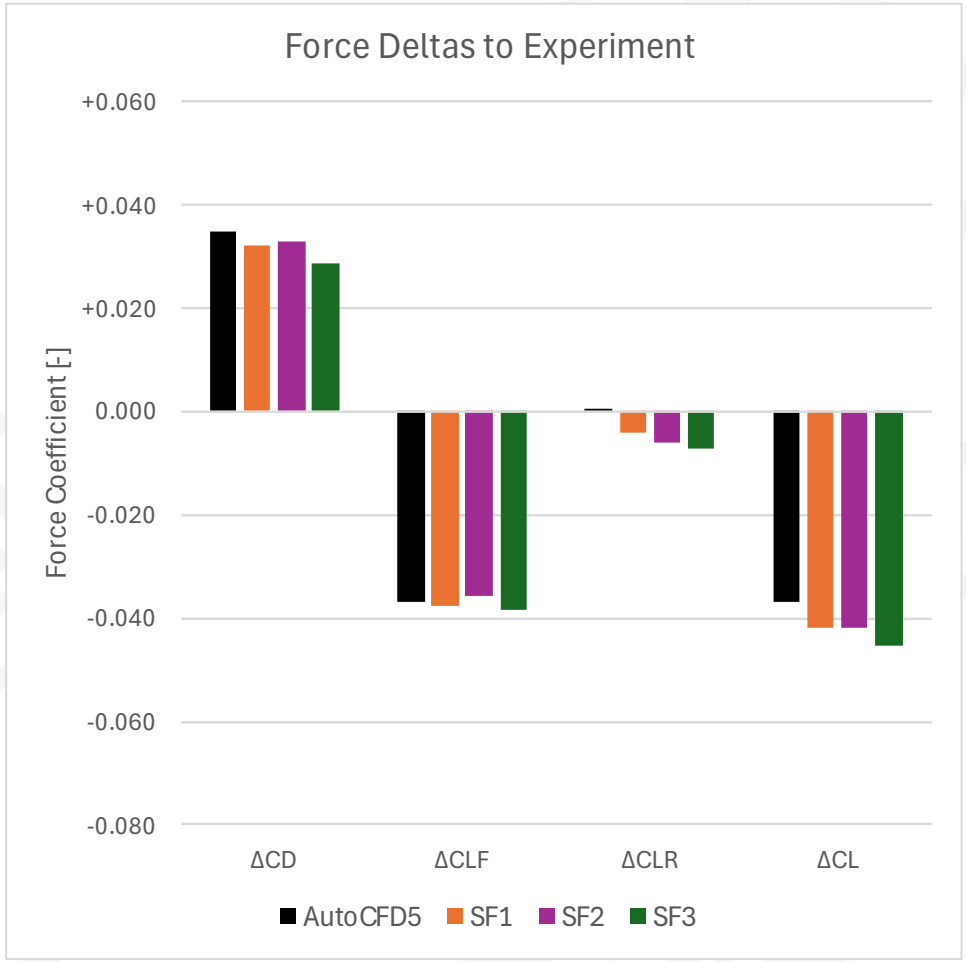


X = 450 mm

Effect on Forces

Forces show more variation with this study than previous mesh changes

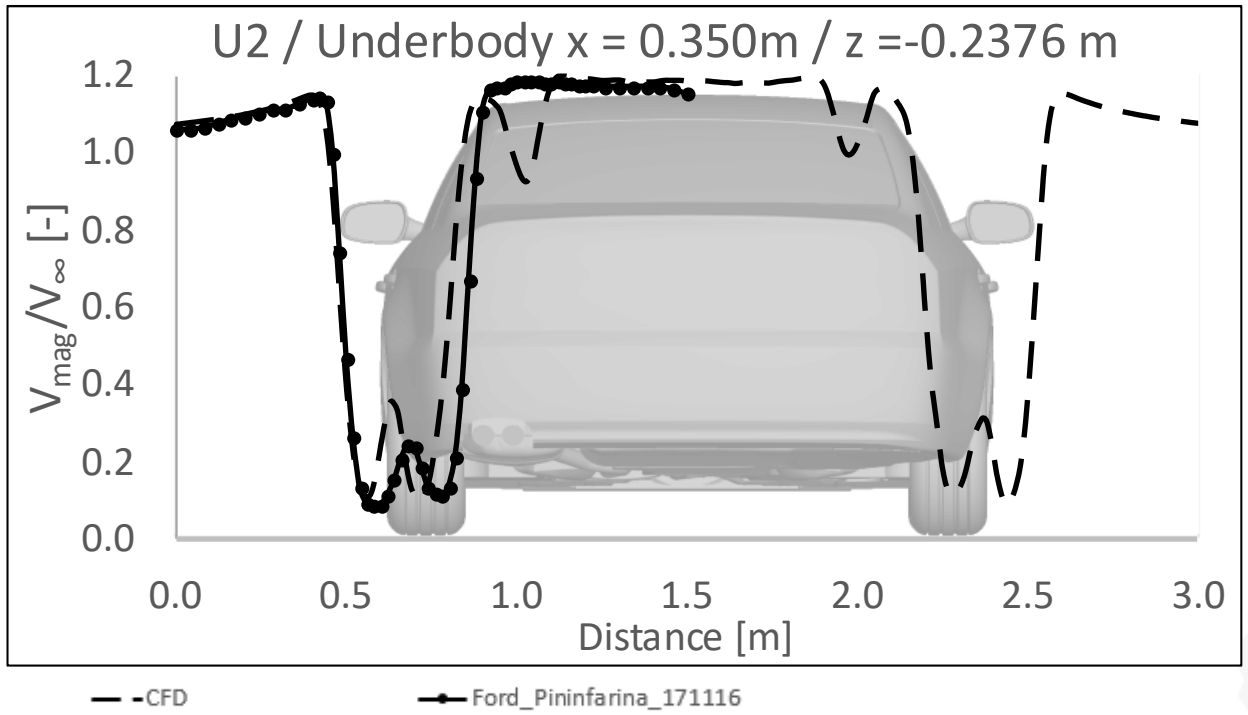
- First three mesh steps are within 1.5 drag counts of each other
- Final mesh step is a larger change (3 drag count improvement)
  - *Change makes the drag predictions more accurate with Multimatic's solver*
- Lift shows more variation overall, driven by changes in rear lift, primarily

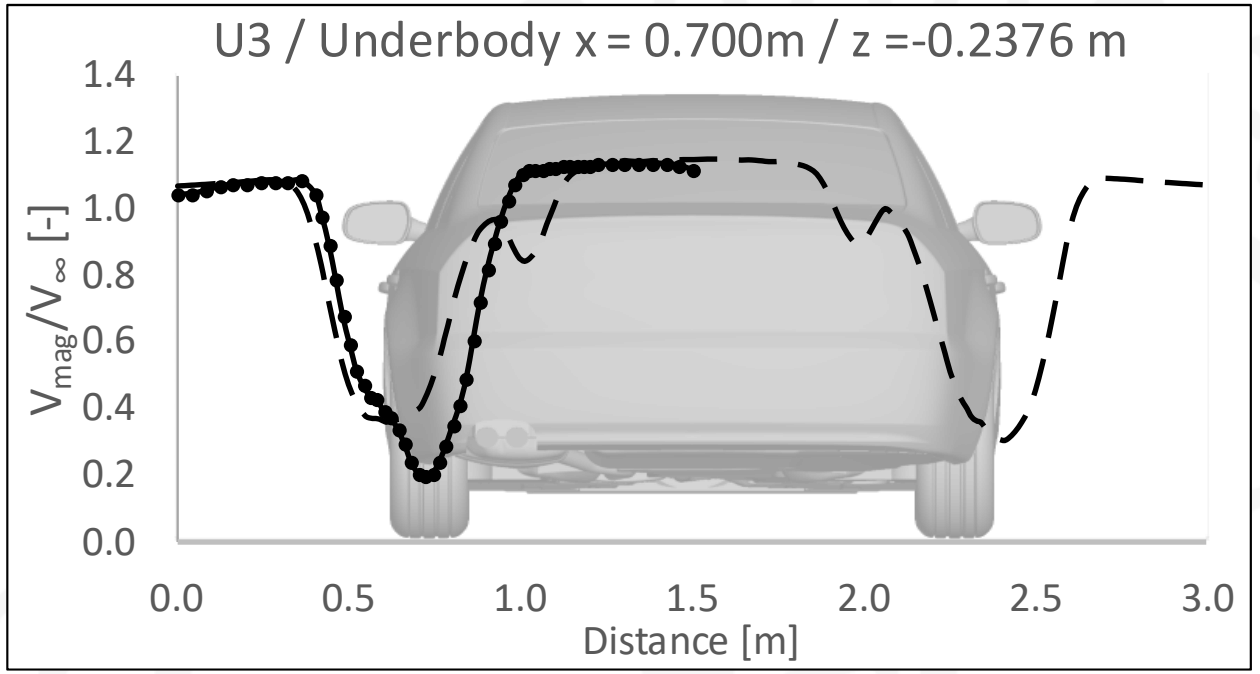


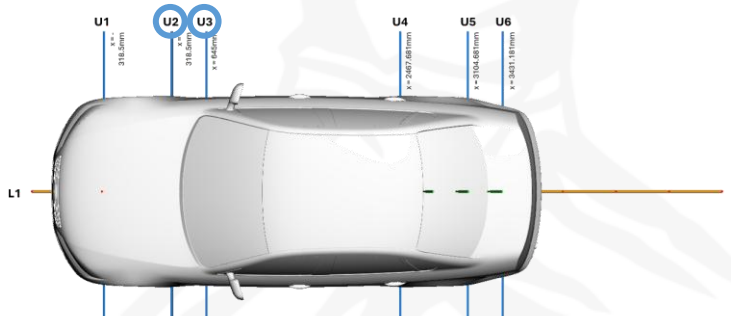
Force results show some variation due to mesh changes, though drag prediction tends to become more accurate

- Mesh changes could still be adopted

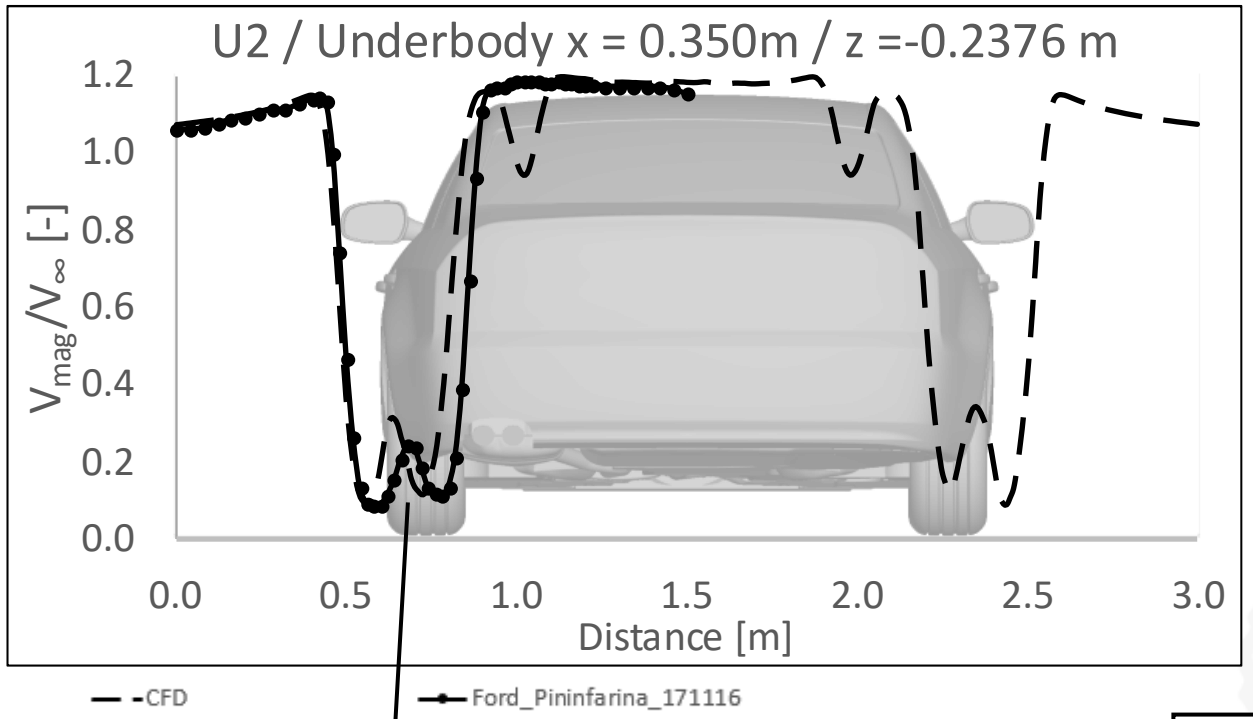
U2, U3 – Baseline





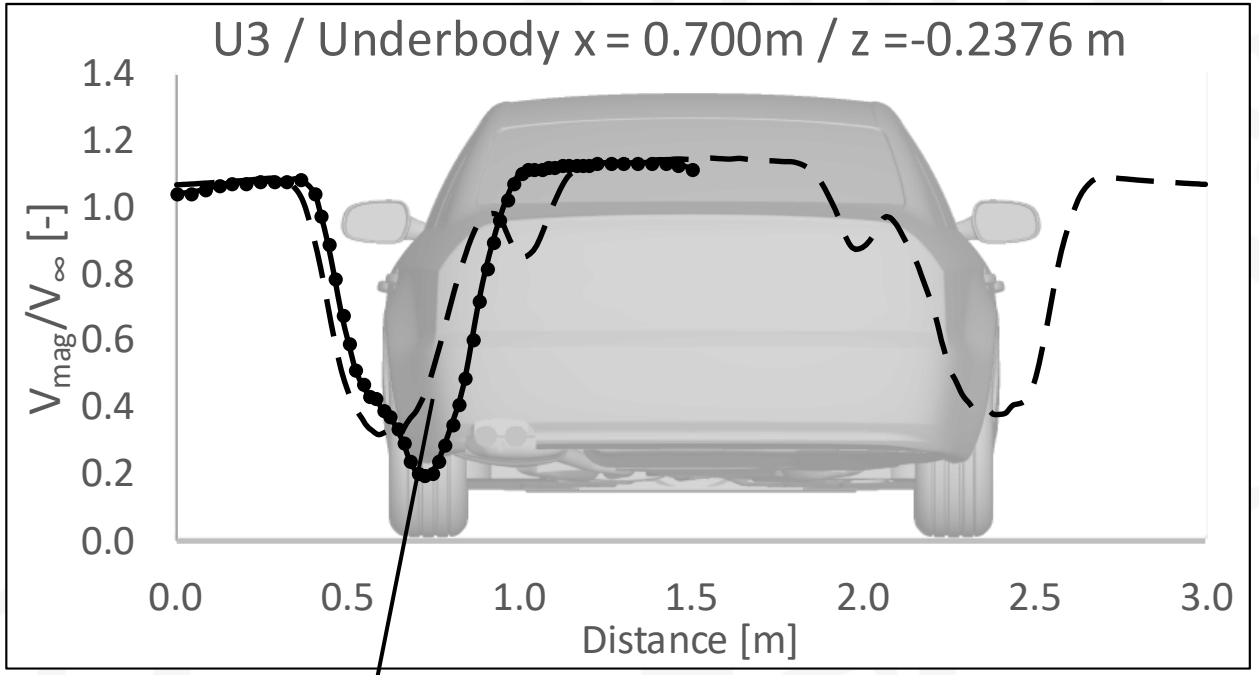


U2, U3 – SF1

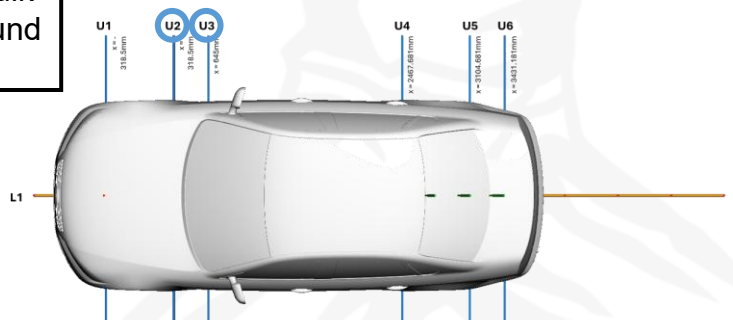


Minor variation in velocity profile.

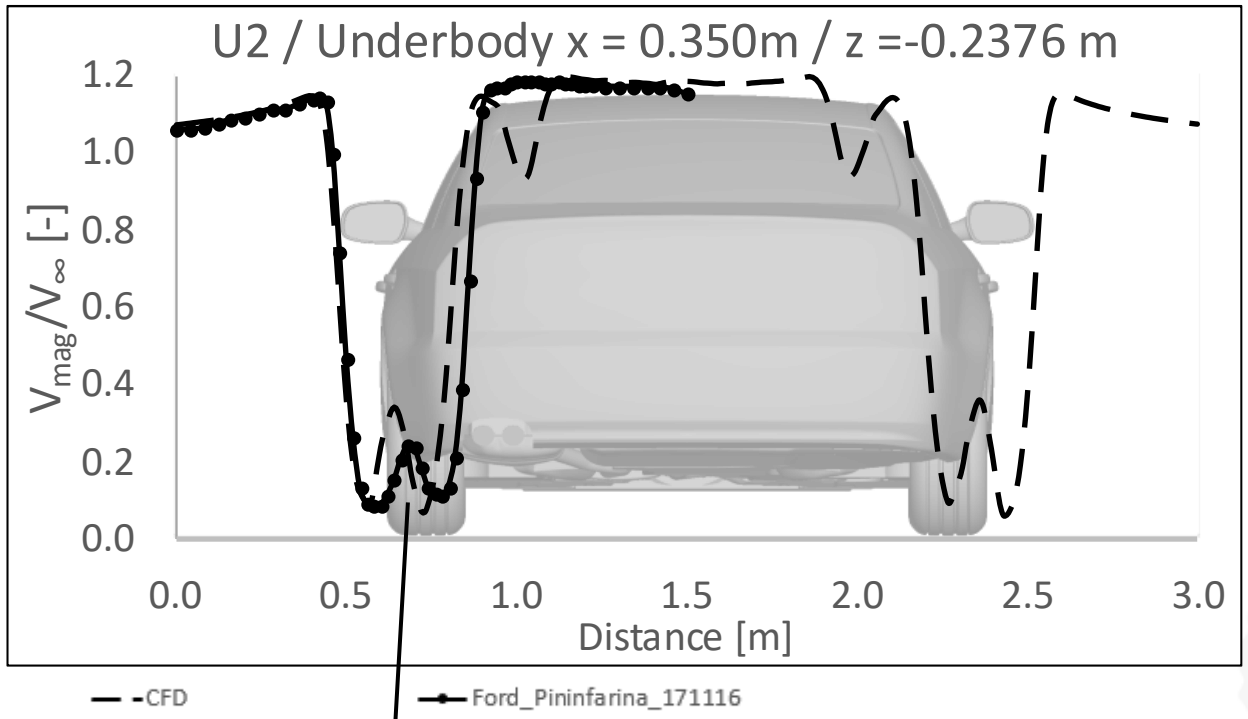
Slight changes in the wake shape, but wake is still more narrow than experiment



Some loss of velocity in the bulk wake, no change in mesh around this region driving change

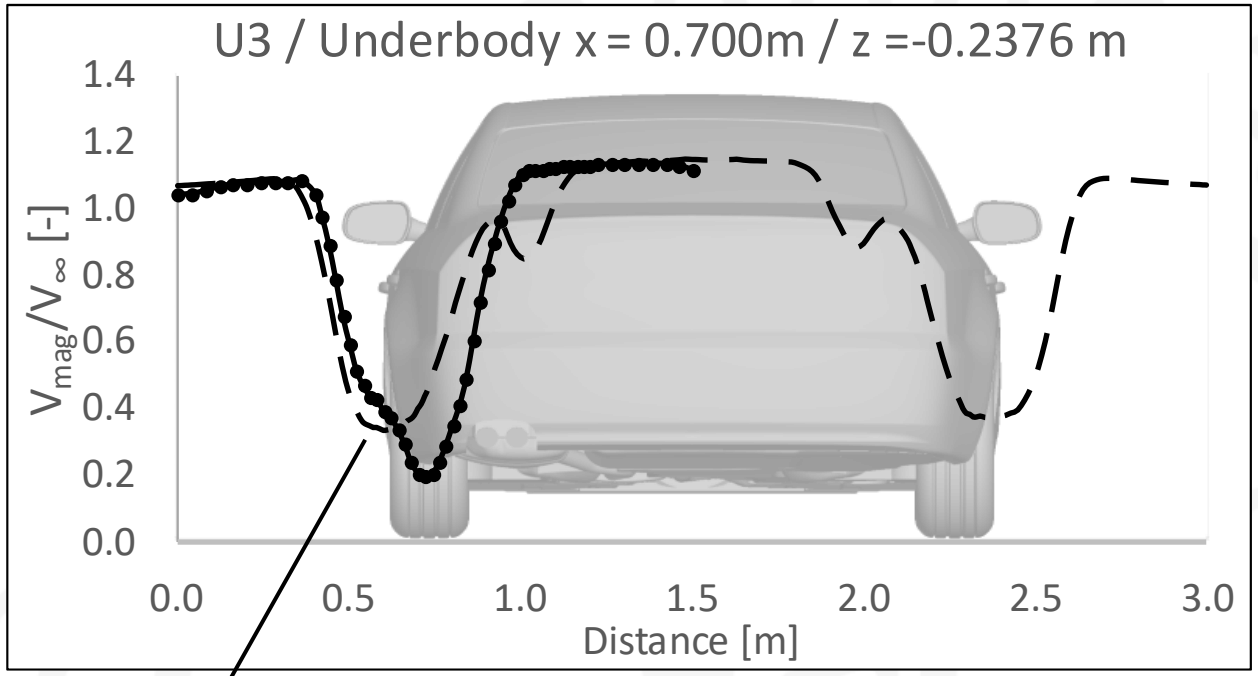


U2, U3 – SF2

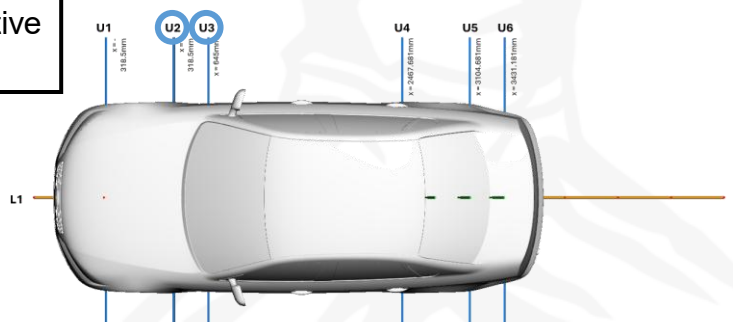


Minor variation in velocity profile.

Slight changes in the wake shape, but wake is still more narrow than experiment

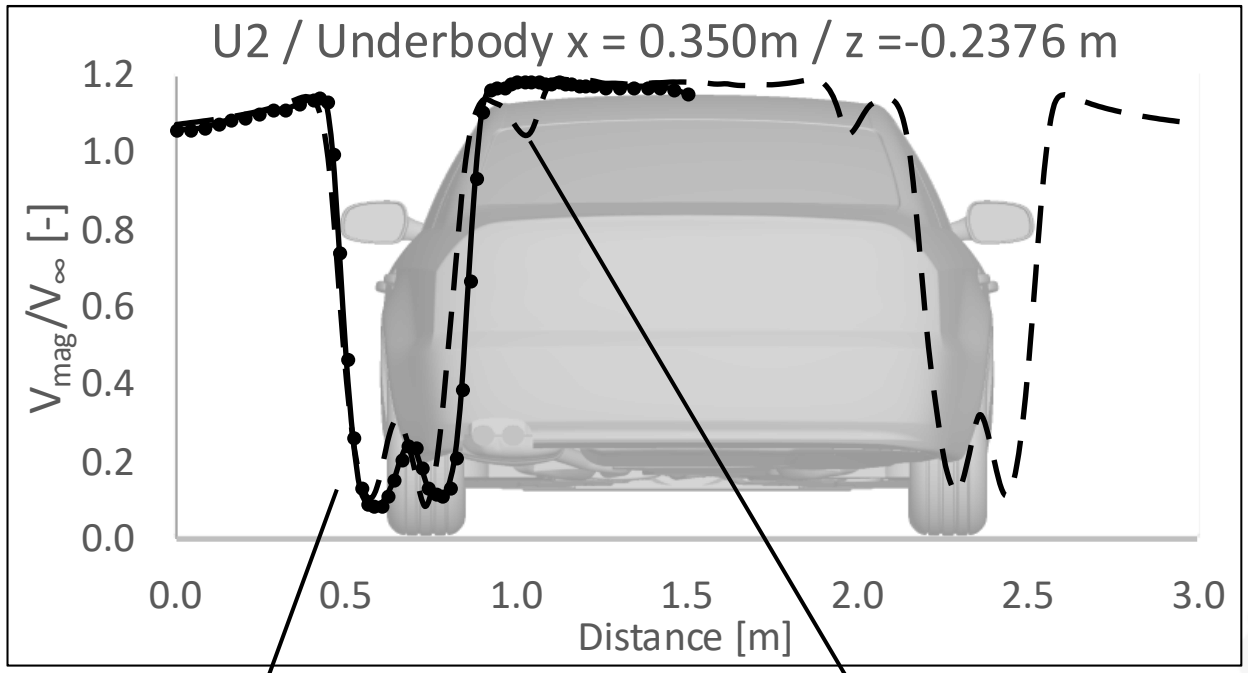


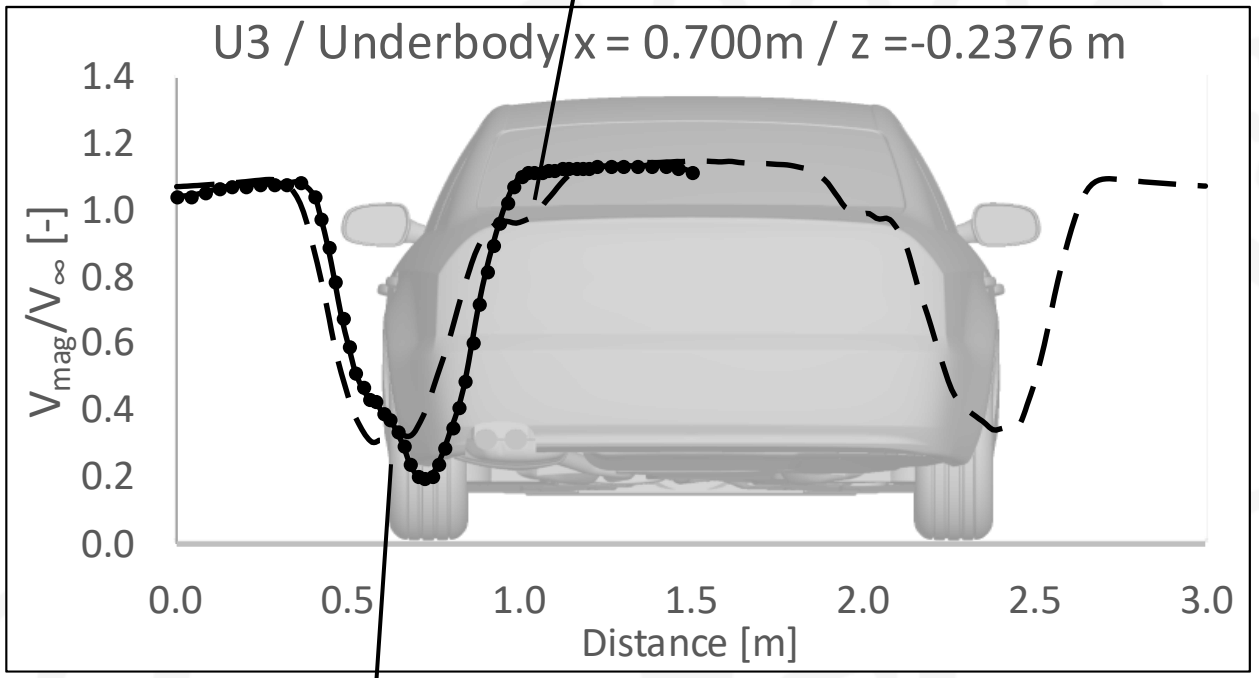
No meaningful change relative to previous step



U2, U3 – SF3

Multimatic





Inner wake profile quite closer to experimental.

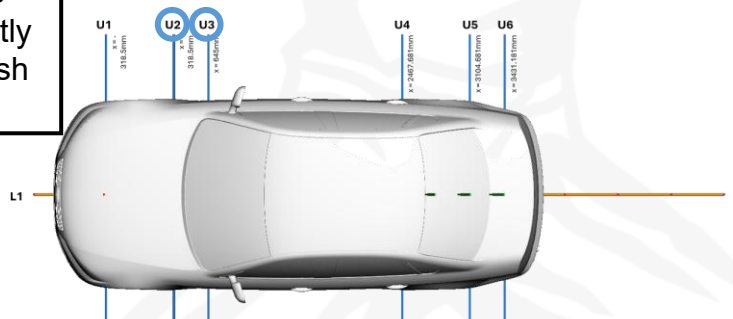
Less velocity deficit in inner wake

Minor variation in the outer region velocity profile. In-line with averaging changes from previous solutions.

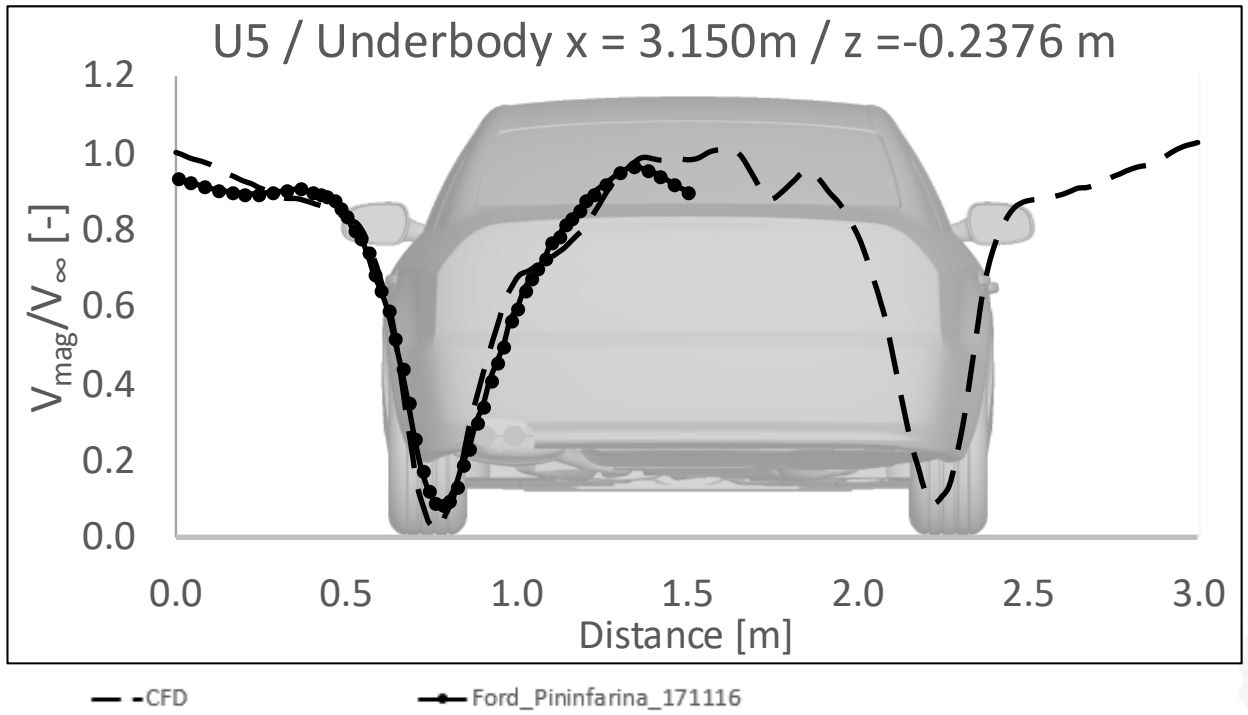
Additional wake refinement does not seem to be necessary to resolve near-wake

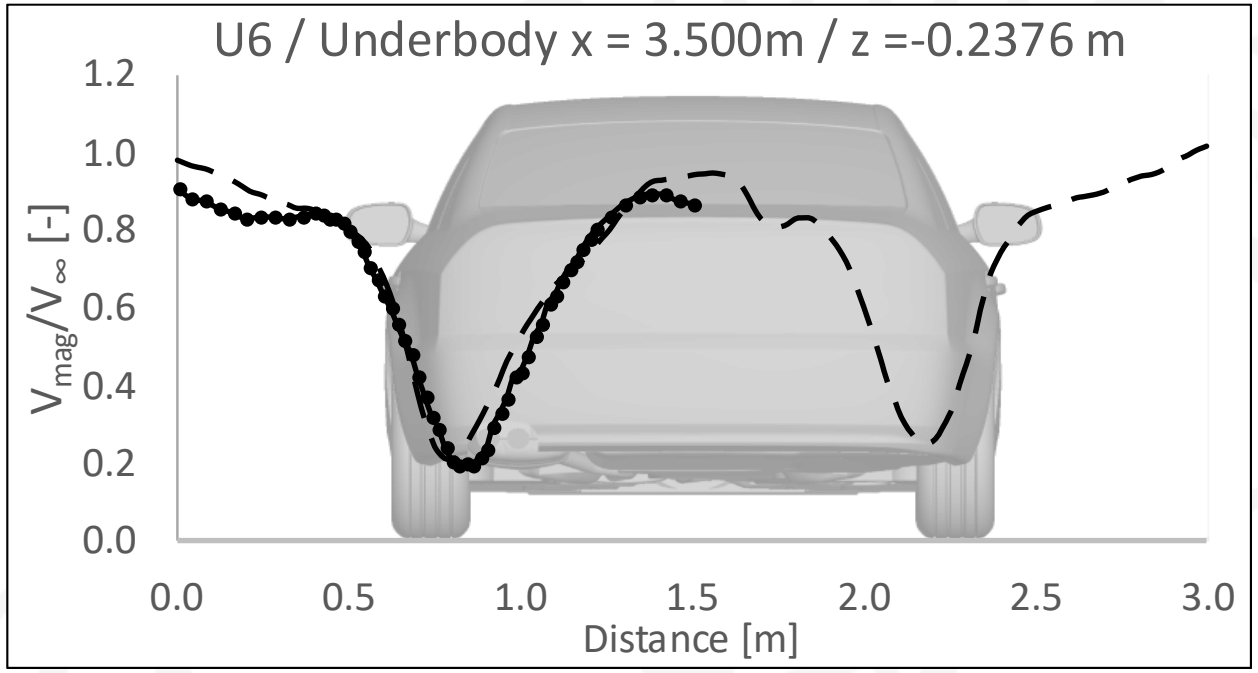
Significant improvement in inner portion of wake prediction

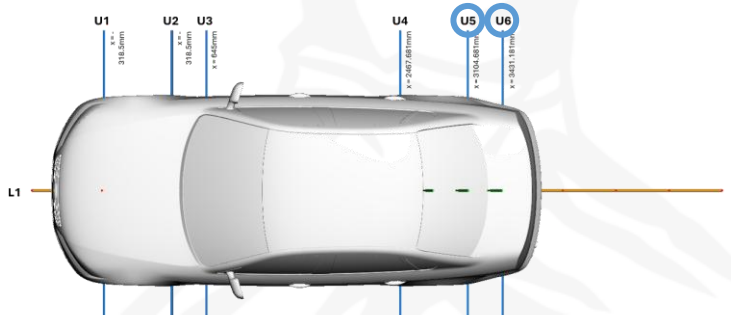
Wake shape shows more variation, but not significantly different from previous mesh steps



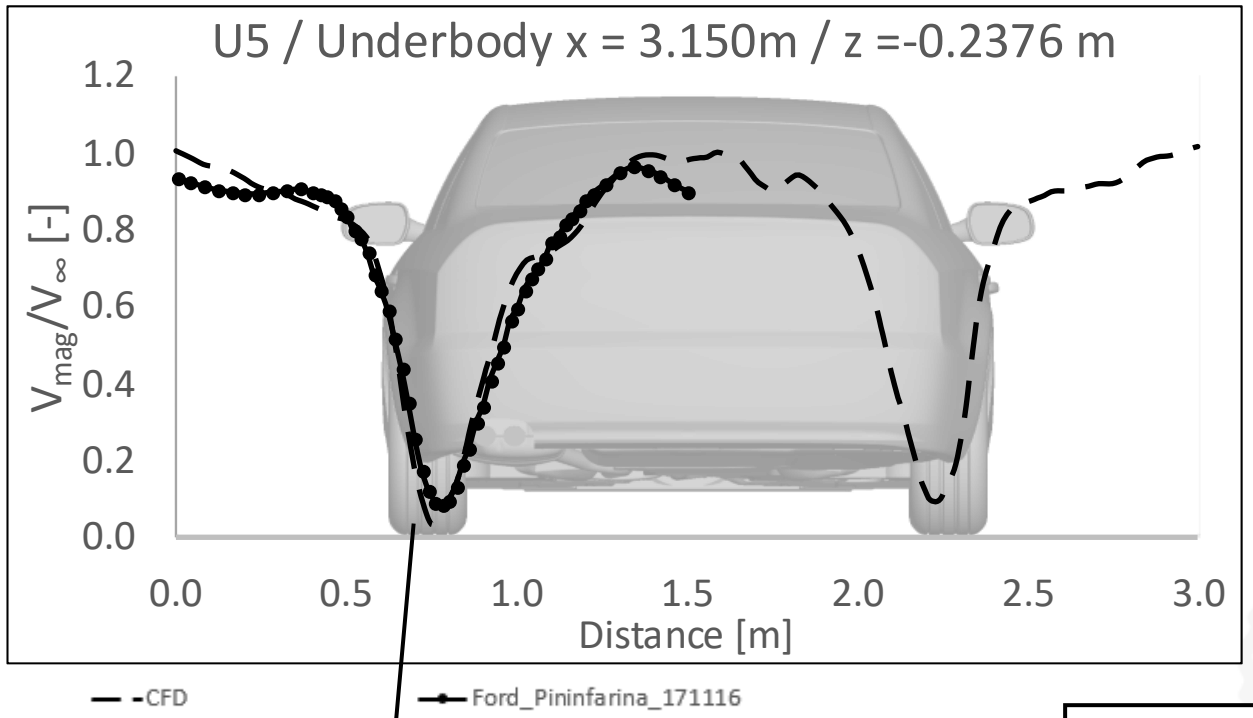
U5, U6 – Baseline



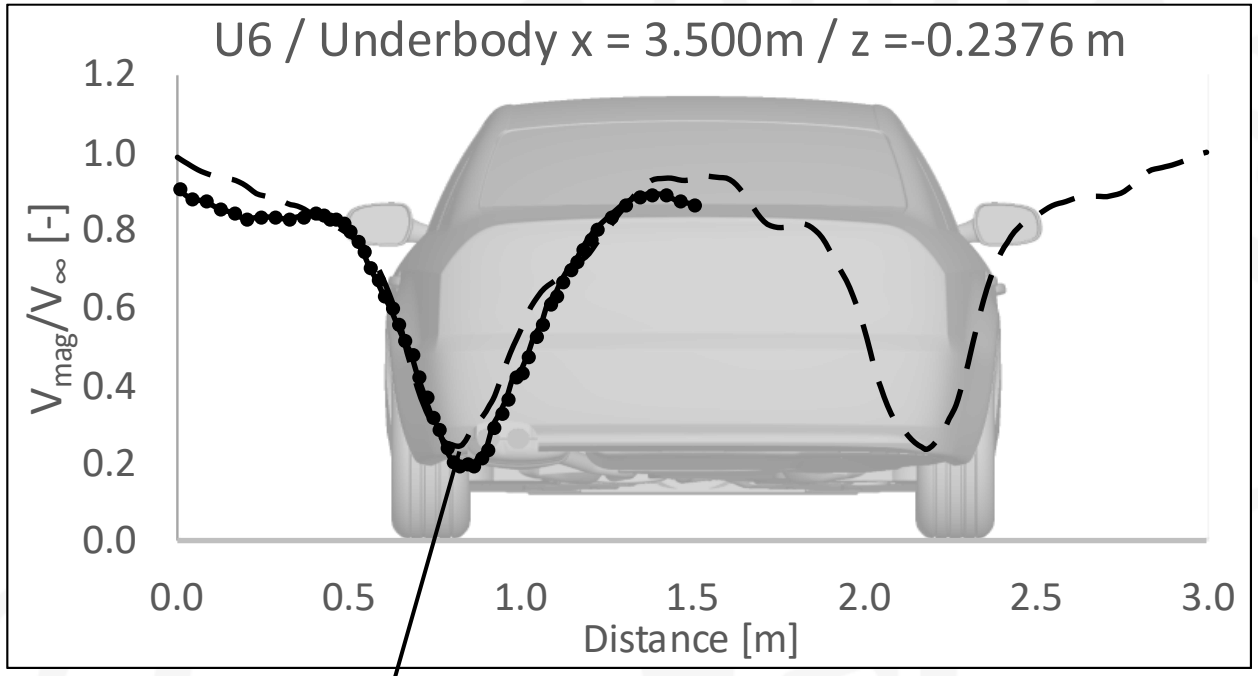




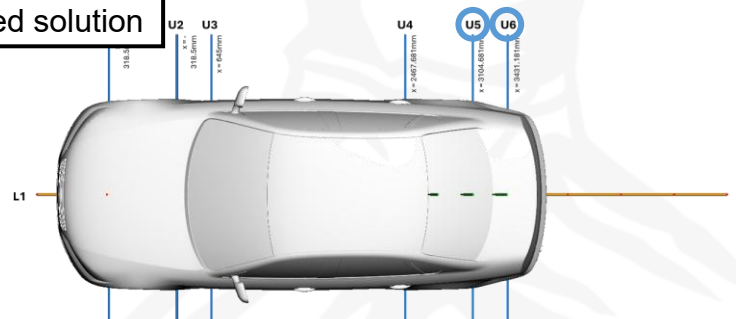
U5, U6 – SF1



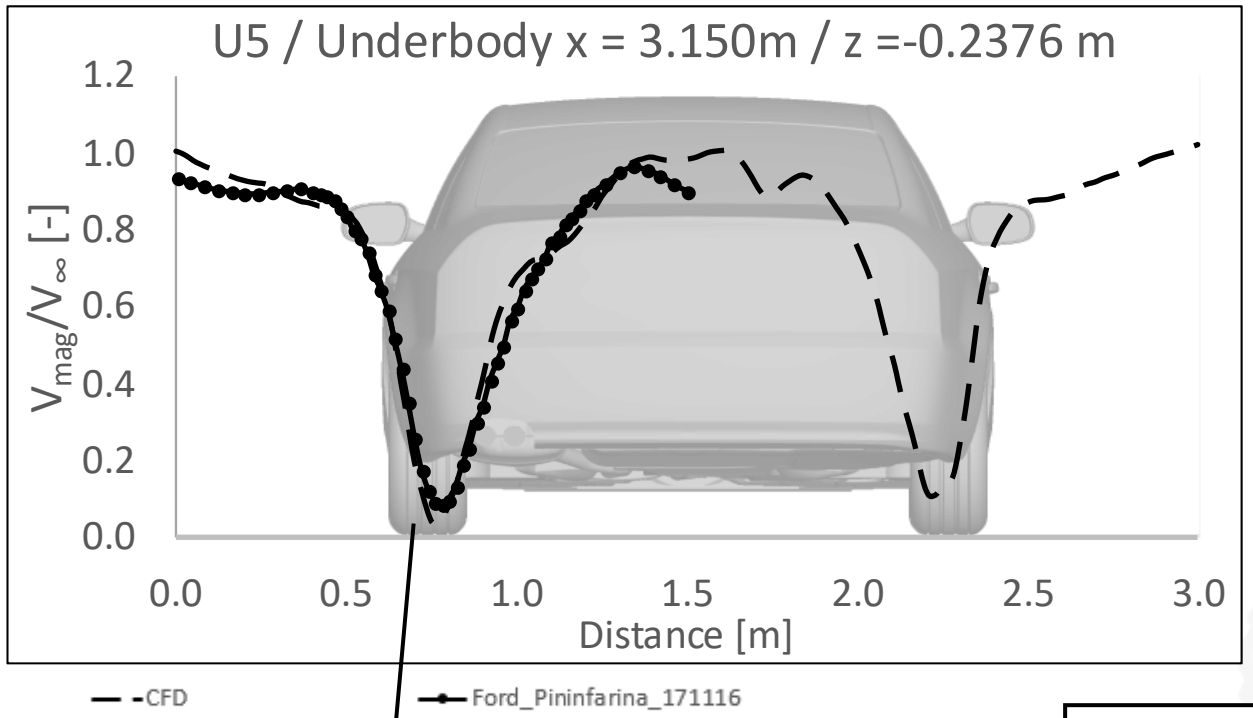
No meaningful change in bulk wake predictions, variation due to uncertainty in averaged solution



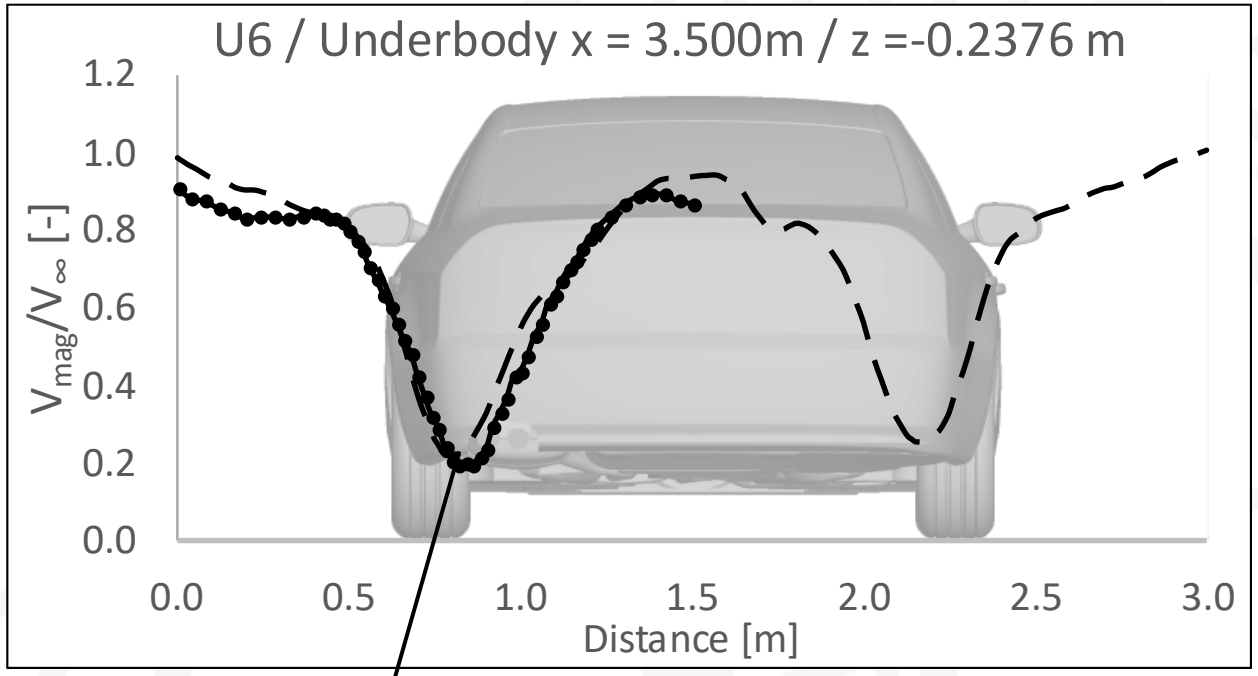
No meaningful change in bulk wake predictions, variation due to uncertainty in averaged solution



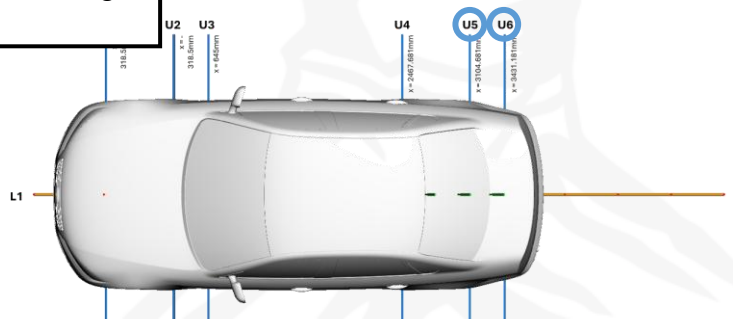
U5, U6 – SF2



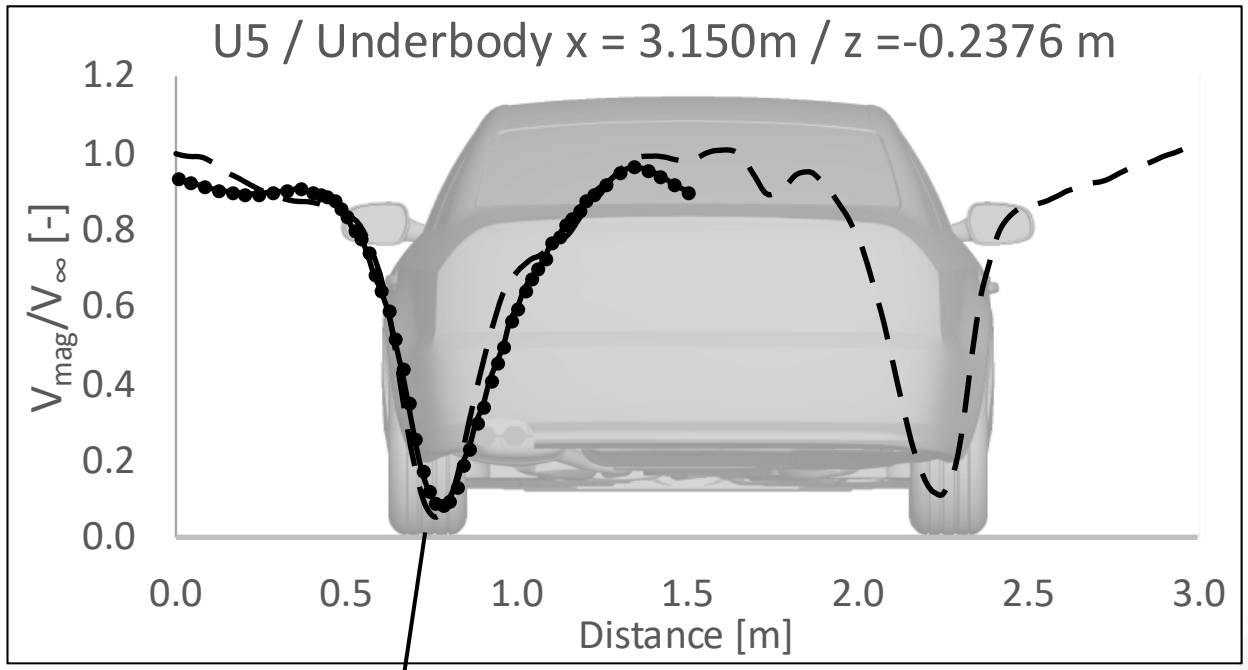
No meaningful change in bulk wake predictions, variation due to uncertainty in averaged solution

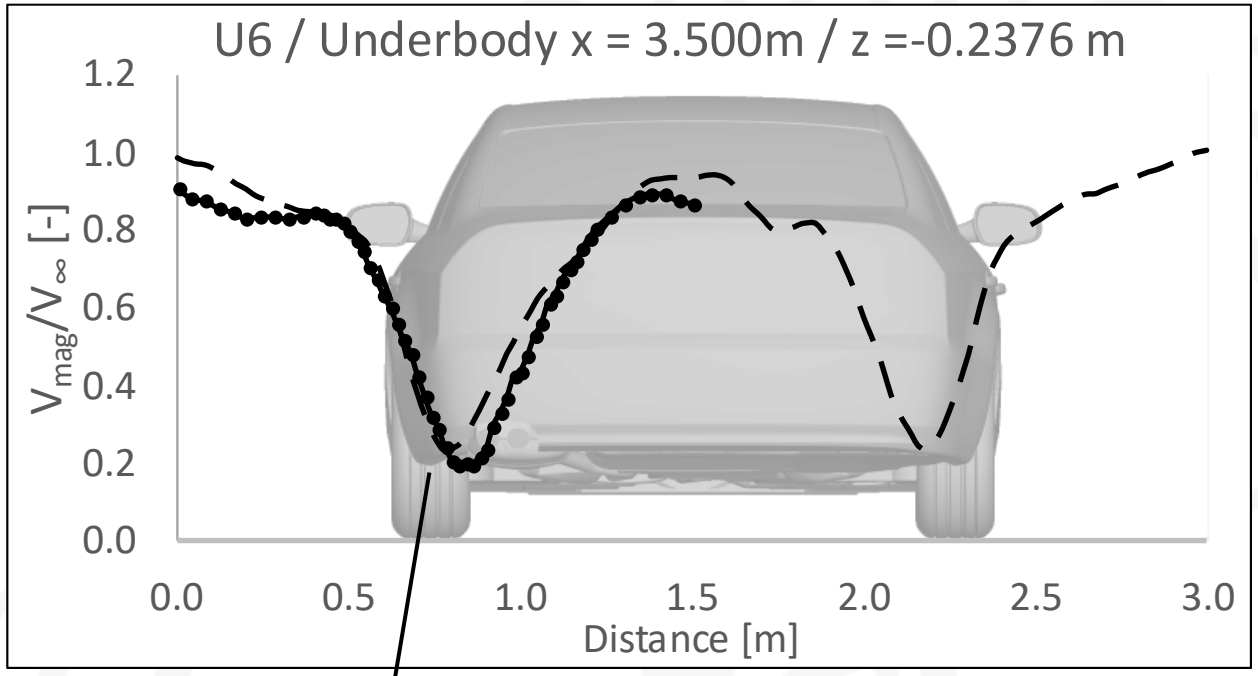


Slightly more variation in rear tire wake, though no nearby mesh changes



U5, U6 – SF3



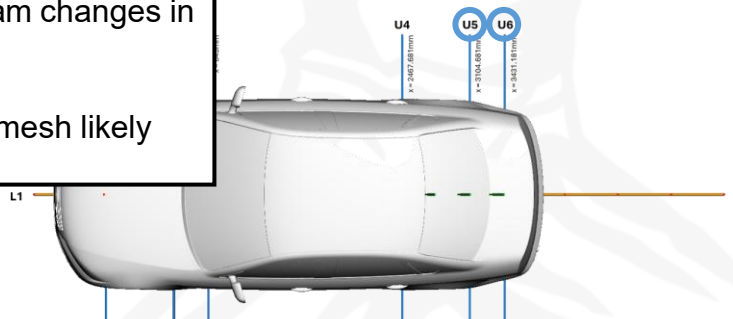


Outer tire wake most accurate of all meshes.

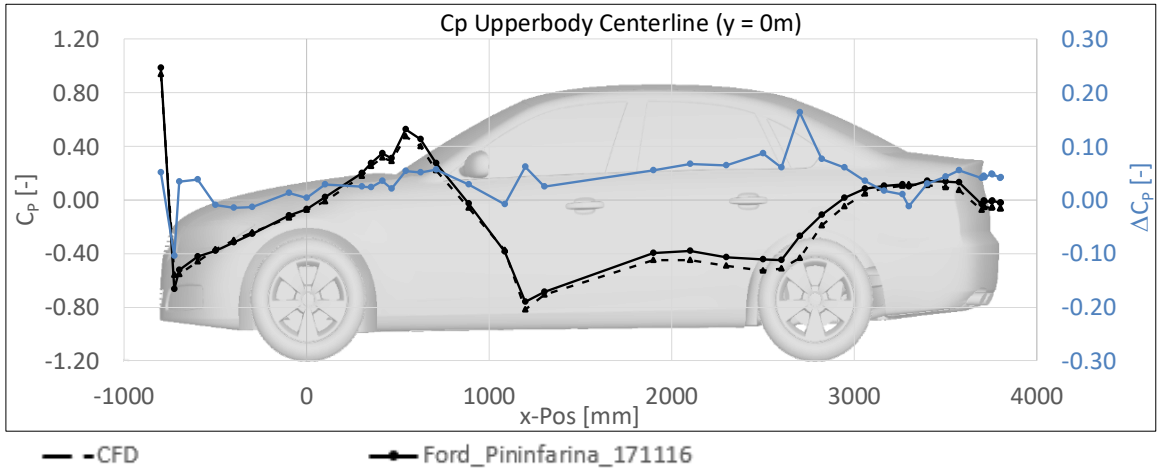
Mesh coarsening in this region from removal of 4 mm tire wake sweep rule

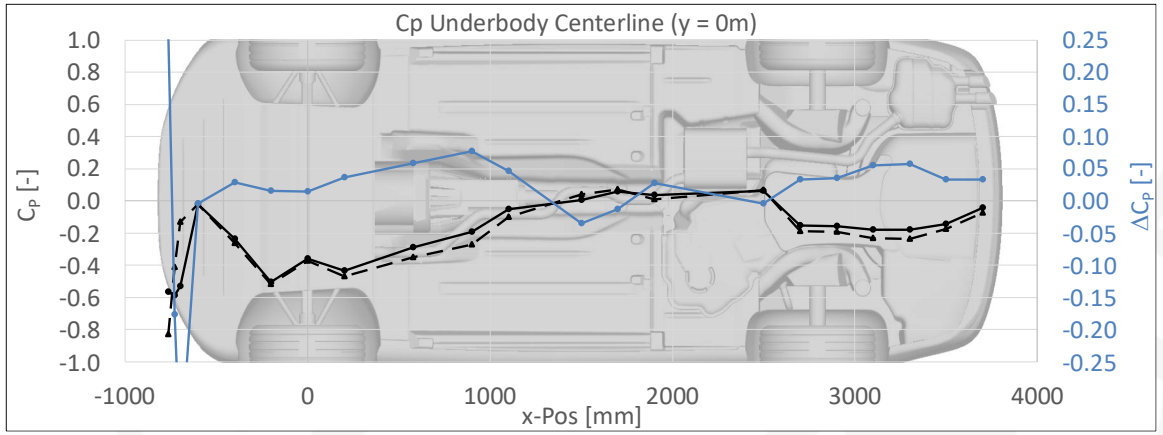
More energy in wake/less wide overall. Could be a combination of wake propagation/upstream changes in front tire wake.

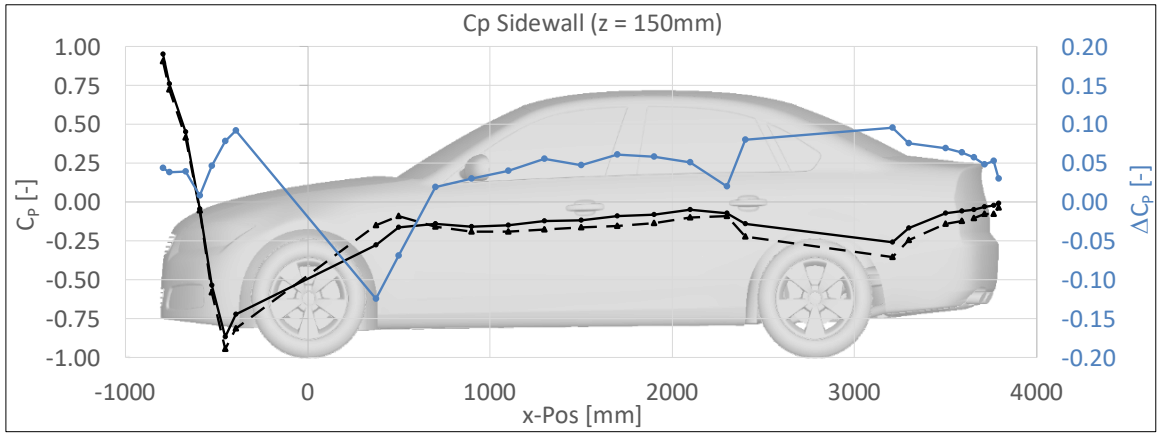
Front tire wake variation seen in SF3 mesh likely major cause

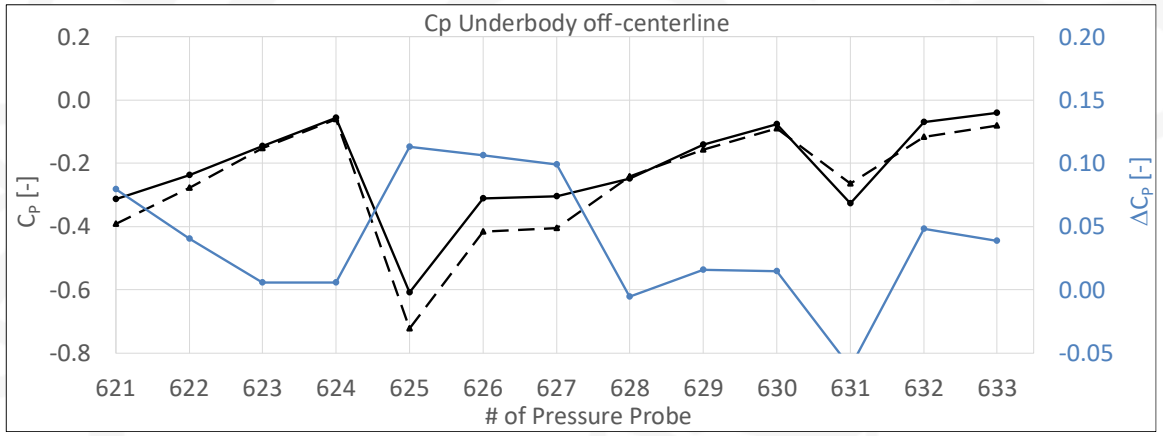


Primary Pressure Taps – Baseline

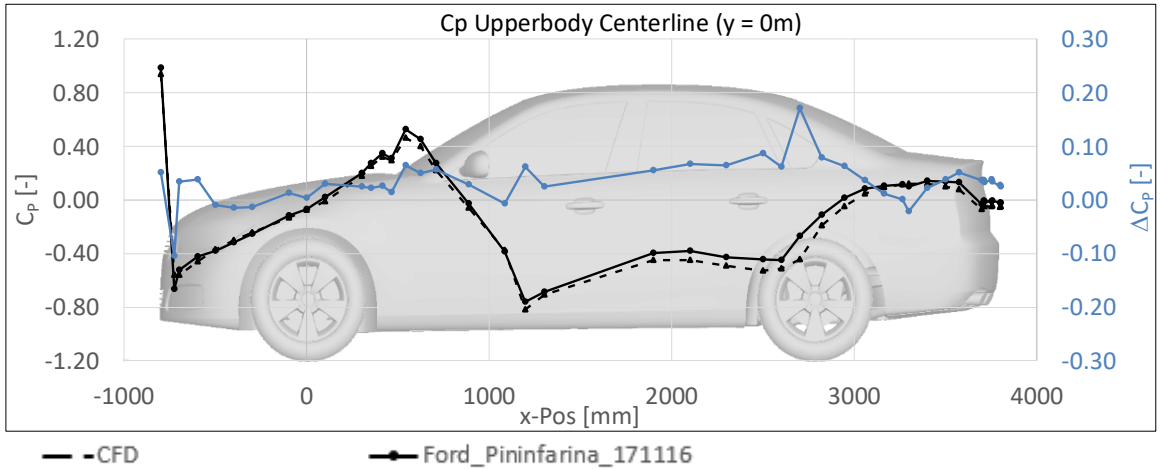


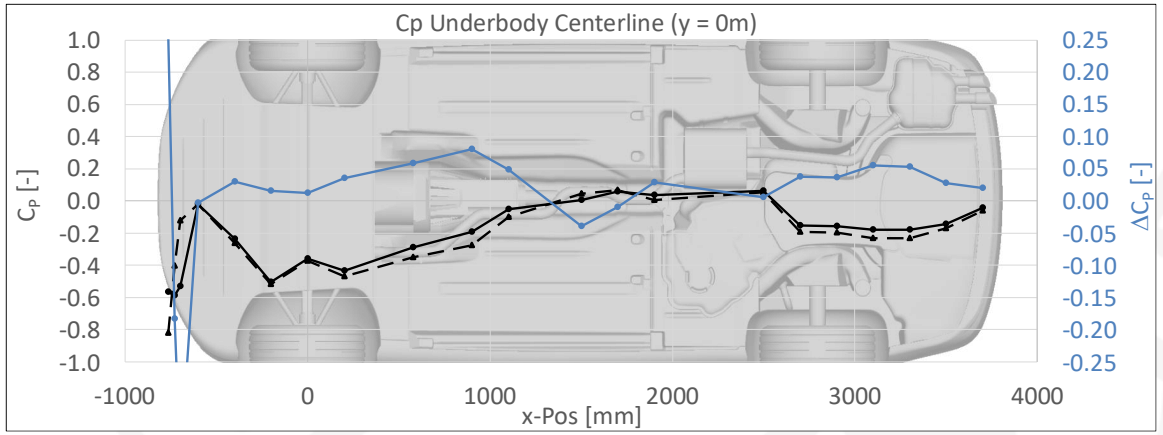




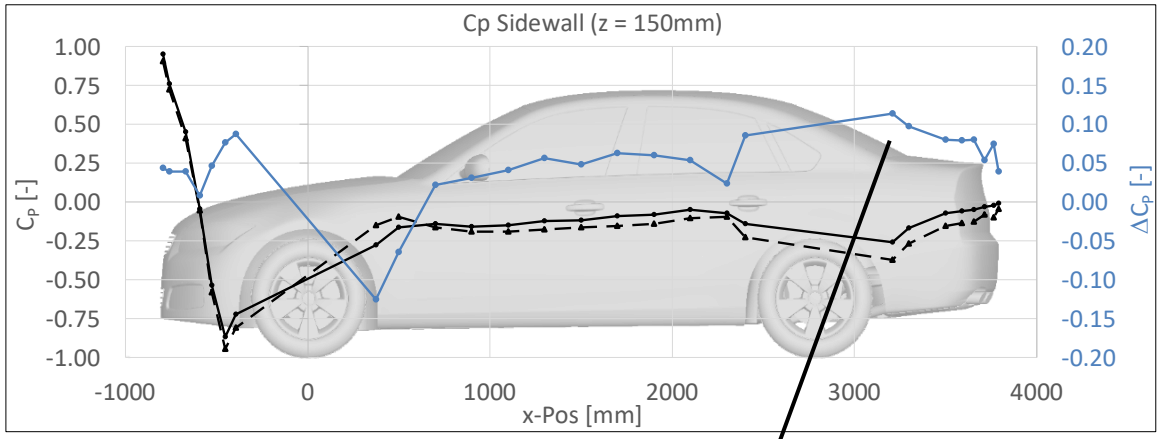


Primary Pressure Taps – SF1



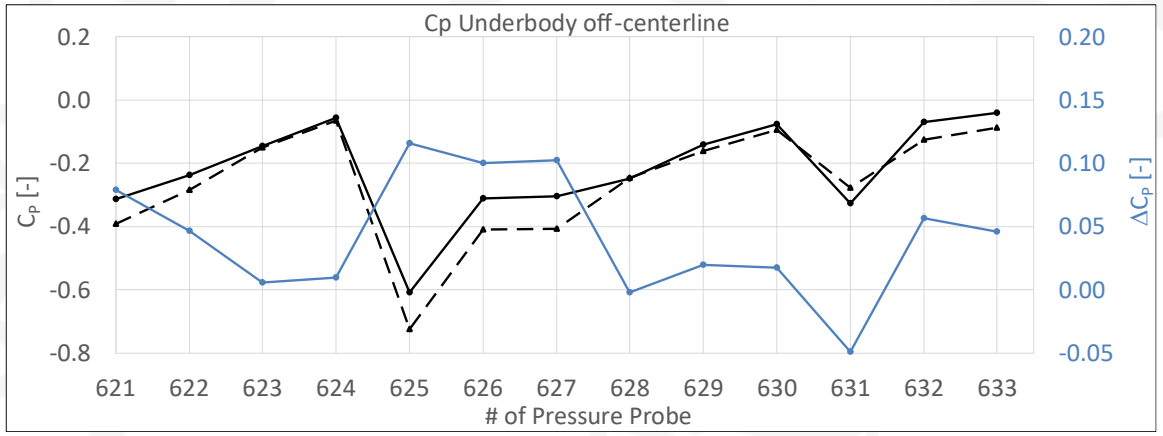


No meaningful change in centerline probes



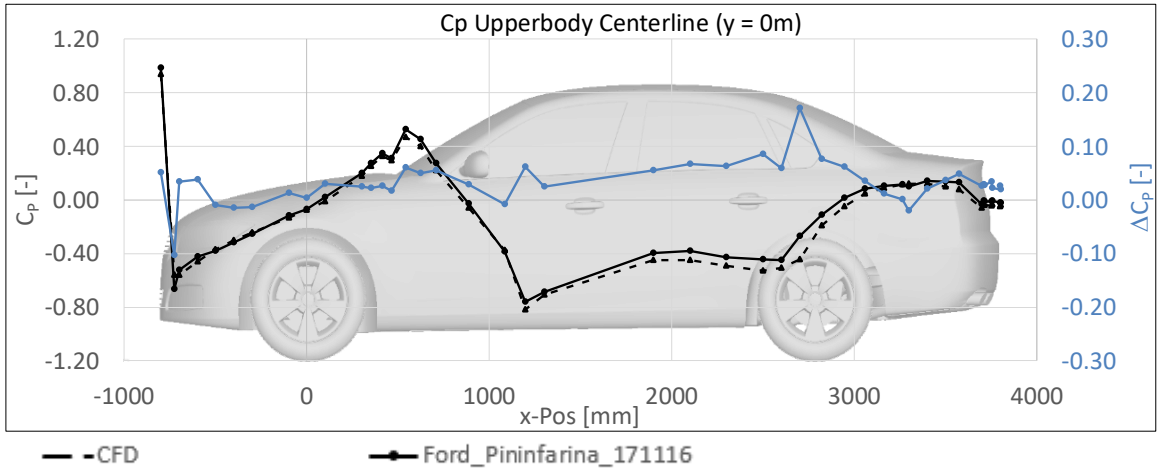
More variation in downstream pressure. No change in mesh around this area, so no clear indication of cause

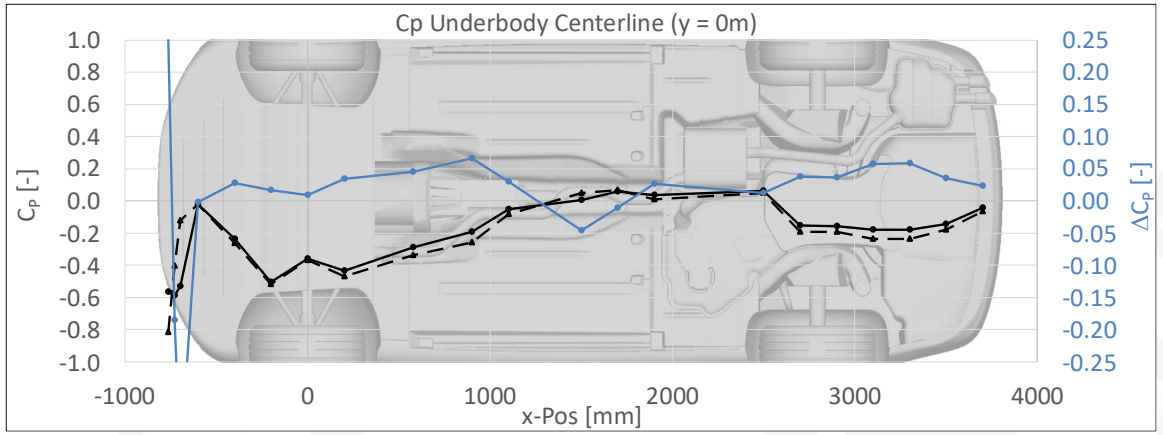
Seems to be variation in the averaged solution, rather than a mesh-driven result



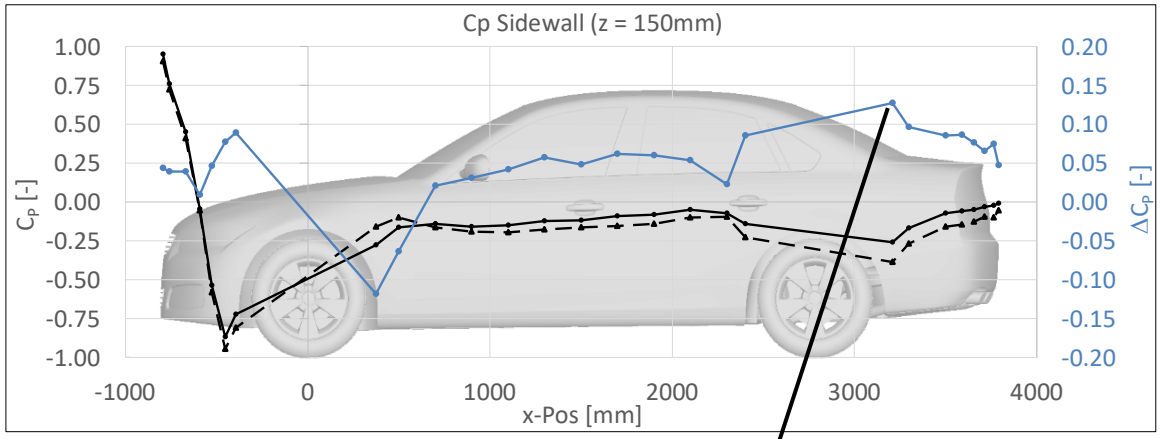
No meaningful change in off-centerline probes

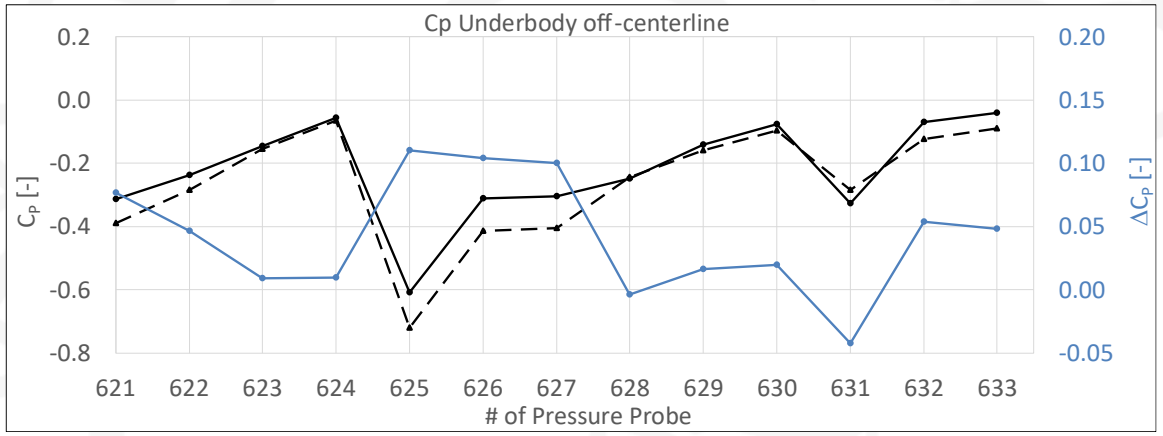
Primary Pressure Taps – SF2





No meaningful change in centerline probes



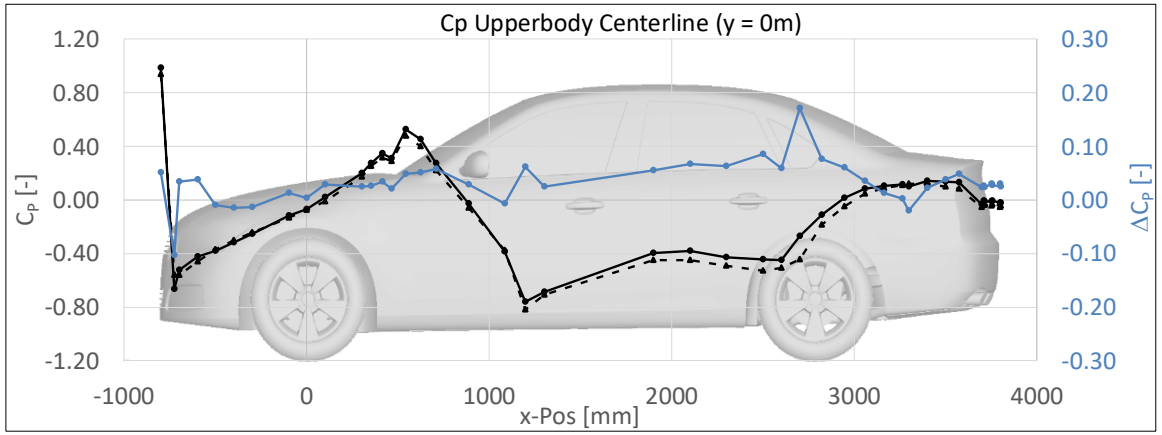


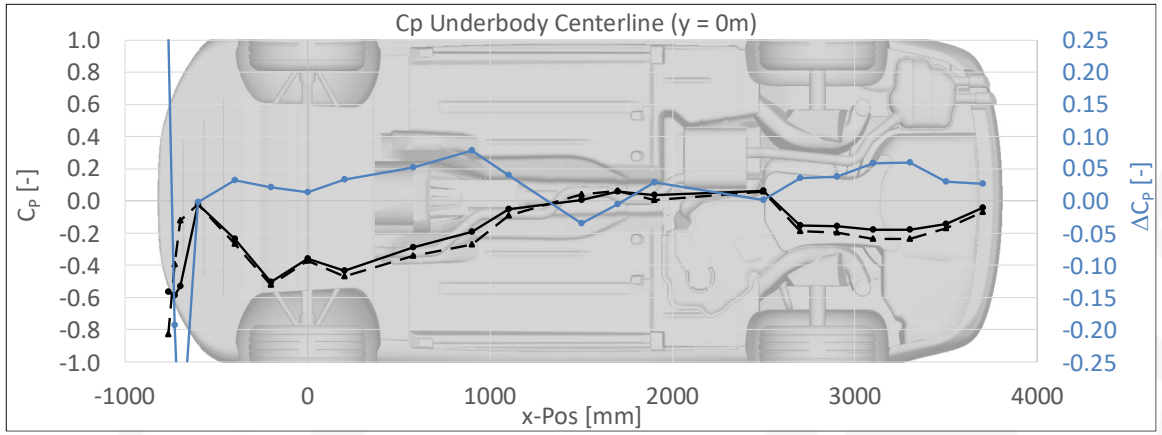
No meaningful change in off-centerline probes

Rear fender pressure very similar to SF1 mesh.

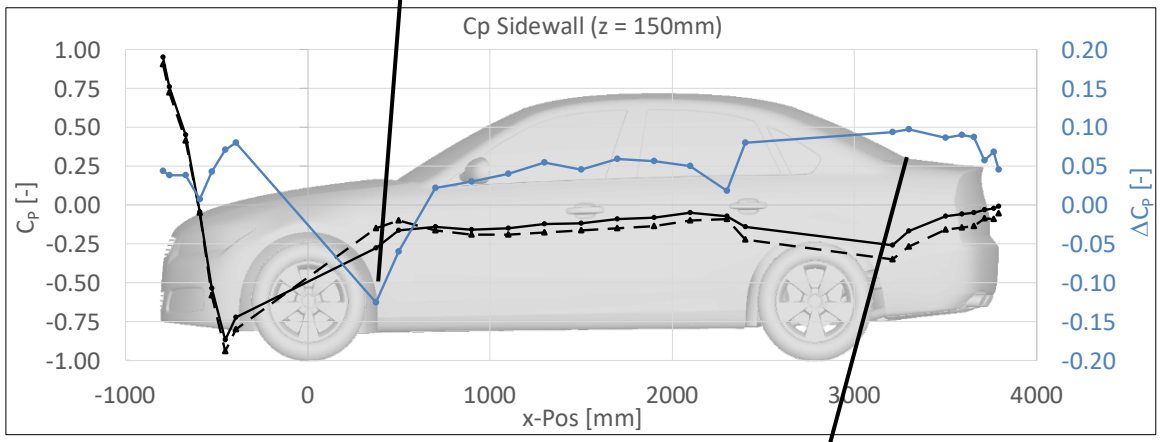
Seems to be an unsteady flow phenomenon that can be easily triggered by small mesh changes

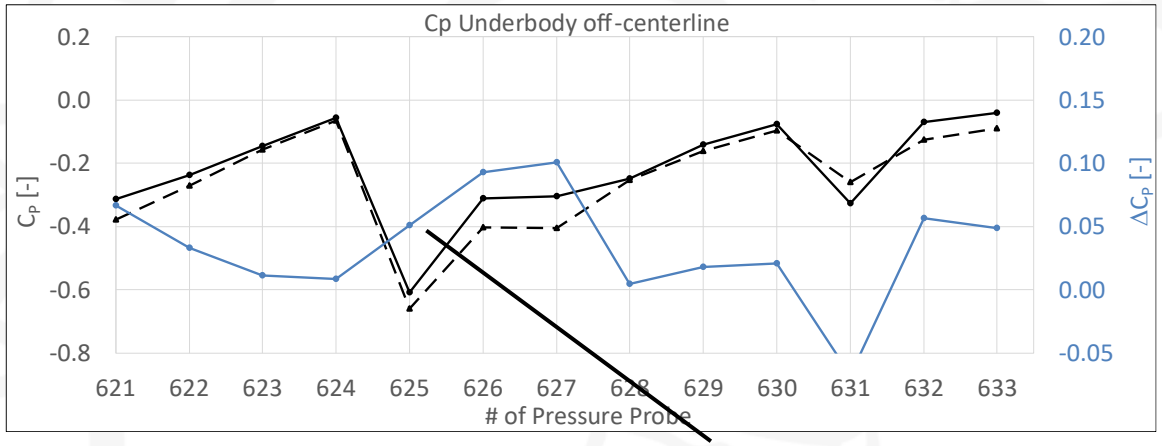
Primary Pressure Taps – SF3





Slightly less accurate immediately downstream of front tire. Likely caused by removal of tire wake refinement





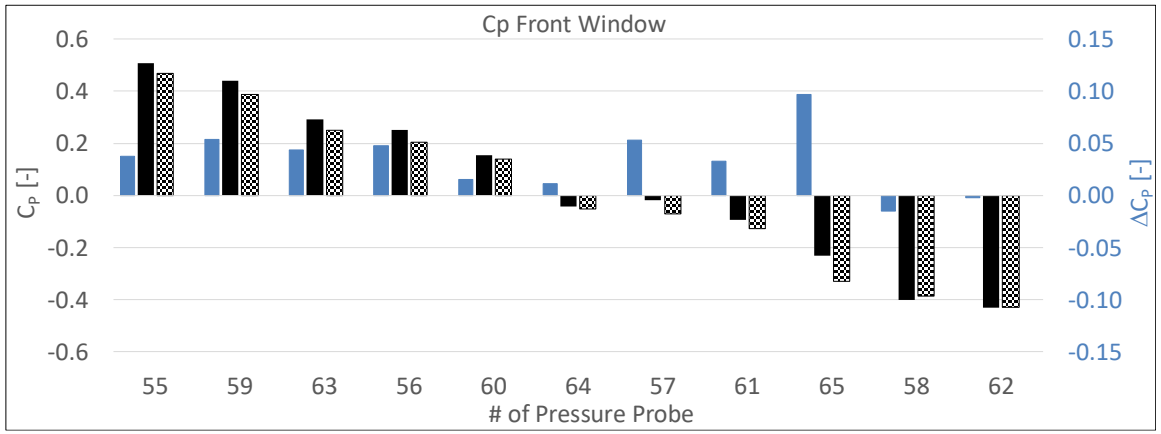
Rear fender pressures become more accurate relative to SF1/SF2 meshes, despite removal of 4 mm tire wake refinement.

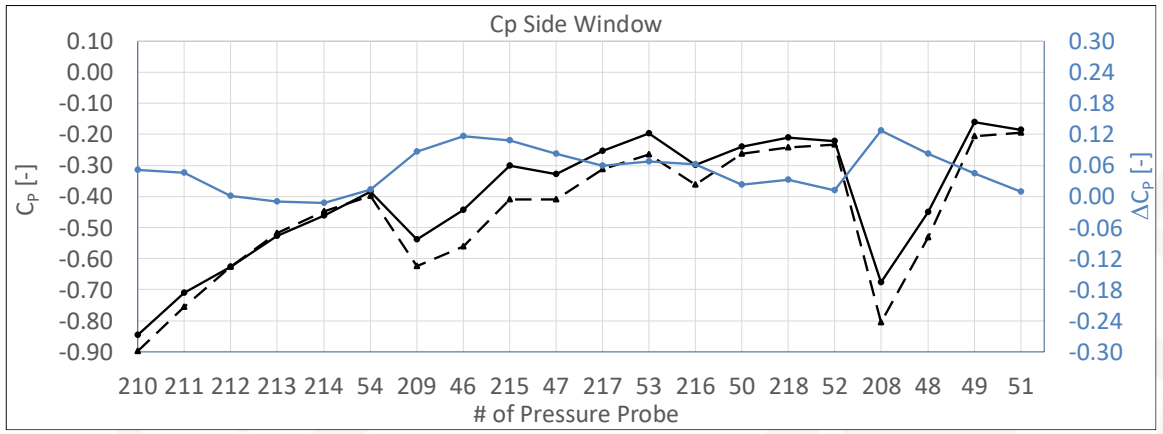
More evidence that there is an unstable flow feature present, which additional mesh refinement is not necessarily capturing

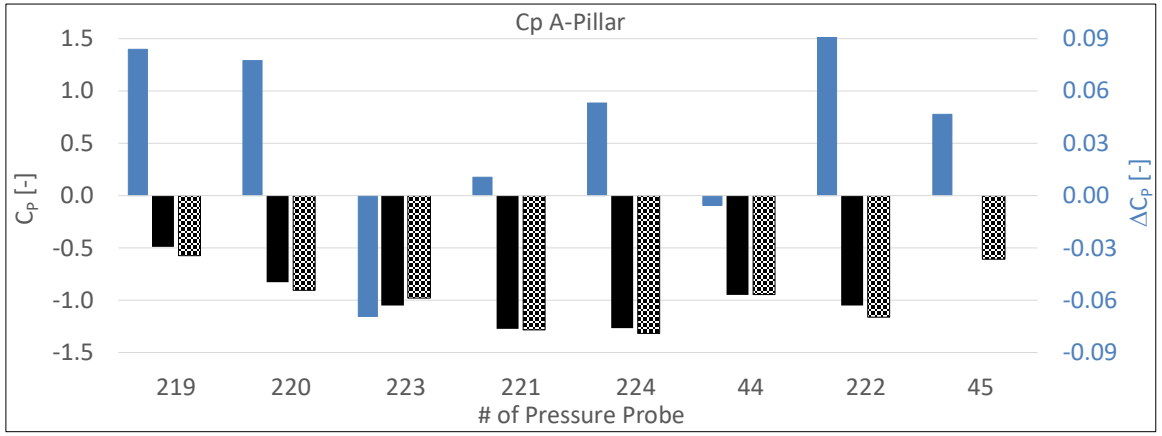
Probes just downstream of front tire become much more accurate.

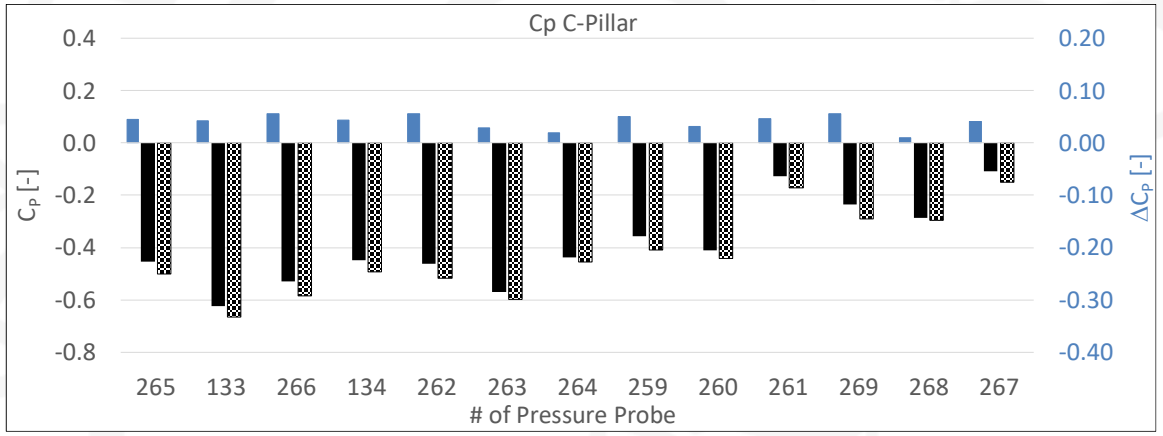
Suggests 4 mm tire wake refinement over-predicts separation on wheelhouse to floor transition

Greenhouse Pressure Taps – Baseline



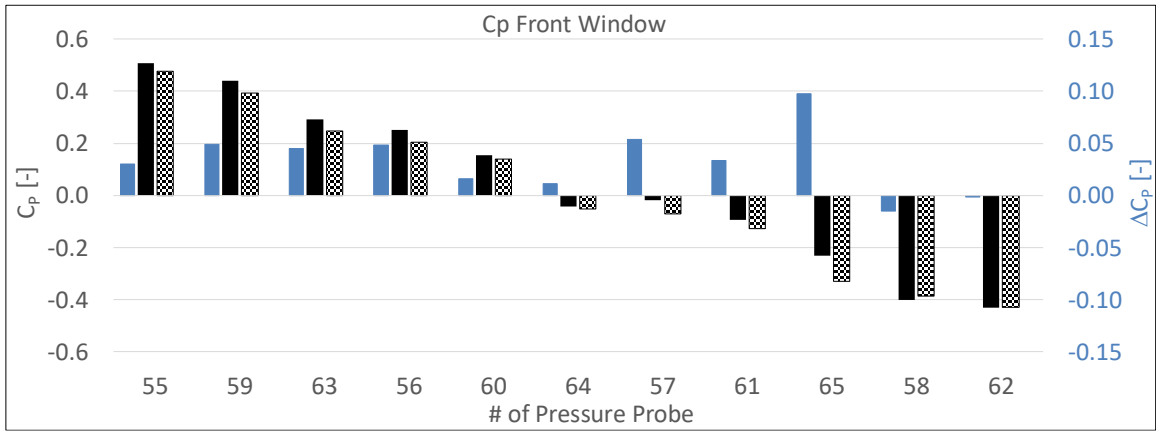




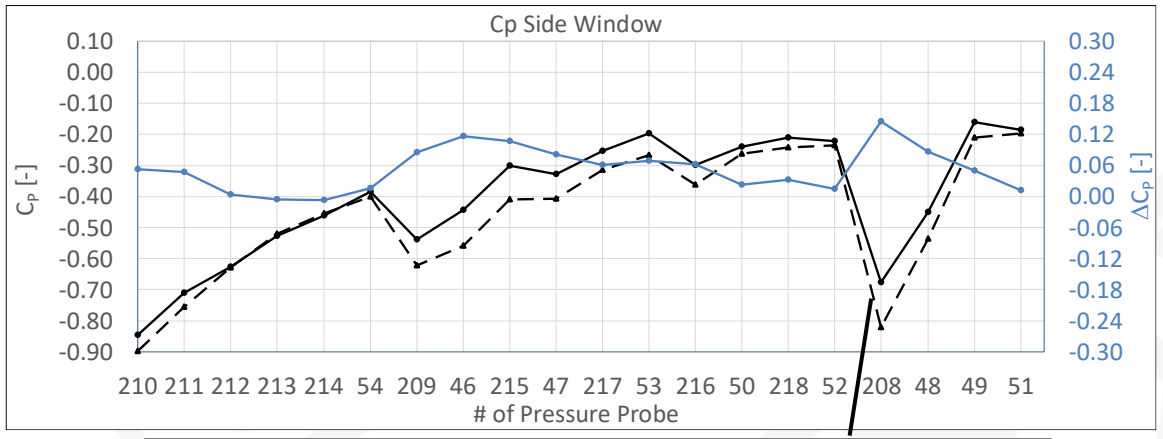


■ Ford Pininfarina 171116 ▨ CFD ■ Test - CFD

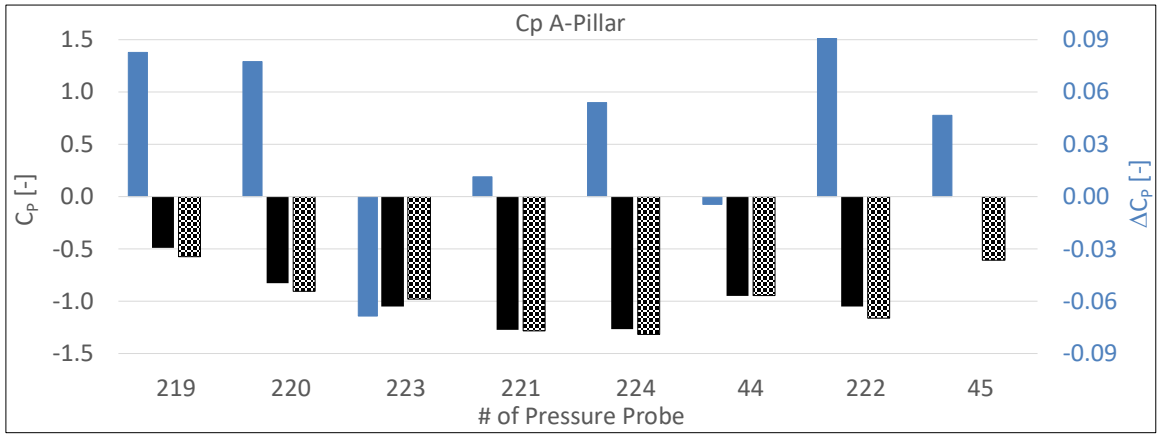
Greenhouse Pressure Taps – SF1



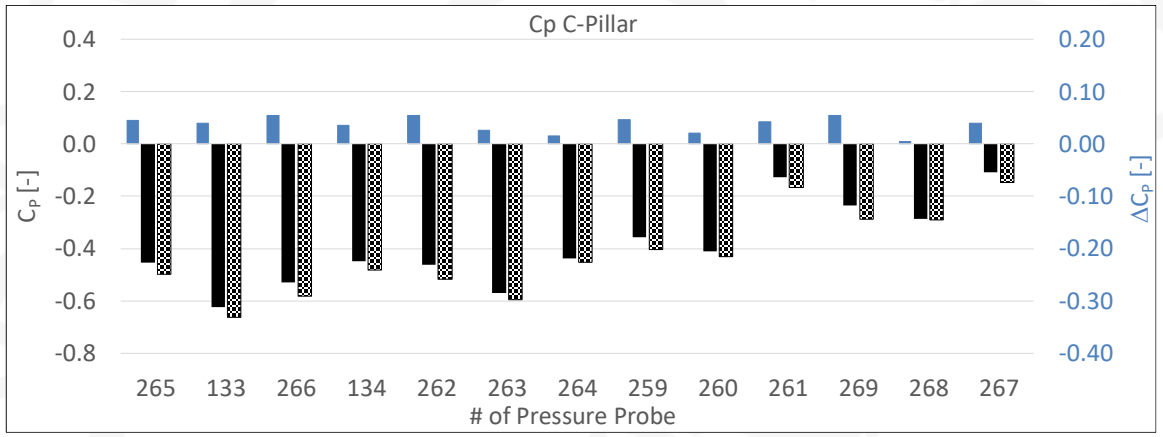
Front window is comparably predicted to baseline



Probe 208 sees slightly more change. Separation around mirror stem is varying slightly more



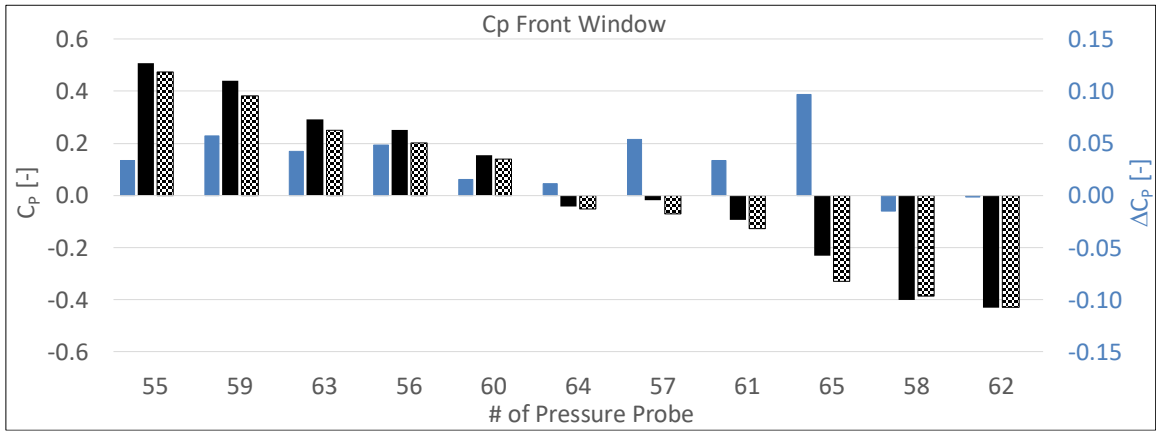
A-pillar is comparably predicted to baseline



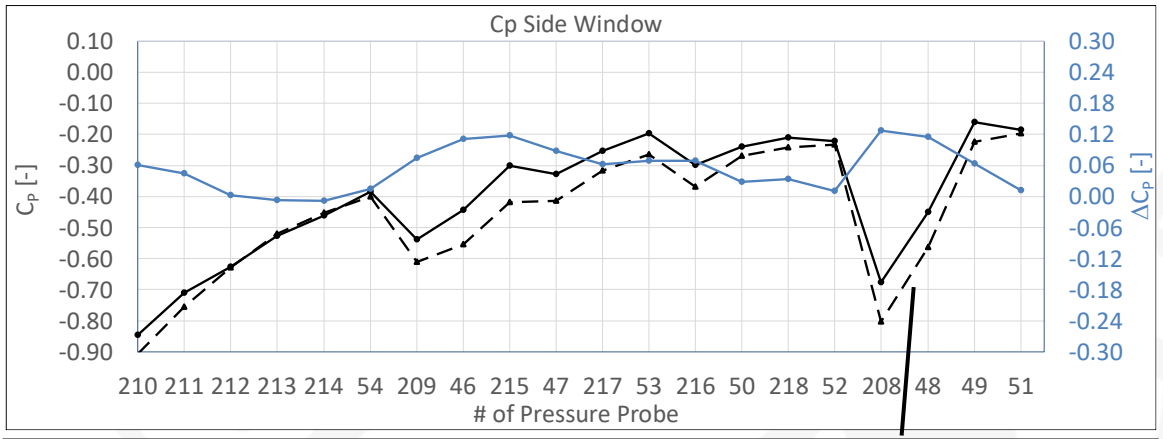
C-pillar is comparably predicted to baseline

■ Ford Pininfarina 171116 ▨ CFD ■ Test - CFD

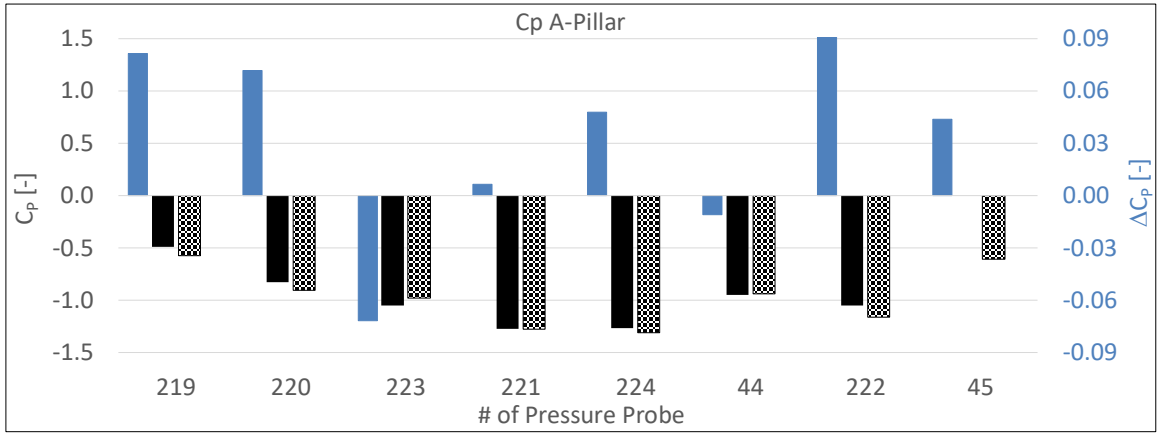
Greenhouse Pressure Taps – SF2



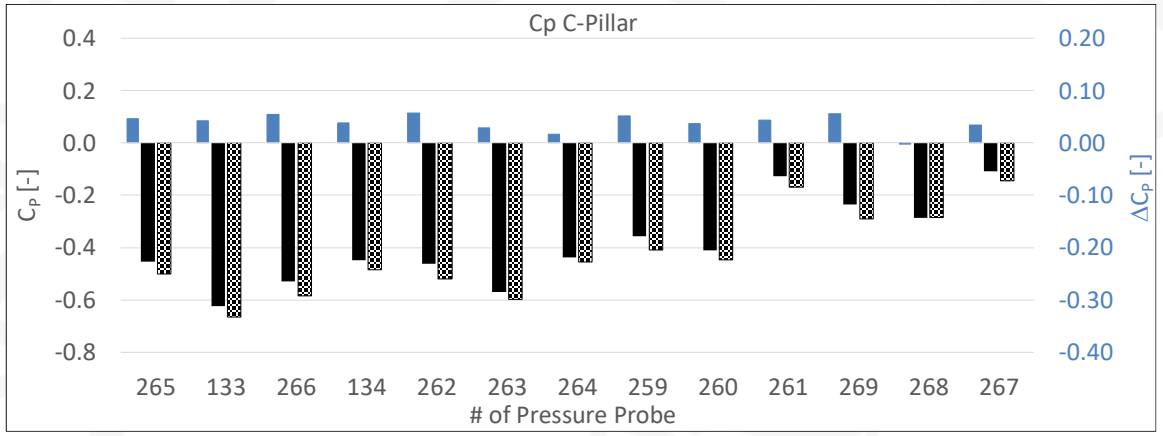
Front window is comparably predicted to baseline



Probe 48 changing now too. Suggests that 4 mm mirror offset may be valuable for side window pressures, but downstream refinement not needed



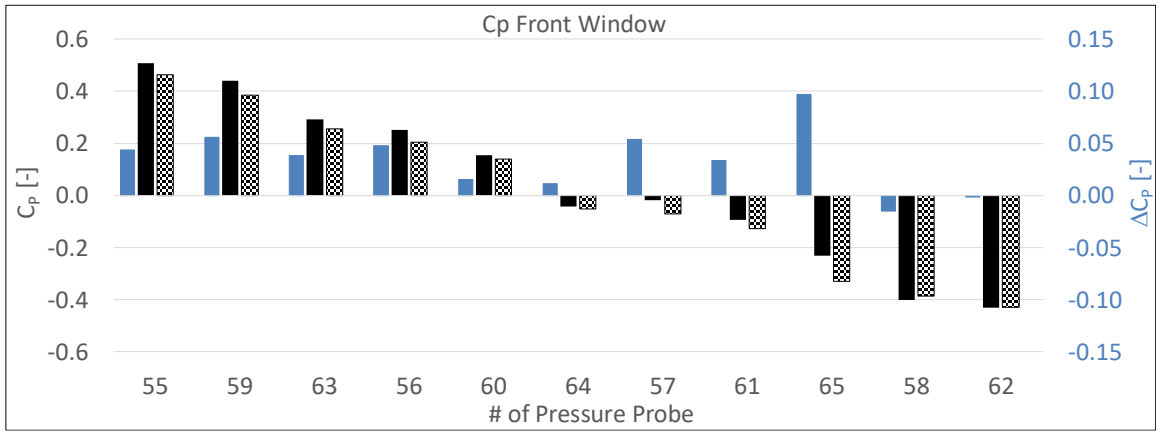
A-pillar is comparably predicted to baseline



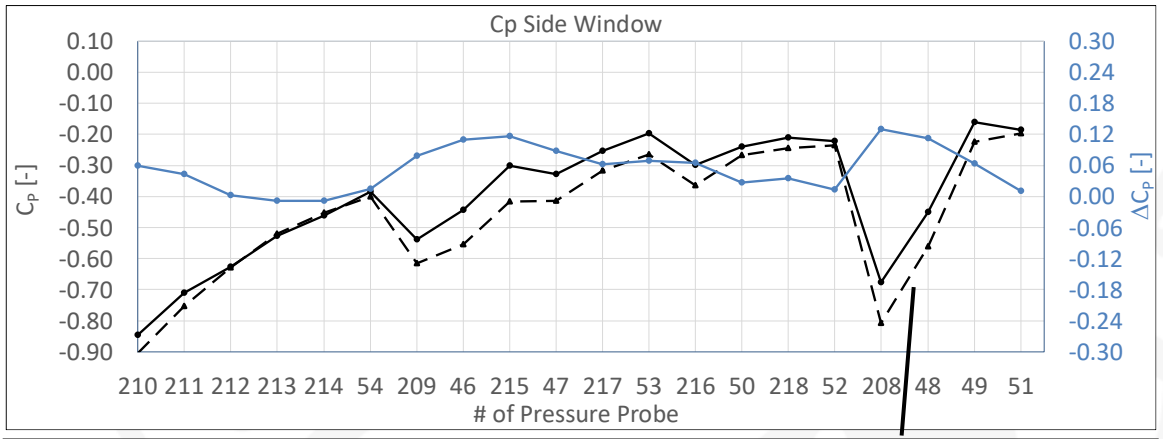
C-pillar is comparably predicted to baseline

■ Ford Pininfarina 171116 ▨ CFD ■ Test - CFD

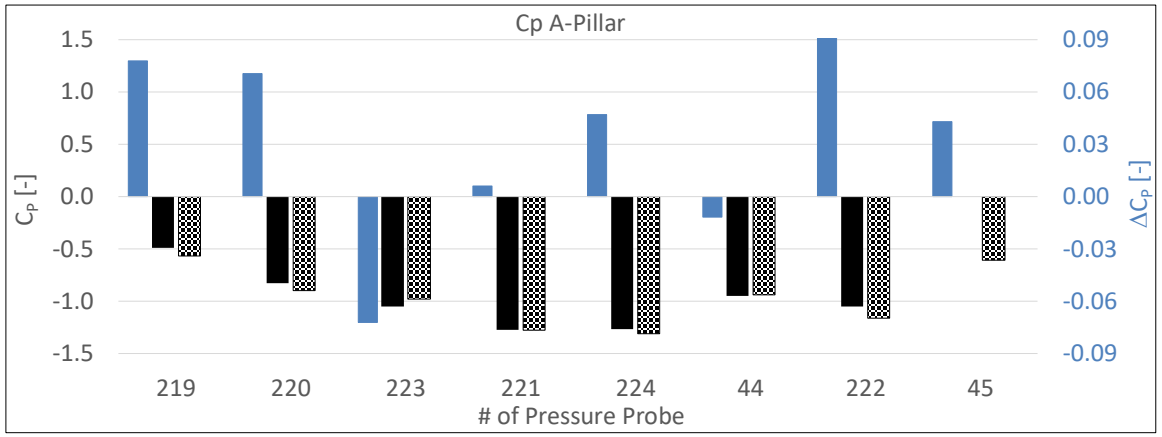
Greenhouse Pressure Taps – SF3



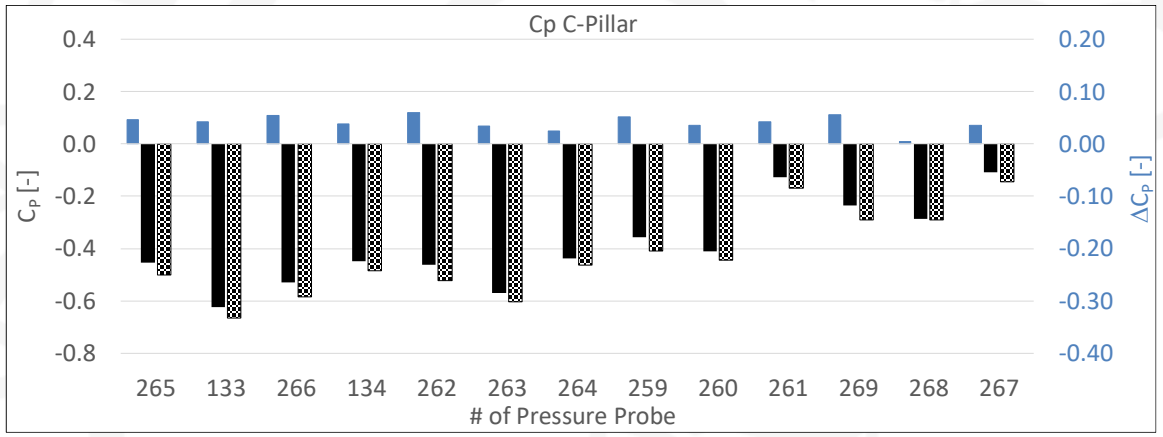
Front window is comparably predicted to baseline



Probes 208 and 48 are unchanged from previous step. No impact from changes in mesh resolution around the tires



A-pillar is comparably predicted to baseline



C-pillar is comparably predicted to baseline

■ Ford Pininfarina 171116 ▨ CFD ■ Test - CFD

Size Field Changes Conclusions

Mesh coarsening has had the following impact on forces, the flow field, and surface pressures:

- Drag tended to decrease with the introduction of all proposed mesh changes
  - *Improves correlation in Multimatic simulations, but is a larger change than may be desired*
- Flow field predictions tend to improve, with some deficiencies noted in the propagation of the front tire wakes affecting the rear tire wake predictions
- Surface pressures show some indication that the tire wake refinement is unnecessary (within Multimatic's process), but the mirror wake refinement helps with side window correlation
  - *The 4 mm side mirror size rule can be modified to terminate ~100 mm earlier, if desired*
  - ***This change was adopted for AutoCFD5***