# 3rd Automotive CFD Prediction Workshop

## Case 2A/2B and Mesh Sensitivity Study

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# Outline

- Simulated Case 2A/2B with IconCFD 4.2.9 on ANSA mesh:
  - Cell centered, Finite Volume
  - Pressure-based, segregated solver
  - $2^{nd}$ order in space/time
  - SA-DDES Turbulence Model
  - Time step $2x10^{-4}$
  - Run Length 6s, starting averaging at 2s

- Performed mesh sensitivity study – how much influence do small perturbations to mesh have?

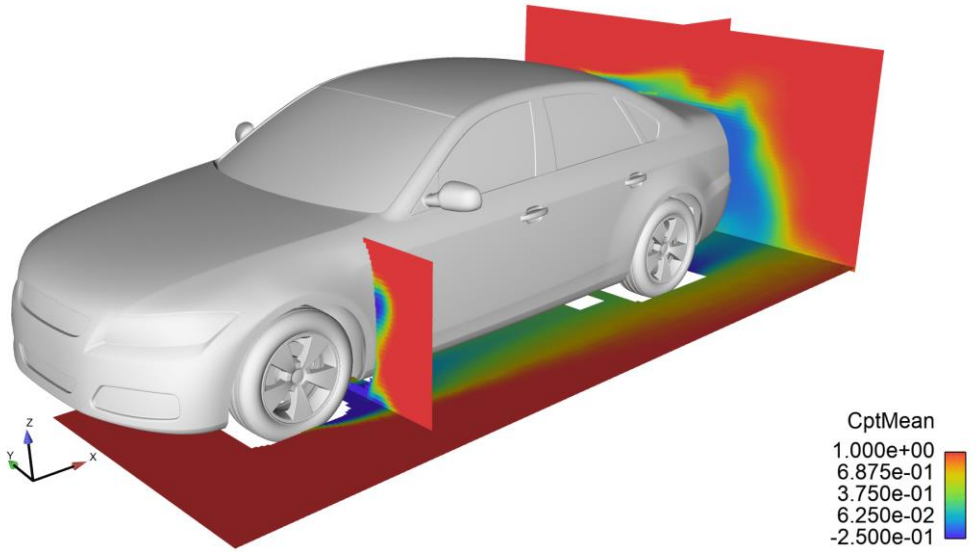
# Experimental Comparison

CFD

| | $C_d$ | $C_l$ |
|---|---|---|
| Case 2a | 0.2804 | 0.0525 |
| Case 2b | 0.2697 | 0.0490 |
| delta | 0.0107 | 0.0035 |

Experiment

| | $C_d$ | $C_l$ |
|---|---|---|
| Case 2a | 0.255 | 0.087 |
| Case 2b | 0.242 | 0.082 |
| delta | 0.013 | 0.005 |




Despite different absolute $C_d/C_l$, the $\Delta C_d/\Delta C_l$ are in reasonable agreement

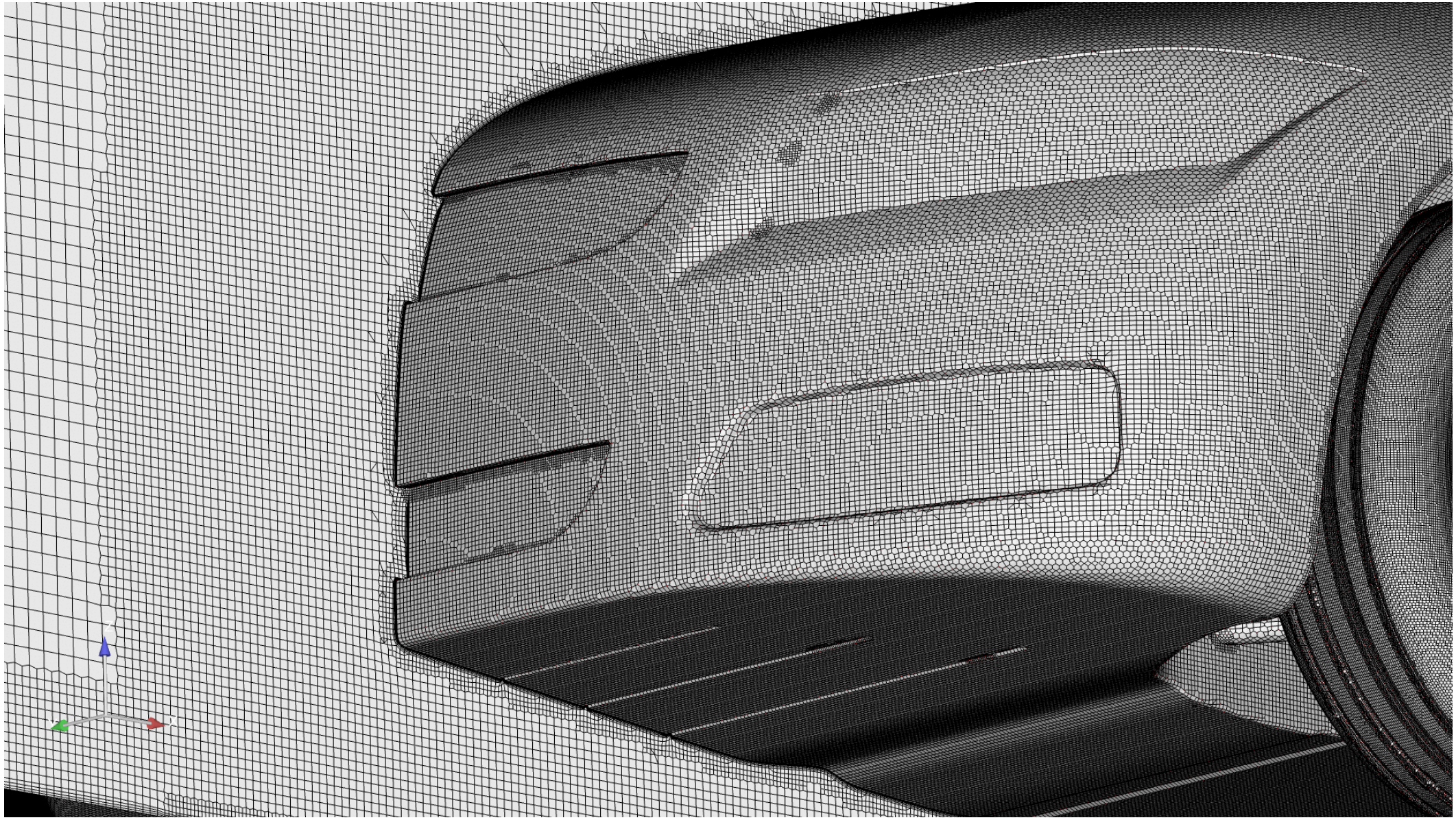
# Mesh Noise/Sensitivity Study

- Small changes in the mesh can lead to small changes in $C_d$, $C_l$ etc. For some very sensitive shapes and less clean CAD/Mesh the difference can be significant. Coarser meshes tend to suffer from this more.

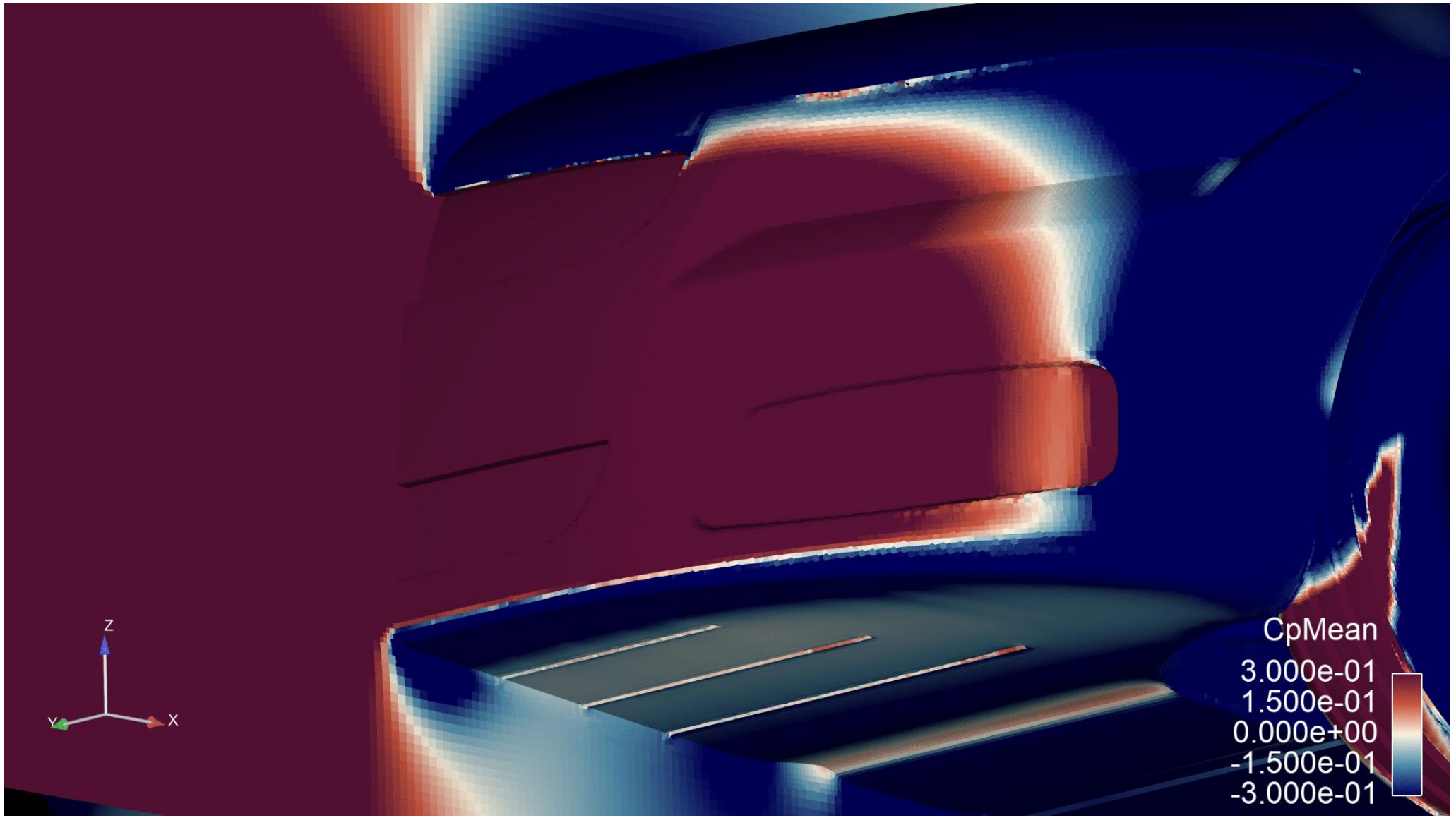
- We will perform this study on the ANSA high and low y+ meshes from Auto CFD workshops, and an alternative Snappy based mesh.

- We will study one way to induce small changes in the mesh – by shifting the background block mesh/vehicle by increments of 0.1 mm.

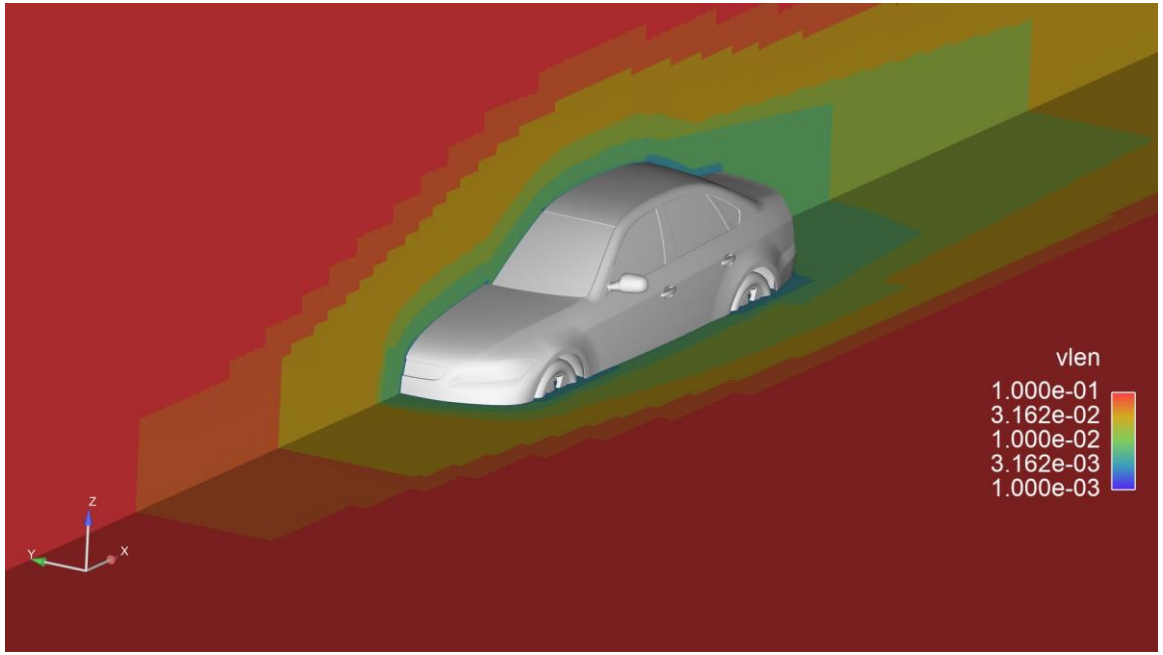
# Example - Block Mesh Shift on Alt Mesh



# Block Mesh Shift Results



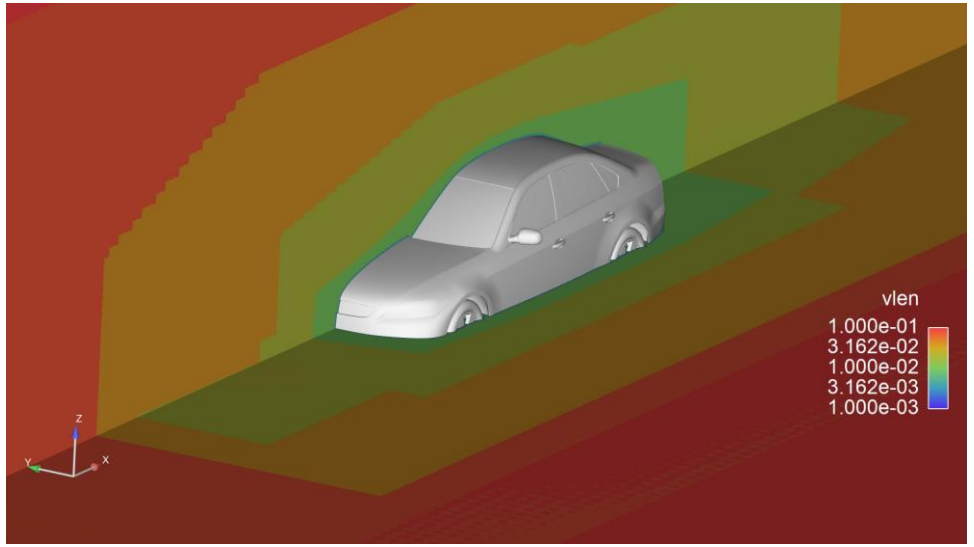
# Mesh Density



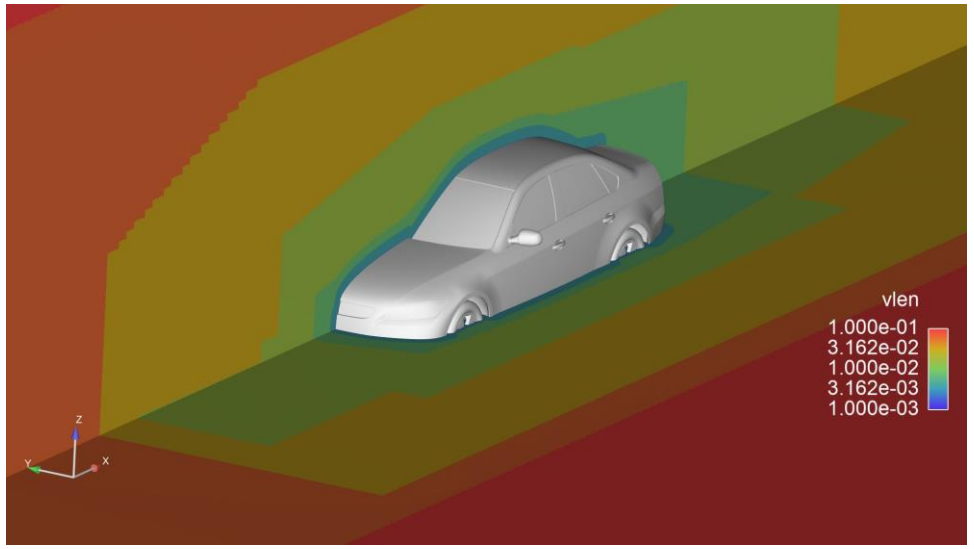

ANSA Mesh (low y+ 128 Million/ high y+ 240 million)

Surface Mesh ~3mm, 1.5mm @ refinements, curvature

Surface Mesh 5mm, 2.5mm @ feature lines




Alternative Mesh Coarse (58M)




Alternative Mesh Fine (137 Million)

# Setting Run Length

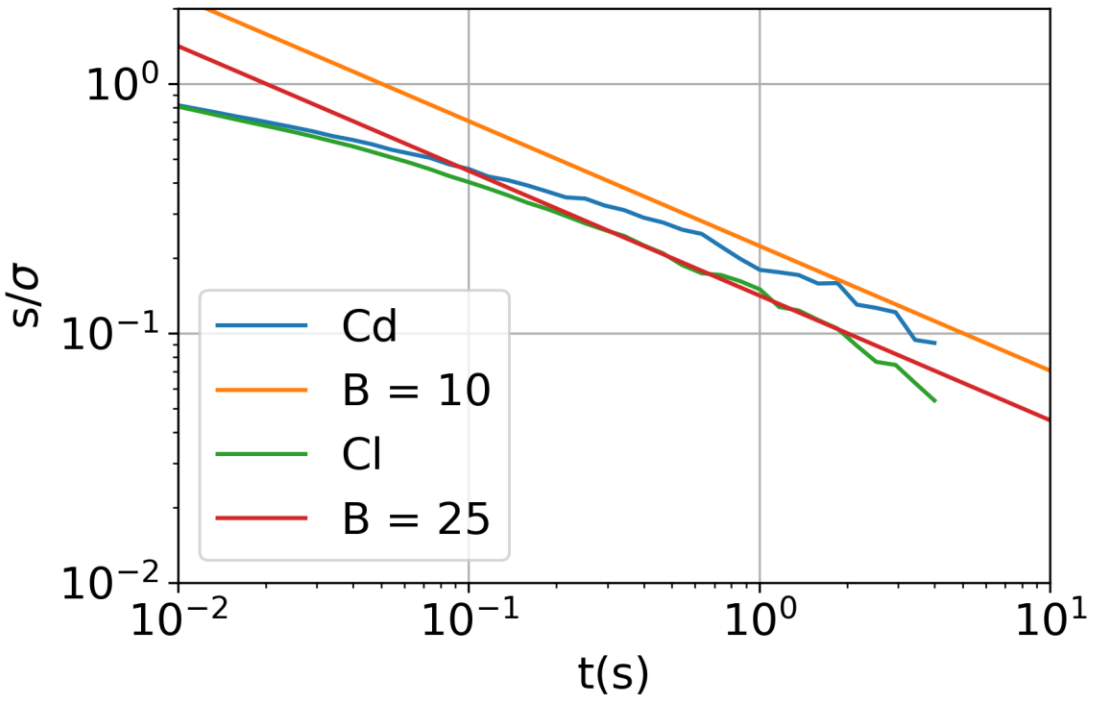
To study mesh noise, want to minimize time series noise

At long times the uncertainty in the mean ($s$) scales as[1]:

$$\frac{s}{\sigma} = \frac{1}{\sqrt{2Bt}}$$

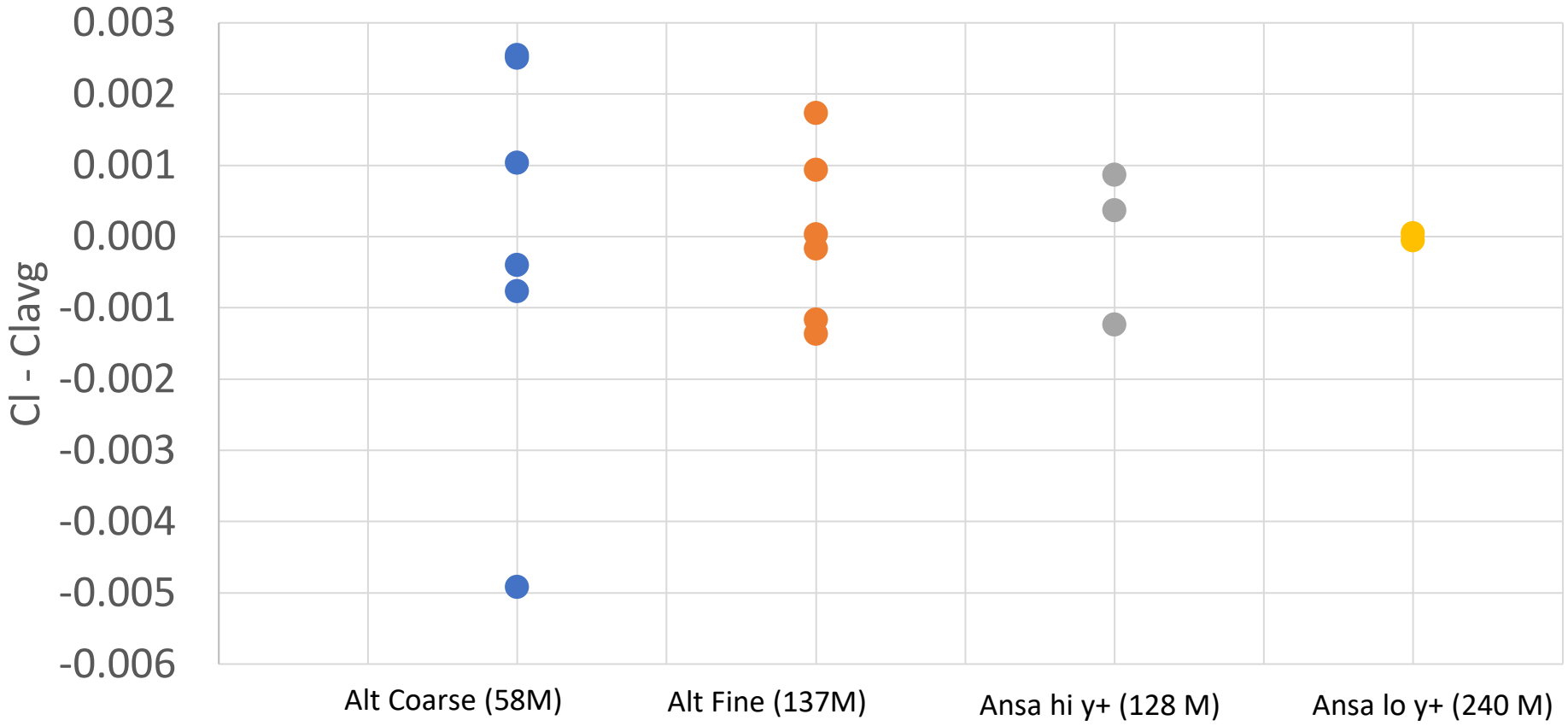
We will aim to achieve s ≈ σ/10, by running for 50/B. For B of 10 $s^{-1}$ would be running ~5 s.

Alternative Mesh Coarse: 2s initialization + 18 s run
Alternative Mesh Fine/ANSA Meshes: 2s initialization + 6 s run




[1] C. Mockett, T. Knacke and F. Thiele, "Detection of Initial Transient and Estimate of Statistical Error in Time-Resolved Turbulent Flow Data," Conference: 8th International Symposium on Engineering Turbulence Modelling and Measurements, 2010.

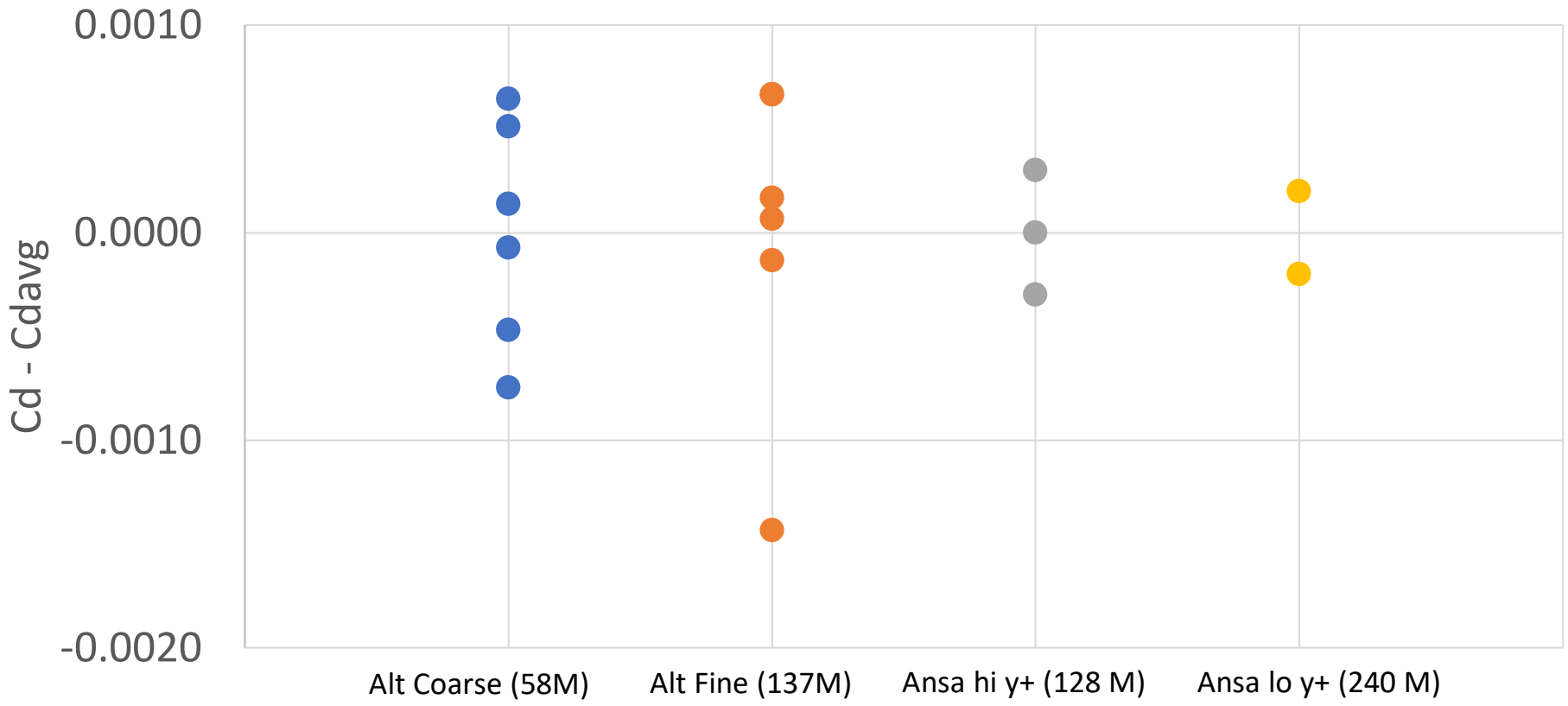
# Block Mesh Shift Results




Despite the coarse simulation being run 3x longer, there is more scatter in the Cl results. Evidence of mesh noise

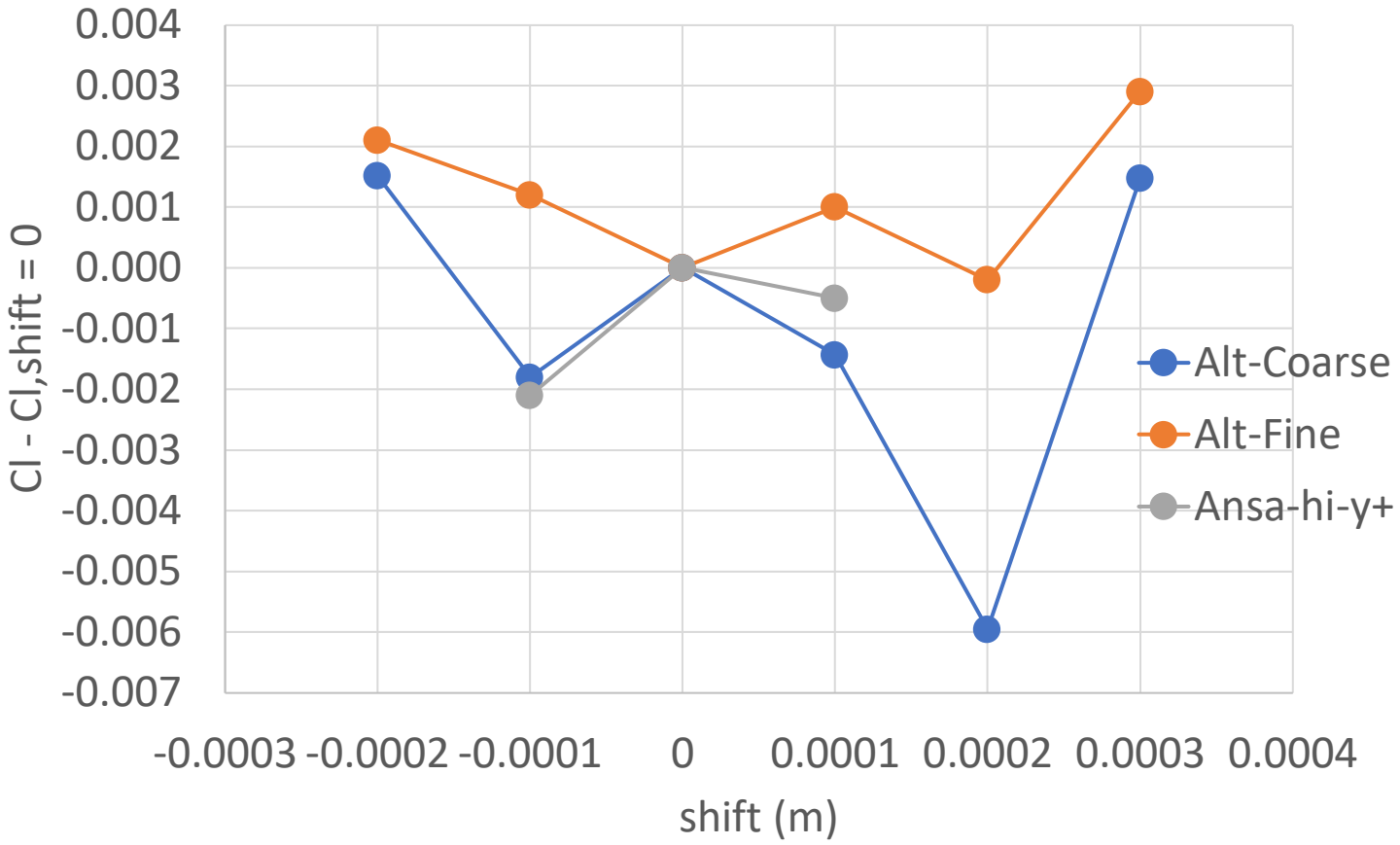
No observed issues with convergence of residuals, velocity limiting

# Block Mesh Shift Results




Less overall noise in Cd, with exception of one outlier

# Effect of Shift Amount




The most extreme changes come from higher block mesh shifts

Would be interesting to sample larger range (avg surf mesh ~ 5 mm Alt-Mesh)

# Estimating Mesh Noise

| | Alt Coarse | | Alt Fine | | ANSA Hi y+ | |
|---|---|---|---|---|---|---|
| | $C_d$ | $C_l$ | $C_d$ | $C_l$ | $C_d$ | $C_l$ |
| Std (Cx) | 0.53 | 2.8 | 0.77 | 1.2 | 0.30 | 1.09 |

STD(27.1, 25.6, 21.1, 28.6, 25.3, 28.6)

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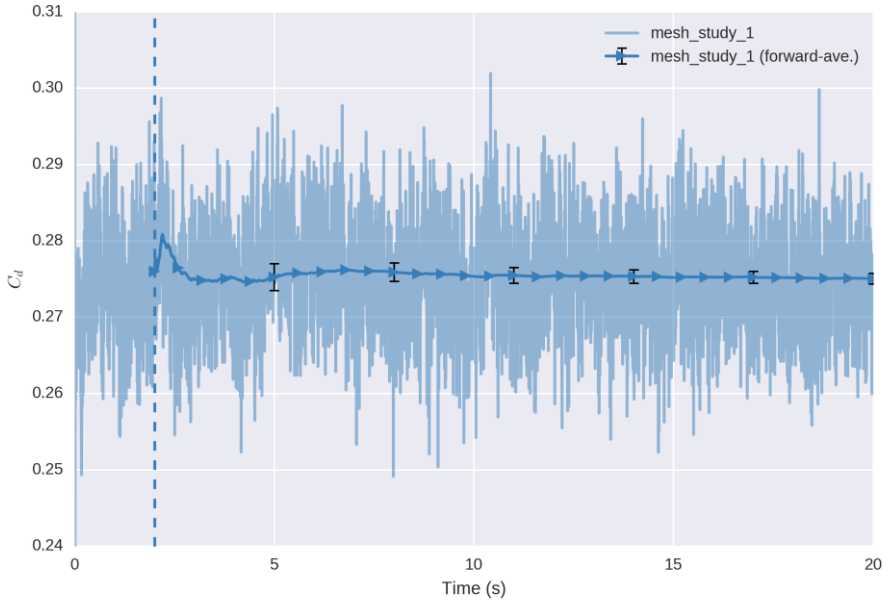
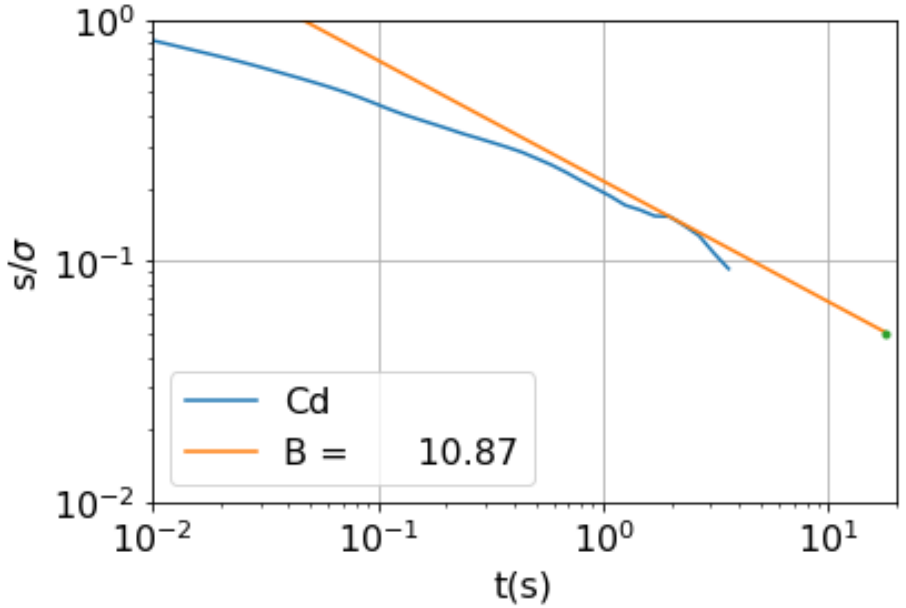
| Std (Cx) | 0.53 | 2.8 | 0.77 | 1.2 | 0.30 | 1.09 |
| Avg TS Err | 0.30 | 0.68 | 0.47 | 0.97 | 0.44 | 1.22 |

AVG(0.66, 0.66, 0.74, 0.74, 0.65, 0.75)



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| Avg TS Err | 0.30 | 0.68 | 0.47 | 0.97 | 0.44 | 1.22 |
| χ2 P-val | 0.007 | 1E-16 | 0.02 | 0.17 | 0.63 | 0.45 |

$$\chi^2 = \frac{(n-1)s^2}{\sigma^2} = 16.2$$

# Estimating Mesh Noise

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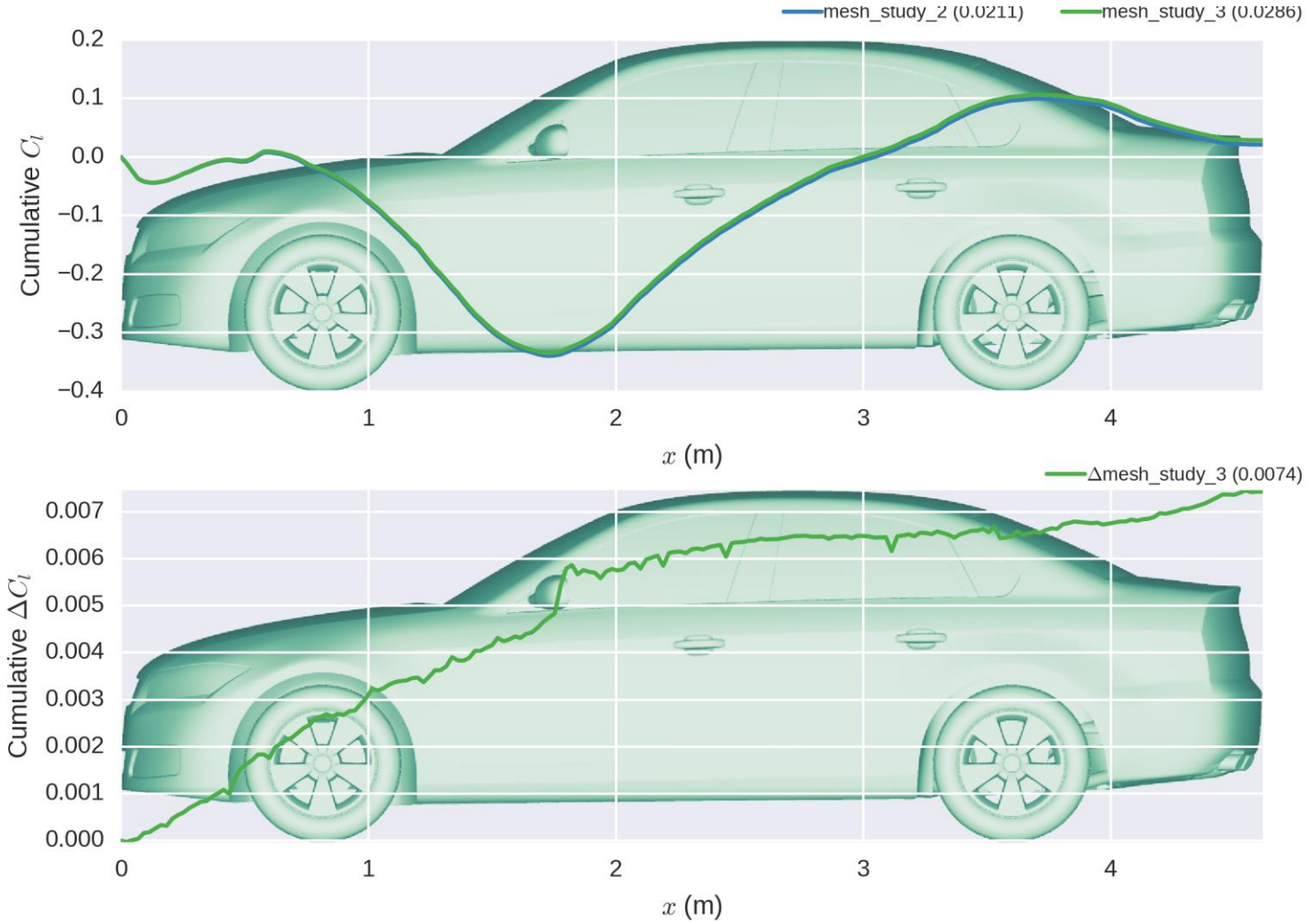
| χ2 P-val | 0.007 | 1E-16 | 0.02 | 0.17 | 0.63 | 0.45 |
| Est Mesh Err | 0.44 | 2.7 | 0.62 | 0.7 | | |

↓

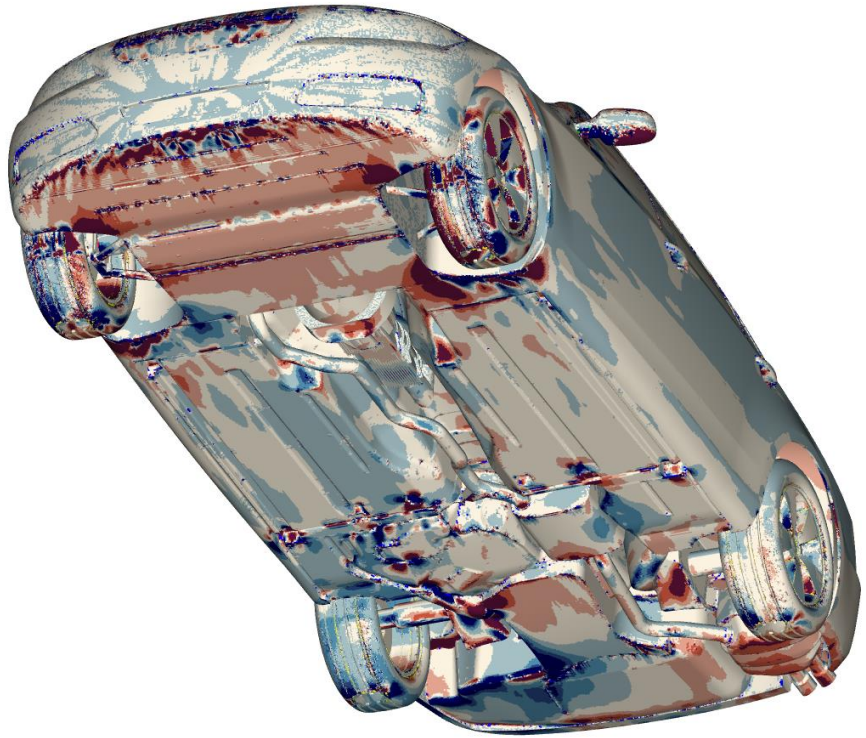
$$s_{tot}^2 = s_{time}^2 + s_{mesh}^2$$

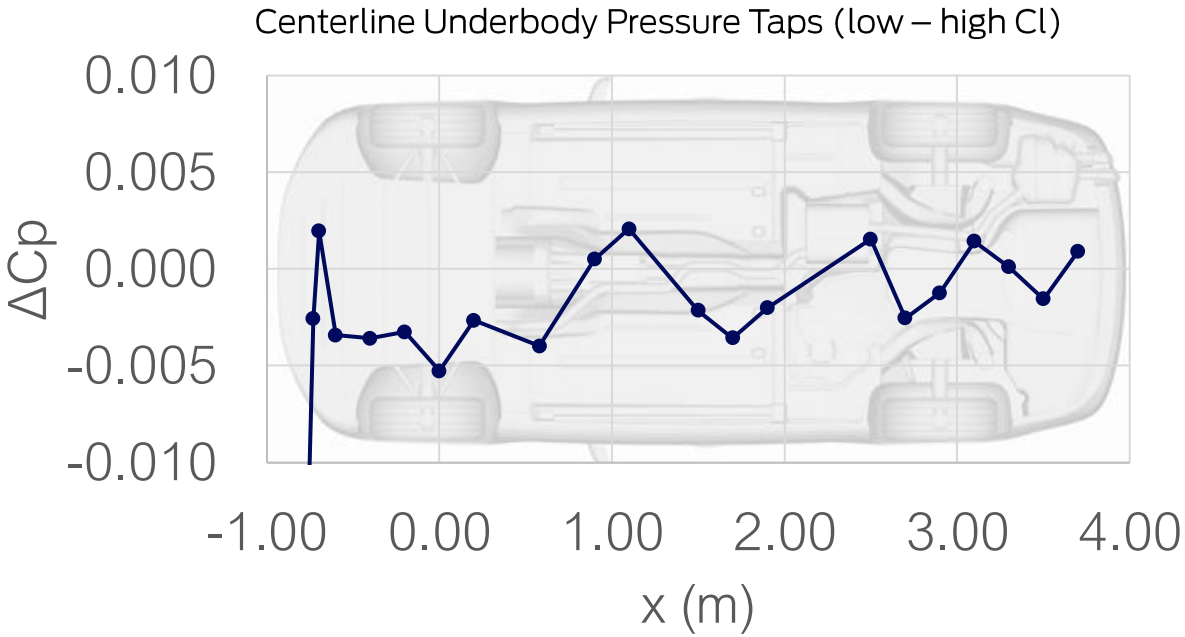
# Flow Differences Due to Mesh Noise



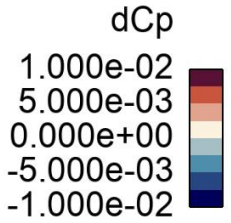

High – Low $C_l$ Cases for Alt Coarse Mesh

# Flow Differences Due to Mesh Noise




Main difference is in the bellypan




High – Low $C_l$ Cases for Alt Coarse Mesh

# Conclusions

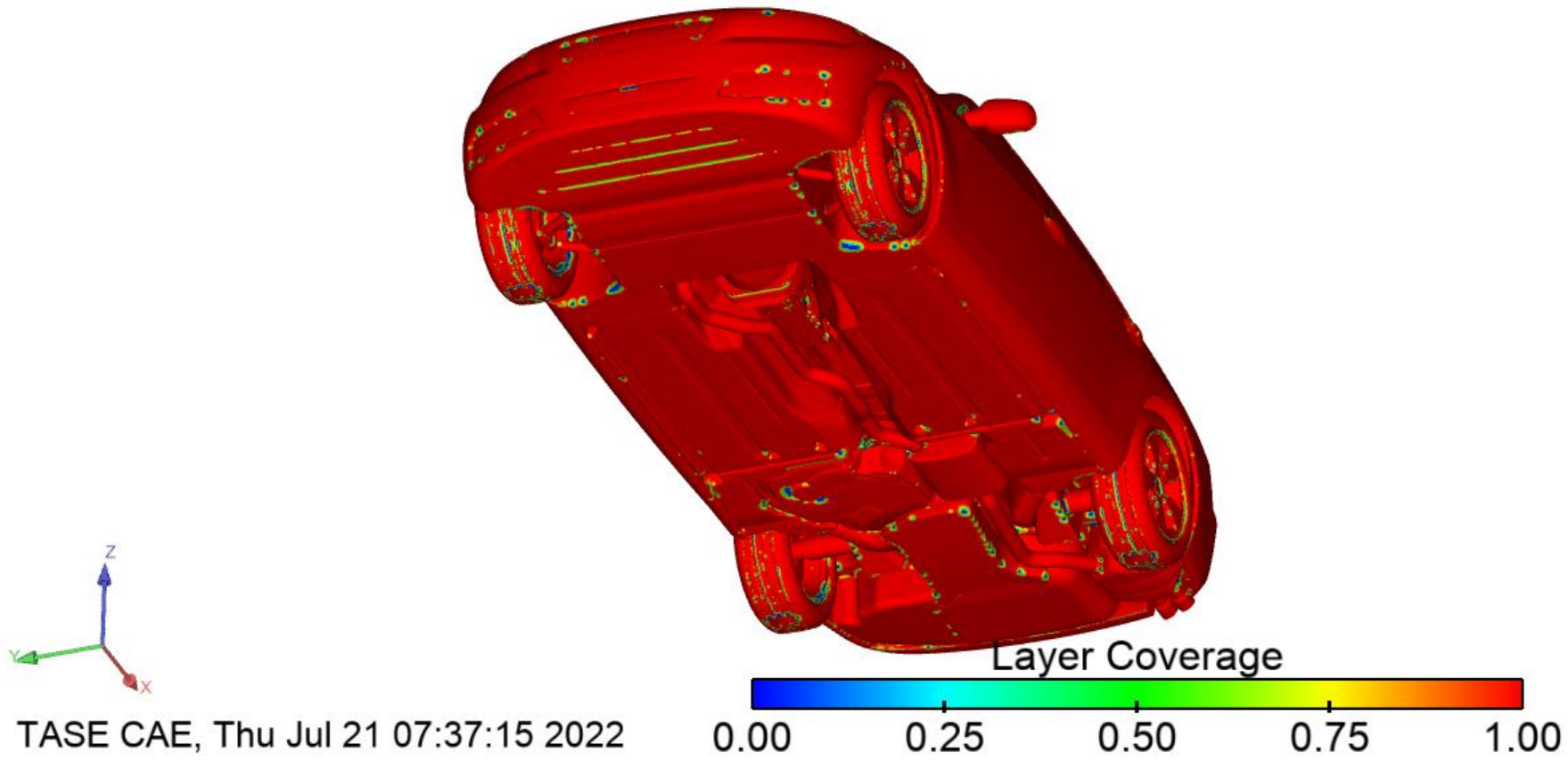
- Comparison to experiment: Despite larger differences in absolute $C_d$ values, the $\Delta C_d$, $\Delta C_l$ values between the two cases are consistent.
- Studied ‘Mesh Noise’, accomplished by a small block mesh shift/vehicle shift.
- For ANSA meshes used in this workshop little change in results was seen for shifting vehicle
- For alternative mesh, there was small effect on $C_d$ and moderate effect on $C_l$ for the coarse mesh. The effect was reduced for the finer mesh. Primary difference is in bellypan area.
- Which regions of the mesh could be refined on the coarse mesh to minimize mesh noise?

# Thank you!

# Layer Coverage –Alt Coarse Mesh

mesh_study_base

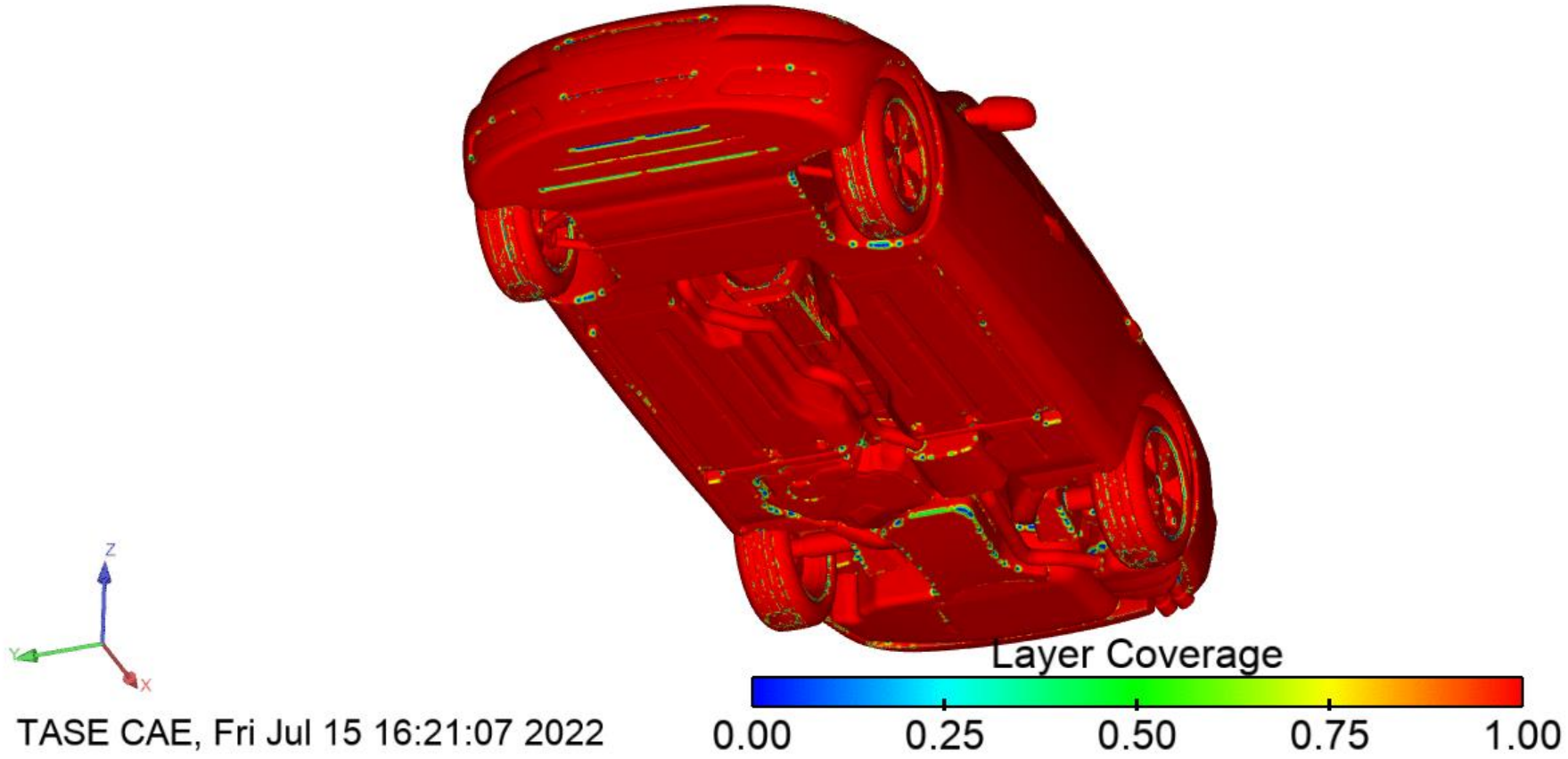
0 = No Prism layer, 1 - Fully Grown Prism Layer



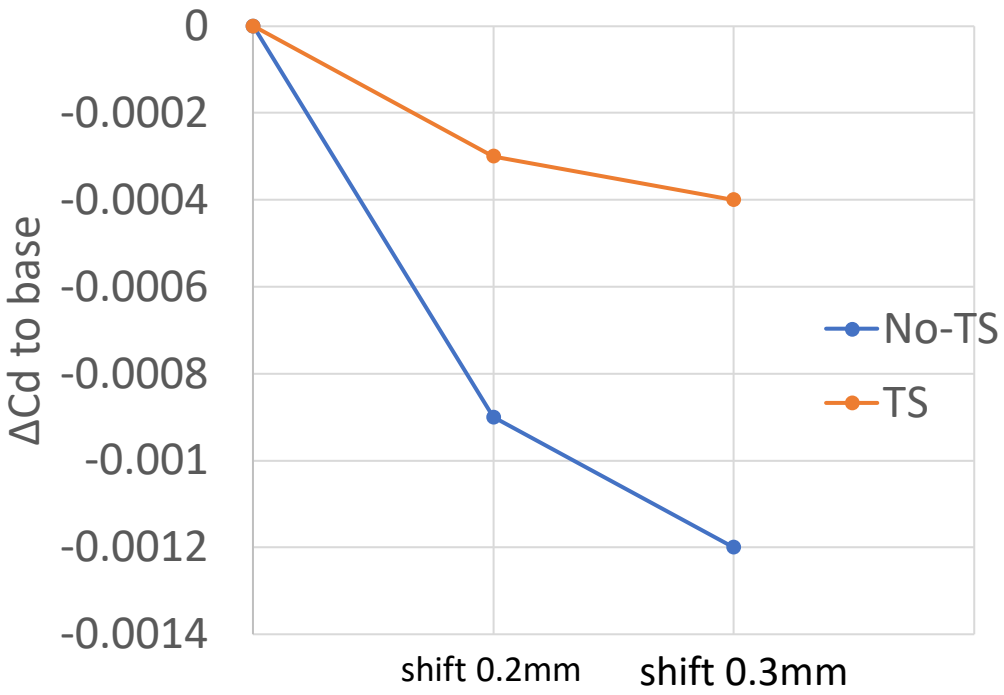
# Layer Coverage –Alt Fine Mesh

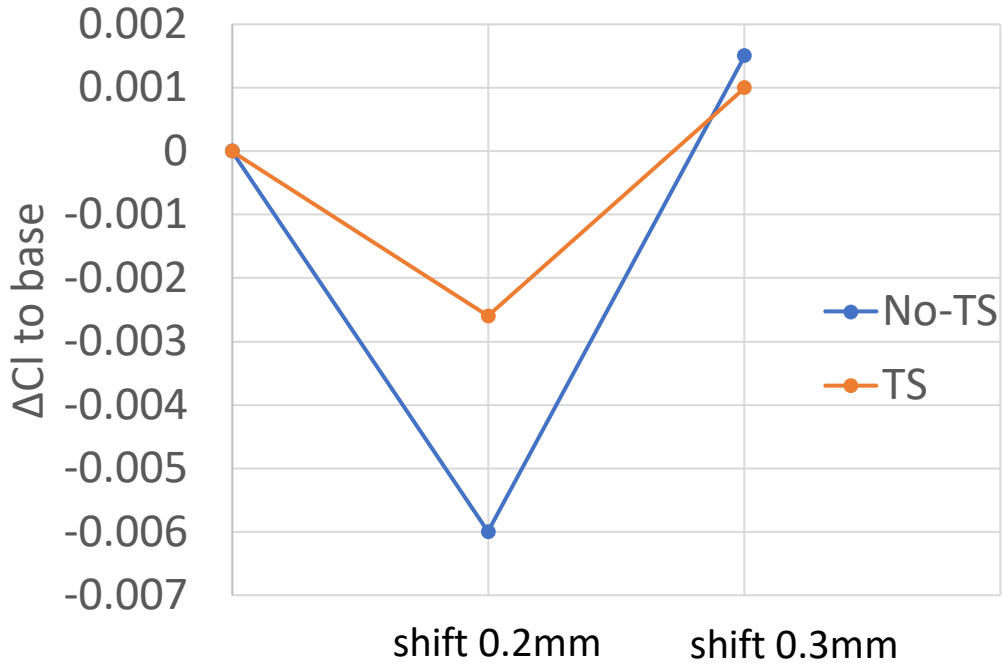
mesh_study_base

0 = No Prism layer, 1 - Fully Grown Prism Layer



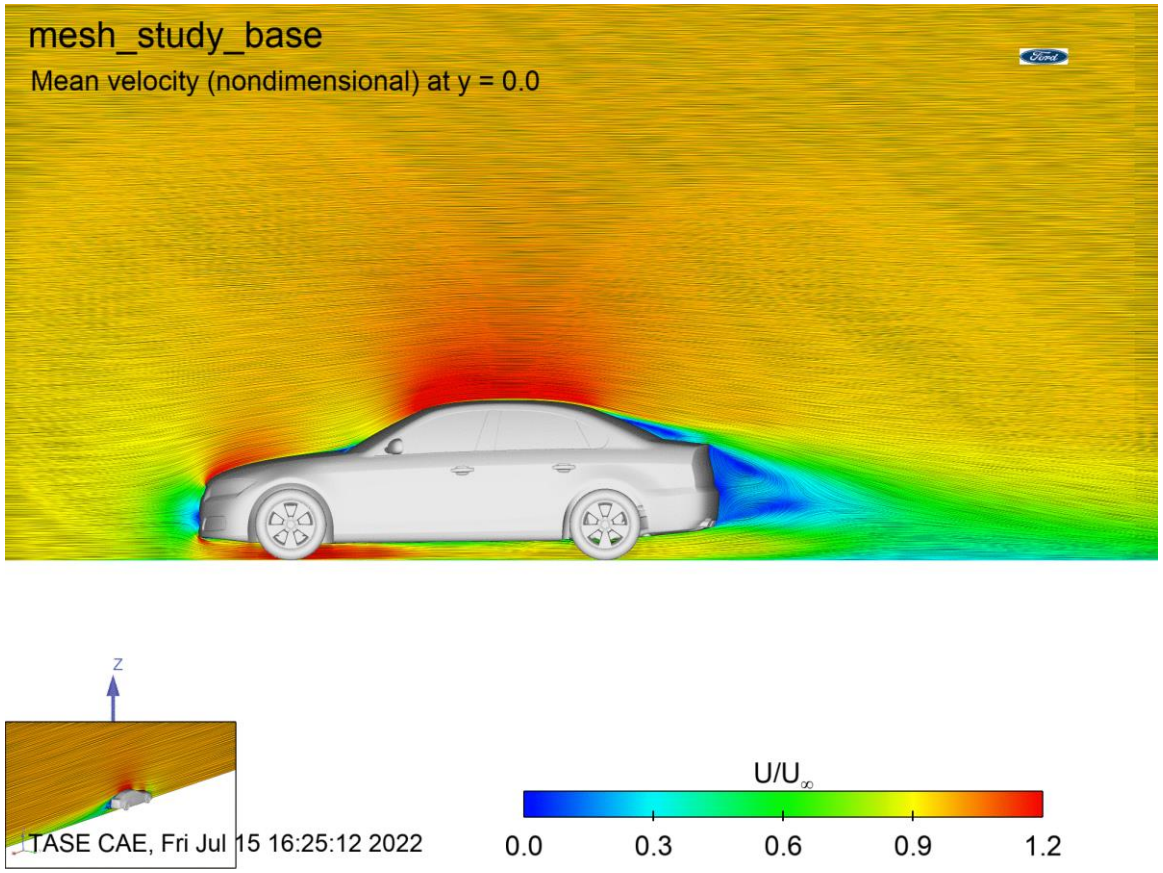
# Does Block Mesh Shift Produce Consistent Change?

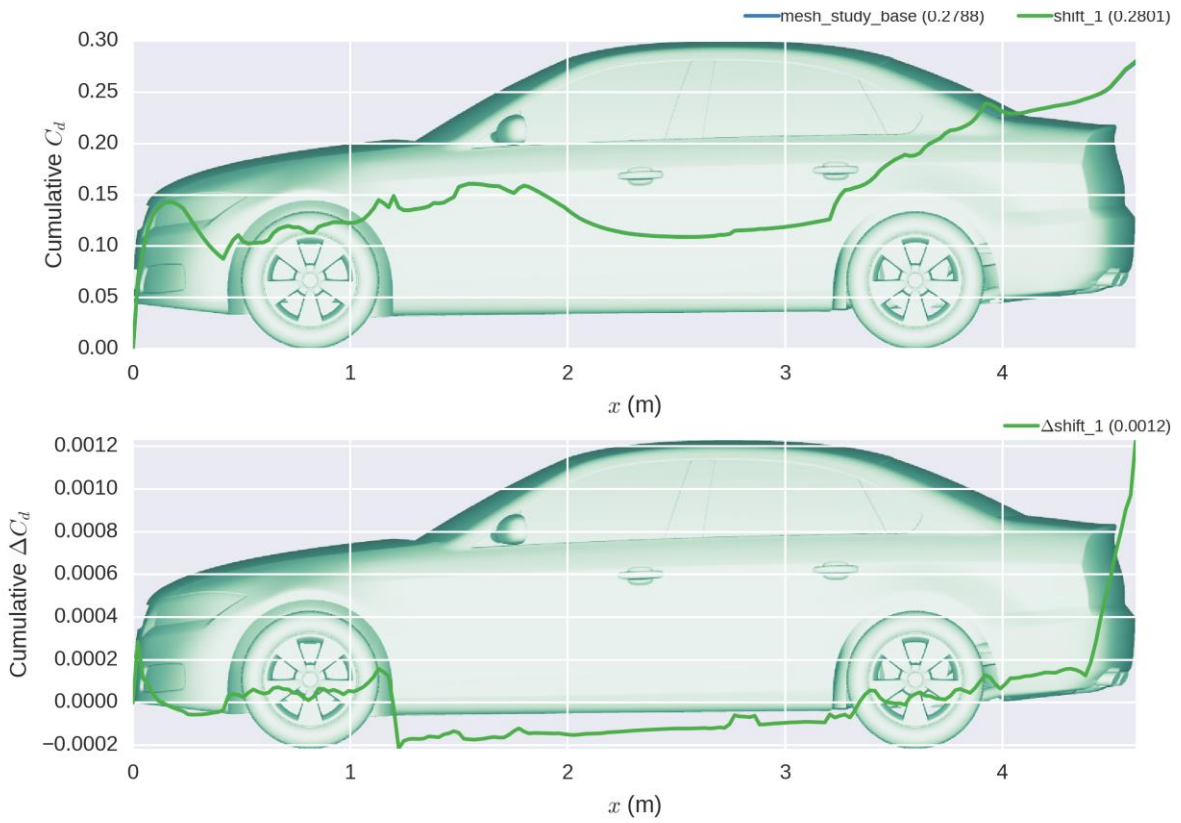


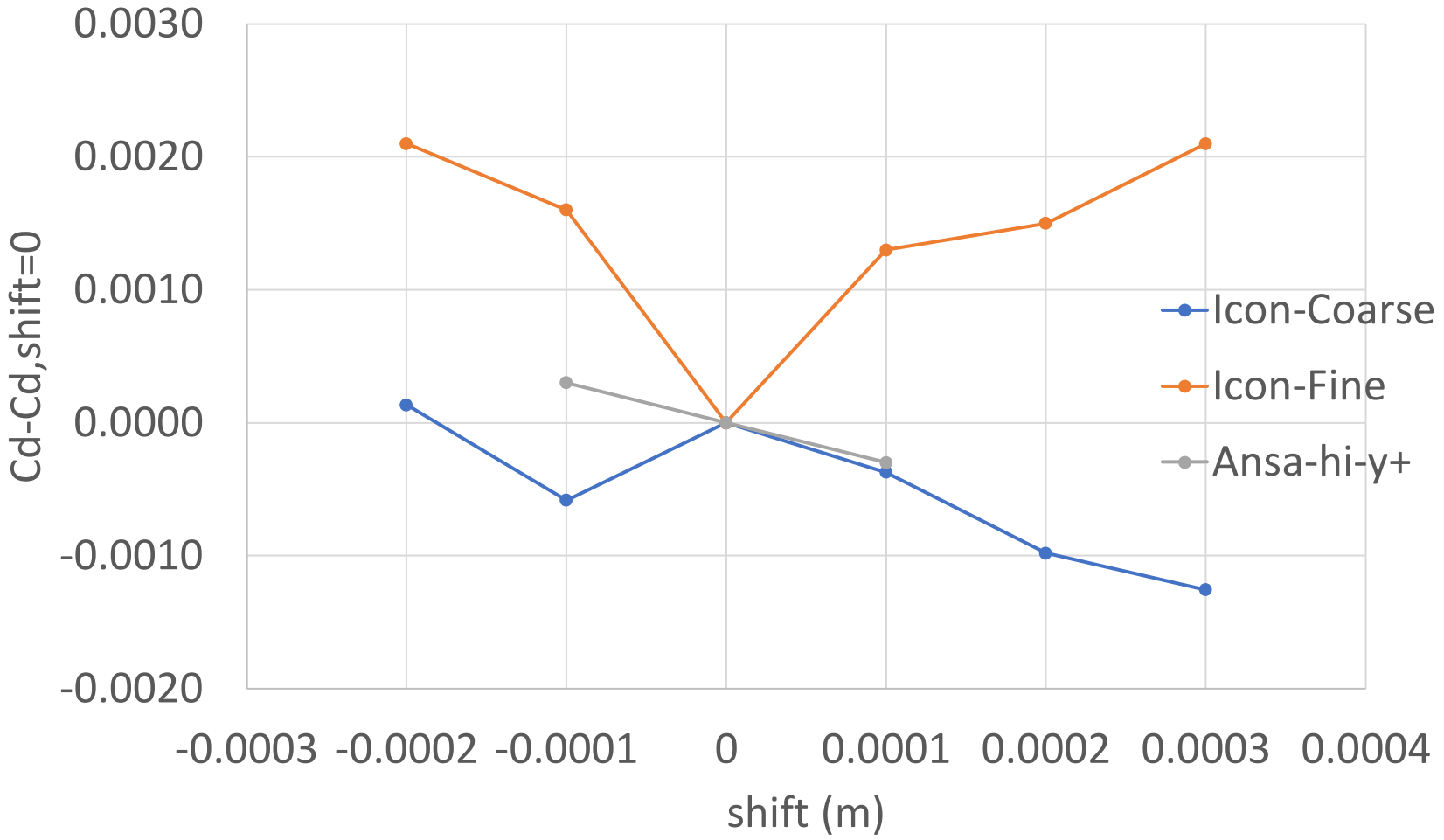

It appears the effect is consistent, although the magnitude changes somewhat

# Alt Fine Mesh Outlier

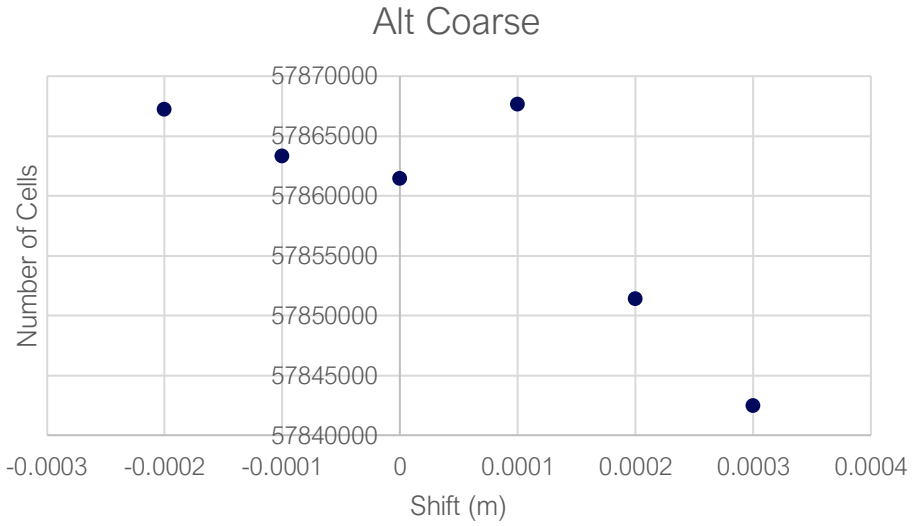


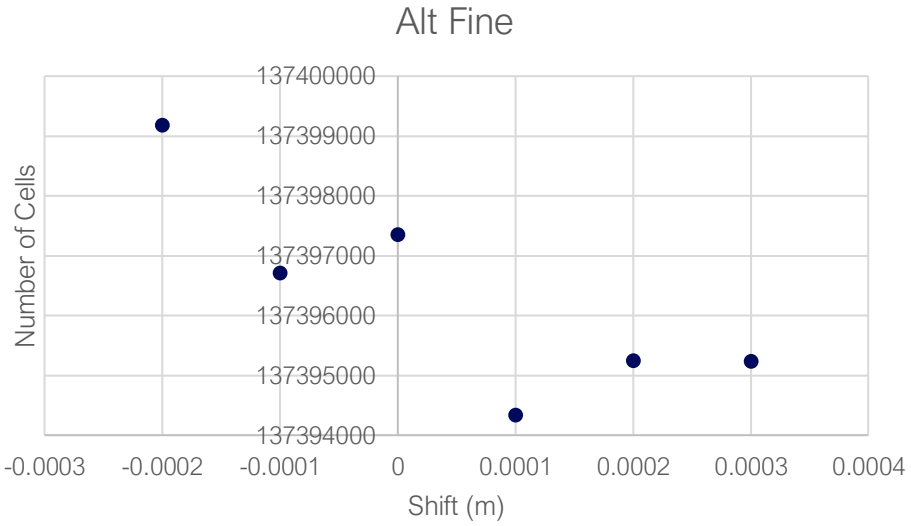



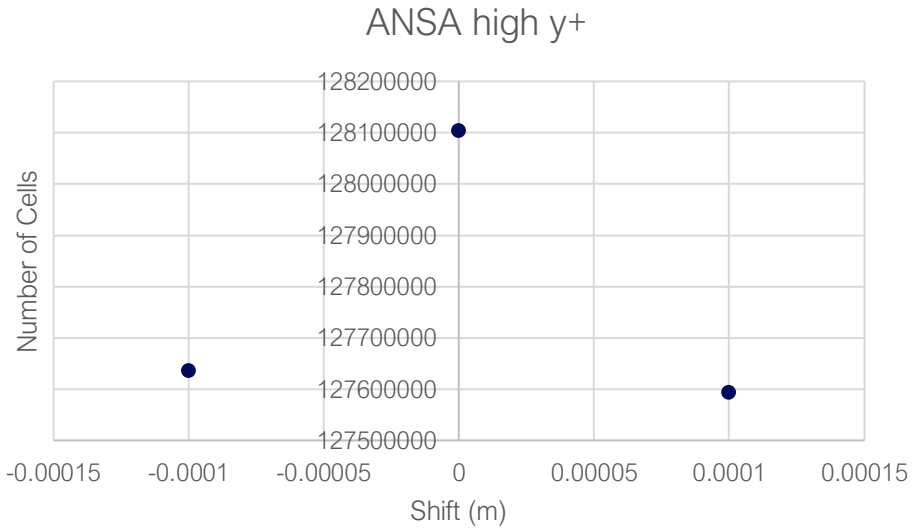
# Cd Shift Data

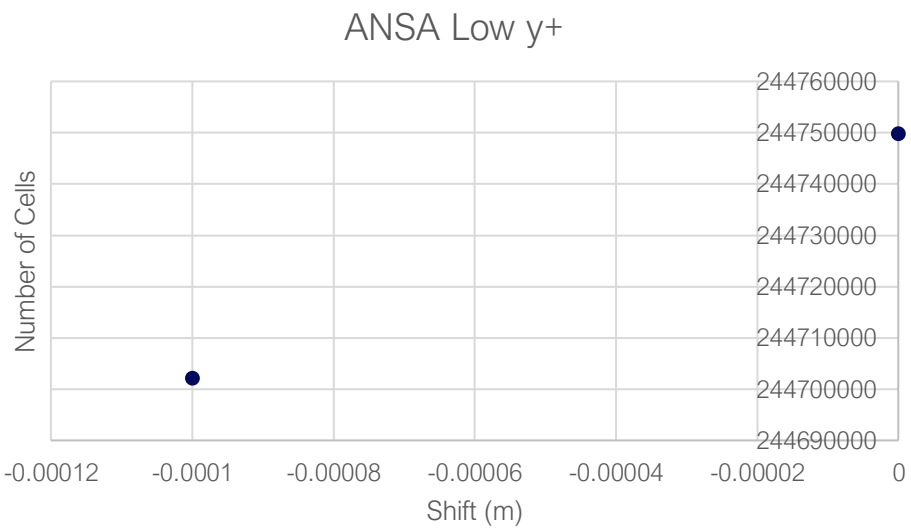


# Mesh Size By Shift



# ANSA vs Alt Mesh