bramble
Data *Driven* Engineering

PUBLIC DOCUMENT

Effect of Time Step on DDES Flow Topology

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Introduction and Agenda

Who we are

- **Bramble CFD** operate a cloud platform that automates CFD workflows. Principally OpenFOAM, but designed to integrate other codes.
- Part of the **TotalSim** group of companies.
- Based in the UK at the **Catesby Tunnel** test facility.

Agenda

1. **Effect of time step on DDES flow topology**
2. **Hardware options and core-count scaling**
3. **Validation routes: PIV at Catesby Tunnel**

Why Engineers Shortcut a DDES Run

Time to solution, compute and cost all push us to shorten the transient. Two levers are reached for first, and both change what the flow looks like.

3 s → 1.5 s

Physical time simulated

averaging window cut from 2 s to 1 s

0.0002 → 0.0005 s

Time step

2.5× fewer steps per second of flow

≈ 5×

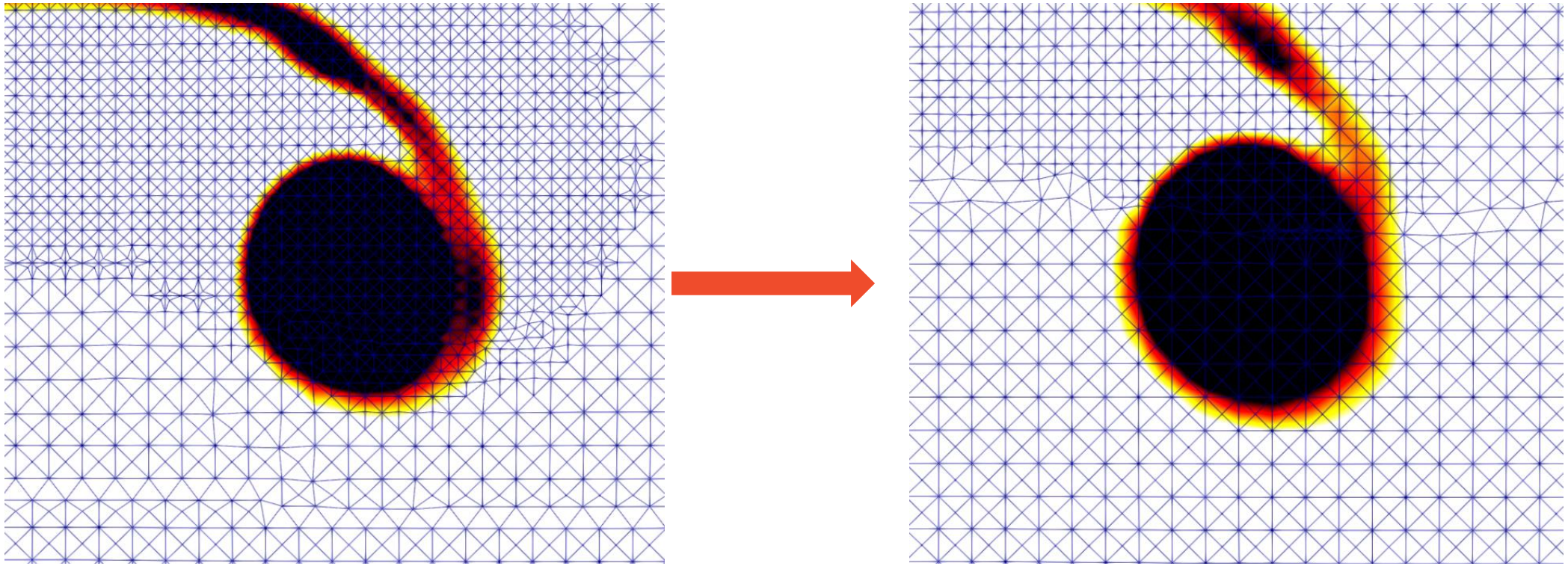
Faster wall-clock

By reducing averaging window and increasing time step

A larger step saves real money and the result still looks plausible. What does it do to the flow topology?

A coarse mesh looks coarse. A coarse time step still looks right

Mesh coarsening is rarely chosen as a shortcut because its effect is obvious in the post-processing. A larger time step produces fields that look plausible, so the error hides in plain sight.



Fine mesh

Coarsened mesh

Study setup

- **Case:** AutoCFD test case 2a on the committee mesh
- **Solver:** OpenFOAM (TotalSim variant), pimpleFoam
- **Turbulence:** Spalart-Allmaras DDES
- **Flow time:** 2 s total, averaged over the final 1.5 s
- **Variable:** time step only. Mesh, schemes and settings identical across the three runs

0.0005 s

Shortcut step

baseline for this study

0.0002 s

Intermediate step

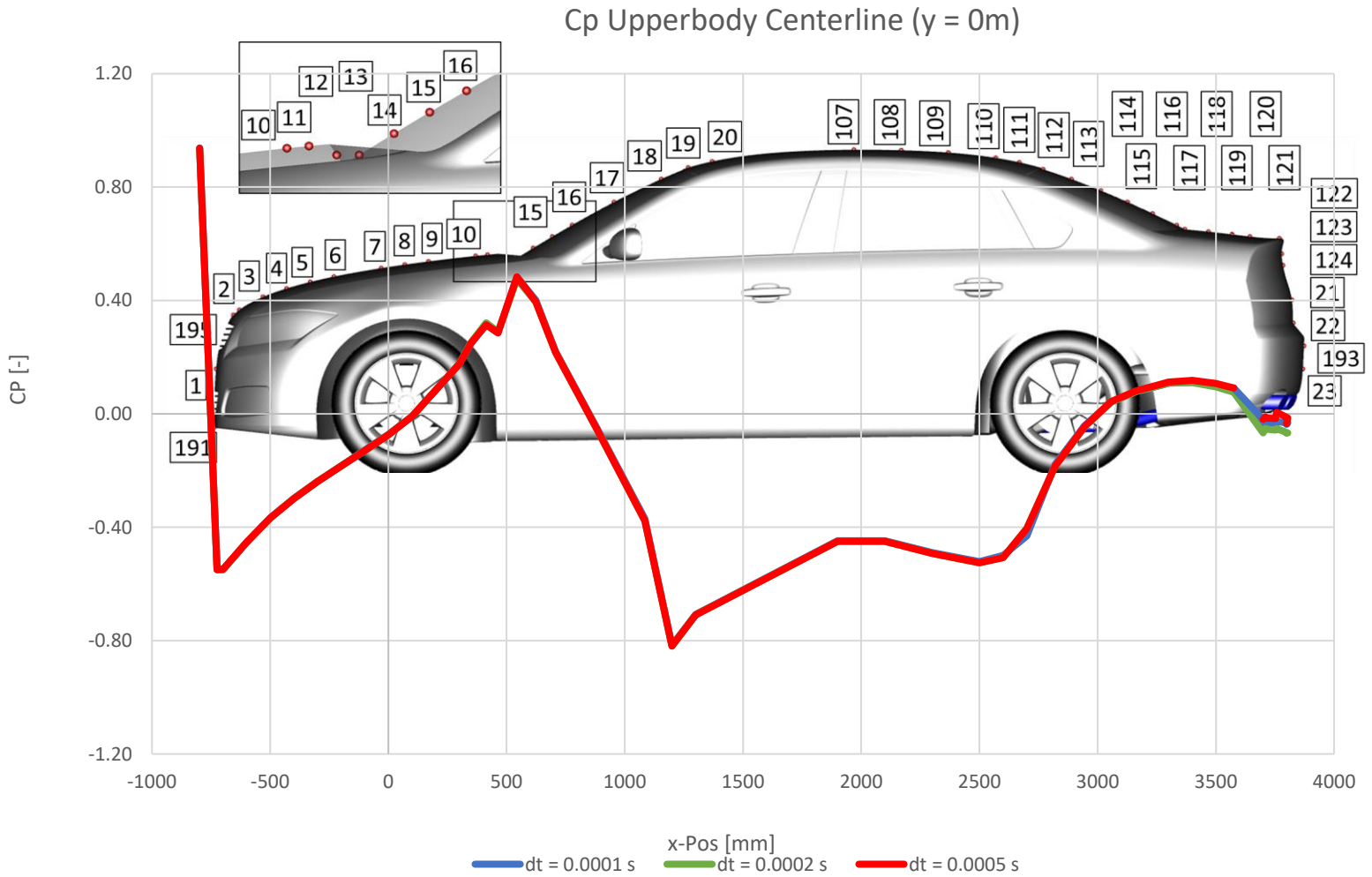
2.5× the steps

0.0001 s

Reference step

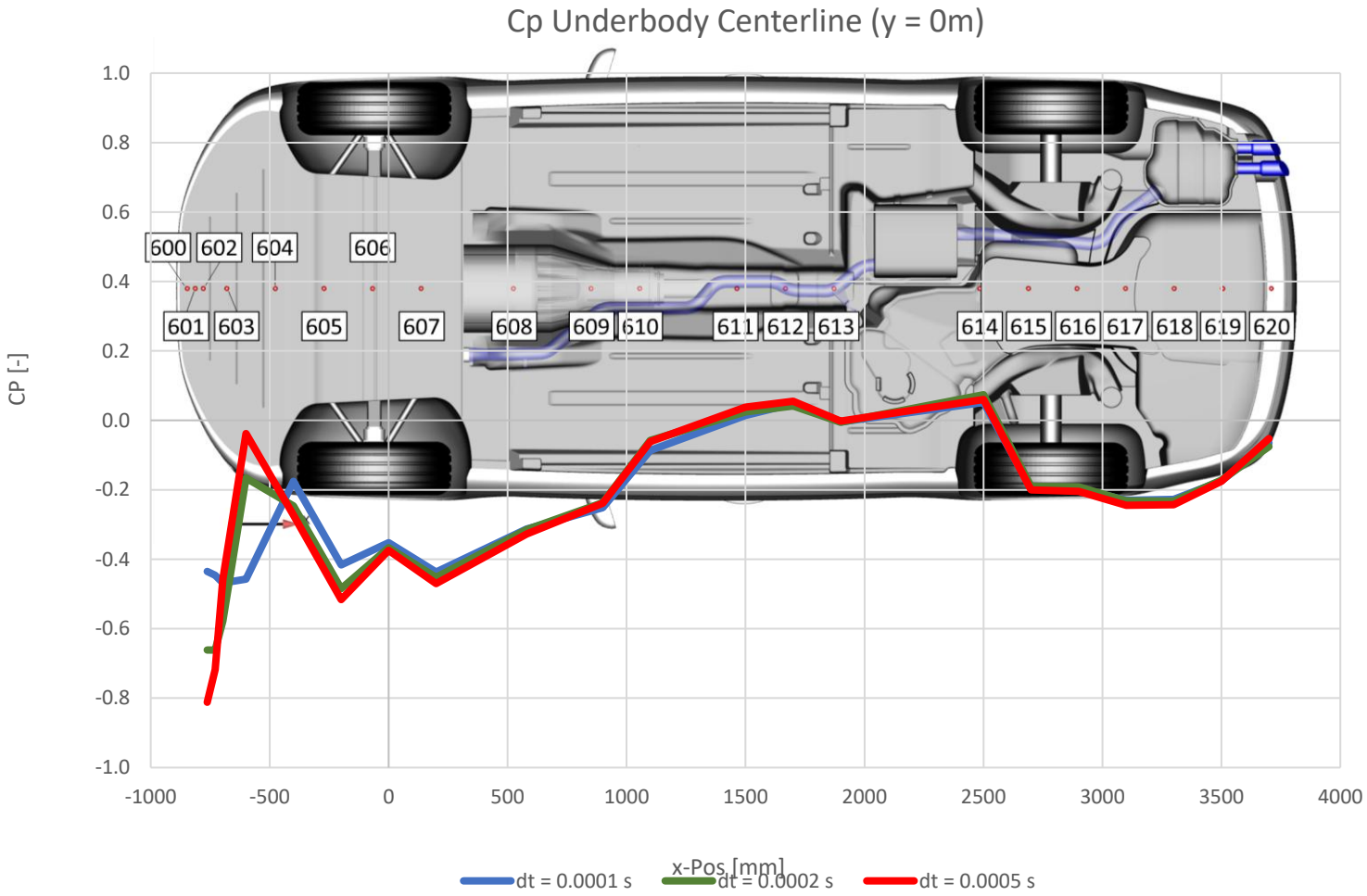
5× the steps

Upper Body Cp: Insensitive to the Time step



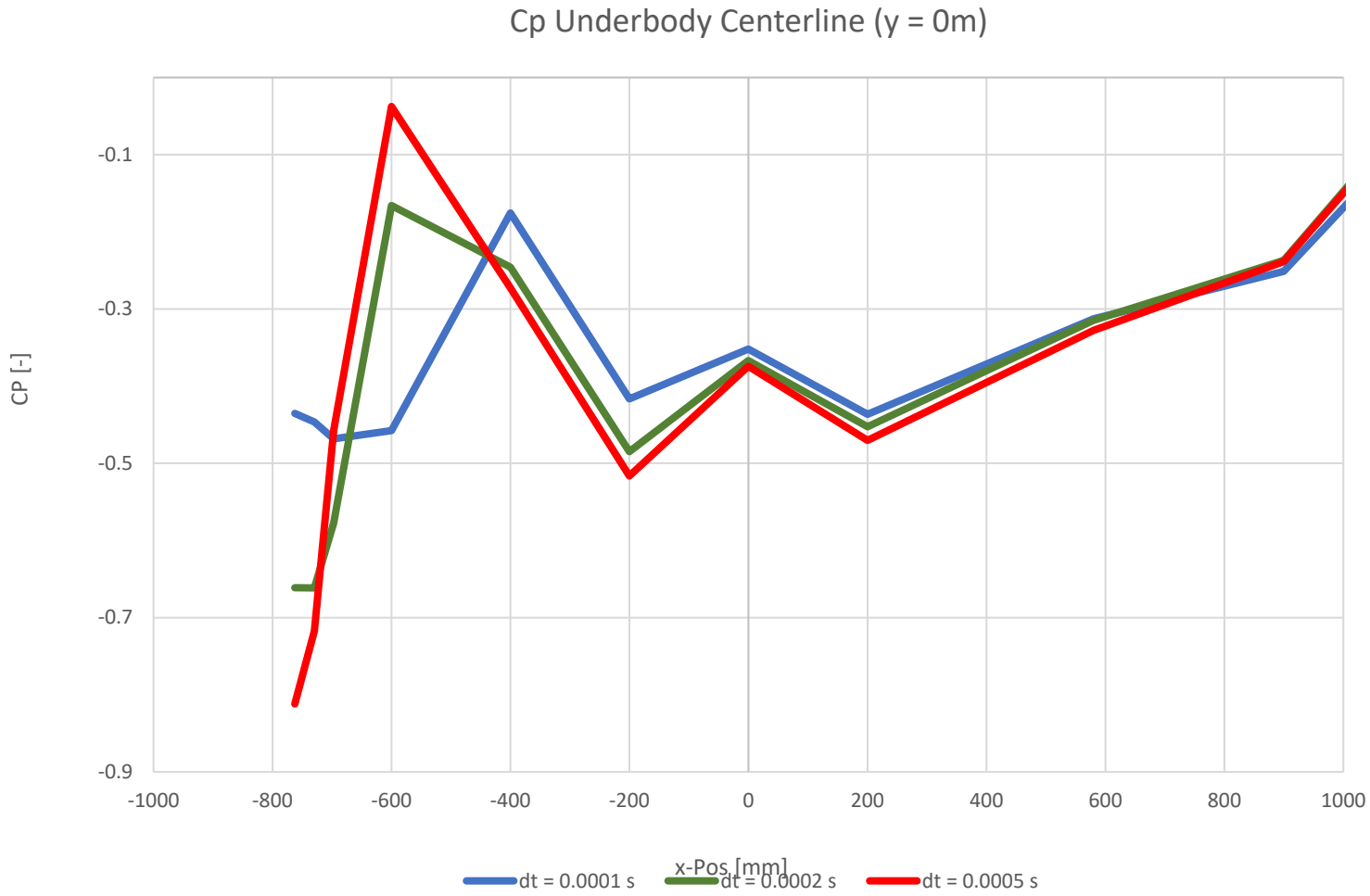
- All three steps collapse onto one curve along the roof, bonnet and screen.
- Only the base region moves, by a few hundredths of Cp (see backup).
- **If you only looked here, the shortcut looks free.**

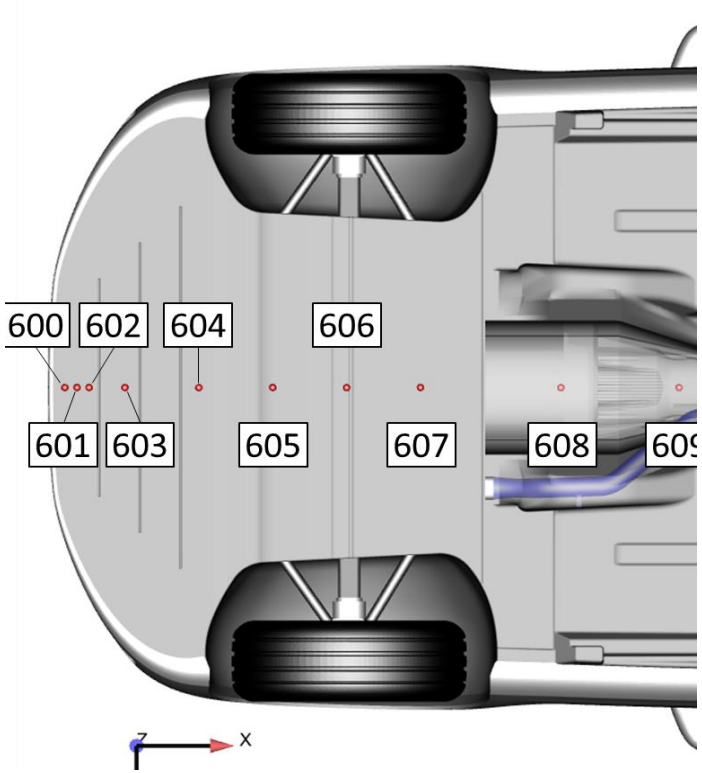
Lower Body Cp: Sensitivity Local to Front Bumper



Differences are confined to the front bumper region; the rest of the underbody is step-independent.

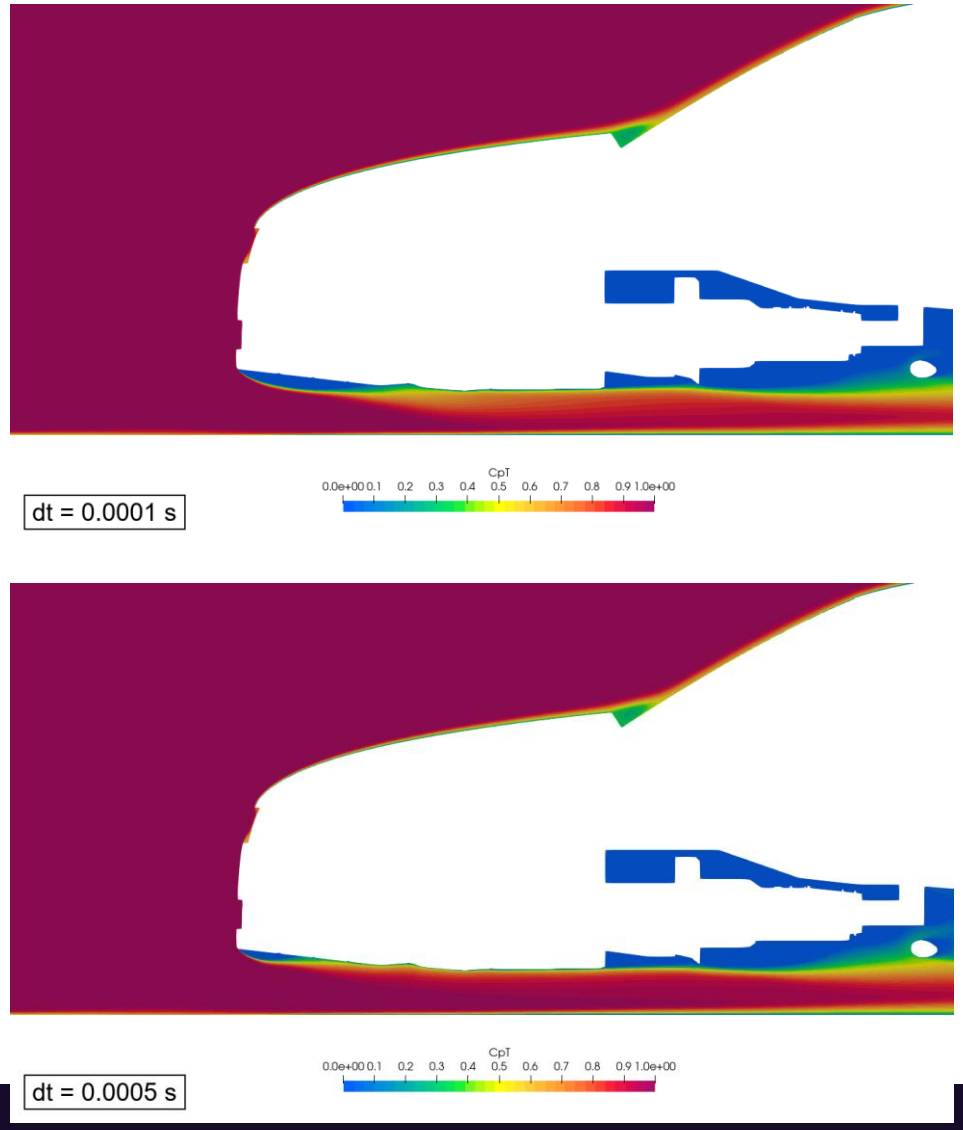
Front underbody Cp: the bumper lip diverges





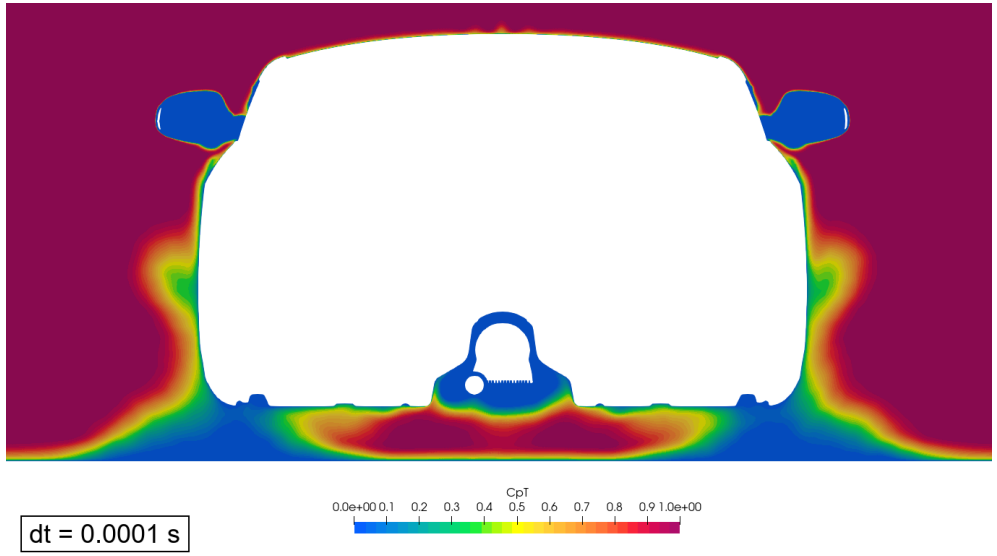
Up to ~0.4 in Cp between steps at the lip. Downstream of the front axle the curves collapse again.

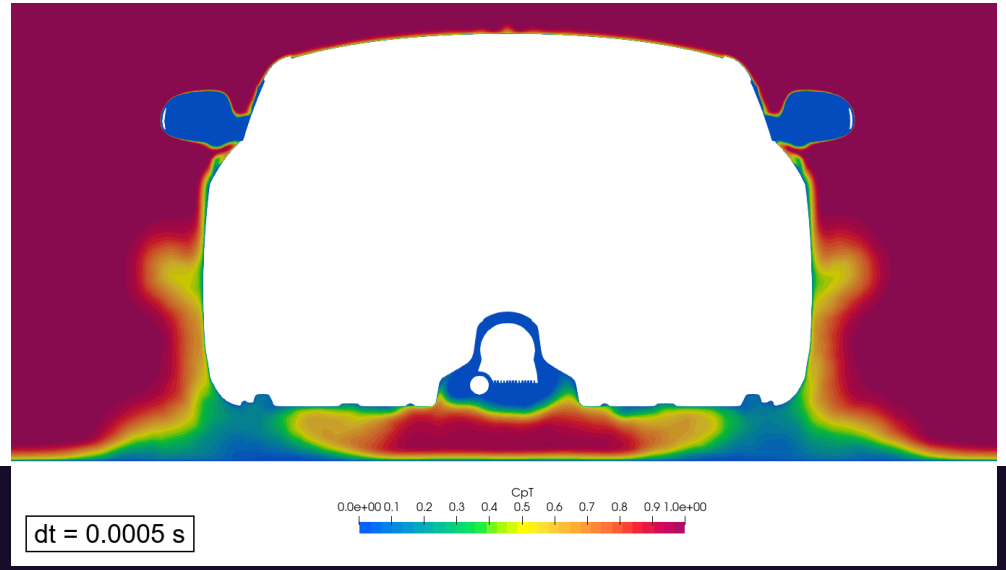
Centreline Total Pressure: Separation under the bumper lip grows as the step reduces



- Blue region is the separation bubble under the front bumper lip.
- At 0.0001 s it is larger and sharper; at 0.0005 s it is thinner and smeared.
- Higher total pressure is being passed under the car with the larger time-step.

Effect of Time Step on Front Wheel Wakes





- The larger timestep produces higher retained total pressure in the tyre wake and a more diffuse shear layer
- Same signature as the lip: the larger step smears and narrows every shear region.
- Timestep has a significant impact on the underbody flow.

Likely Causes of the Change in Flow Structure

```
398  DILUPBiCGStab:  Solving for Uy, Initial residual = 4.7732897e-06, Final residual = 1.9424772e-07, No Iterations 1
399  DILUPBiCGStab:  Solving for Uz, Initial residual = 5.0879885e-07, Final residual = 1.9458373e-08, No Iterations 1
400  GAMG:  Solving for p, Initial residual = 0.010267094, Final residual = 0.00050405186, No Iterations 2
401  time step continuity errors : sum local = 8.6799096e-10, global = 4.9183471e-13, cumulative = 4.4083782e-11
402  PIMPLE: iteration 5
403  DILUPBiCGStab:  Solving for Ux, Initial residual = 6.2815552e-08, Final residual = 4.751981e-10, No Iterations 1
404  DILUPBiCGStab:  Solving for Uy, Initial residual = 2.8663062e-06, Final residual = 7.0210122e-09, No Iterations 1
405  DILUPBiCGStab:  Solving for Uz, Initial residual = 2.965603e-07, Final residual = 6.9847028e-10, No Iterations 1
406  GAMG:  Solving for p, Initial residual = 0.0085204383, Final residual = 8.1918834e-06, No Iterations 20
407  time step continuity errors : sum local = 6.6764316e-10, global = -2.1724725e-13, cumulative = 4.3866535e-11
408  DILUPBiCGStab:  Solving for nuTilda, Initial residual = 2.4534475e-05, Final residual = 2.4367209e-08, No Iterations 1
409  PIMPLE: not converged within 5 iterations
410  ExecutionTime = 73.93 s  ClockTime = 76 s
411
412  Min{p} = -2045.9532 at (0.95522559 0.75133508 0.71273458)
413  Max{p} = 1099.5796 at (-0.027488897 -0.76162195 -0.31746361)
414  Max{|U|} = 71.621216 at (0.40842575 0.72746688 -0.16034511)
415  Max{coNum} = 398.18307 at (-0.026454551 -0.74771428 -0.31757534)
416  Max{mut/mu} = 16408.654 at (4.9672432 -0.081250027 0.39675233)
```

1. **Larger temporal discretisation error**

   Solution is less temporarily resolved and the increased time step effectively smears/shifts the unsteady structures, making the shear layer appear broader.

2. **Higher local Courant number and altered numerical diffusion**

   Larger timestep pushes the local Co significantly higher and the temporal/spatial discretisation errors become more important, particularly in regions of high velocity gradients (like the bumper)

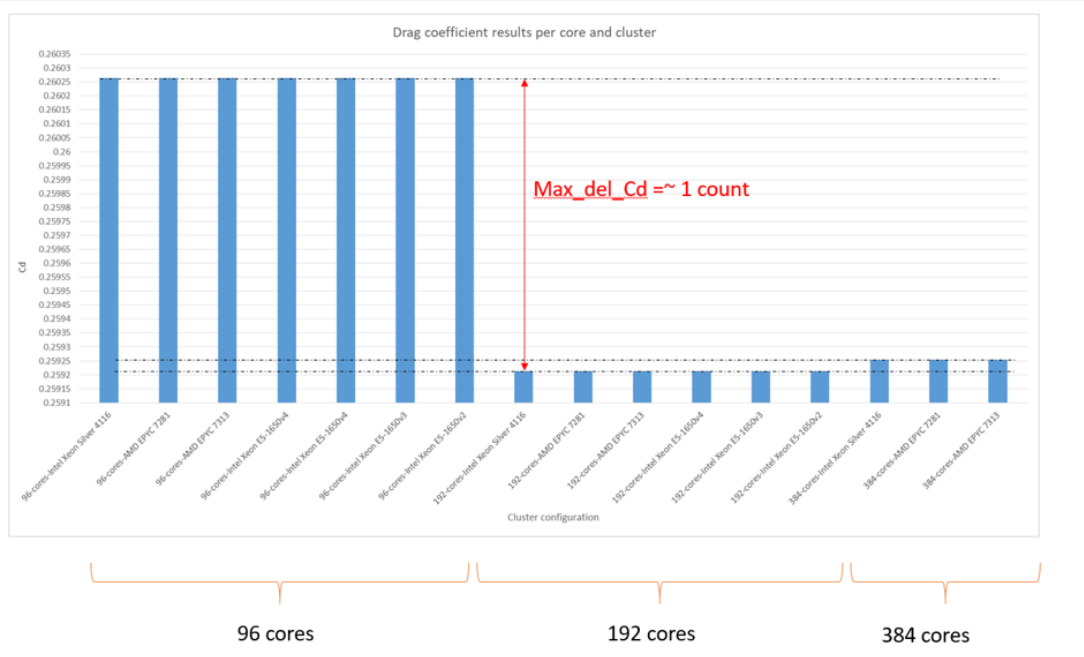
3. **PIMPLE is not converging equally well within each timestep**

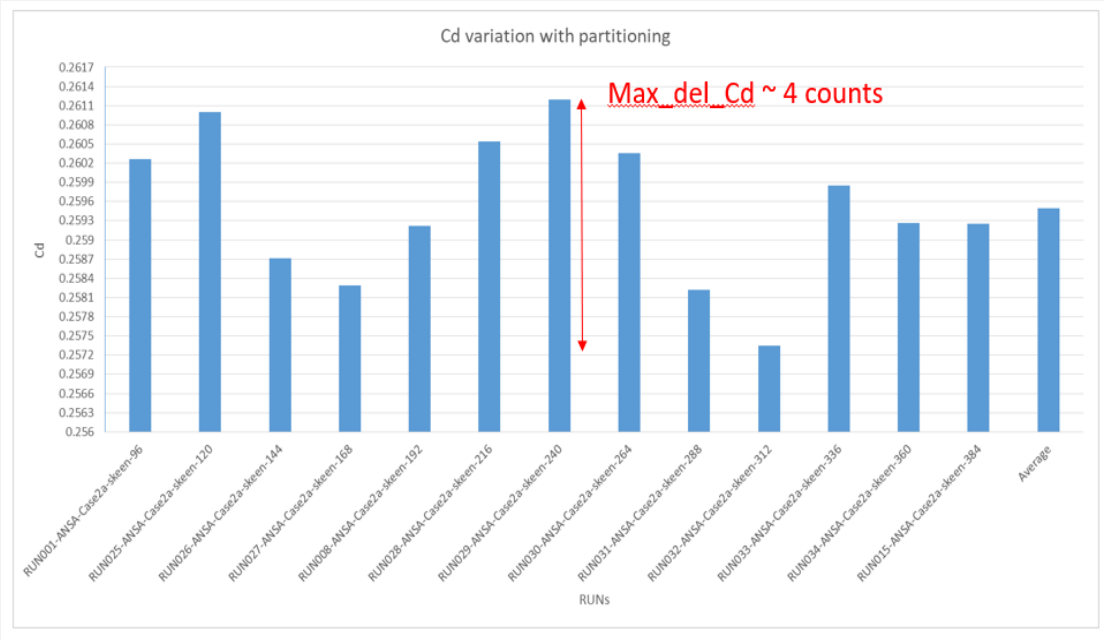
   Comparison of PIMPLE logs suggest poorer convergence within each timestep, giving artificial changes in separation, recirculation and wake mixing.

Effect on Hardware and Core Count on Solution

Same case, same settings, different machines – same solution

Changing number of partitions produces a larger variation. In part due to snappyHexMesh generating a slightly different mesh.





PIV Validation at Catesby Tunnel

Over the past year, Catesby Tunnel has been used to generate ‘real world’ flow visualisations for CFD correlation studies

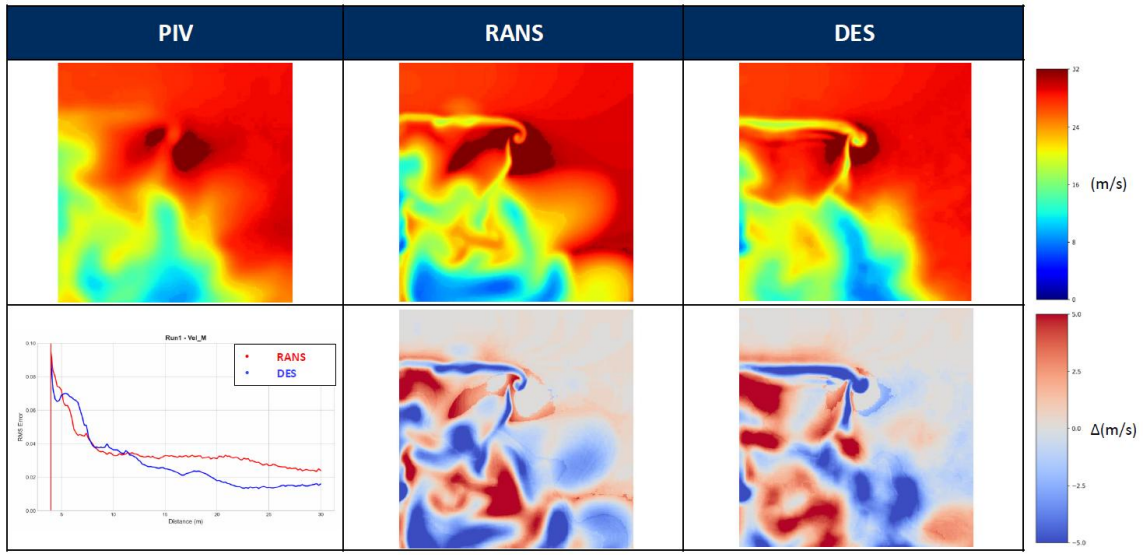


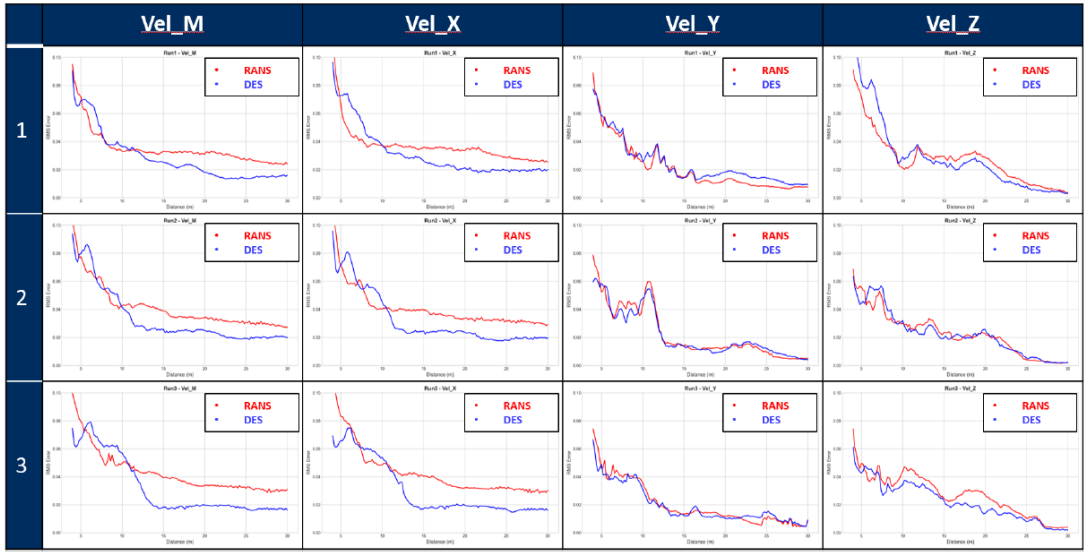
FEDERATION INTERNATIONALE DE L’AUTOMOBILE

Images courtesy of Will Stone and the FIA

PIV Validation at Catesby Tunnel

Bubble velocity and paths are tracked and used to determine the development of the wake behind the vehicle.





FEDERATION INTERNATIONALE DE L'AUTOMOBILE

Images courtesy of Will Stone and the FIA

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