High-Order Workshop Results for Case CR1 RANS of the Common Research Model (6th AIAA Drag prediction workshop)

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Flow Solver

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- Discontinuous Galerkin Finite Element Method
- Modal basis functions
- Hybrid mixed element unstructured meshes (tetrahedra, prisms, pyramids, and hexahedra)
- p-enrichment and h-refinement using non-conforming elements (hanging nodes)
- Independent polynomial degree for solution and mapping basis
- Non-linear system solver: PTC Newton-Rhapson method
- Linear system solver: preconditioned flexible-GMRES (Saad 1986)
- Line implicit Jacobi, Gauss-Seidel relaxation, ILU(0)

Physics

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- Compressible Navier-Stokes in conservative variables
- PDE-based Artificial Viscosity (Barter and Darmofal, Burgess)
- Spalart-Allmaras turbulence model (negative-SA variant)
- Inviscid flux: Lax-Friedrichs, Roe, AUFS
- Viscous flux: symmetric interior penalty (SIP)

Drag and Lift Results

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Ma= 0.3, Roe Flux, ILU(0)

$$time/dof = \frac{cputime \times procs}{\tau \times dofs}$$

case	p	dof $\times 10^6$	C_L	C_D	time/dof
1	1	7.7	0.39934	.020747	0.153
2	1	9.99	0.39597	.021177	0.098
3	1	19.1	0.39531	.021243	0.048
4	1	42.8	0.39593	.021248	0.101
5	2	19.2	0.39628	.020588	0.202
6	2	249	0.39386	.021104	0.111
7	2	47.7	0.39368	.021164	0.054
8	2	107	0.39372	.021177	0.095
9	3	38.4	0.39542	.020545	0.327

Drag Results

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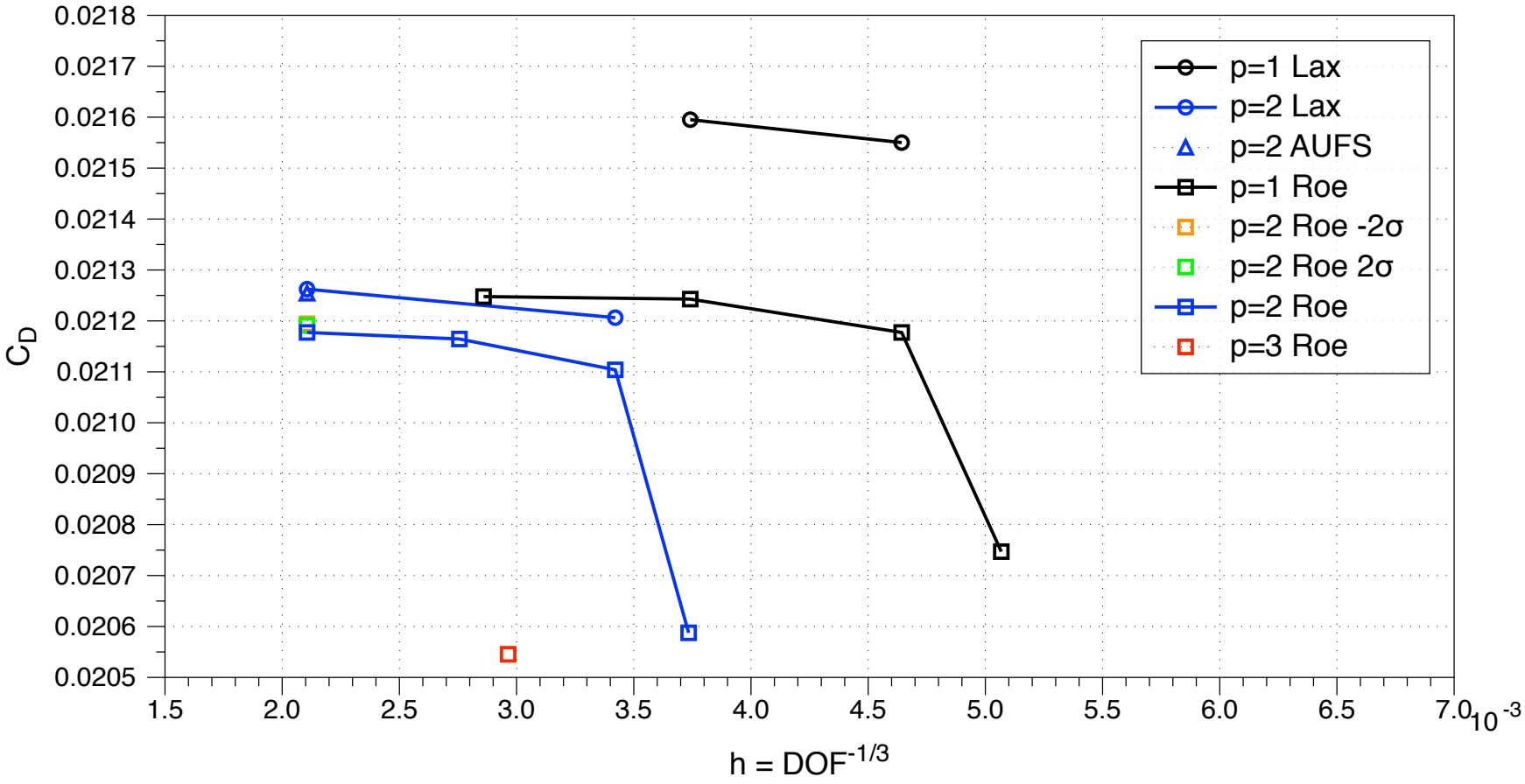
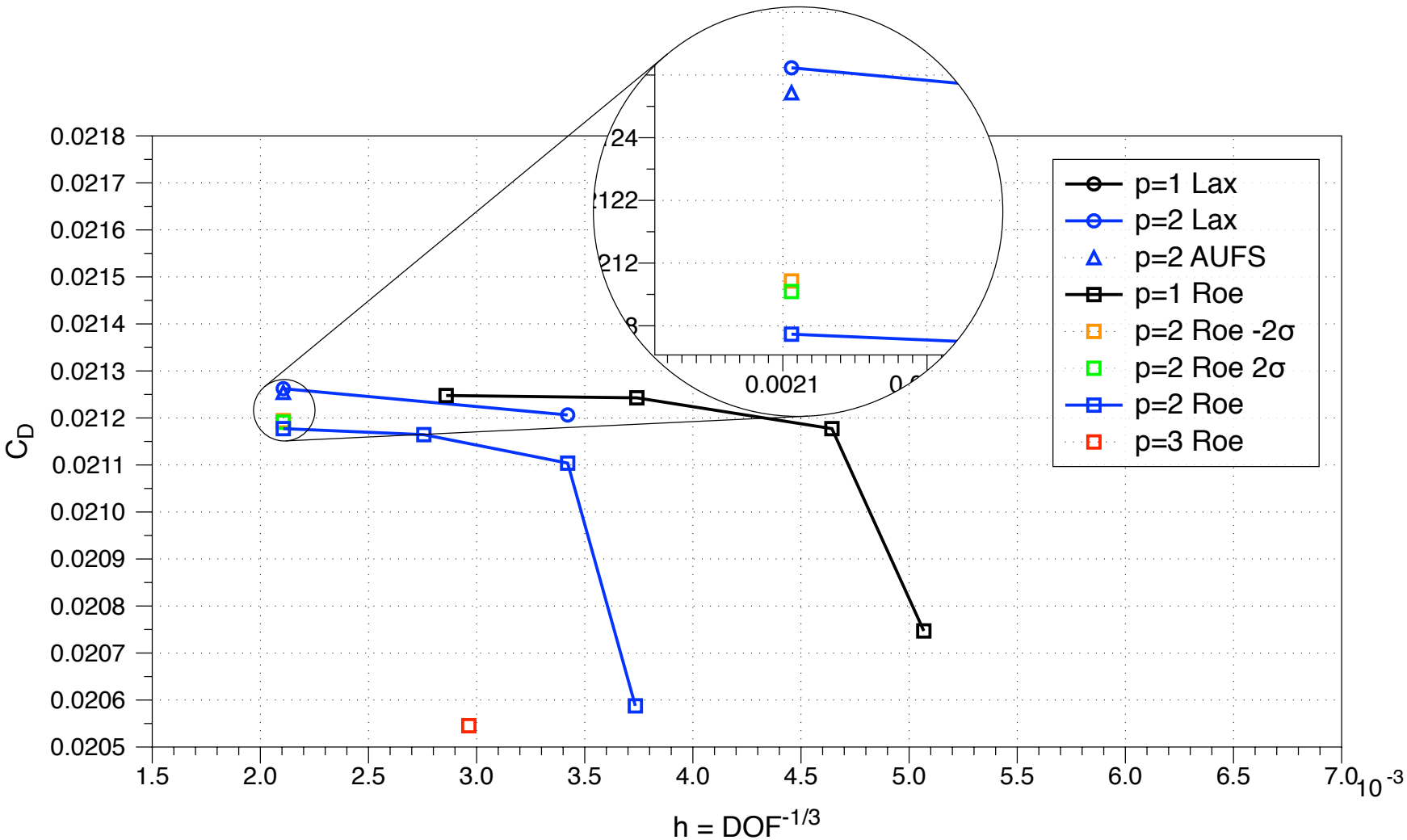
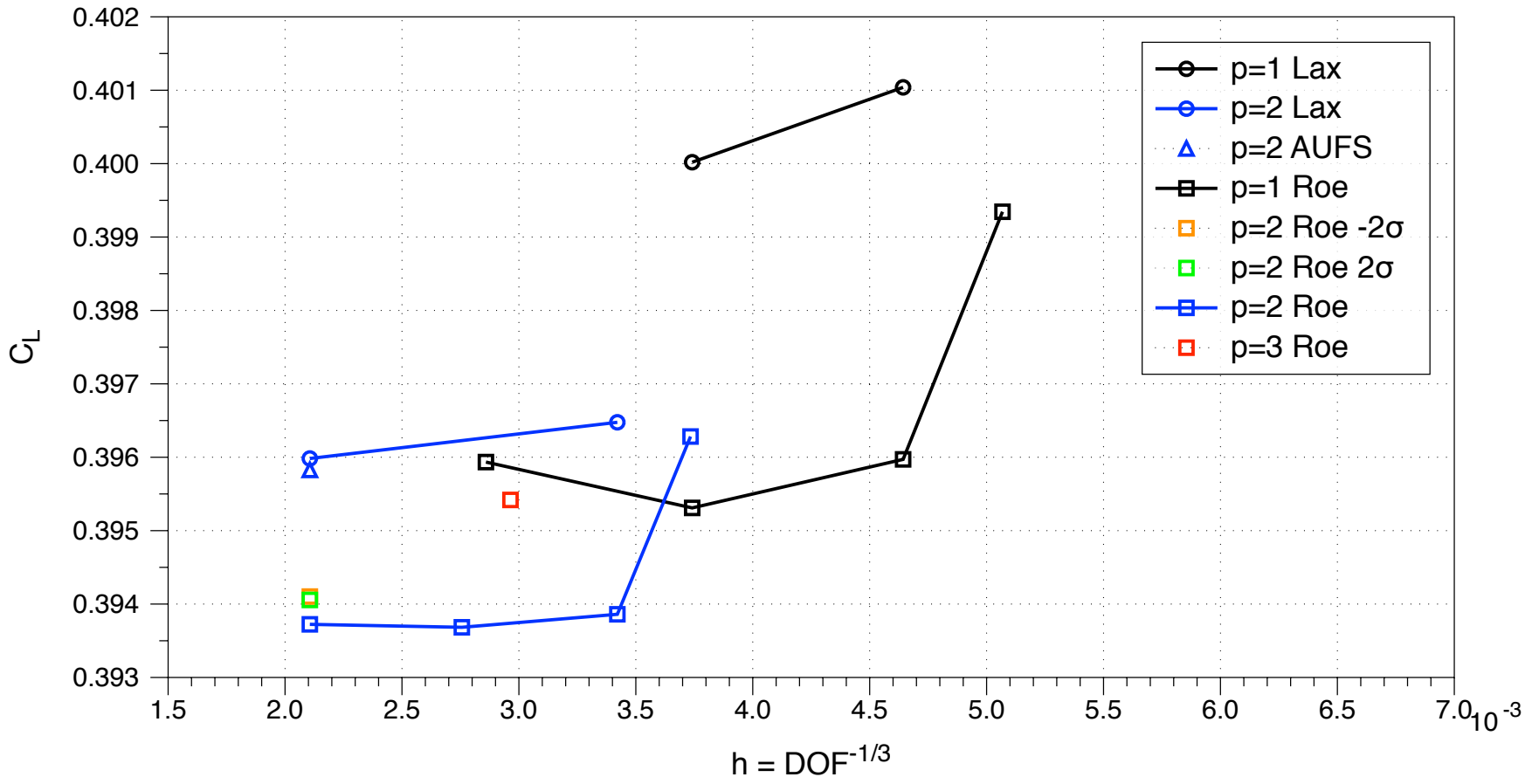


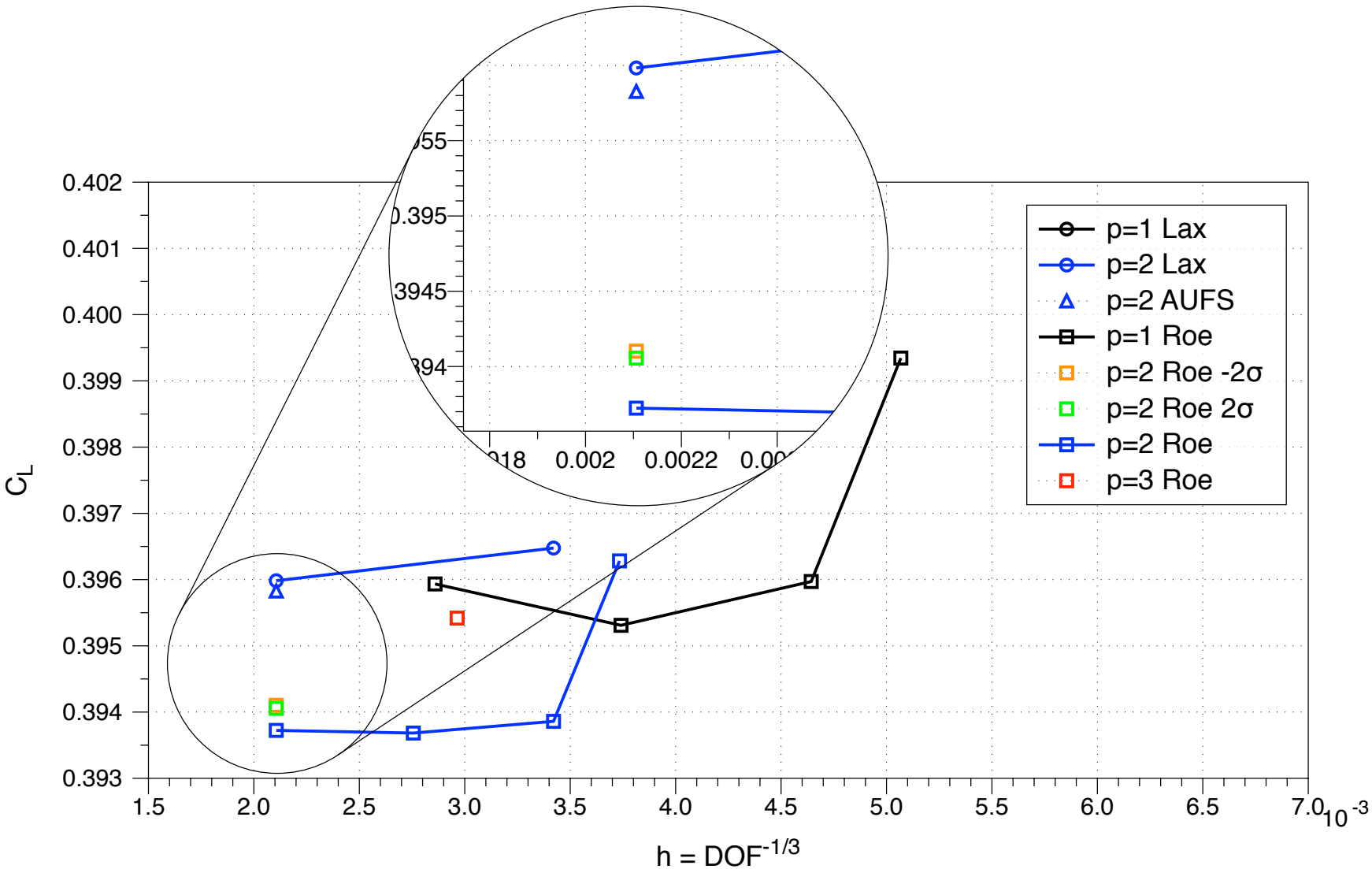
Drag Results Zoom



Lift Results



Lift Results Zoom



Residual, tiny mesh, Ma = 0.3

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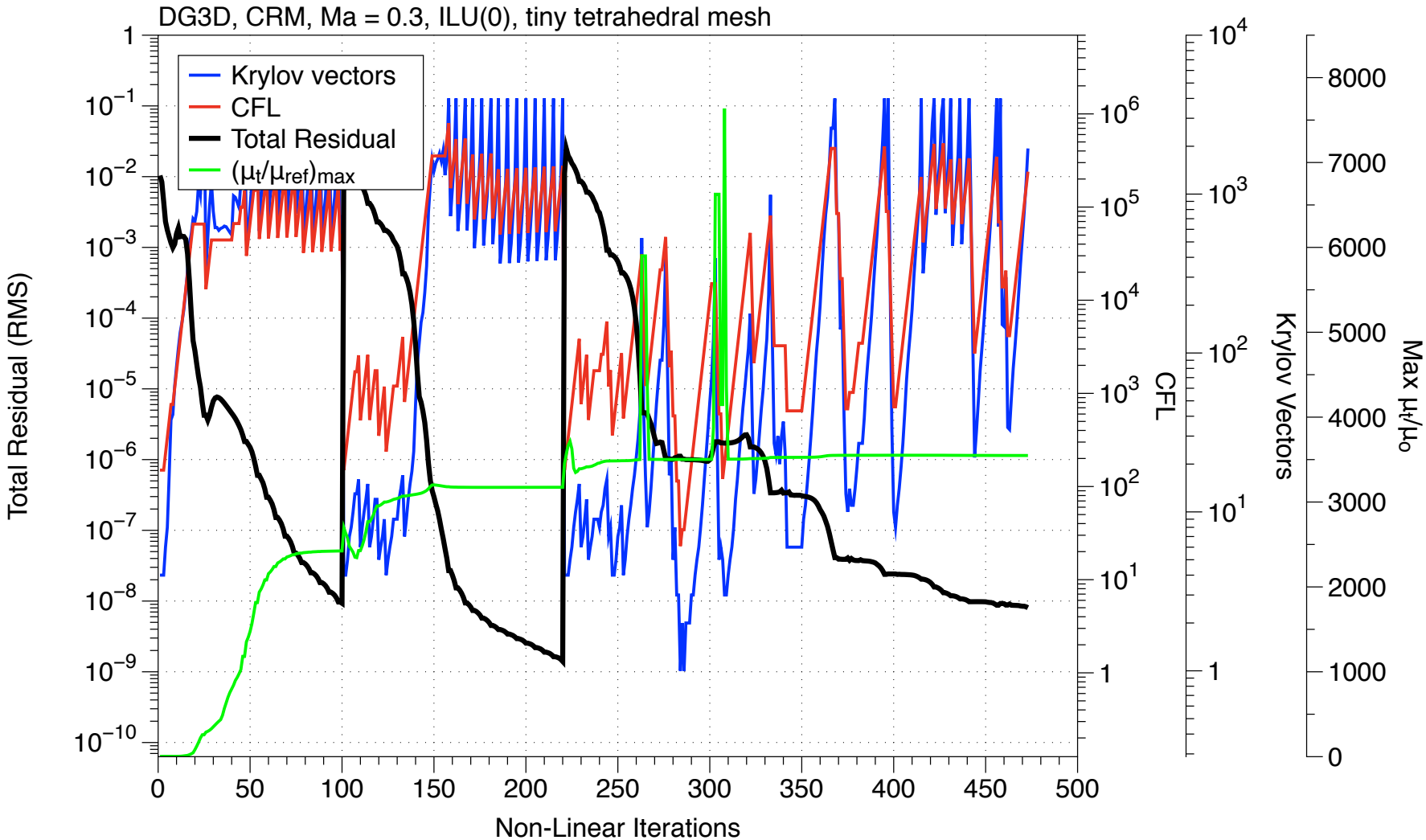
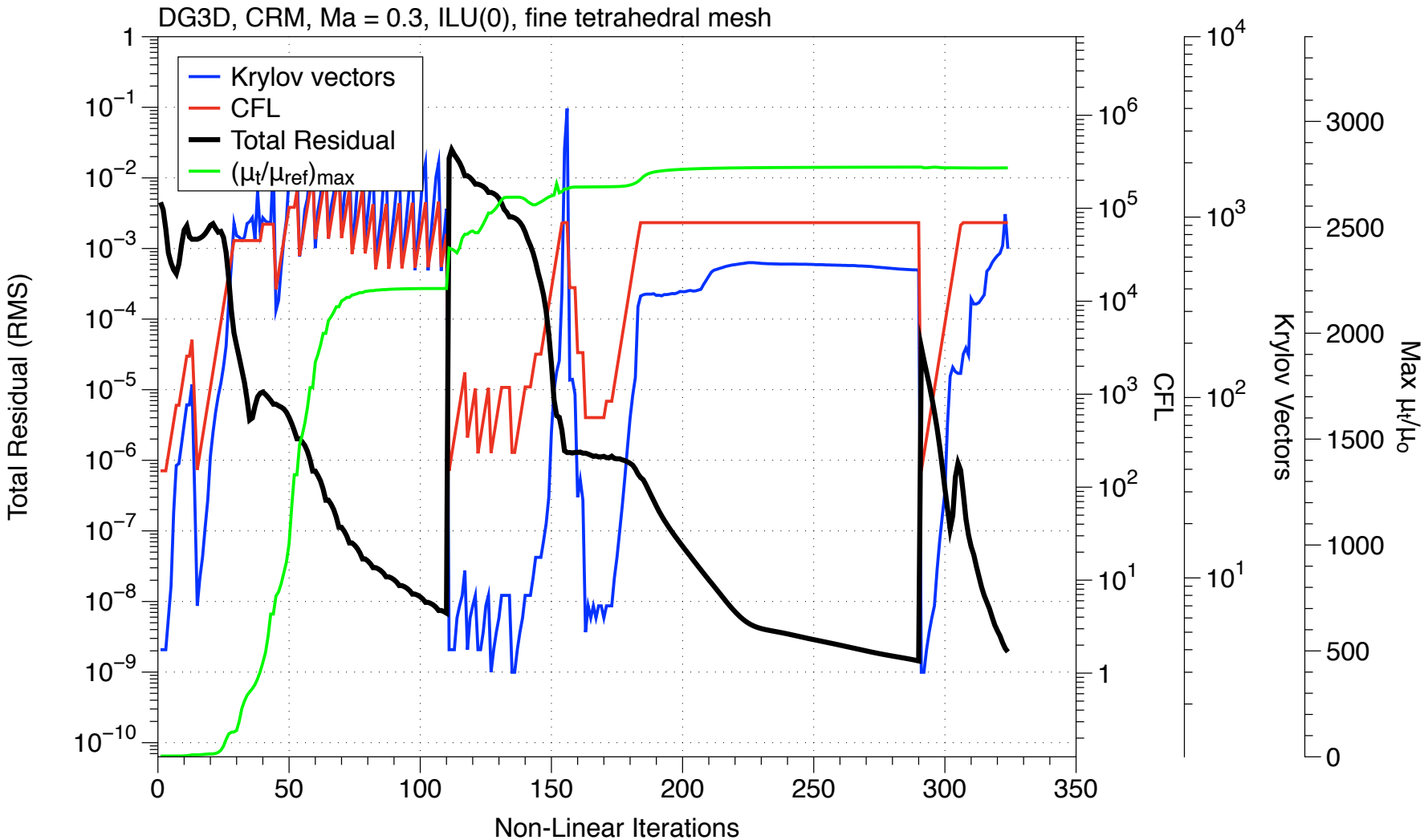
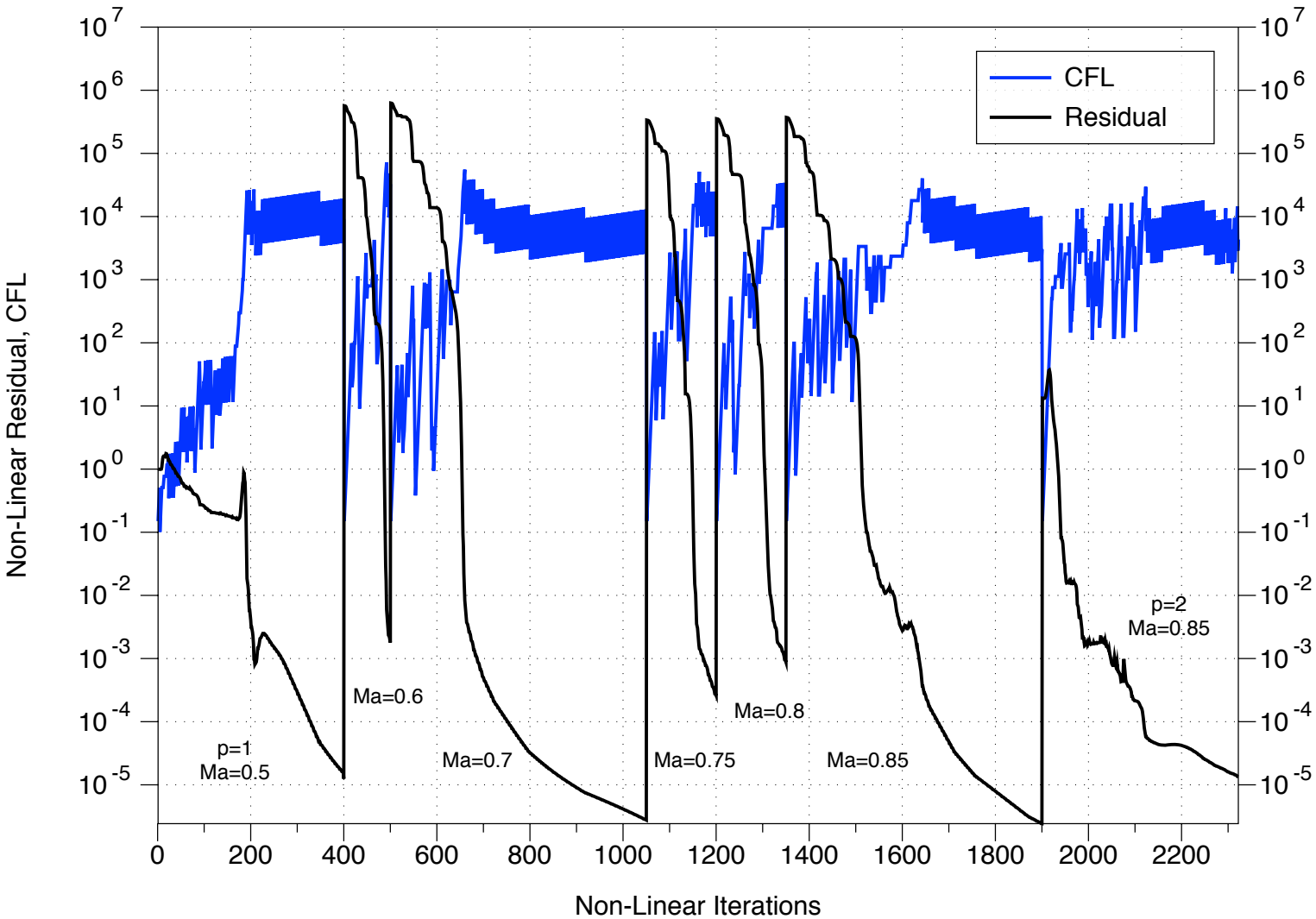


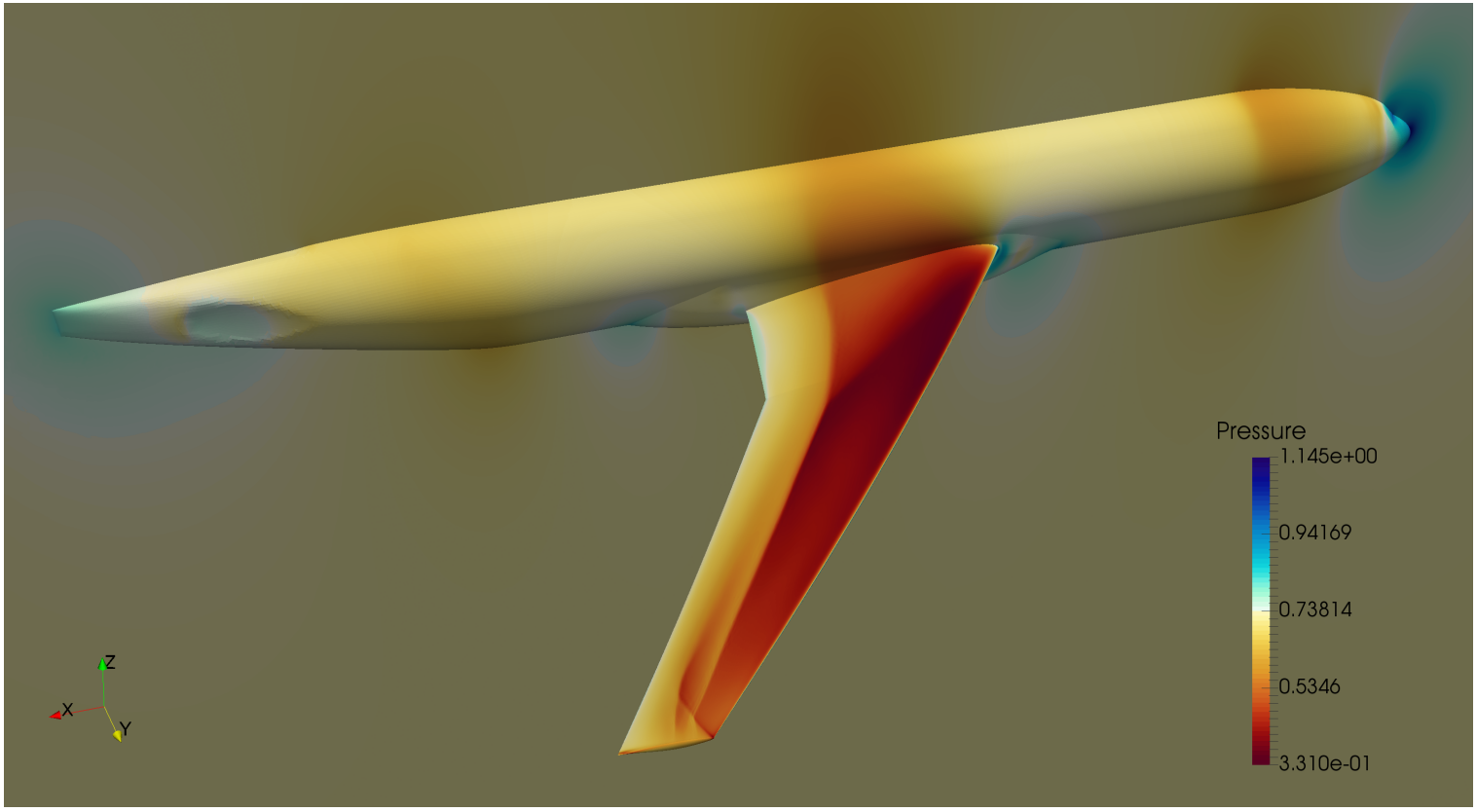
Residual, fine mesh, Ma = 0.3



Res., coarse mesh, Ma = 0.85

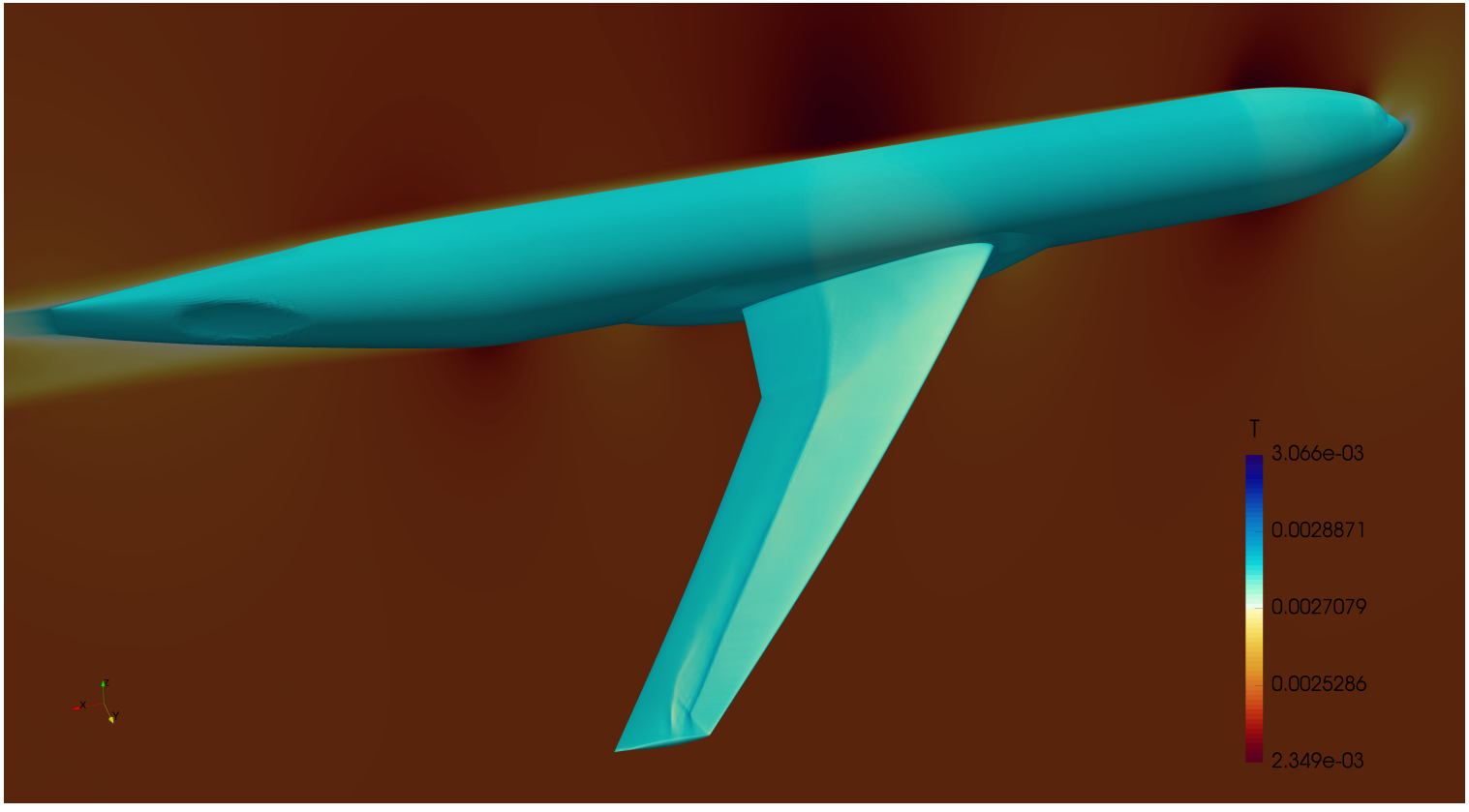


Pressure contours



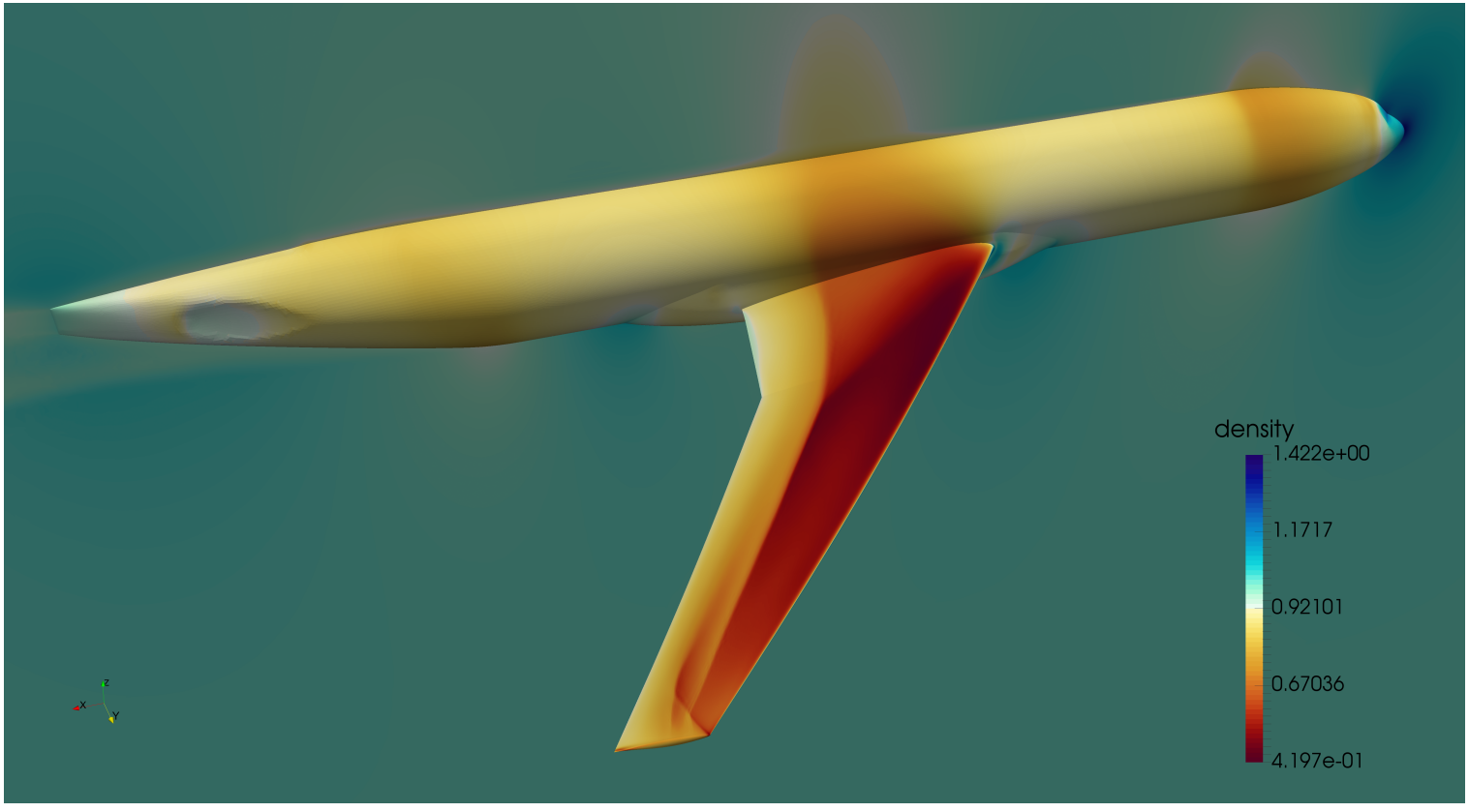
Ma = 0.85, P2Q2

Temperature contours



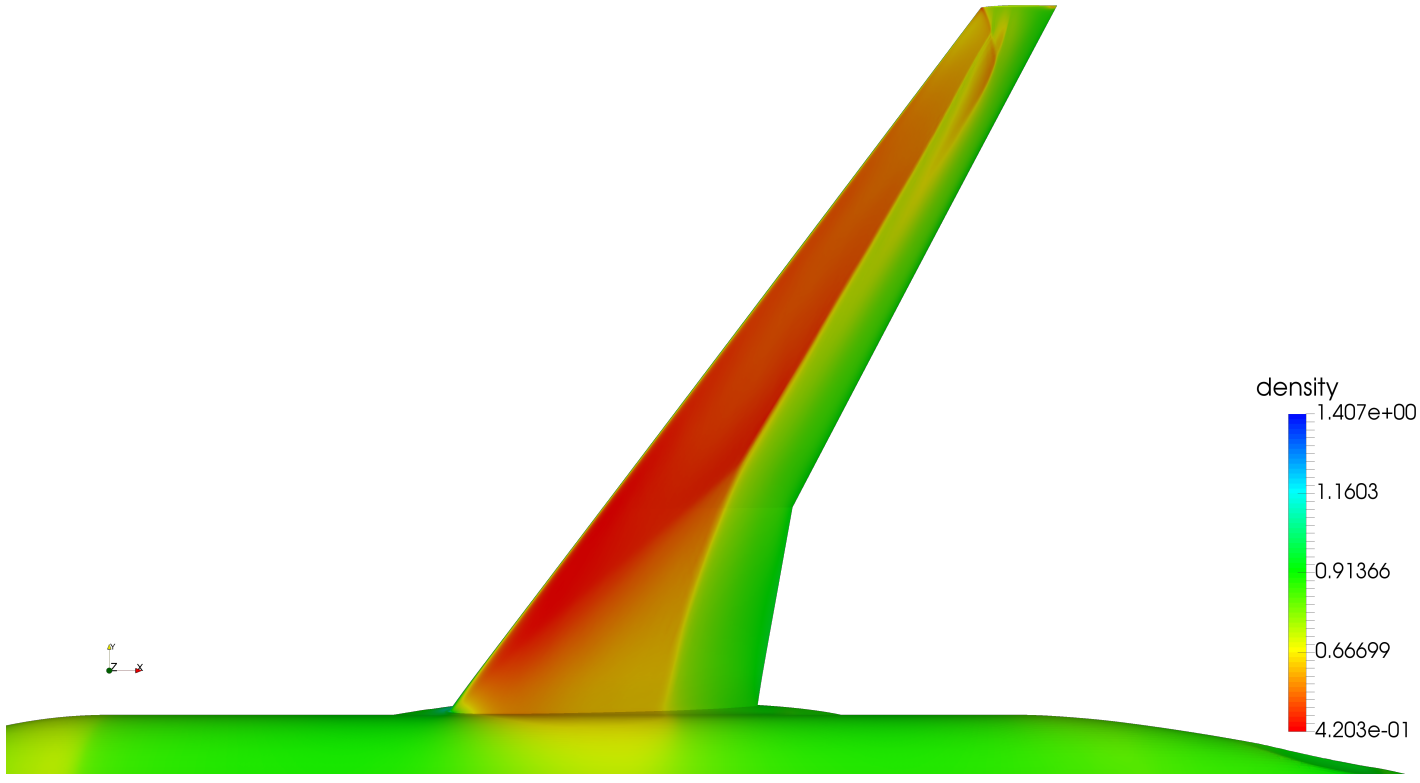
Ma = 0.85, P2Q2

Density contours



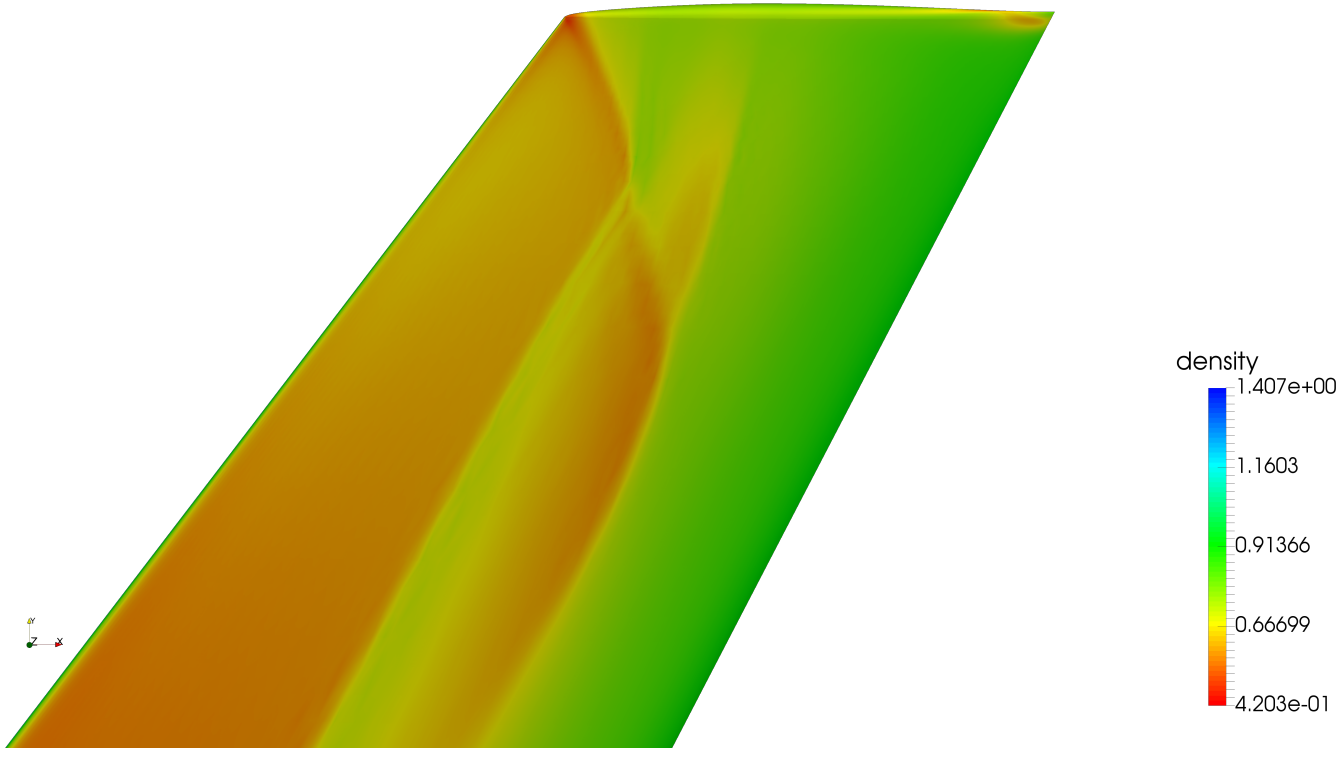
Ma = 0.85, P2Q2

Density contours



Ma = 0.85, P2Q2

Density contours



Ma = 0.85, P2Q2

Conclusions

- Converging to a different drag value than other FE codes
- Face fluxes caused larger variation than expected
- Once p=1 is converged rapid convergence is observed for p=2,3
- Transonic case was very difficulty to initialize and required mach ramping
- p=1 tetrahedral meshes are painful for DG
- If meshing goes in direction of pure tetrahedral need to develop cell-based lines that do not rely on prisms
- ILU(0) requires a lot of memory, lines will help with this but also need matrix free high-order preconditioners